

Noise levels in an urban Asian school environment

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Abstract

Background noise is known to adversely affect speech perception and speech recognition. High levels of background noise in school classrooms may affect student learning, especially for those pupils who are learning in a second language. The current study aimed to determine the noise level and teacher speech-to-noise ratio (SNR) in Hong Kong classrooms. Noise level was measured in 146 occupied classrooms in 37 schools, including kindergartens, primary schools, secondary schools and special schools, in Hong Kong. The mean noise levels in occupied kindergarten, primary school, secondary school and special school classrooms all exceeded recommended maximum noise levels, and noise reduction measures were seldom used in classrooms. The measured SNRs were not optimal and could have adverse implications for student learning and teachers' vocal health. Schools in urban Asian environments are advised to consider noise reduction measures in classrooms to better comply with recommended maximum noise levels for classrooms.

Keywords: Classroom noise, sound-field amplification, teacher vocal health

Introduction

Background noise refers to sounds that hinder an individual's ability to listen to what they want or need to hear.^[1] Classroom background noise can arise from several possible sources, including external noise (such as traffic noise), internal noise (students running in corridors), and room noise (such as students talking).^[2] Studies have shown that noise has direct negative effects on student learning, with language and reading development particularly affected.^[3-6] There are also problems related to attention, memory and motivation.^[7] In order to compensate for the noise level in classrooms, teachers often have to speak loudly while teaching. Such a speaking habit is known to be a risk factor that may lead to voice disorders in teachers.^[8] It is crucial to address the background noise in classrooms so that both students and teachers may learn and work in a healthy environment.

Background noise in classrooms has become an important field of research.^[9] On-going research has identified a number of common noise sources, including external traffic noise and interior noise from school heating, ventilation

and air-conditioning systems. Past Western studies have consistently reported that the noise level in classrooms did not meet the appropriate standards and that levels in unoccupied classrooms could be as high as 65 dBA.^[10] The noise in occupied classrooms was higher, and some studies even suggested that the cumulative occupational noise exposure of teachers could cause hearing impairment. For example, the mean all-day noise level for 3 day care centers in Sweden was 82.6 dBA.^[11] Maffei *et al.*^[12] reported that physical education and music teachers could reach a weekly noise exposure of 80 dBA and 87 dBA, respectively. However, as yet little is known concerning the long-term effects of occupational noise exposure in school environment. Noise exposure has been measured in diverse ways, and estimates of damage risk criteria are difficult to make for nonindustrial noise spectra.^[13]

A number of factors related to the noise level have been suggested in past studies [Table 1], but the results showed considerable variability. Broadly speaking, the factors may relate to:

1. The classrooms (e.g., classroom design, age of school building, location of classroom, classroom dimensions),
2. The students (e.g., grade level, gender, number of students in class), or'
3. The activity level in the class.

A review from Picard and Bradley^[3] compared the noise levels reported in day-care centers, kindergartens, elementary schools and junior high schools. They found a 10 dB reduction in noise levels with increasing academic year. Smaller class

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Table 1: Representative studies on factors affecting noise levels in schools

Study and country	Number and types of classrooms	Factors investigated	Results
Lundquist, <i>et al.</i> , Sweden ^[17]	24 classrooms at 3 upper elementary schools (grade 6-9)	External noise, class subjects, class size, grade of students	External noise was negligible. Noise levels differed with class subjects. Noise appeared to increase with class size, but correlation was not statistically significant. No difference in noise levels by grade
Mendel <i>et al.</i> , United States ^[18]	14 kindergarten classrooms	Presence of students	Occupied classrooms were significantly noisier than unoccupied ones
Shield and Dockrell, United Kingdom ^[14]	140 primary classrooms	Presence of students, class size, student's age, activity level, age of school building	Occupied classrooms noisier than unoccupied ones. A significant correlation between class size and noise levels (for class size >18). Noise increased with activity level and in several schools, decreased with age of students. Older schools had slightly higher noise levels, but sample size was too small
Zannin, <i>et al.</i> , Brazil ^[19]	4 elementary classrooms	Activity in adjacent classrooms	Activity in adjacent classrooms increased noise levels in measured classroom
Sato and Bradley, Canada ^[20]	27 primary classrooms	Activity level, class grade	Noise level increased with higher activity level. Influence of grade levels was not significant
Zannin and Zwirter, Brazil ^[21]	5 classrooms in 5 public schools (ages 11-14)	School design	Close proximity of classrooms to schoolyards and sports courts increased background noise in classrooms
Mohan and Rajagopal, India ^[22]	120 classrooms in 25 schools	External noise	External noise had a significant effect on background noise in unoccupied classrooms with opened windows
Golmohammadi <i>et al.</i> , Iran ^[23]	244 classrooms in 90 primary, secondary and high schools	Gender of students and outdoor district noise	Boy schools were significantly noisier than girl schools. Outdoor noise did not significantly affect the indoor noise levels
Kristiansen <i>et al.</i> , Denmark ^[24]	10 secondary schools	Class size, age of students and teacher seniority	Larger class size, younger students and lower teacher seniority increased the self-reported noise exposure of teachers

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size was also found to have reduced noise levels.^[14] For activity level, both Western and Asian studies have found that occupied classrooms were noisier than unoccupied classrooms.^[15,16] The overall noise level was also higher when the students participated in a cooperative instruction activity than when they were engaged in a quiet activity.^[16] These and other factors previously studied are summarized in Table 1.

Noise reduces speech intelligibility and affects speech recognition by masking the acoustic and linguistic cues in the signal.^[2,3] The speech-to-noise ratio (SNR), which is the relationship between the intensity of the speech and the intensity of the background noise at the listener's ear, is found to affect speech understanding.^[25] The younger the child, the greater the SNR that is needed for speech understanding. By comparing students of three different grades, Yang and Bradley^[26] showed that grade 1 students needed an SNR of 5 dB higher than grade 6 students for speech recognition. For young children with normal hearing, at least +6 dB SNR is required, but this would be inadequate for a child with even a minimal hearing loss (pure tone average of 15-25 dB HL).^[1] For a listener with hearing loss, an SNR of +15 dB is needed for optimum auditory comprehension.^[2] Other students who require more favorable SNRs include those learning in their second language, students with learning disabilities, attention disorders, and other auditory disorders.^[27]

A number of organizations around the world including the World Health Organization and the American National Standards Institute^[8] have set up standards for suitable noise levels in classrooms.^[28] In general, these organizations recommend that the noise level in unoccupied classrooms

should be 35 dBA or less. For occupied classrooms, the recommended noise level should not exceed 40-50 dBA.^[29] For SNR, it was recommended that classrooms have an SNR of +15 dBA or higher.^[30]

Acoustic Modifications in Classrooms

One of the key factors to ensure good speech intelligibility for students is to reduce the background noise level in classrooms. This can be achieved by making acoustic modifications to the classrooms. The noise source should be placed away from the listener if possible. If the problem is caused by external noise, double-glazing and solid concrete barriers can be installed.^[31] For internal noise and room noise, modifications may include installation of carpets, ceiling tiles, acoustically treated furniture and/or curtains. To improve the SNR, researchers have suggested using sound field (SF) amplification systems, which use a wireless microphone to transmit the teacher's speech signal to an amplifier-loudspeaker system.^[1] The amplified speech can provide 5-10 dB improvement in the SNR.^[29] Many investigators have reported benefits with SF amplification for both students and teachers.^[28,29] Recently, an Australian study^[32] reported that SF systems were more likely to be useful in classrooms with good pre-existing acoustical conditions.

Aims of the study

Urban Asian school classrooms are likely to have greater problems with background noise than their Western counterparts. Asian cities have population densities some twelve times more than those of cities in North America or Australia.^[33] High urban population density increases levels

of ambient noise pollution.^[34] However, most studies of classroom acoustical conditions have focused on classrooms in Western communities. The present study aimed to:

1. Determine the background noise level in occupied classrooms and other educational environments across different types of Hong Kong schools and determine its effect on teacher speech level during class; and
2. Investigate factors that may affect the background noise in occupied classrooms in this urban environment.

The results may assist policy makers and professionals to better design and furnish teaching and learning environments in urban Asian schools.

Methods

Types of classrooms

The data were recorded from February 2008 to June 2010 by research assistants trained in basic acoustical measurement procedures. Data were collected from 37 schools consisting of kindergartens, primary schools, secondary schools and special schools in Hong Kong. A total of 248 measurement sites were selected, to represent a typical range of Hong Kong classroom environments. Of the 248 sites, 231 were successfully evaluated, in which 146 measurements were taken in closed classrooms, and 85 measurements were taken in school playgrounds. For the playgrounds, 49% (42/85) were covered playgrounds. Table 2 shows a summary of the classroom characteristics and Table 3 shows the age range of students in each of the four school types and the academic subjects undertaken in class. All the classrooms were rectangular shaped, and layouts of the typical classroom

and laboratory are displayed in Figures 1 and 2, respectively. Most of the classrooms were located in quiet zones, which were away from main traffic roads or secondary roads and were least affected by traffic noise (25.4% near main roads; 35.1% near secondary roads; 43.1% in quiet zones).

Acoustic measurements

Noise and speech levels during class were measured with a Brüel and Kjær sound level meter equipped with a quarter-inch condenser microphone. Two types of measurements were taken, noise level and teacher speech level during class. Noise measurements were obtained when classes were ongoing, and teachers and students were generally not talking. Speech measurements were obtained when teachers were addressing the whole class. Three 10-second measurement samples were taken and averaged. The small set of brief duration samples was taken to reduce to a minimum any disruption to classroom teaching. The acoustic parameters indicating the lowest ($L_{Amin, 10s}$), highest ($L_{Amax, 10s}$), and the average level ($L_{Aeq, 10s}$) of noise and speech during the 10s samples were recorded. Noise measurements were taken at one location (the central point) in each classroom. The unamplified speech levels of teachers were measured approximately 1 m before the teacher, and the amplified speech level measurements were taken 1.5 m from the loudspeaker (if used by the teacher). These were considered the closest points that children would normally be located in relation to the classroom teacher or teacher's loudspeaker. Measurement length was made using standardized lengths of measuring tape. The average speech levels were subtracted from the average noise levels of each classroom to derive an SNR. Descriptive data on environmental and acoustic noise reduction treatments were

Table 2: Summary of classroom conditions

Surveyed conditions	School type (number of classrooms)				
	Kindergarten (<i>n</i> = 23)	Primary school (<i>n</i> = 23)	Secondary school (<i>n</i> = 78)	Special school (<i>n</i> = 22)	Total (<i>n</i> = 146)
Gender of students					
Co-ed %	100 (23)	100 (23)	74 (57)	100 (22)	86 (125)
Construction year					
Mean	1985	1989	1982	1978	1983
SD	13	13	9.5	13	11.7
Range	1965-2001	1960-2003	1969-2003	1962-1999	1960-2003
Size of classroom (m ²)					
Mean	42.0	57.5	72.1	37.7	59.9
Range	25.6-54.4	6.8-153.8	7.8-126.7	6.1-60.2	6.1-153.8
Height of ceiling (m)					
Mean	3.0	3.1	3.2	3.3	3.0
Range	2.2-3.5	3.0-3.5	2.5-3.5	2.5-5.0	2.2-5.0
Number of students per class					
Mean	21	31	28	9	25
Range	11-31	22-40	10-44	2-17	2-44
Classroom environment					
Heating on %	0 (0)	0 (0)	4 (3)	(0)	2 (3)
AC on %	70 (16)	61 (14)	47 (37)	27 (6)	50 (73)
Windows opened %	44 (10)	44 (10)	56 (44)	77 (17)	55 (81)

AC = Air-conditioner, Co-ed = Co-educational (male and female students)

also documented using a checklist of facilities based on that suggested in a previous Hong Kong study.^[15]

Test-retest reliability

To ensure test-retest reliability of the acoustic measurements, the three 10s measurements were analyzed for correlation, and their results were used to determine the test-retest reliability.

Results

Descriptive and analytic statistics

Descriptive statistics of all the acoustic parameters are shown in Table 4.

Noise level

All except one classroom were exposed to excess background noise over the recommended level of 50 dBA for occupied classrooms. The following sections examine the possible factors contributing to the raised levels.

Classroom, teaching activity and student factors

There was no difference in noise level with variations in classroom location, construction year of the school building, classroom dimensions, classroom teaching activities (language, science and others) and air-conditioner on/off ($P > 0.05$). In addition, there was a low, non-significant intra class correlation for noise levels within schools, ICC (2, k) = 0.097, $P = 219$, indicating only a relatively small proportion of the variance in noise levels was associated with differences among schools.^[35] To investigate the effect of student age on the noise levels in classrooms, classrooms in special schools ($n = 22$) were excluded from the analyses because the students in the special schools were not grouped into class according to their age level. Table 5 shows the means, standard deviations (SD), and ranges of background noise levels by grade levels.

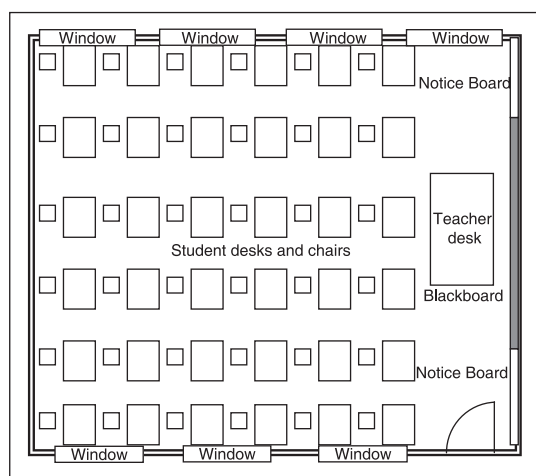


Figure 1: Typical layout of a classroom in primary and secondary schools

There was no statistically significant difference between class level, $F(3, 120) = 1.78, P = 0.15$. In addition, no strong correlation was found between number of students in class and the noise level, $r = 0.17, n = 146, P = 0.04$.

Comparison with playgrounds and sports grounds in schools

Noise levels in playgrounds and sports grounds were also recorded, while outdoor physical education classes were being

Table 3: Grade and class subjects of measured classrooms

School type (number of classrooms)	Grades	Age of students (years)	Class subject
Kindergarten (23)	Lower grade	3-6	Theme/language~
	Upper grade		Free play
Primary (23)	Primary 1-6	6-12	Language~
Secondary (78)	Secondary 1-3	12-15	Language~
	Secondary 4-6	15-17	Science
			Home economics
Special (22)	Primary 1 to secondary 5	6-18	Language~

~Language lessons include Chinese, English and foreign languages

Table 4: Means, SD and ranges of background noise levels, speech levels and speech-to-noise ratios in closed classrooms

Parameters measured	Average level (dBA)	Minimum level (dBA)	Maximum level (dBA)
Noise levels			
Mean	68.17	65.37	71.85
SD	6.36	6.61	5.96
Range	49.03-85.17	46.83-82.17	52.37-87.47
Speech levels			
Mean	76.57	72.04	80.38
SD	5.37	5.33	5.21
Range	59.93-89.00	56.43-84.87	64.87-93.13
Speech-to-noise ratios (dB)			
Mean	8.39		
SD	5.82		
Range	-13.87-26.70		

SD = Standard deviation

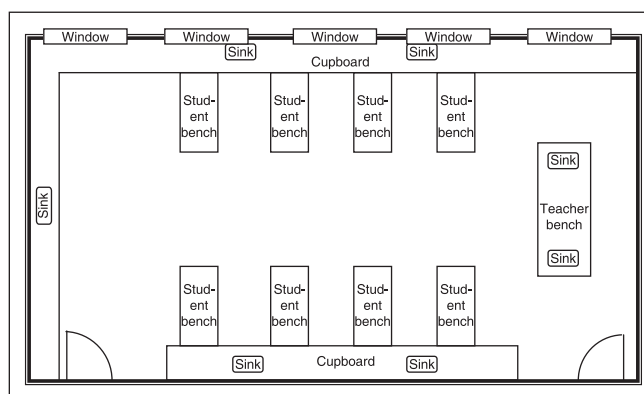


Figure 2: Typical layout of a laboratory in secondary schools

held. These lessons typically involved one or several classes of children. The data from the playgrounds/sports grounds was not normally distributed, and non-parametric tests were conducted. An independent-samples Mann-Whitney U-test revealed that the noise level in playgrounds/sports grounds ($M = 76.25$, $n = 85$, $SD = 5.71$) was significantly higher than those in closed classrooms ($M = 68.17$, $n = 146$, $SD = 0.6.4$; $U(231) = 2145.5$, $P < 0.001$).

Speech Level

Amplified versus unamplified speech level

An independent-samples t -test showed that the speech level in classrooms when using an amplification system ($M = 79.84$, $n = 61$, $SD = 4.43$) was significantly higher than when not using an amplification system ($M = 74.22$, $n = 85$, $SD = 4.72$) ($t[144] = 7.29$, $P < 0.001$).

Lombard effect

A scatterplot summarizes the results of the speech levels of teachers against the noise levels in class [Figure 3]. The correlation between noise level and teacher speech level was statistically significant, $r(146) = 0.52$, $P < 0.0001$, two-tailed. There was a tendency for increasing speech level to be associated with increasing noise level, and the estimated regression line is drawn to clarify the trend ($y = 0.44x + 46.79$). Linear regression demonstrated a significant positive relationship ($F [1, 144] = 52.80$, $P < 0.0001$). The result suggests that for every 1 dBA increase in noise levels, the teacher speech level increased by 0.44 dBA, an example of the Lombard effect.

Classroom speech-to-noise ratio

The average SNR for all the classrooms measured was 8.39 dB ($SD = 5.82$, range = -13.87 - 26.70). Table 6 summarizes the SNR across different school types. There was no statistically significant difference among the four different school types, $F(3, 142) = 2.32$, $P = 0.08$. However, it can be seen from Table 6 that there was a tendency for SNRs to improve with increasing student age group, progressing from kindergarten through secondary school.

Effect of amplification on speech-to-noise ratio

Fixed public address (PA) amplification systems or portable PA systems were installed in less than half (42%, $n = 61$) of the classrooms and most (88%, $n = 54$) of these were portable PA systems and the rest (12%, $n = 7$) were built-in PA systems. An independent t -test showed that the SNRs for classrooms with PA systems ($M = 10.58$, $SD = 4.72$) was significantly higher than those for classrooms without PA systems ($M = 6.82$, $SD = 6.05$; $t(144) = 4.04$, $P < 0.001$).

The improved SNR with amplification was due to the increased speech level. The use of PA systems did not increase the background noise level in the classrooms and there was

Table 5: Means, SD and ranges of average background noise levels (dBA) in closed classrooms according to class level

Background noise levels (dBA)	Kindergarten ($n = 23$)	Primary ($n = 23$)	Lower secondary ($n = 48$)	Upper secondary ($n = 30$)
Mean	66.80	70.11	68.93	66.88
SD	6.34	6.33	6.10	6.15
Range	53.80-79.13	57.87-78.60	53.73-85.17	49.03-76.17

SD = Standard deviation

Table 6: Means, SD and ranges of speech-to-noise ratios (dB) in closed classrooms according to school type

SNR (dB)	Kindergarten ($n = 23$)	Primary school ($n = 23$)	Secondary school ($n = 78$)	Special school ($n = 22$)
Mean	6.91	8.02	9.49	6.46
SD	6.16	6.26	4.85	7.50
Range	-4.27-18.90	-0.733-26.70	-3.90-20.60	-13.87-21.30

SD = Standard deviation

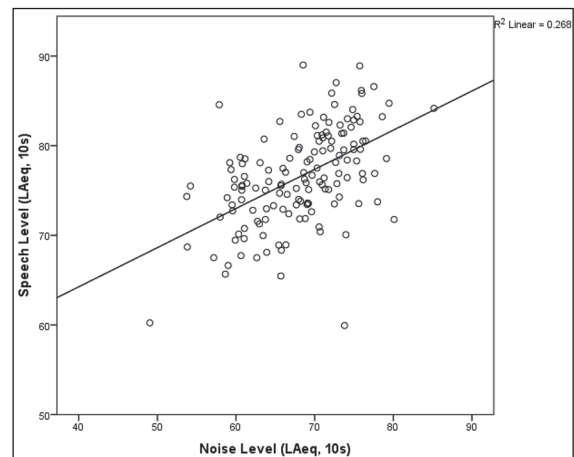


Figure 3: Scatterplot of speech levels versus noise levels in classrooms, with regression line

no significant difference in the noise level in classrooms with PA systems ($M = 69.27$, $n = 61$, $SD = 6.20$) when compared with those without such systems ($M = 67.40$, $n = 85$, $SD = 6.39$; $t(144) = 1.79$, $P = 0.08$).

Noise reduction measures in classrooms

Most classrooms had noise reduction measures (17.1% had no noise reduction measures; 74.7% had one type; 8.2% had two noise reduction measures). However, the range of measures was limited. The most commonly used acoustical treatment was installation of cork bulletin boards (in 74.7% of classrooms). None of the classrooms used acoustically modified furniture and only a few classrooms used partitions, carpets, draperies or acoustically treated Venetian blinds, or acoustic ceiling tiles.

Test-retest Reliability

The background noise level and speech levels of each classroom were measured three times. The three

measurements were significantly correlated with a range of $r = 0.61-0.93$ ($P < 0.01$).

Discussion

The primary aims of this study were to determine the background noise in occupied classrooms in an urban Asian environment and factors that may modify the background noise. A number of observations can be made from the results. First, background noise affected all classrooms and the level almost universally exceeded the recommended level of 50 dBA in occupied classrooms. The mean noise level ranged from 67 to 70 dBA in the four classroom types (kindergarten, primary, junior secondary, and senior secondary). The range is comparable with mean occupied classroom noise levels of 53-72 dBA derived from a review of twelve European and North American classroom studies.^[4]

Without amplification, the mean speech level of the teachers was 74.22 dBA, which is considerably higher than the normal conversational speech level of 65 dBA. As noise levels increased, the speech levels increased as well. This suggests that teachers increased their vocal effort to overcome the high noise levels in classrooms so that their students could hear them. However, this was not an effective strategy because with every 1 dBA increase in noise level there was only a 0.44 dBA increase in speech level. This result is comparable to a 0.63 dB increase found by Picard and Bradley.^[3] On the other hand, the use of an amplification system increased speech levels by an average of 5.62 dBA. The results suggested that the use of an amplification system is helpful to improve the SNR in class by increasing the speech level without increasing the noise level. This is consistent with results of the study undertaken by Leung and McPherson,^[36] which revealed that both portable PA systems and fixed PA systems improved SNR in Hong Kong special school classrooms.

Factors that may affect background noise

The current study did not find the location of the schools, classroom size, age of the students, nor the activity level of the class, to have any direct effect on the background noise in occupied classrooms. However, the type and number of acoustical treatments for classroom noise reduction was minimal in all schools. Noise reduction measures have been shown to help reduce noise levels in classrooms. The high level of background noise level in the surveyed classrooms could be reduced if more noise reduction acoustical treatments were installed in the classrooms. The use of PA systems in the classrooms had no statistically significant effect on classroom noise level. However, a 1.87 dB mean increase in background noise level was detected in classrooms with PA systems, and this factor should be considered, and measured, in any noise reduction treatment activity.

Implications for student learning

Given the high level of noise, the SNR was adversely affected in the occupied classrooms. Without an amplification system, the mean SNR was 6.82 dB, much poorer than the 11 dB SNR found in Canadian elementary schools but within the range of other surveys in Europe and North America.^[20,37] Based on the results, it appears that in many schools, student learning could be adversely affected. The situation is of more concern for younger children as they need a higher SNR for understanding speech.^[1] The problem of high level of noise also has additional implications for schools in multilingual Asian countries or cities, such as Hong Kong. In Hong Kong, 90% of the population speaks Cantonese as their usual language.^[38] However, most students are additionally required to learn Mandarin and English in class. In order to facilitate the learning of these languages, many schools have chosen to conduct some or all of their lessons in these languages. For such lessons, appropriate classroom acoustics is very important. Yang and Bradley^[26] studied the speech perception of children who used English as a second language. Results indicated that these children performed significantly poorer than their English-speaking peers for sentence perception and the differences between the two groups increased as SNR decreases. It is important for schools with a multilingual curriculum to keep the classroom background noise to a minimal level. Therefore, although the mean SNR value for the surveyed Hong Kong classrooms is slightly above the +6 dB SNR recommended minimum, it does not appear favorable when the local language environment is considered.

Implications for teacher vocal health

The current study revealed that generally teachers were speaking at a level louder than normal, and their speech levels increased with noise levels. With every 1 dBA increase in noise, there was a 0.44 dBA increase in speech levels. This Lombard effect may help maintain the SNR to a certain extent, but in this environment, teachers are more likely to acquire voice disorders due to the straining of the vocal folds. Such long-term straining of the vocal folds will increase the teachers' risk of developing vocal fold pathology, which may damage the vocal folds permanently and require medical treatment.^[39] Studies have also shown that voice disorders have a negative impact on teachers' quality-of-life and job performance and satisfaction.^[40]

Limitations and future study

Due to classroom scheduling constraints, the current study only measured the SNR in one position in each classroom. Given that the transmission of speech across a classroom differs significantly in different positions in the room, measuring at multiple locations would better estimate the average SNR and the spatial distribution of noise within the classroom.^[41] The use of a single microphone measurement position in the present study may have led to under or over-estimation of noise exposure for some

students in some classrooms. Classroom noise levels across different frequencies and the reverberation times (RT) of the classrooms should also be measured in future studies. RT of a classroom has been shown to be an important parameter for speech intelligibility along with SNR and should be within a 0.4-0.6 s range.^[31,42] It may also be of value to measure and express the SNR as a function of frequency because speech and the dominant background noise may have significant spectral differences.

Conclusions

The current study found that the noise levels in occupied Hong Kong classrooms were higher than the recommended levels and commensurate or higher than those found in Western nations. Analysis of the classroom noise showed no significant relationship with the age of the school building, location of the classrooms, class size and student. Speech levels of the teachers had a positive correlation with the measured noise levels in classrooms. In order to provide adequate SNR for student learning and to protect teachers' vocal health, in high density urban environments such as Hong Kong, teachers should consider using SF amplification during class and schools should install appropriate noise reduction measures whenever possible.

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