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Effects of acoustical descriptors on speech intelligibility in Hong Kong classrooms

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Abstract

This study investigated the effects of classroom acoustics on speech intelligibility in secondary school and university classrooms. Speech intelligibility tests were conducted in 9 secondary school classrooms and 18 university classrooms and the acoustical measurements were performed in these classrooms. Subjective speech intelligibility tests were obtained from phonetically balanced (PB) word lists on a total of 672 students and acoustic descriptors such as signal-to-noise ratio (SNR), early decay time (EDT), and sound clarity (C_{80}) were conducted in different listening positions in each classroom. The relationships between speech intelligibility scores (SI) and acoustical descriptors were fitted based on non-linear curve fitting regression models. The "S" form regression model was selected with modification as the basic regression equation to describe the effects of SNR on speech intelligibility. The combination effects of SNR with reverberation condition and sound clarity condition on speech intelligibility were investigated. The impact of different age groups and linguistic environment on speech intelligibility were discussed.

The results reveal that SI increases with the increase of SNR value for all age groups. The results indicate that nearly 0.06s increasing in EDT values will result in a 1% decrease in SI. Furthermore, the results also suggest that a 1 dB increasing in C_{80} values will result in a 1.23% increase in speech intelligibility scores. The SI increases as the age increases under the same SNR condition. The speech intelligibility scores are always lower than the comparison research results with a constant reverberation value as well as sound clarity value for an equal SNR value.

Keywords: Speech intelligibility; Acoustical measurement; SNR; Reverberation condition; Sound clarity.

1. Introduction

The education of students is essential to modern societies. Most formal education takes place in the classrooms, where a high level of acoustical quality is required [1]. 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 [2]. Speech intelligibility is highly correlated with classroom acoustic conditions. Various studies revealed the effects of acoustical factors on speech intelligibility.

Bradley [3] pointed out that the signal to noise ratio (SNR) was an essential factor to affect speech intelligibility after the measurements of ten classrooms in Canada. The mean measured reverberation time in these classrooms was 0.7 s at 1 kHz, and ambient noise levels in occupied classrooms without student activity varied from 38 to 45 dBA. He also reported values of various room acoustics parameters and related intelligibility scores to combinations of reverberation time and signal-to-noise ratios.

Yang and Bradley [4] conducted measurements and speech intelligibility tests in elementary school classrooms. Subjects consisted of grade 1, 3, 6 students (aged 6, 8, and 11 years old) and adults. The authors recognized that reverberation time (RT) is not a complete descriptor of room acoustics conditions. Simulated conditions included realistic early-to-late arriving sound ratios as well as various reverberation time. The authors indicated that the speech intelligibility scores (IS) increased with decreasing RT, for conditions of constant SNR, whereas for conditions including realistic increases in speech level with varied reverberation time for constant noise level, the intelligibility scores were nearly maximum for a range of reverberation times.

Two papers proposed by Bradley and Sato [5-6] described acoustical measurements and speech intelligibility tests in 41 classrooms in 12 different elementary schools. Acoustical parameters including SNR, RT, early decay time (EDT), clarity (C50), and strength (G) were discussed in the occupied and unoccupied classrooms. The results indicated that the +15 dB signal-to-noise ratio was not adequate for the youngest children. The study found, that on average, the students experienced: teacher speech levels of 60.4 dBA, noise levels of 49.1 dB A, and a mean speech-to-noise ratio of 11 dB A during teaching activities.

Astolfi et al. [7] investigated speech intelligibility tests and measurements in different reverberation times (RT) and types of noise in elementary school classrooms in Italy. 983 pupils from grade 2-5 (aged from 7-10) participated in the diagnostic rhyme tests. The authors proposed a logarithmic regression function curves of speech intelligibility scores and speech transmission index (STI).

Choi [8] focused on the effects of occupancy on acoustical conditions in 12 university classrooms in Korea. He compared two different groups of classrooms (6 reflective classrooms and six absorptive classrooms) to analyze the effect of added occupants. The author concluded that the occupants might contribute to achieving more ideal reverberation times for speech (typically 0.4–0.7 s in classrooms) in the more reflective classrooms, but not in the more absorptive classrooms

Peng and his co-workers [9-10] investigated acoustical parameters (e.g., RT, sound pressure level (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.

Zhu et al. [11] conducted Chinese speech intelligibility tests and in-situ measurements four different rooms (office, laboratory, lecture hall, and semi-anechoic chamber).

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 [12]. It has been noticed that the differences in intelligibility among different linguistic environments. The language specification effects became a factor causing disparity among 10 Western language tests was proposed by Houtgast and Steeneken [13]. Different relationships between speech intelligibility and acoustical parameters can be influenced by different linguistic environments and different educational modes. The differences in intelligibility between English and Mandarin under reverberation conditions and noisy conditions were compared by Kang [14]. Other impacts of room acoustical conditions on the speech intelligibility of different languages were also reported [15].

Yang and Mak [16] investigated speech intelligibility tests and acoustical measurements in university classrooms and secondary school classrooms in Hong Kong. The authors summarized the relationship between speech intelligibility scores and speech transmission index under two typical ventilation conditions. The authors pointed out that the special educational condition that English is an educational language, not the official language in Hong Kong. They also compared the regression results with those results in other linguistic environments. However, the effects of other acoustic descriptors were not included in that paper.

From the analysis of previous studies, it emerged that the following issues on the topic of speech intelligibility in classrooms still need to be tackled:

(1) The effects of classroom acoustics on speech intelligibility should be deeply studied except for STI in Hong Kong classrooms.

(2) The combination effects of SNR with reverberation condition and sound clarity on speech intelligibility should be investigated.

(3) The results of different intelligibility tests in different linguistic environments should be compared.

In the current paper, A sound source with its directivity similar to the human's mouth was used for reproducing the speech intelligibility test signals, which was recorded in the anechoic chamber. The purpose is to obtain the speech intelligibility scores (SIs) among students in Hong Kong and compare the relationships between SIs and acoustical descriptors to the native language speaking country.

2. Experimental Procedure

2.1 Classrooms in case studies

In this study, 9 classrooms in a secondary school and 18 classrooms in a university were investigated in Hong Kong. Classrooms in secondary school were without acoustical treatment, while classrooms in the university were well decorated with acoustical treatment. A comparative table of the decorating materials of classrooms in secondary school and the university was given in Table 1. All the classrooms were rectangular in shape. The dimensions of the selected classrooms are shown in Table 2. Classrooms 3A, 3B, 3C, and 3D are the classrooms of Grade C students (aged from 14 to 16). Classrooms 2A, 2C, and 2D are the classrooms of Grade B students (aged from 12 to 14). Classrooms 1C and 1D are the classrooms of Grade A students (aged from 12 to 13) in secondary school.

Table 1 Decorated materials of classrooms comparison

Sides	Secondary School classrooms	University classrooms
Floor	Concrete floor	Loop pile tufted carpet
Sidewalls	Painted concrete walls	Painted concrete walls
Ceiling	Painted concrete walls	Metal perforated plates
Windows	Double glazing windows	Double glazing windows
Door	Solid wooden door	Solid wooden door
Front and rear walls	Painted concrete walls	Wooden perforated plates

Table 2 Dimensions of selected classrooms

School	Classroom	Length*Width/ m^2	Height/m	Volume/m^3
	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
Secondary School	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
	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

University	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
	L	7.121*7.182	2.633	134.66
	M	12.113*7.682	3.621	336.94
	N	11.265*7.842	3.251	287.19
	O	7.843*3.849	2.682	80.96
	P	16.525*12.648	5.028	1050.89
	Q	8.175*5.538	2.492	112.82
	R	11.488*9.025	3.136	325.14

According to the sizes of the chosen classrooms, four listening positions (L1-L4) were selected in each classroom. As shown in Fig 1, an example (Classroom 3A) was given (Other specifications were hidden in this classroom). Speech intelligibility tests were accomplished with junior students in secondary school classrooms and undergraduates in university classrooms. The junior students from the secondary schools were aged from 12 to 16, while undergraduates were aged from 19 to 23 (adults). In the current study, the speech intelligibility test results of the mentioned respondents were studied for discussing the effects of different age groups.

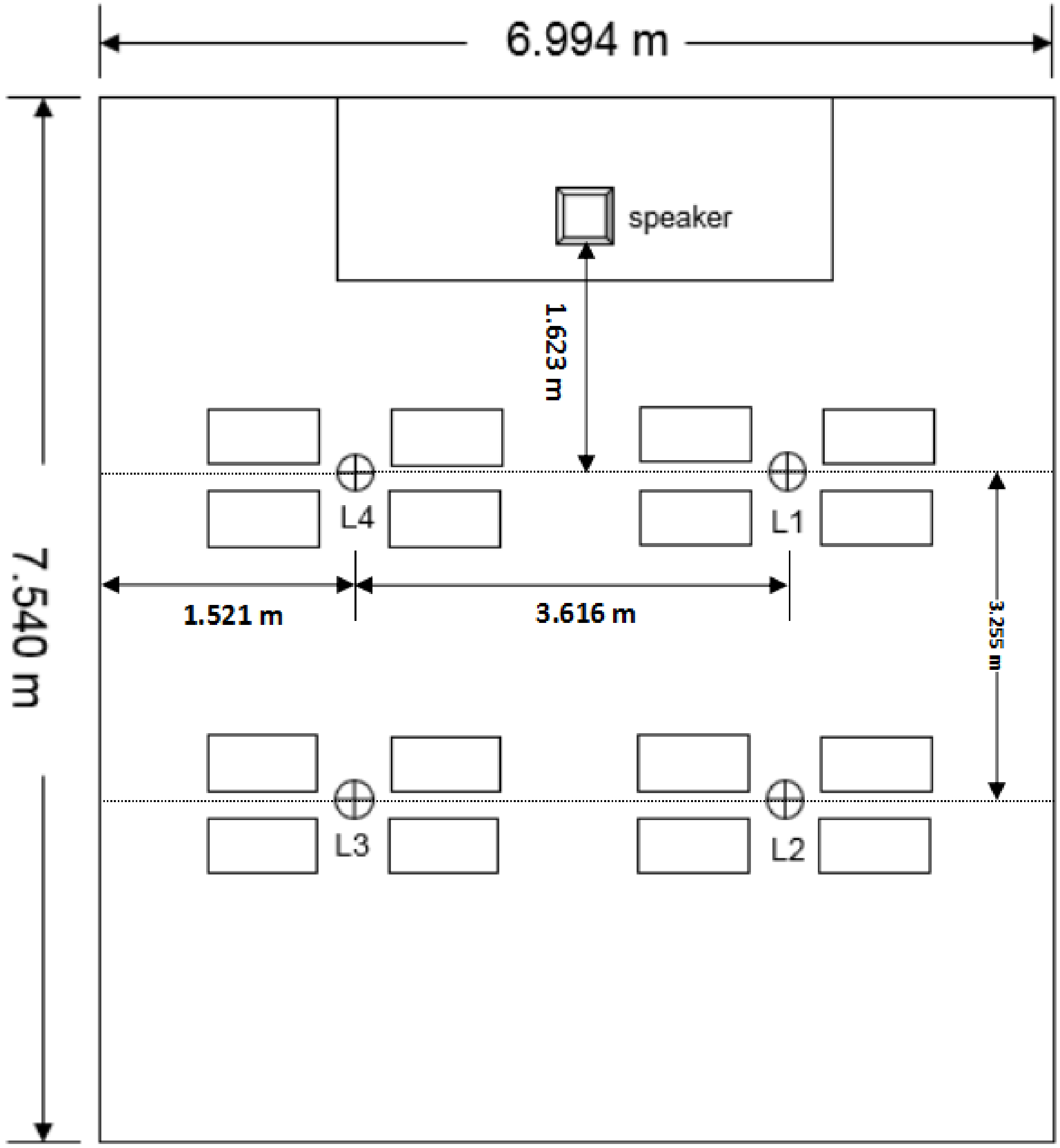

Fig. 1 schematic drawing of classroom 3A and showing of listening positions

2.2 Speech intelligibility test materials

In this paper, the speech intelligibility test materials were highly dependent on the American National Standard ANSI S3.2-1989 [17]. The phonetically balanced (PB) word lists were chosen as the test materials for the respondents. This test word list consisted of 50 rows of six-word similar-pronouncing English words. The test lists in the carrier phrase were “The x row reads y,” where x and y were replaced by the rows number and the pronunciation of the corresponding word. A male and a female local English teacher in secondary schools were invited as readers for recording the test materials. Readers were asked to read the prepared test materials at a constant speed (4 words per second) and a continuous SPL (65 dBA). The whole recording procedure was conducted in the anechoic chamber. A random-field microphone (B&K type 4935) was settled at a 0.5m distance from the reader and a 1.0m height above the floor in the anechoic chamber. Meanwhile, the reader was asked to sit on a chair, and the microphone was settled on the tripod in front of the reader. The recording signal was collected through pulse hardware (B&K type 3160-B-042) and passed to the notebook (see Fig 2).

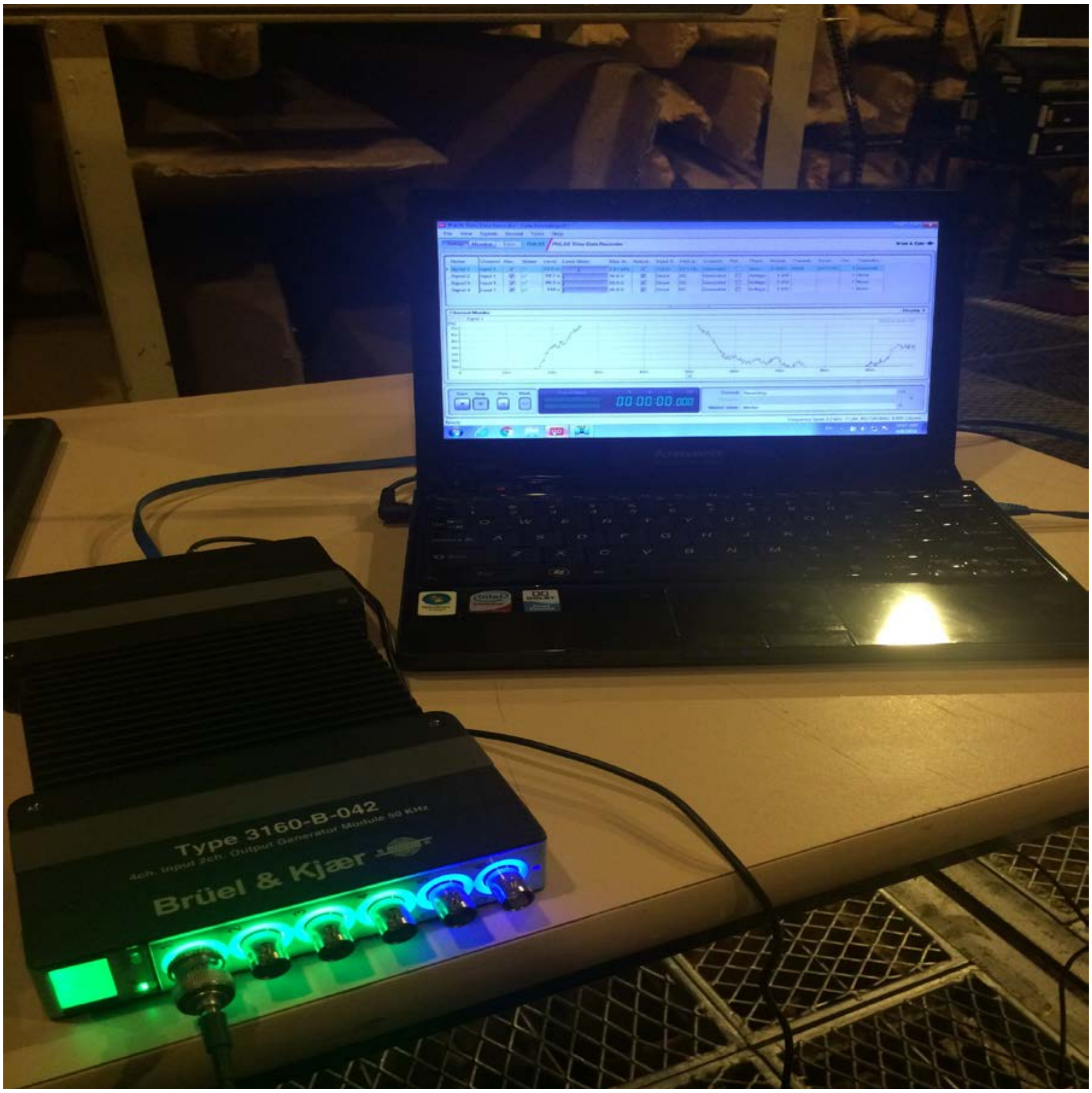

Fig 2 B&K Pulse system for signal recording in the anechoic chamber

2.3 Speech intelligibility tests in the classrooms

The speech intelligibility test signals which were recorded in the anechoic chamber were arranged to reproduce by an echo speech source (B&K Type 4720), which is a mouth directivity sound source. The sound source was placed at the platform center. This simulated that a teacher stood and oriented toward the students (the sound source location is given in Fig.1). The sound source was settled a 1.5m distance above the ground and a 0.5m distance front the blackboard. In the objective measurement, different speech sound pressure levels (SPLs) were controlled from 30 dBA to 90 dBA by changing the speech source (B&K 4720), which includes the possible changing range of the speech levels in the classrooms. The speech intelligibility tests were conducted in classrooms with the background noise level (BNL) varied from 31.5 dBA to 57.6 dBA. The SNR changes in the current study were varied from -8.5 dBA to 32.4 dBA.

284 students from 9 secondary classrooms participated in the survey. Students came from Grade A (aged from 12 to 13), Grade B (aged from 12-14), Grade C (aged from 14-16). Besides, 388 undergraduate participants aged from 19 to 23 participated in the speech intelligibility tests in 18 university classrooms. The gender of the students was not taken into account in this paper, and the difference in the number of genders was nearly negligible. Four listening positions (L1-L4 shown in Fig.1) were selected in each classroom, in addition, four students were asked to sit around every listening position. Two different test word lists (one with the male reader, the other with the female reader) were used for asking the respondents in each testing condition. Instruction prior to the tests was given to the respondents. Besides, they were told not to communicate with others while answering the speech intelligibility tests. During the tests, the respondents were told to choose the words they heard from the sound source. The four respondents' speech intelligibility scores (SIs) at every proposed listening position across all 8 lists (4 students×2 readers=8 lists) were calculated according to ISO/TR 4870 [18], and the mean SI was obtained. In these speech intelligibility tests, all students were native Cantonese speakers. Besides, there are no

medical reports about their hearing impairment that were provided from them. They roughly represented the typical listening audiences in classrooms.

2.4 Classroom acoustic measurements

The classroom acoustic measurement system in the current study was using DIRAC (B&K Type 7841) 6.0 system (as shown in Fig 3). DIRAC software is a widely used architecture acoustic software that is based on measurements and analysis of impulse response. In the current study, the impulse responses were measured by using MLS (Maximum Length Sequence) signal generated from internal DIRAC MLS source at the four listening positions in occupied and unoccupied classrooms. Impulse response was measured in one pass using intermittent MLS stimulus followed by an equally long period of silence. USB Audio Interface B&K ZE-0948 is a sound device for line-level interface to microphone and speaker systems. A sound level meter (B&K 2250) and an echo speech source (B&K 4720) were selected in the measurement. In the meantime, B&K 2270 sound analyzer was employed for measuring the BNLs at selected listening positions.

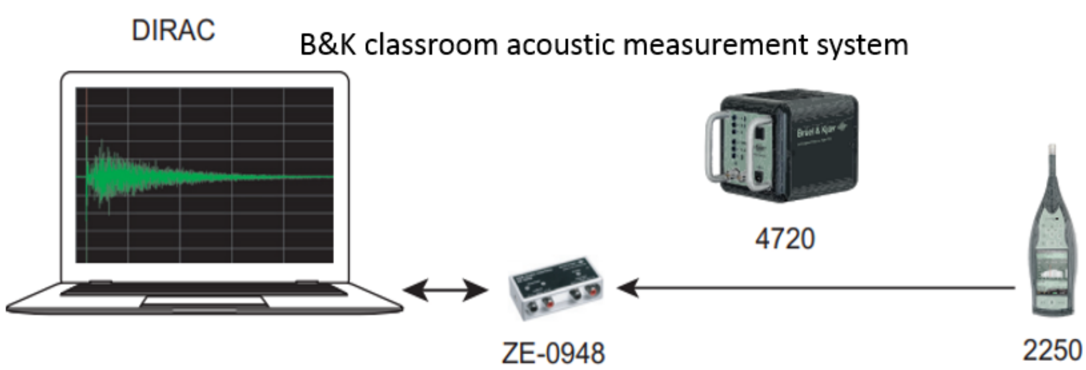

Fig 3 Dirac classroom acoustic measurement system (figure from B&K users' menu)

3. Results

3.1 Regression model

In order to clearly distinguish the effects of acoustical descriptors on speech intelligibility, regression models were discussed and studied variously in previous studies. Three primary forms of non-linear curve fitting regression models were employed in fitting curves in classroom acoustics. Bistafa and Bradley proposed a third-order polynomial equation to simplify the SIs with the SNR and other acoustic parameters [19]. Astolfi et al. pointed out a logarithmic model as the best fitting model to illustrate the relationships between speech intelligibility scores and acoustic descriptors [7]. Peng et al. revealed an "S" form regression function to describe the relationship between Chinese SIs and speech transmission index (STI) [9]. In this paper, the mentioned three regression models were employed and compared to describe the relationships between SIs and acoustical descriptors. The basic model functions of the mentioned three regression models were as follows:

$$y = a + bx + cx^2 + dx^3 \tag{1}$$

$$y = a + bln(x) \tag{2}$$

$$y = 100(1 - 10^{-x/a})^b \tag{3}$$

where a, b, c, and d are the regression parameters generated from the fitting process. Fig 4 shows the fitting curves based on the three mentioned regression models for the description of SIs and SNR values in university classrooms. The regression parameters and statistical characteristics were given in Table 3.

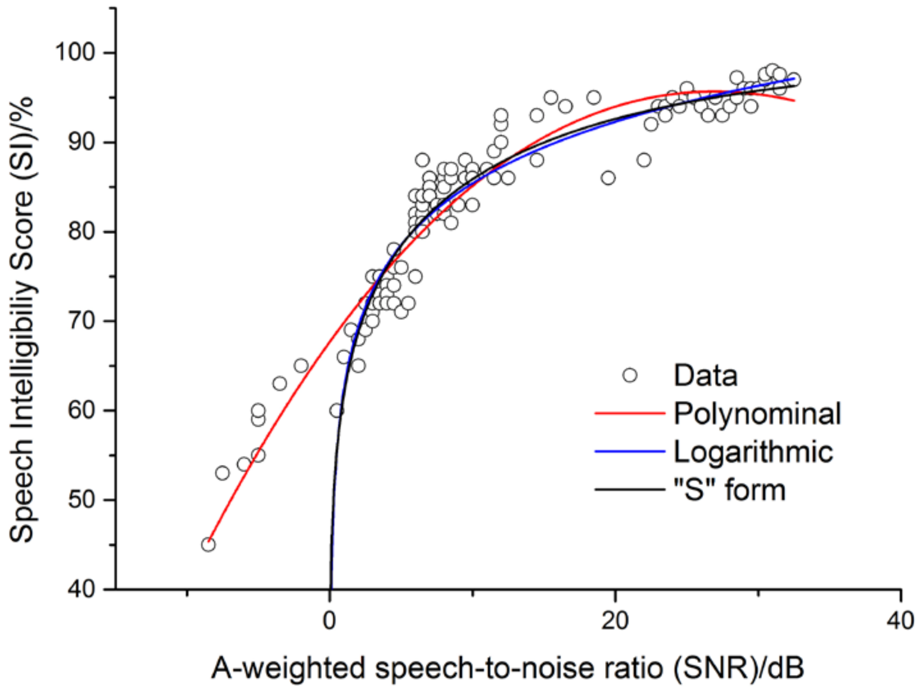

Fig 4 Comparison results of three regression models in university classrooms

Table 3 Regression parameters of the three regression models and statistical characteristics

	a	***b***	***c***	***d***	Adj. $\boldsymbol{R^2}$
Third-order polynomial	67.702	2.206	-0.481	0.002	0.924
Logarithmic	9.927	62.559			0.789
“*S*” form	48.790	0.156			0.786

Where Adj. R^2 denotes the adjusted R^2 which reveals the effects of the number of regression parameters and the fitting quality. As shown in Fig 4, the logarithmic model and *“S”* form model are significantly deviate from the plotted data when the SNR value approaches zero. The logarithmic regression model equation (2) was proposed by Astolfi et al. to describe the relationship between SIs and STI values. The STI values were constantly above zero in real classrooms. However, the SNR values are able to below zero in classroom measurements. Therefore, Eq. (2) need be modified to be appropriate for evaluating SIs and SNR values. As for the "S" form regression equation (3), the basic formula was similarly proposed by Peng et al. to illustrate the relationship between SIs and STI. According to the regression parameter results in Table 4, the values of a and b are both above zero. Therefore, two conditions should be discussed, x (SNR value) > 0 and $x < 0$, respectively. When $x > 0$, $0 < x/a < 1$. This condition is similar to that in evaluating STI. While $x < 0$, $x/a < 0$, $10^{-x/a} > 1$. Therefore, Eq. (3) need be modified to be appropriate for evaluating SIs and SNR values. According to the previous analysis, the modifications of Eq. (2) (3) can be added a constant c to avoid the mentioned derivate phenomenon as well as improve the fitting goodness. The modification regression models are given as follows:

$$y = a + bln(x + c) \tag{4}$$

$$y = 100(1 - 10^{-(x+c)/a})^b \tag{5}$$

Fig 5 shows the fitting curves based on the two modification regression models for the description of speech intelligibility scores and SNR values in university classrooms. The corresponding regression parameters and statistical characteristics were given in Table 4.

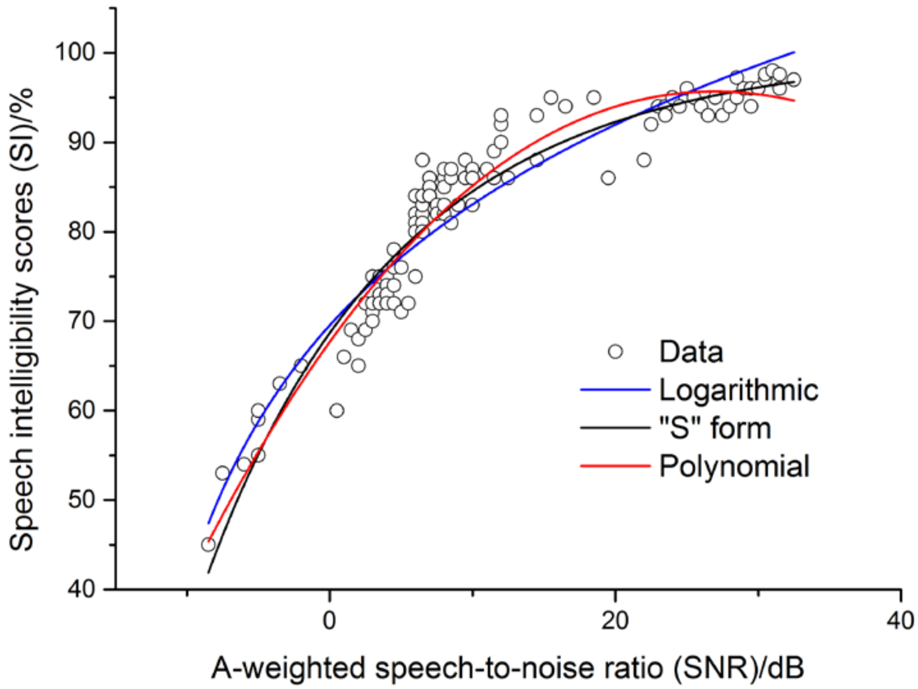

Fig 5 Comparison results of three regression models in university classrooms

Table 4 Regression parameters of the three regression models and statistical characteristics

	a	***b***	***c***	***d***	Adj. $\boldsymbol{R^2}$
Third-order polynomial	67.702	2.206	-0.481	0.002	0.924
Logarithmic	-2.174	26.482	13.879		0.893
"*S*" form	33.455	0.853	15.125		0.914

The modification regression fitting curves were plotted with data collected from university classrooms in Fig.5. Besides, the regression parameters were given in Table 4. The third-order polynomial regression curve (red line in Fig 5) can obviously be seen that it is not monotonically increased with the increase of SNR. The SIs in the logarithmic fitting curve (blue line in Fig 5) will be more than 100% when the SNR is greater than a certain value. Therefore, in the current study, the "*S*" form regression fitting model is employed to describe the relationships between SIs and SNR as well as other acoustic descriptors.

3.2 Effects of SNR on speech intelligibility

SNR is a critical factor in affecting speech intelligibility. The average SIs at listening positions versus A-weighted speech-to-noise ratios were plotted in Fig 6. They are plotted separately for the results collected from the occupied secondary school classrooms (Grade A, B, and C) and university classrooms.

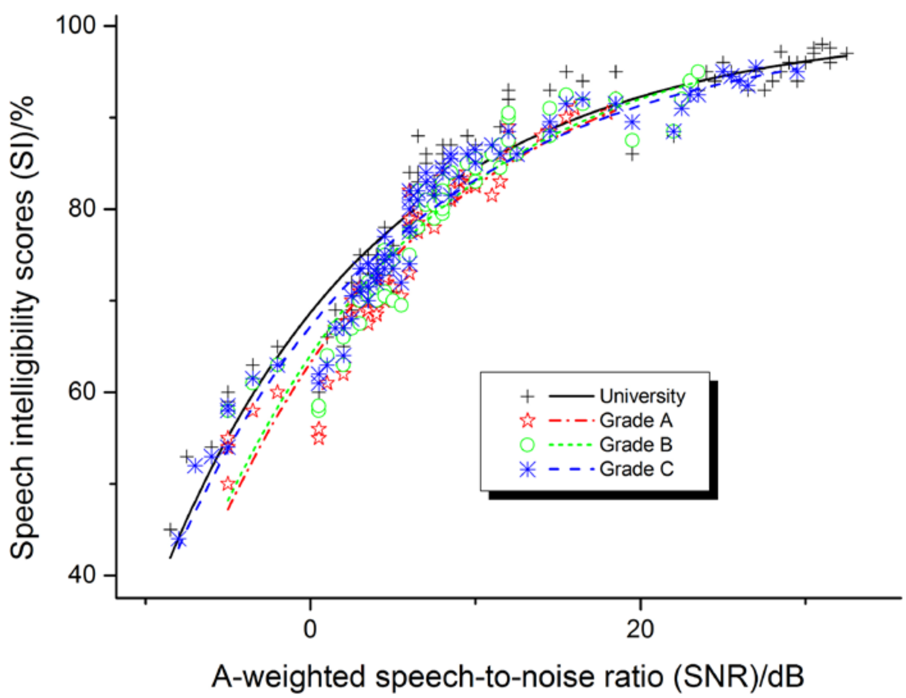

Fig 6 Relationships between speech intelligibility scores and SNR

The regression parameters and statistical characteristics are given in Table 5. An analysis of variance (ANOVA) indicated that there were highly significant main effects of age ($p<0.001$) and SNR ($p<0.001$) and a highly significant interaction effect of these two independent variables ($p<0.001$).

Table 5 Regression parameters of the results and statistical characteristics

	a	b	c	**Adj. R^2**	**Root-MSE**
University	33.455	0.853	15.125	0.914	3.433
Grade C	30.173	1.196	12.889	0.891	3.261
Grade B	30.112	1.166	13.815	0.884	3.378
Grade A	35.396	0.840	14.096	0.934	3.057

Where “Root-MSE” is an abbreviation of root-mean-square error.

Students from grade A, B, and C normally aged 13, 14, and 15, respectively. The undergraduates’ curves represent the participants from university aged from 19 to 23 (adults). Therefore, the younger students need significantly higher SNR values to obtain the same SIs as the older students in these classrooms.

3.3 Effects of early decay time (EDT) on speech intelligibility

The relationship of the SIs and SNR analyzed above excludes the effect of other acoustic descriptors. These acoustic descriptors include those parameters associated with the nature of reverberation (RT, EDT) and those parameters of energy balance between direct and delayed sound (Sound clarity C, Definition D). Multiple regression analyses were employed to analyze SNR values and one of the room acoustics parameters to investigate the additional effects of classroom acoustic parameters on SIs. EDT is defined as the time in which the first 10 dB fall of a decay curve occurs, multiplied by a factor 6. Since the EDT is strongly influenced by the early energy (which can vary significantly from seat-to-seat), the EDTs for a given space vary in value more than RT. A short EDT provides an acoustical advantage for communicating in a reverberant space. Fig 7 illustrates the multiple regression analyses fitting results for speech intelligibility scores versus SNR and EDT values.

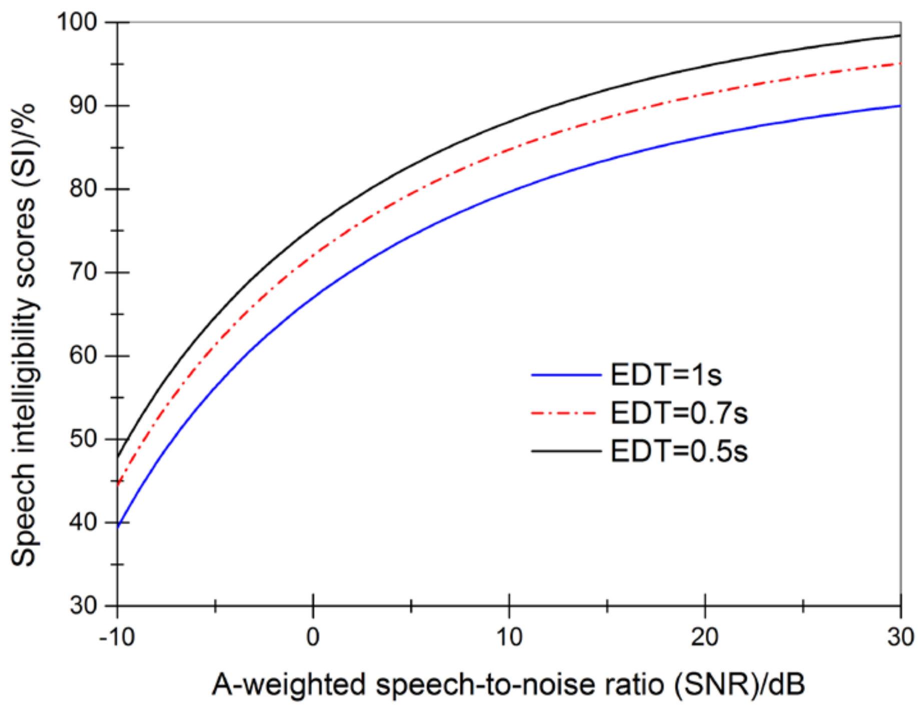

Fig 7 Combination effects of SNR and EDT on SIs

The regression equation in Fig 7 is given as follows:

$$y = 100(1 - 10^{-(SNR+14.8)/41.5})^{0.57} - 16.78EDT + 11.6 \quad (6)$$

The regression curves in Fig 7 were based on this same regression equation. SIs in university classrooms versus SNR and 1000Hz EDT values of 0.5s, 0.7s, and 1s, were plotted separately. The results indicate that nearly 0.06s increasing in EDT values will result in a 1% decrease in SIs.

3.4 Effects of sound clarity (C_{80}) on speech intelligibility

C_{80} is expressed in dB, and it is related to the attribute clarity. It is an objective descriptor of the clarity or speech intelligibility. The basis for C_{80} is the fact that late reflections are unfavorable for speech intelligibility because it causes speech sounds to merge, making speech unclear. However, if the delay does not exceed a certain time limit, the reflections will contribute positively to the intelligibility. The definition of C_{80} is shown as follows:

$$C_{80} = 10log\frac{\int_0^T h^2(t)dt}{\int_T^\infty h^2(t)dt}$$

Where “T” is time (80ms) elapsed after the arrival of the direct sound wave, and $h(t)$ is the impulse response. Fig 8 illustrates the multiple regression analysis fitting results for speech intelligibility scores versus SNR and C_{80} values.

$$y = 100(1 - 10^{-(SNR+15.2)/35.7})^{0.72} + 1.23C_{80} - 7.81 \quad (7)$$

The regression curves in Fig 8 were based on this same regression equation. SIs in university classrooms versus SNR and 1000Hz C_{80} values of 3 dB, 6 dB, and 9 dB were plotted separately. The results indicate that 1 dB increasing in C_{80} values will result in a 1.23% increase in speech intelligibility scores.

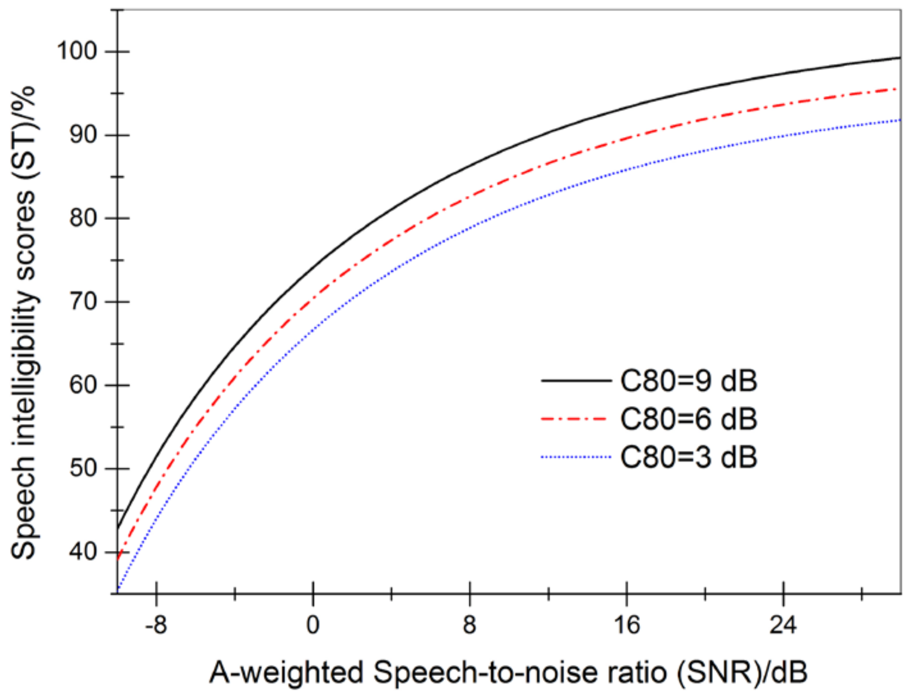

Fig 8 Combination effects of SNR and C_{80} on SIs

4 Discussion

4.1 Comparison with other studies

A set of comparisons of the proposed regression curves with other studies were discussed in the following section. However, these studies used different sample sizes, age groups of the respondents, the language, and test materials from the current work. Both similarities and differences were listed for a comparison between the previous studies and the current study.

Previous studies proposed regression curves for evaluating SNR as well as RT effects on speech intelligibility scores. Bradley [3] used a Fairbanks rhyme test to obtain English speech intelligibility results from Grade 7-8 students (12-13 years old) in ten classrooms in Canada. The regression curve was described by the quadratic regression curve to evaluate the results. Peng [10] used Chinese rhyme test word lists to obtain Chinese speech intelligibility scores from undergraduate students (aged 20-24) in China. The regression equation was similarly described by the quadratic regression curve. The regression equations of the mentioned studies were given as follows:

Bradley (1986): $$\mathrm{SI} = 2.26\mathrm{SNR} - 0.0888\mathrm{SNR}^2 - 13.95RT + 95 \quad (8)$$

Peng (2010): $$\mathrm{SI} = 3.12\mathrm{SNR} - 0.064\mathrm{SNR}^2 - 6.15RT + 57.2 \quad (9)$$

As shown in Eq. (8) (9), combination effects of SNR and RT were concluded by using quadratic regression curves in previous studies. Although the regression models were selected differently, the basic increasing trends of the SNR and RT (EDT) values were similar to the current results. The better SNR values and less RT (EDT) values are needed to obtain higher speech intelligibility scores. However, the significance of reverberation values is distinct in the regression equation (6) (8) (9). As shown in Eq. (6) nearly 0.06s increasing in EDT values will result in a 1% decrease in SIs. The value of changing of RT in Eq. (8) (9) are 0.07s and 0.16s respectively. This means in the current study, the reverberation condition of the classrooms more easily influences the students. Since the quadratic regression model is a parabola curve. The symmetry axis in Eq. (8) (9) are SNR= 12.7dB and 24.4dB respectively. This means under a constant RT condition, and the speech intelligibility scores will decrease with the increase of SNR values, which are above the corresponding symmetry axis. This conclusion was different from the results in the current study. Eq. (6) reveals that the speech intelligibility scores will increase continuously with the increase of SNR values under a constant EDT condition. As shown in Fig 7, the slope of the regression curve will decrease with the increase of SNR values under a constant EDT condition. This means that with the increase of SNR values, the rate of the increase of speech intelligibility scores will be reduced.

The combination effects of SNR and sound clarity (C_{50}, C_{80}) were investigated on speech intelligibility scores in several studies. Bradley and Sato [5] used Word Identification by Picture Identification (WIPI) tests to obtain English speech intelligibility results from Grade 1, 3, and 6 students in 41 classrooms of twelve different schools in Canada. A quadratic regression model was employed for evaluating the results. Choi [20] used Korean standard-monosyllabic tests to obtain Korean speech intelligibility results from 12 university classrooms in Korea. A linear regression model was employed for evaluating the results. The regression equations of the mentioned studies were given as follows:

Bradley and Sato (2008): $$\mathrm{SI} = 0.772\mathrm{SNR} - 0.0189\mathrm{SNR}^2 + 1.53C_{50} + 74.46 \quad (10)$$

Choi (2020): $$\mathrm{SI} = 14.69\mathrm{SNR} + 2.92C_{50} + 34.91 \quad (11)$$

As shown in Eq. (10) (11), the regression results for the effects of SNR and sound clarity were proposed by various regression models. Similarly, the primary trend effects of the two independent variables in the mentioned formulas are the same as the proposed equation (Eq. 7) in this work. The better SNR values and better C_{50} (C_{80}) values are positive to obtain higher speech intelligibility scores. However, the significance of sound clarity values is distinct in the regression equations (7) (10) (11). As shown in Eq. (7) nearly 1dB increasing in C_{80} values will result in a 1.23% increase in SIs. While the values changing of C_{50} in Eq. (10) (11) are results in 1.53% and 2.92% increase in speech intelligibility scores respectively. This means in the current research, and the students are uneasily influenced by sound clarity of the classrooms. As the regression results of Eq. (10) is a parabola curve with a constant sound clarity value. The symmetry axis of Eq. (10) is SNR= 20.4dB under a constant sound clarity value. Since the sound clarity values can hardly reach upon 20.4 dB in the measurements of real classrooms. The Eq. (10) can be seen as a monotonically increasing function with a constant sound clarity value. It is similar to the results in Eq. (7) (11) with a constant sound clarity value. However, the changes in slopes in the three mentioned equations are distinguished. In Eq. (11) proposed by Choi, the slope of the SNR regression curve with a constant sound clarity value is constant. While in Eq. (7) (10), the slopes are gradually decreased with the increase of SNR under a constant sound clarity condition. This means that with the increase of SNR values, the rate of the increase of SIs will be reduced in Eq. (7) (10).

4.2 The influence of age effects and linguistic environment on speech intelligibility

The best-fit curves between SIs and SNR value for different age groups were given in Fig 6. The regression parameters are given in Table 5. The undergraduates' curves represent the participants from university aged from 19 to 23 (adults). "S" form-fitting model curves were used as the regression models. It is seen from Fig 6 that the SIs increase as the age increases under the same SNR condition. Fig 9 compared the proposed regression curves for the combination of reverberation condition and SNR with those curves obtained by Bradley [3] and Peng [10]. Furthermore, Fig 10 compared the proposed regression curves for the combination of sound clarity and SNR with those curves obtained by Bradley and Sato [5]. Results are given for RT (EDT) values (0.5s and 1s) and C_{80} (C_{50}) values (3dB and 6 dB), which are roughly corresponding to the range of frequently found conditions in the measured classrooms. It is obviously shown from Fig 9 that speech intelligibility scores are always lower than the comparison research results with a constant RT (EDT) value for an equal SNR value. Similar results can be obtained from Fig 10 that speech intelligibility results are always lower than the results in the reference with a constant sound clarity value for an equal SNR value. As the results in the mentioned references were obtained from their native language speech intelligibility tests. The results in the current study were obtained from English speech intelligibility tests. It is mainly because English is the official educational language in Hong Kong, while it is not the native one. The special linguistic environment results in a better acoustical environment are needed for students in Hong Kong.

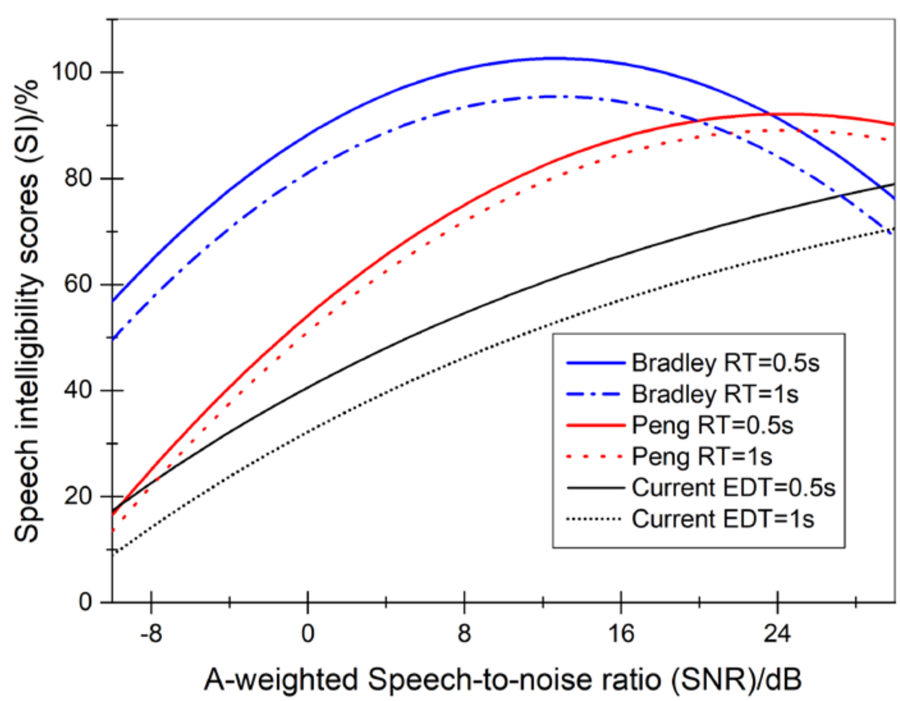

Fig 9 Comparison of combination effects of SNR and reverberation condition

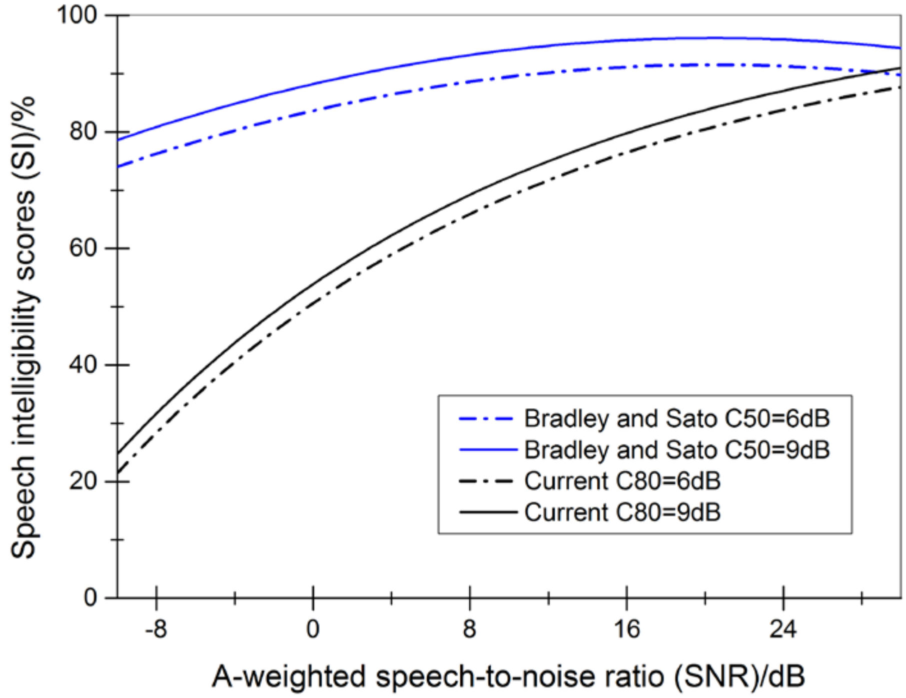

Fig 10 Comparison of combination effects of SNR and sound clarity

5 Conclusion

This study proposes data analyses that describe the speech intelligibility of students from secondary school and university to understand speech with noise and reverberation in real classrooms. 9 secondary school classrooms and 18 university classrooms were selected for speech intelligibility tests on total 672 students in Hong Kong. PB word lists were employed for speech intelligibility tests, while objective acoustical measurements were conducted in the same classrooms. Several findings emerged from the data analyses as follows:

(1) Three basis regression models were compared in the current work for evaluating the relationship between SIs and SNR values. "S" form regression curves were selected to describe SI versus SNR for grade A, B, C, and university students.

(2) Combined effects of SNR and EDT, as well as C_{80} were discussed based on "S" form regression curves. The results indicate that nearly 0.06s increasing in EDT values will result in a 1% decrease in SIs. Furthermore, the results also indicate that 1 dB increasing in C_{80} values will result in a 1.23% increase in SIs.

(3) The influence of age effects and linguistic environment were also discussed. The SIs increase as the age increases under the same SNR condition. The SIs are always lower than the comparison research results with a constant reverberation value as well as sound clarity value for an equal SNR value.

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