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Letter to the Editor

Speech transmission index or rapid speech transmission index for classrooms? A designer's point of view

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1. Introduction

Classrooms, especially those related to the early development of individuals, are very important nowadays as they play a crucial role in the development of human characters and the attitude towards learning, both of which eventually define whether or not an individual will have a successful life. It is therefore very important that a high level of speech intelligibility inside classrooms can be achieved so that the communications between teachers and students and the passing of instructions from teachers to students can be effective. This must be done in the design stage as it is usually more difficult and very costly to correct for acoustic defect after the construction is completed.

Research suggests that speech intelligibility can be described by several indices which take into account the room reverberation and the background noise level. Examples of which include the articulation index [1], the speech transmission index (*STI*) [2], the percentage articulation loss of consonants ($\%AL_{con}$) [3] and the useful-to-detrimental sound ratio (U_{50}) [4], among which the *STI* and the $\%AL_{con}$ appear to be the more common ones adapted in the acoustic profession. The results of Bradley [5] indicate that there are substantial correlation between *STI*, $\%AL_{con}$ and U_{50}, implying that these indices are equivalent in the assessment of speech intelligibility. The rapid speech transmission index (*RASTI*) was developed in the 1980s by Houtgast and Steeneken [6] as a quick mean for the estimation of the speech intelligibility. The principles of *STI* and *RASTI* are very similar except that the calculation of the latter requires information from the 500 Hz and 2 kHz octave frequency bands only such that the measurement time is substantially shortened. *RASTI* has been used in many studies related to speech intelligibility in indoor spaces 4(for instance, Refs. [7,8]).

The advances in measurement technology and the computer nowadays make it possible to estimate both the *STI* and *RASTI* from a captured pulse decay in an enclosure within seconds [9] and thus, the idea of 'rapid' for *RASTI* is no longer meaningful. However, the speech intelligibility in a room cannot be predicted in the design stage without information of the octave band background noise levels and the room reverberation, but the former may not be precisely known

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in reality. The room reverberation is quantified by the sound absorption or the reverberation time in practice. In simple building acoustic consideration, the absorption and reverberation times are related through the Sabine's formula [10] and they are known in the design stage. Computation may help, but the validation of the computed results can be problematic and the process can be costly as well. A confident relationship between reverberation times and the *STI* or *RASTI* will be beneficial to acoustic design.

An earlier study by the authors shows that there exists reasonable correlation between reverberation times and the *STI* in modern classroom environment in Hong Kong though there are variations in the background noise levels [11]. Similar correlation between *RASTI* and reverberation time has also been observed by Carvalho [8] in churches. However, it is unclear whether the *RASTI* will give similar or even better correlation in the classrooms. This forms the main objective of the present study.

2. Site measurements

In the present study, pulse decays were measured in the classrooms of 18 government subsidized schools. Most of them are modern schools. The architectural layouts and the furnishing of the classrooms in these schools are very much standardized. The measurements and the calculations of the *STI*, the *RASTI* and the reverberation times were done by the software DIRAC [9] together with the sound analyzer Brüel & Kjær 2260B, which captured the sound pulse decay signals to the software and measured the octave band background noise levels. Measurements were carried out after school hours or on school holidays to minimize the influence of school activities on the pulse measurements. At least six measurements at different locations were carried out in each classroom under each operation condition (described later).

The pulses were created by bursting inflated balloons at the mouth level of an adult in front of the blackboards and the pulse decay patterns were captured at the ear level of the seated students. The types of classrooms include the general teaching rooms, computer rooms, music rooms and the laboratories. The sound absorption in the general teaching rooms and laboratories is very limited, while carpets and chairs with sound absorption materials are usually found in the computer rooms. There is some absorption in the music rooms.

Three normal conditions of the classrooms are considered. The first one is 'window closed, air conditioning off' (C1). This reflects the fundamental classroom acoustics. The second condition is 'window closed, air conditioning on' (C2), which is the summer operation mode of the classrooms. This rises up the background noise levels while the room reverberation is not much affected. The last condition is 'window opened, air conditioning off' (C3). This is the most usual operation mode of the classrooms in Hong Kong. The reverberation is reduced, but the unsteady external noise is allowed to go into the classrooms. The classrooms are basically rectangular. Table 1 summarizes the geometrical information of the classrooms.

3. Overall octave band statistics

Table 2 illustrates the basic statistics of the octave band spectral levels and the reverberation times within the frequency range related to speech intelligibility study. One can notice that in all

Table 1
Statistics on classroom dimensions

		Classroom[a]			
		GT	LA	MU	CO
Floor area (m^2)	Mean	60.8	104.3	59.6	57.6
	S.D.	7.9	4.8	19.0	14.1
	Maximum	73.0	108.0	94.5	87.7
	Minimum	45.5	95.4	42.0	46.7
Surface area (m^2)	Mean	216.0	331.9	211.3	206.5
	S.D.	21.2	12.7	52.4	39.4
	Maximum	249.8	342.0	306.0	289.4
	Minimum	172.0	308.4	162.0	175.6
Volume (m^3)	Mean	183.2	312.9	178.7	172.8
	S.D.	22.6	14.3	57.0	42.4
	Maximum	219.0	324.0	283.5	263.1
	Minimum	136.5	286.2	126.0	140.1

[a] GT: general teaching, LA: laboratory, MU: music room, CO: computer room.

cases, the octave band levels and reverberation times decrease with frequency. As expected, the background noise levels in the C1 cases are the lowest, while the air conditioning noise is more significant in affecting the noise levels in the classrooms than the external noise transmission in the C3 cases. The background noise levels in the C2 cases, which are due to air conditioning, appear to be steady all over the classrooms surveyed.

It can also be observed from Table 2 that the reverberation times in the C3 cases (windows opened) are the lowest for each type of classroom. The opened windows allow sound to escape from the classrooms and thus effectively increase the apparent sound absorption in these rooms. The average reverberation times in the laboratories are the longest since there are usually not much sound absorption installed in them. Those of the computer rooms are the shortest as the chairs are made of soft materials and the corresponding floors covered with carpets.

4. Regression analysis

In the design stage of a classroom, either the octave band sound absorption or the reverberation times are known and the target is to design for a satisfactory speech transmission performance. Therefore, only room-averaged data will be considered in the foregoing discussions.

Fig. 1 shows that there is a substantial correlation between *STI* and the *RASTI* in the surveyed classrooms when the windows were closed without air conditioning (C1). Though there are considerable scattering in the C2 and C3 conditions at $STI < 0.65$, such correlation remains reasonable well for site measurement data.

Table 2
Octave band data statistics

Classrooms	Operation mode	Octave band centre frequency (Hz)	Background noise level (dB)				Reverberation time (s)			
			Mean	S.D.	Max.	Min.	Mean	S.D.	Max.	Min.
GT	C1	250	47.2	6.2	69.8	34.7	1.13	0.36	2.24	0.52
		500	42.1	5.4	58.1	30.0	0.98	0.28	1.78	0.45
		1000	40.0	5.7	55.8	28.5	0.96	0.31	1.68	0.36
		2000	36.9	5.7	54.1	25.5	0.96	0.31	1.44	0.37
		4000	30.8	4.9	51.6	20.0	0.86	0.26	1.22	0.37
	C2	250	59.7	5.1	78.1	47.2	1.17	0.36	2.28	0.46
		500	54.9	4.4	61.8	44.3	1.01	0.29	1.69	0.32
		1000	52.2	4.3	60.0	40.6	0.98	0.31	1.58	0.36
		2000	47.7	4.5	57.0	34.1	0.98	0.30	1.50	0.36
		4000	41.3	4.7	49.2	26.7	0.88	0.25	1.21	0.37
	C3	250	55.3	5.3	75.2	42.6	1.00	0.30	1.71	0.38
		500	52.4	4.8	66.4	41.3	0.87	0.24	1.38	0.39
		1000	51.4	5.2	62.7	41.3	0.87	0.26	1.31	0.36
		2000	47.5	5.4	60.6	37.3	0.86	0.25	1.25	0.33
		4000	40.7	5.5	58.4	31.4	0.78	0.22	1.07	0.33
MU	C1	250	48.1	3.4	57.4	38.7	1.29	0.51	2.54	0.56
		500	43.7	4.0	50.8	30.4	1.03	0.46	2.00	0.40
		1000	41.2	4.5	53.2	27.0	0.99	0.44	1.84	0.39
		2000	36.9	4.7	51.7	23.0	0.98	0.41	1.74	0.44
		4000	30.6	4.6	45.8	20.7	0.89	0.34	1.54	0.43
	C2	250	58.4	4.3	66.3	49.5	1.29	0.53	2.70	0.47
		500	54.0	3.9	61.3	43.2	1.02	0.45	2.03	0.38
		1000	51.3	3.7	57.7	42.2	0.99	0.43	1.87	0.41
		2000	47.2	4.1	54.2	37.6	0.98	0.41	1.78	0.43
		4000	40.9	4.5	50.8	30.8	0.88	0.33	1.53	0.37
	C3	250	55.2	4.0	66.2	44.8	1.08	0.43	2.16	0.37
		500	51.7	4.7	64.8	41.2	0.88	0.38	1.71	0.37
		1000	50.1	5.3	64.8	38.4	0.86	0.37	1.60	0.38
		2000	45.3	5.5	60.7	33.6	0.85	0.34	1.50	0.41
		4000	37.8	5.4	53.5	26.1	0.77	0.27	1.31	0.42
LA	C1	250	48.0	5.0	64.0	39.1	1.56	0.23	2.02	1.13
		500	44.1	5.5	57.4	34.1	1.45	0.22	1.86	1.09
		1000	43.0	7.0	59.2	33.8	1.49	0.19	1.81	1.19
		2000	38.6	7.5	57.6	29.9	1.47	0.16	1.74	1.20
		4000	32.8	7.1	52.2	21.5	1.32	0.15	1.54	1.12
	C2	250	61.4	3.8	66.8	46.6	1.63	0.32	2.41	0.92
		500	57.2	3.6	62.8	44.2	1.48	0.25	2.04	1.02
		1000	54.9	3.1	60.7	41.4	1.54	0.22	1.96	1.16

Table 2 (*continued*)

Classrooms	Operation mode	Octave band centre frequency (Hz)	Background noise level (dB)				Reverberation time (s)			
			Mean	S.D.	Max.	Min.	Mean	S.D.	Max.	Min.
		2000	50.9	3.3	56.6	37.7	1.49	0.17	1.75	1.19
		4000	45.1	3.4	52.1	33.6	1.33	0.15	1.54	1.12
	C3	250	56.8	4.6	66.8	48.9	1.37	0.21	1.74	0.92
		500	53.9	4.0	64.1	43.8	1.33	0.21	1.72	0.87
		1000	51.8	4.5	63.7	42.1	1.37	0.16	1.78	1.10
		2000	47.3	4.9	62.6	39.2	1.33	0.11	1.49	1.09
		4000	40.4	5.3	57.2	32.7	1.21	0.11	1.38	1.06
CO	C2	250	55.9	4.9	65.9	46.9	0.90	0.20	1.14	0.47
		500	53.3	4.2	62.5	46.6	0.81	0.17	1.24	0.56
		1000	51.5	3.0	57.7	45.3	0.83	0.18	1.33	0.56
		2000	46.7	3.5	53.8	38.8	0.83	0.21	1.46	0.55
		4000	40.4	4.1	48.6	33.2	0.77	0.19	1.14	0.46

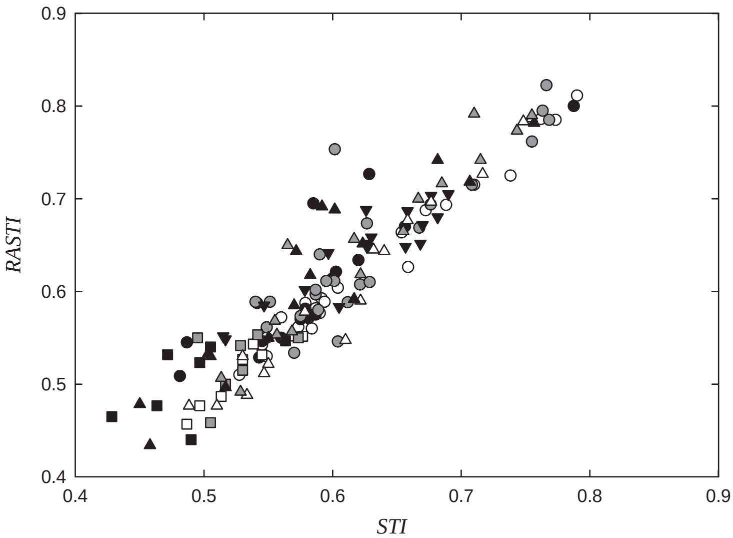

Fig. 1. Correlation between the *STI* and the *RASTI*. ○, General teaching rooms; □, laboratories; △, music rooms; ▽, computer rooms; opened symbols, C1; black symbols, C2; gray symbols, C3.

Figs. 2a and b manifest the significant correlation between *RASTI* and the reverberation times in the 1 and 2 kHz octave bands. A regression analysis involving 100 different simple curve forms suggest the curve of the form $RASTI = a - b\log_{10}(RT)$ best fits the measured room-averaged data. The regression lines are also shown in Fig. 2. The corresponding regression results of these 100 curve forms have no bearing with the present study and thus are not presented. The same is

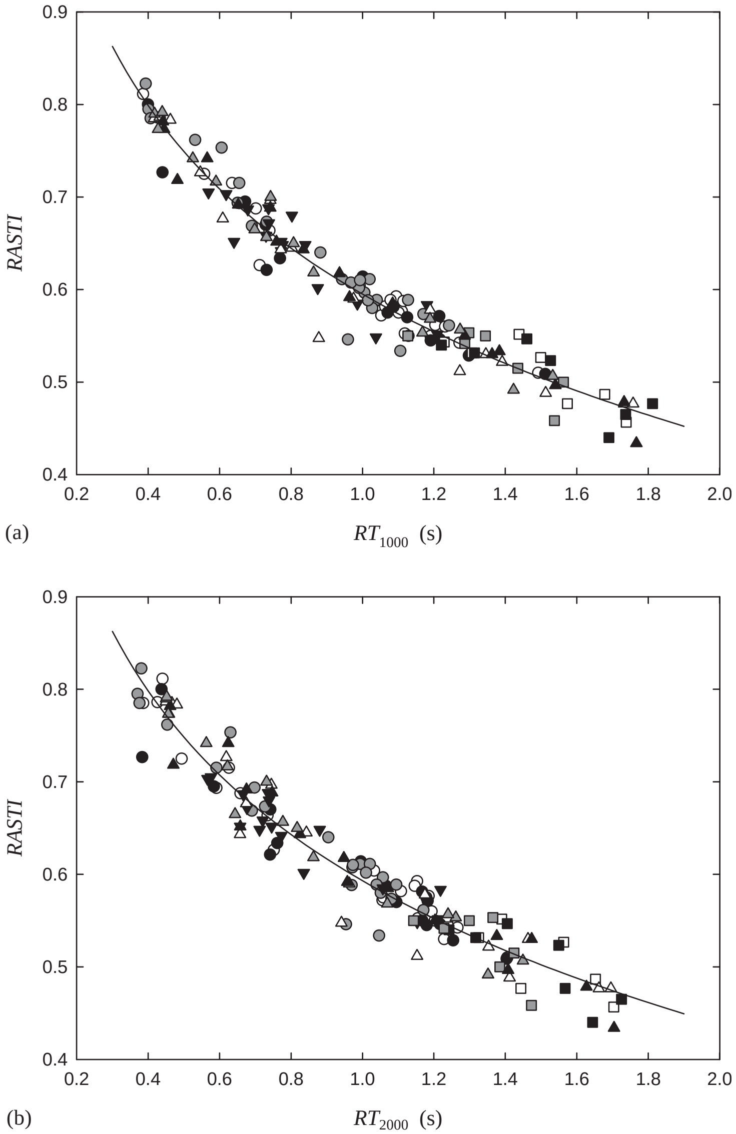

Fig. 2. Examples of correlation between the reverberation times and the *RASTI*. (a) 1 kHz octave band; (b) 2 kHz octave band; ○, general teaching rooms; □, laboratories; △, music rooms; ∇, computer rooms; opened symbols, C1; black symbols, C2; gray symbols, C3. ———, regression line.

also true when the *STI* is concerned. The definition of the *STI* or the *RASTI* also tends to favor regression formulae involving the logarithm of reverberation times.

Both the *STI* and the *RASTI* depend on the information in several octave bands. It is then important to check whether or not the apparently strong correlation observed in Fig. 2 can be improved by considering broadband reverberation times. Certainly, the frequency ranges included in these broadband parameters should be related to those currently used in building acoustics. In the present study, the following broadband reverberation times are defined using octave band reverberation times:

$$RT_{speech} = (RT_{250} \times RT_{500} \times RT_{1000} \times RT_{2000} \times RT_{4000})^{1/5}, \quad (1)$$

$$RT_{SIL} = (RT_{500} \times RT_{1000} \times RT_{2000} \times RT_{4000})^{1/4}, \quad (2)$$

$$RT_{mid} = (RT_{500} \times RT_{1000})^{1/2}, \quad (3)$$

and

$$RT_{rasti} = (RT_{500} \times RT_{2000})^{1/2}. \quad (4)$$

The first one, RT_{speech}, refers to the mean reverberation time within the whole speech frequency range [10]. The frequency bands included in the estimation of the RT_{SIL} correspond to those used for the calculation of speech interference level [10], which is expected to have influence on the speech communication in enclosed space. The third one, RT_{mid}, represents an average over the mid-frequency range. The last one is specially defined here as the *RASTI* depends only on reverberation information in the 500 and 2000 Hz octave bands [6]. Geometric averages appear, to the opinion of the authors following the definition of the *STI* [12], to be better than the arithmetic averages in the present application.

The regression results for the *STI* and the *RASTI* are summarized in Table 3a and b, respectively. The corresponding F-test results for the regressions at 95% confidence level [13], F,

Table 3
Regression between reverberation times and (a) the *STI* and (b) the *RASTI*

Reverberation time	a	b	R^2	F	Standard error
(a) *Regression formula*: $STI = a - b\log_{10}(RT)$					
RT_{250}	0.6191	0.4425	0.7389	424.5	0.04
RT_{500}	0.5895	0.4422	0.8300	732.5	0.03
RT_{1000}	0.5868	0.4269	0.8715	1017.6	0.03
RT_{2000}	0.5851	0.4316	0.8635	949.0	0.03
RT_{4000}	0.5665	0.4626	0.8492	844.7	0.03
RT_{speech}	0.5890	0.4595	0.8662	970.8	0.03
RT_{SIL}	0.5818	0.4493	0.8710	1013.1	0.03
RT_{mid}	0.5880	0.4386	0.8594	917.0	0.03
RT_{rasti}	0.5870	0.4458	0.8644	956.2	0.03
(b) *Regression formula*: $RASTI = a - b\log_{10}(RT)$					
RT_{250}	0.6338	0.5308	0.8118	646.8	0.04
RT_{500}	0.5981	0.5354	0.9292	1969.4	0.02
RT_{1000}	0.5951	0.5121	0.9574	3374.1	0.02
RT_{2000}	0.5931	0.5154	0.9401	2355.1	0.02
RT_{4000}	0.5710	0.5506	0.9185	1690.0	0.03
RT_{speech}	0.5977	0.5509	0.9505	2878.0	0.02
RT_{SIL}	0.5891	0.5385	0.9556	3224.9	0.02
RT_{mid}	0.5964	0.5285	0.9527	3023.4	0.02
RT_{rasti}	0.5952	0.5360	0.9539	3105.7	0.02

are also given. One can find that correlation between reverberation times, no matter they are defined using Eqs. (1)–(4) or are referred to single octave bands, with the *RASTI* is considerably better than that with the *STI* in the present classroom environment. The broadband reverberation times and the 1 kHz octave band reverberation time correlate especially well with the *RASTI*. This conclusion does not depend on the classroom function and the operation condition as already shown in Figs. 1 and 2. It can also be observed from Table 3 that all the broadband versions of the reverberation times correlate nearly equal well with the *RASTI*, but there is a small difference if the *STI* is considered. The better correlation between *RASTI* with reverberation times (and thus room absorption) and its weaker dependence on broadband information suggest that the *RASTI* is more suitable to be set as a design target for classrooms. Results obtained with arithmetic averages of the octave band reverberation times produce the same conclusions. In the present ranges of octave band reverberation times, the geometrically averaged broadband reverberation times do not practically differ from those obtained by the arithmetic averaging (not shown here).

5. Conclusions

In the present study, site measurements of reverberation were performed in the classrooms of 18 government subsidized primary and secondary schools in Hong Kong. Most of them have standardized architectural layouts and room furnishing. Classrooms for general teaching, laboratory, computer learning and music were included. The relationships between the measured reverberation times, the speech transmission indices and the rapid speech transmission indices are compared.

Results suggest that regardless the sizes, the operation condition and the usage of the classrooms, the rapid speech transmission index correlates significantly better with the single octave band and broadband reverberation times than the speech transmission index in the present classroom environment. Also, the correlation between the rapid speech transmission index and the broadband reverberation times appears to be less dependent on the number of frequency bands included. The overall results of the present study suggest that the rapid speech transmission index is more suitable to be the design target in term of speech intelligibility in classrooms.

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