

Profiling Indian Classroom Listening Conditions in Schools for Children with Hearing Impairment

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Abstract

Introduction: An optimal classroom acoustic environment is essential for children with hearing impairment to achieve academic success. The aim of the present study is to provide an overview of classroom listening conditions in schools for children with hearing impairment in a developing country context. **Materials and Methods:** Noise levels were measured in 37 classrooms from four schools in Chennai, India. Teacher speech levels were measured to obtain classroom speech to noise ratio (SNR) data. The reverberation time was estimated for each classroom. **Results:** The mean noise level and reverberation time in all classrooms exceeded recommended maximum levels. The measured SNRs were not optimal for children with hearing impairment. Observations of the classrooms revealed that acoustical treatments were inadequate. **Conclusion:** The results indicated that Indian schools for children with hearing impairment should take steps to improve classroom listening environments. Possible solutions that may alleviate suboptimal classroom sound environments are discussed.

Keywords: Acoustics, classroom noise, hearing loss, India, reverberation, schools for the deaf, teacher voice

INTRODUCTION

Children rely upon the acoustical output of their teachers and peers for educational achievement. The faithful transmission of acoustical information in a classroom is basic for perception of speech and academic accomplishments. Unfortunately, this transmission of information in the classroom setting can be detrimentally affected by the acoustical factors in the classroom environment. These factors include the overall level of the background noise, the reverberation time (RT) of that area, the ratio of the level of teacher speech to background noise level (the signal to noise ratio of the environment), and the distance between the teacher to the child.

Background noise refers to unwanted acoustical stimuli that hinder the speech perception.^[1] Background noise in the classroom can be from many sources, including external noise (such as traffic noise), internal noise (such as noise from rooms adjacent to a classroom and from hallways), and room noise (such as children speaking to one another, and the shuffling of hard-soled footwear).^[2,3] Heating, ventilating, and air-conditioning (HVAC) systems also make a notable

contribution to classroom noise levels. As well as it affects speech perception detrimentally, background noise can also impact on metacognitive skills, literacy skills, and behavior in children.^[4-6]

Classroom noise not only affects school children but also has an impact on teacher performance.^[6] Teachers may have to raise their voice while teaching to compensate for loud noise levels in classrooms. This kind of behavior is a causative factor which may lead to voice problems. Studies consistently show that there was considerably higher prevalence of vocal problems in teachers than the general population.^[1,7]

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Similarly, reverberation can undesirably influence the speech perception in classrooms. Reverberation refers to the perseverance or prolongation of sound inside an enclosed area as a result of reflections of sound waves from the hard surfaces.^[8] RT is defined as the time (in seconds) taken by the direct sound to diminish in level by 60 dB after the sound source has ceased sound generation. By masking the direct and early reflected speech sounds, reverberation can affect speech perception ability.^[8] Reverberation tends to affect consonant perception more adversely than vowel perception, particularly the consonants in word final positions. In extremely reverberating environments, reverberant words will intersect with words from a direct source, by filling the temporal pauses between words and sentences.^[2] In the classroom setting, noise and reverberation effects will interact with each other and further adversely affect speech perception ability.^[9,10]

A final acoustic factor which influences speech perception within the classroom is the distance between the teacher and the students. When the child is comparatively near to the teacher, the direct sound field is dominant and the acoustical signal is minimally affected by environmental factors (i.e., teacher and child are within the “critical distance”—distance beyond which reverberant sound will degrade the speech signals).

For many individuals with sensorineural hearing loss (SNHL), their primary complaint would be difficulty in understanding speech in the presence of noise. Listeners with mild SNHL and upwards require a 4–12 dB increase in SNR value and for rooms with moderate level reverberation they need an additional 3–6 dB in order to obtain speech perception scores identical to those of normal hearing listeners.^[2] If RT exceeds 0.4 second, listeners with SNHL show more difficulties in speech perception ability.^[11,13,10] Crandell^[12] investigated the speech perception ability of children with minimal degrees of SNHL in different SNR environments. In all listening conditions, children with minimal degrees of hearing impairment showed poorer performance than normal hearing children, similar to those with higher degrees of hearing loss. In schools for children with hearing impairment, children with severe to profound bilateral SNHL are typically seen and reverberation is an important consideration in their learning environment.

To reduce the effects of background noise and reverberation in classrooms, organizations such as the World Health Organization (WHO),^[13] The American National Standards Institute,^[14] and the National Building Code of India^[15] have provided standards for permissible noise levels for typical schools. Most standards consist of guidelines on following factors: ambient noise levels in various types and size of classroom; RTs; sound insulation of the school facade and between rooms. There are also there are separate guidelines for classrooms specifically used by students with hearing impairment, such as American Speech-Language-Hearing

Association,^[16] British Association of Teachers of the Deaf (BATOD, 2001), and the Building Bulletin 93 (2014) guidelines.

Even though the importance of better listening environments, particularly for children with hearing impairment, is well acknowledged the current listening conditions in schools for children with hearing impairment in most developing countries, including India, are uncertain. Therefore, the present study aimed to survey the current classroom listening environments of schools for children with hearing impairment in Chennai, an Indian city (ranked third in terms of GDP per capita among Indian cities^[17]), to give an insight into current acoustic conditions. Findings will provide a better understanding of the existing acoustical status of classrooms for children with hearing impairment in urban India and provide guidance for viable adjustments and alterations to existing classrooms and also for succeeding construction projects of schools to facilitate better classroom listening conditions.

MATERIALS AND METHOD

The study aimed to document the classroom acoustic conditions in schools for children with hearing impairment, which included measuring background noise levels and estimating RT. The study consisted of three parts. Part I of the study focused on detailed observational assessment of factors which will increase background noise and reverberation. Based on the adapted “Acoustical classroom screening survey worksheet” found in ANSI/ASA S12.60–2009/2010 standards,^[18] factors were listed and a checklist was made for the observations. Part II consisted of measuring background noise in occupied and unoccupied conditions, including teacher speech level for computing SNR for each classroom. In Part III, RT was estimated with the use of the Sabine equation.

The methodology of the present study was approved by the Ethics Committee, Sri Ramachandra Institute of Higher Education and Research (DU). In Chennai there were eight recognized schools for children with hearing impairment. The study was carried out in the four schools that gave consent for the study. They were located in different zones (southern, western, and central Chennai) of the city. As shown in Table 1, all the four schools were in the high or medium external noise category. They consisted of one primary school and three higher secondary schools (includes primary, secondary, and higher secondary classes). Primary school consists of classes up to and including 5th grade for children aged between 5 and 10 years. Higher secondary school includes primary, secondary, and higher secondary classes for children and adolescents aged between 5 and 17 years. Overall 39 classrooms were randomly selected from the 70 classrooms located within the four schools. Since in two classrooms teachers had voice problems, those two classrooms were excluded from measurements and hence 37 classrooms were measured. While the native language

Table 1: Locations of schools and classrooms surveyed

| Location | Number of schools | Number of classrooms |
|---|-------------------|----------------------|
| High external noise (e.g., near to main traffic roads) | 3 | 30 |
| Medium external noise (e.g., near to small roads or in residential areas) | 1 | 7 |
| Lower external noise (e.g., in urban fringe area) | 0 | 0 |
| Total | 4 | 37 |

of the children is Tamil, the medium of instruction is English in all the schools.

Both the noise and speech levels were measured using a 3M sound examiner SE-402 sound level meter (SLM) type II, with a half inch condenser microphone. The equipment was calibrated with reference to ANSI/ASA S1.4-2014/Part 1/IEC 61672-1:2013 standards.

Part I: Observational information

In this part of the study, observations were made regarding classroom setup. The details obtained from the observations were the acoustic qualities of the classroom materials, along with communication access strategies and resources.

Sources related to background noise. Aspects of schools, external and internal to the classroom, which may affect background noise, were documented in the survey sheet. These included noise from heating and ventilation systems, mechanical equipment, playgrounds, road traffic, and air traffic, as well as adjacent classroom and corridor noise.

Sources related to reverberation. The reverberation level for a particular room is contingent upon the geometric shape of the room and its volume, and the absorptive and reflective properties of the materials present in the classroom. Information related to any sound reflecting or absorbing materials such as hard/ flat surfaces with or without acoustic ceiling tiles, ceiling height more than 3.35 meters (as per Acoustical Classroom Screening Survey Worksheet), acoustic ceiling tiles, and wall and floor materials (for example concrete and tiles) which may all impact the RT was noted.

Communication access strategies and resources are those used to receive and exchange information. Appropriate tools and methods can include speech, gestures, writing, typing on a communication device or via a human assistant, and/or assistive devices which enhance sound or speech. Teacher to student distance was important data categorized under communication access as it affects the speech to noise ratio level and therefore communication accessibility. Along with this information, primary instruction style (such as large group teaching, small group work or individual one-on-one teaching), classroom styles (such as traditional classroom, open classroom, or portable classroom), and seating arrangements were surveyed.

Details regarding hearing impairment status, including type of amplification device used, cochlear implant or hearing aid

fitting, and monaural or binaural fitting were noted. Information regarding the use of assistive listening devices, such as hardwire systems, frequency modulation systems, infrared systems, and induction loop systems was also noted.

Part II: Noise measurement

Background noise levels were measured in occupied and unoccupied classroom conditions, where the occupied condition refers to presence of students and teachers in classroom, without any speaking activity and heating ventilation air conditioning (HVAC) systems on. The unoccupied condition refers to a situation where there were no students and teachers in the classroom and HVAC systems were on.

Noise measurements were taken with A- and C-weighted networks, slow response time mode and averaged over a 5-minute sampling duration. Five measurements were taken in each survey classroom. These were background noise levels in occupied and unoccupied conditions with A- and C-weighted networks and teacher speech levels in the occupied condition with A-weighted network. Background noise levels were measured at the location where the farthest child was seated as it was observed that all the children sat very closely to the teacher to gain better audibility. The SLM was placed at the height equal to the child's ear level.

Teacher speech level. Teacher speech level was measured in occupied conditions during teaching activity. The teacher and students were seated in their usual locations. During measurement, any obstructions of the sound path between the SLM and teacher were avoided to prevent inaccurate measurements. The teacher was instructed to teach using their routine speech levels for the instructional activity and this speech level was recorded with SLM in the same placement as it was for background noise measurement.

Speech to noise level. Classroom SNR was determined by subtracting the A-weighted background noise level in an occupied condition from the teacher speech level and averaged.

Part III: Reverberation time

RT information was obtained by estimation procedures based on the known absorption coefficients of surface materials in the classroom. By using the Sabine formula,^[19] as recommended by ANSI,^[14] RT was estimated.

Data analysis

Noise levels across classrooms in occupied and unoccupied conditions measured using dBA and dBC networks were presented by descriptive statistics. Analytic statistics (such as *t*-test and ANOVA) were used to compare acoustical environments across schools, and also to determine whether significant differences existed between different school grades for noise level and SNR. A significance level (α) of 0.05 was used in all tests.

RESULTS

Classroom environment

Thirty-seven classrooms in four schools that were located in different zones in the city were included and evaluated in this study. The volume of the classrooms ranged between 21.78 and 139.08 m³. Temporary walls were used in two classrooms (5.4%) for the separation of one classroom from another classroom. The average number of students in each classroom was 6 (range: 2–19).

Part I: Observational information

In this initial step of surveying the classroom acoustics, many factors related to background noise and RT were noted. The average teacher to student distance was 0.98 meter and ranged from 0.42 to 1.57 meters. In all classrooms, the primary instruction style was small group teaching. U-shaped seating arrangements were seen in primary and secondary grade classrooms and row-wise arrangements in higher secondary classrooms [Figure 1]. Children and teachers were sitting across the table in primary and secondary classrooms.

Among the classrooms selected for the study 227 children were present. Eighty percent of children in these schools were wearing hearing aids monaurally. About 15% of children were wearing binaural hearing aids. All of them were wearing behind-the-ear models with earmolds. Only 5% of children used cochlear implant devices. No attempt was made to measure the hearing status of the children in the study. However, it was observed that the hearing aids they use were typically appropriate for children with severe to profound hearing loss. Hardwire amplification systems were installed in 24 classrooms (64.8%), where they were used to teach most lessons.

Sources related to background noise. All classrooms were exposed to audible noise interference from adjacent classrooms and corridors, when HVAC systems were off. All classrooms had ceiling fans instead of a complete HVAC system to provide air circulation and 28 classrooms had audible noise interference from those fans. In twenty classrooms, mechanical equipment usage (such as drilling and gardening work) was ongoing during class time. Two schools (schools 3 and 4) had their playgrounds near classrooms and all sixteen classrooms at those schools had noise interference from the playground. Noise interference

from road traffic was audible in four classrooms and noise from air traffic was audible in fourteen classrooms. School 3 has another school for children with visual impairment within its compound and had noise emanating from the co-located school. All schools except school 2 open the doors and windows during teaching activity increased noise interference from external sources. Figure 2 summarizes information about sources of background noise.

Sources related to reverberation. Only one school had a suspended ceiling setup, with gypsum board in the surrounding walls but tiled floors. The other three schools did not have any acoustically treated walls, ceilings or floors, and rooms were made of concrete material. Classes were conducted with doors and windows open. Hence the RT varied in door/window closed and open conditions. All 37 classrooms had floors and walls that were constructed of sound reflective materials, with no acoustic ceiling tiles. Ceiling height was above 3.35 meters in 16 classrooms. Among those high ceiling classrooms, two classrooms had only partial brick walls on the partition side with a common roof, as they were open plan classrooms. Figure 3 summarizes the factors noted in the classrooms which may increase RT.

Part II: Noise measurement

Background noise levels were measured in occupied and unoccupied conditions. The mean noise level of 37 classrooms in the occupied condition was 63.99 dBA (standard deviation = 3.22 dBA, range = 56.6–69.8 dBA) and 67.96 dBC (standard deviation = 2.70 dBC; range = 62.8–75.4 dBC). Figure 4 shows the noise levels in all classrooms in the occupied condition. Only four classrooms (10.8%) had a noise level below 60 dBA, and most classrooms had a noise level between 60 and 70 dBA.

The mean noise level in the unoccupied condition was 61.31 dBA (standard deviation = 3.59 dBA; range = 53–66.4 dBA), and 65.95 dBC (standard deviation = 3.29 dBC; range = 60.9–77.6 dBC). Figure 5 shows the noise level in all classrooms in an unoccupied condition, and 12 classrooms had a noise level below 60 dBA, and other classrooms had a noise level between 60 and 70 dBA.

An independent *t*-test showed that, for noise levels in occupied and unoccupied conditions in dBA and dBC, there was a statistically significant difference ($t = 3.27$; $P = 0.0016$ and $t = 2.85$; $p = 0.0055$, respectively). Noise levels based on time of day differed. A higher noise level was noted during the afternoon 1 pm to 3 pm period [Figure 6].

The average SNR in all schools was 11.74 dB (standard deviation = 5.91; range = 2–30.9 dB) and the mean teacher speech level was 75.74 dBA. A one-way ANOVA was used to compare noise levels and SNR levels across schools and grades. There was no significant difference between noise levels across schools ($F = 1.76$, $P = 0.17$) in the occupied condition. However, in the unoccupied condition there was a significant difference across schools ($F = 4.28$, $P = 0.01$). The

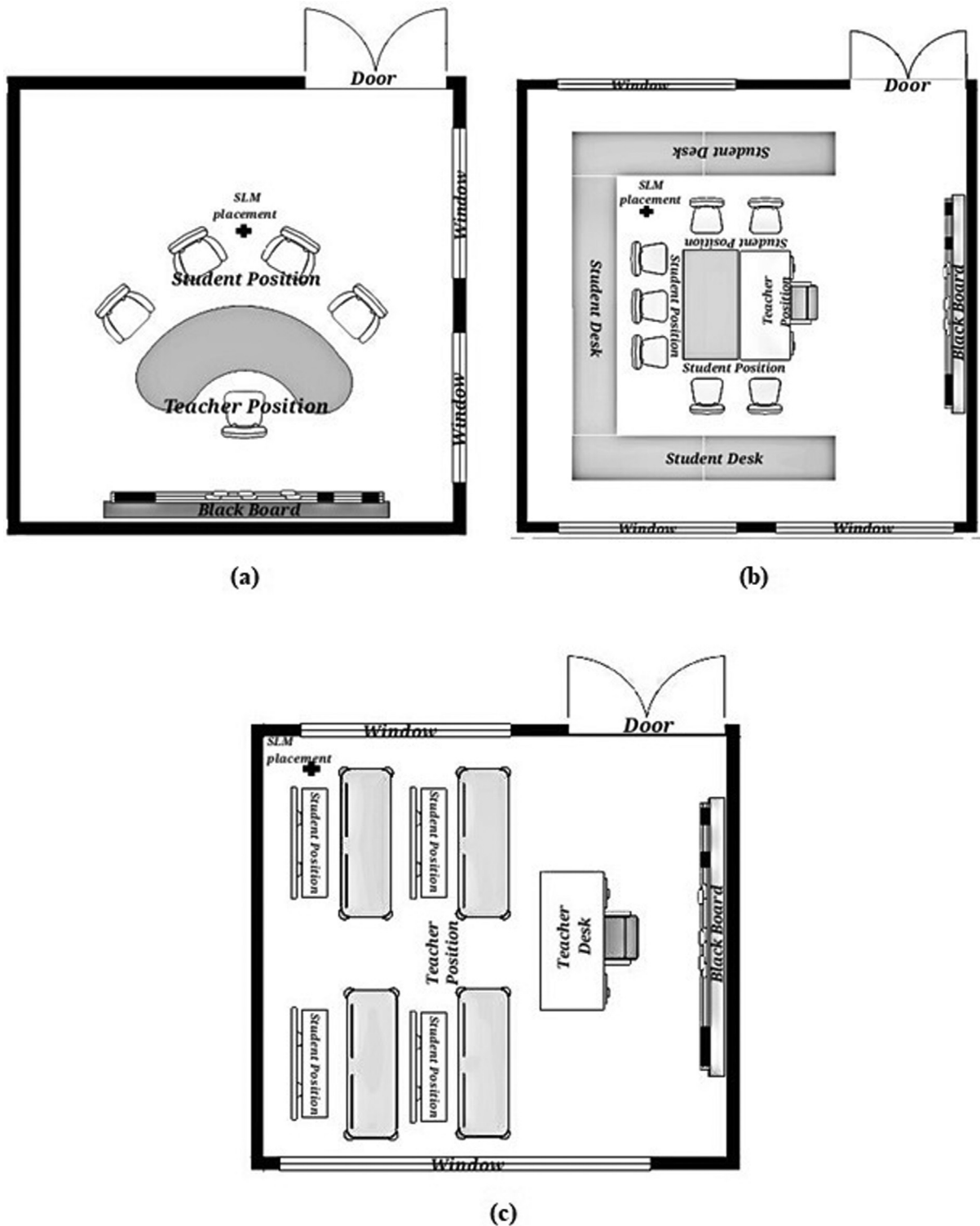


Figure 1: Model of Classrooms along with site of SLM placement: (a) Primary Classroom; (b) Secondary Classroom; (c) Higher Secondary Classroom.

difference was noted in a post hoc least significant difference test, between school 2 and school 3. Figure 7 shows the average noise levels across schools.

For SNR level, there was a significant difference ($F = 9.56$, $P = 0.00$) between schools [Figure 8]. A post

hoc least significant difference test was carried out to determine possible differences among schools. The differences in SNR levels in post hoc analyses between school 3 and other schools were significant. There was no significant difference in noise levels and SNR levels between grades.

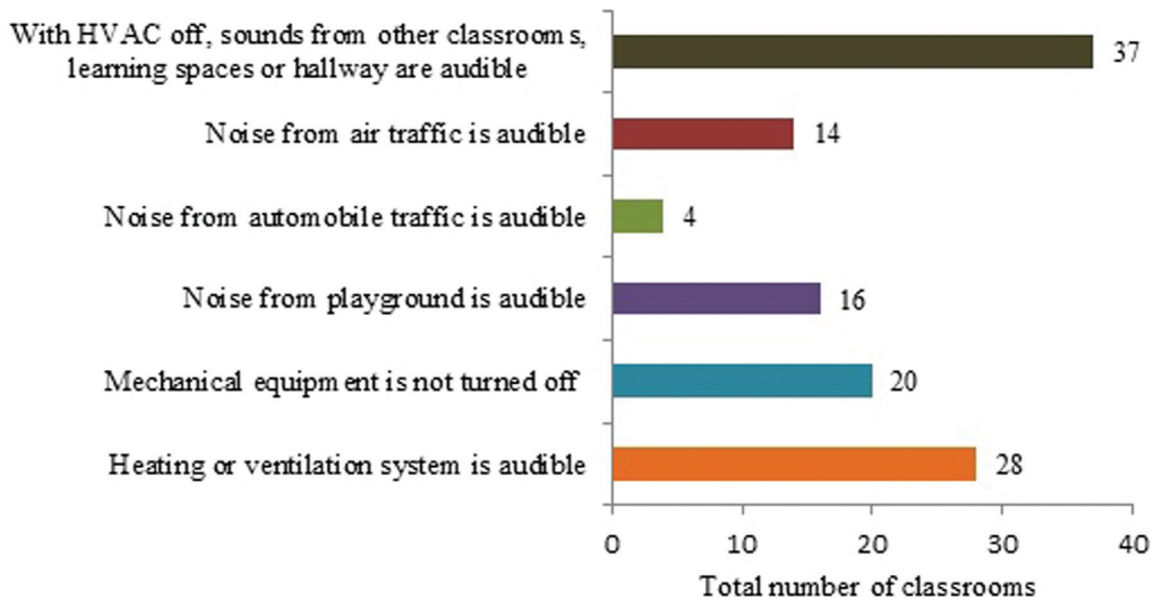


Figure 2: Sources which increased noise levels.

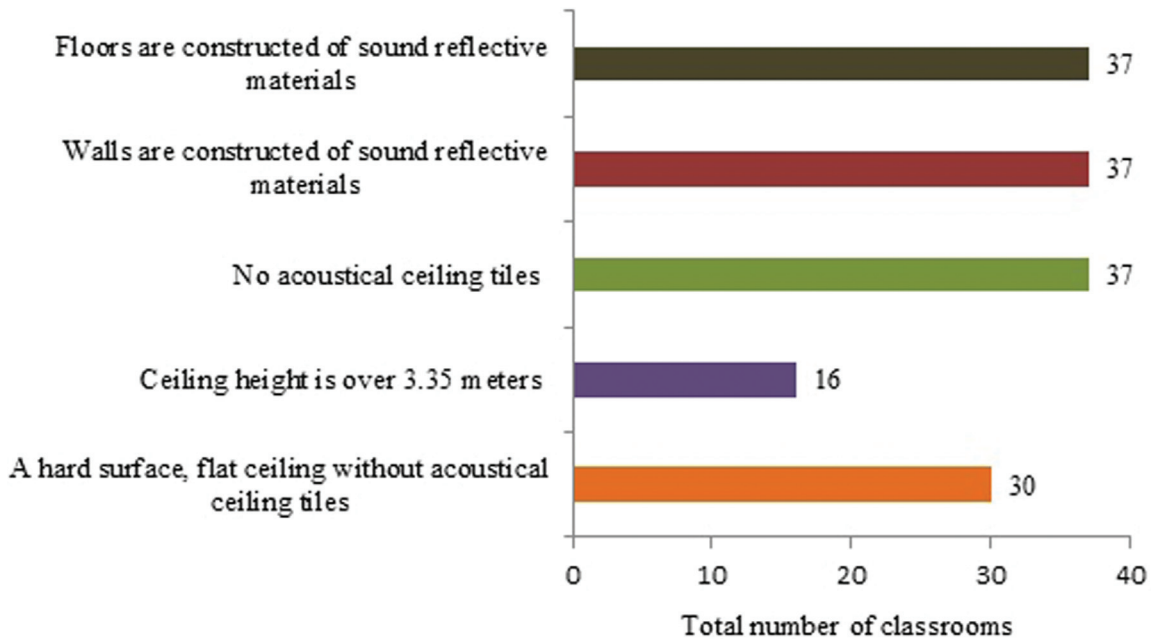


Figure 3: Factors which increased reverberation.

In each school one classroom was taken for background noise measurement in the unoccupied condition with fan off, to determine the effect of background noise by fan. The difference between unoccupied fan on and fan off, that is, the noise produced by the ceiling fan, was 8.36, 4.78, 3.98, and 7.13 dBA for each school with an average of 6.06 dBA.

Part III: Reverberation time

The dimensions of the classrooms varied across schools, and also within schools the classroom dimensions varied (particularly at school 2, since it had been reconfigured as a school from a residential house). Based on the classroom volumes and absorption coefficients the RT was estimated

[Figure 9]. The overall classroom average estimated RT when the doors and windows were in a closed condition was 1.65 seconds, and in an open condition (where classroom teaching is usually conducted) was 0.93 second (standard deviation = 0.17 second; range = 0.58–1.57 seconds). Using a one-way ANOVA procedure, across schools there was a significance overall difference in RT ($F = 5.05$, $P = 0.00$). Post hoc analysis indicated a significant difference between school 1 and school 2.

DISCUSSION

In order to enhance listening, learning, and the teaching environment the classroom acoustics should be within

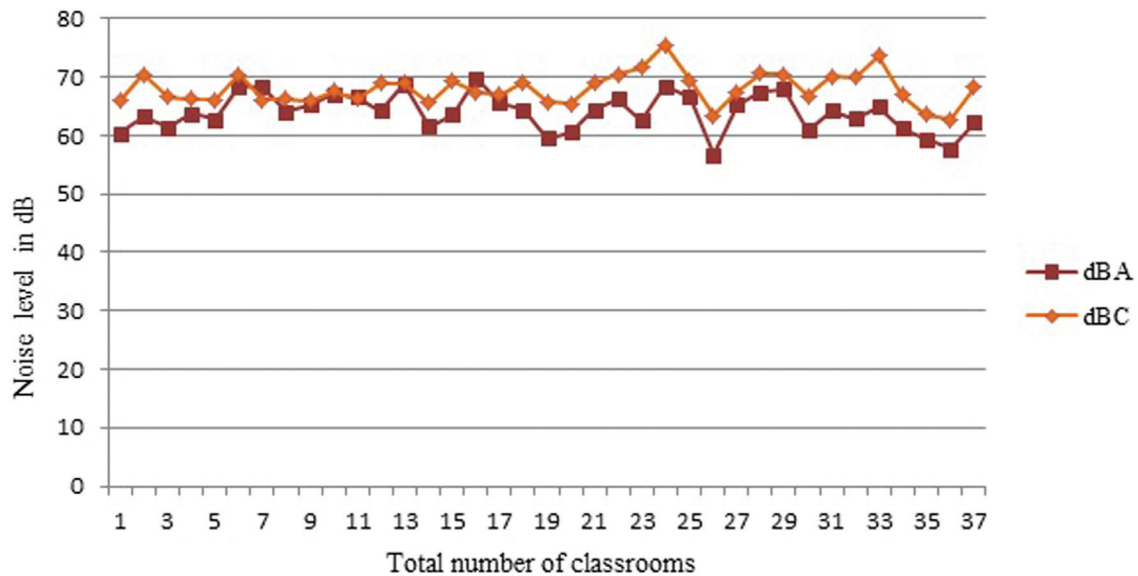


Figure 4: Occupied noise levels in dBA and dBC – weighted networks.

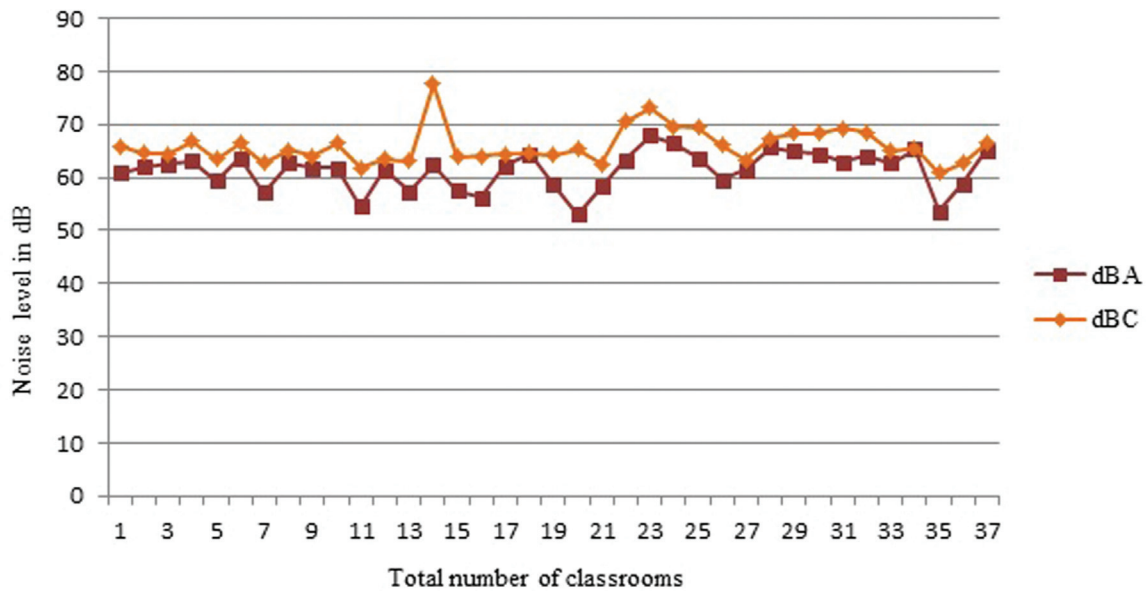


Figure 5: Unoccupied noise levels in dBA and dBC – weighted networks.

recommended specifications. The present study aimed to appraise the classroom acoustics in schools for children with hearing impairment in Chennai, India. Sources contributing to background noise and reverberation were explored. The manner in which each classroom was acoustically treated was reviewed. The following observations were made from the results.

Background noise level

The background noise in all the classrooms for children with hearing impairment exceeded the maximum recommended level of 35 dBA^[16] for unoccupied conditions, with a mean level of 61.31 dBA, ranging from 53 to 66.4 dBA. This indicated that poor acoustic environments with inadequate

acoustical treatment for noise reduction were widespread. Both external and internal room noise sources contributed to this situation.

Globally, studies done in classrooms for normal hearing children in various parts of the world, such as Brazil, Canada, Egypt, Hong Kong, Germany, United Kingdom, and United States, have also reported noise levels that were higher than the recommended levels.^[20-23] Sundaravadhanan, Selvarajan, and McPherson^[24] assessed noise levels in primary schools for typically developing children (normal hearing children) in a semi-urban township in Tamil Nadu, India and found mean unoccupied noise levels ranged from 57.1 to 68.7 dBA in a school environment. Classroom environments in schools for

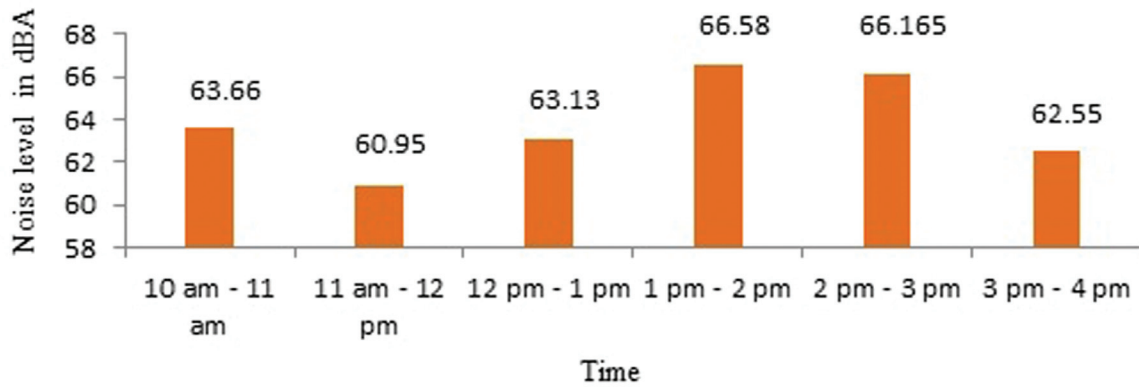


Figure 6: Noise levels in classrooms across school day.

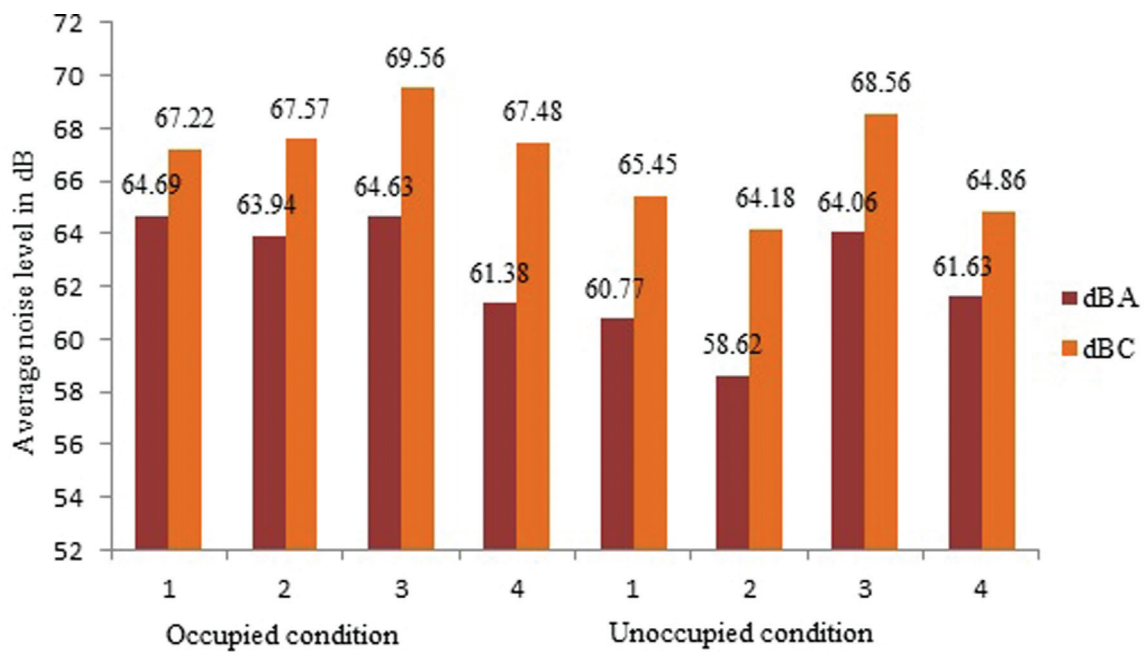


Figure 7: Average noise levels in each school in occupied and unoccupied conditions, in dBA and dBC – weighted network.

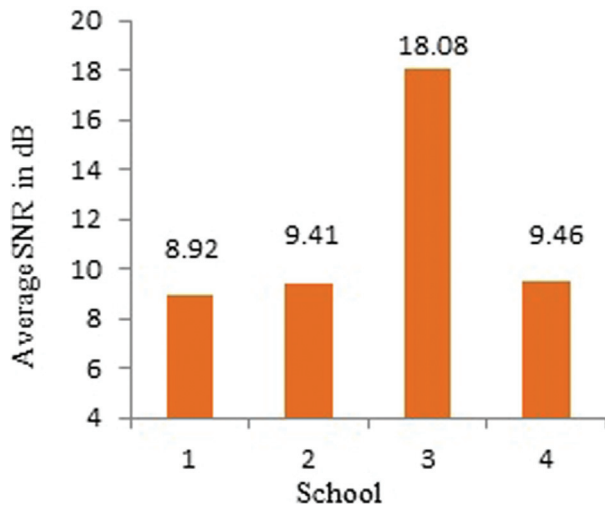


Figure 8: Average SNR levels across.

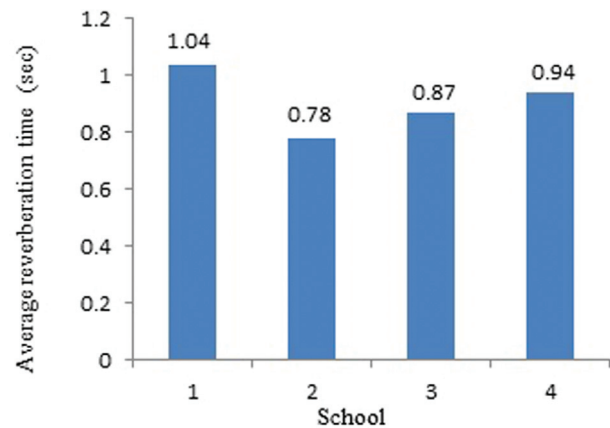


Figure 9: Average reverberation time across schools.

children with hearing impairment would be expected to be better than for normal hearing children but this is not always the case, even in developed countries. Similar results were reported in the study by Crandell,^[11] where the unoccupied noise level in 32 classrooms for children with hearing impairment in Dallas, United State of America, was higher than the recommended level, with mean level of 50.2 dBA.

The external sources which contributed in increasing the background noise level were mainly transportation noise and adjacent school activities. Internal noise sources were mainly from adjacent classrooms and corridors. Noise generated by the ceiling fan was the major source of room noise. These were the predominant sources for the suboptimal background noise level in unoccupied conditions.

Schools 1, 3, and 4 had external noise interference from transportation as they were situated near busy traffic roads and an airport. School 3, which had the highest background noise level in the unoccupied condition, has an adjacent school for children with visual impairment within its compound and it is situated near busy roads. The classrooms of school 3 face a playground on two sides of the classrooms. Sports activities were very frequent in school 3 and its neighboring school. During the measurement period an on-going sports activity with drum and whistle sounds hampered classroom teaching. The noise interference was raised due to the open doors and windows of the classrooms. School 2, which had the lowest unoccupied background noise level, is situated in a residential area with only minor roads nearby. Heavy vehicles were not allowed on those roads. However, some construction work around the school raised the external noise level. In school 1, there was noise interference from air traffic. The city airport was 11 km away from the school. This airport was very busy with both domestic and international connectivity.

There are mixed reports regarding the effect of transportation noise on children's academic performance. For acute effects of aircraft noise, some studies noted a decline in performance^[5,25] but others report no adverse effects.^[26] For chronic effects, consistent associations with reduced reading performance and mixed results for attention and memory abilities have been noted.^[27] However, there is no doubt that such intermittent noise can mask speech signals. This type of noise may impact on children's attention but not diminish the generally available spectral and temporal information of speech^[2] as much as continuous noise. There is little literature on the extent of speech interference caused by intermittent noise, particularly aircraft flyover noise.^[28]

The foremost internal noise source was from adjacent classrooms and corridors as found in previous studies.^[24,29] In the classrooms, the doors and windows were open to provide ventilation and lighting. This is the major reason why these classrooms had high levels of noise interference from external sources and neighboring classrooms. Also, from the total 37 classrooms, 16

classrooms had windows and doors facing toward a playground. These classrooms were exposed to high external noise interference due to frequent sports and recreational activities.

In the Indian scenario, ceiling fans are used in the place of an HVAC system. Ceiling fans are used to provide thermal comfort and support ventilation by making air movement. Noise generated by the ceiling fan was the major source of room noise in 28 classrooms. Most of the fans were more than 5–6 years old. Older fans tend to create more noise and schools did not make provision for regular maintenance to curb the noise. The difference in unoccupied noise levels with fan on and off was more than the recommended level of 6 dBA.^[14] Hence ceiling fans can be considered a primary source of interior-generated noise.

Along with this, in the occupied condition, the leading source of room noise was children talking with one another, which will introduce competing sound.^[27] Children in these schools were taught to speak/read aloud while they were completing writing or reading activities. Although it is encouraged, children were talking aloud between teaching activities, which interfered with their perception of teacher speech. The other room noise sources were sliding of chairs and tables and shuffling of footwear. Only one school had installed rubber bushes on chair and table legs to reduce noise. These causative factors made the occupied noise levels significantly higher than the unoccupied levels.

Noise levels may at times vary according to grade level in classrooms for typically developing children.^[29] In the schools for children with hearing impairment in the current study, there was no such difference in noise levels across grades. However, there were differences in noise levels across the day. Noise levels were higher during the lunch and break periods as the students from the other classrooms were moving in and out of the classrooms, indicating high audible noise interference from corridors, adjacent classrooms, and playgrounds.

Comparison of dBA and dBC network measurements showed significantly higher values obtained in dBC network measurements in both occupied and unoccupied conditions. The difference was 3.97 dB in the occupied and 4.64 dB in the unoccupied condition, indicating a substantial low-frequency energy component. Low-frequency noise sources have a significant masking effect on speech perception because of the upward spread of masking effect.^[2] Importance should be given to decreasing low-frequency noise because most classroom surface materials absorb high frequency sounds effectively and not low-frequency sounds.^[16]

Speech to noise ratio

The speech to noise ratio (SNR) values were calculated by taking the difference between dBA measurements in occupied conditions and teacher's speech levels. The average SNR value obtained was 11.74 dB, lower than the recommended value of 15 dB.^[16]

Speech perception ability is strongly based on SNR value and as SNR value increases perception ability improves.^[10] Children require 5 to 7 dB greater SNR to achieve adult-like performance in perception ability.^[30] Typical younger children (grades one to three) require +20 dB SNR to achieve 95% scores in speech perception in any classroom condition.^[31] Children with hearing impairment require a greater SNR and lesser RT (≤ 0.3 second) for optimal speech perception.^[32]

The results indicate that classrooms surveyed in the present study are unfavorable for children with hearing impairment. Particularly for young children with hearing impairment, higher SNR values are needed. It was noted that, in the surveyed schools, children are taught in English, their second language. It is also been reported that children require a higher SNR to follow teaching instructions in their second language.^[33]

As shown in Figure 8, the average SNR in school 3 was 18.08 dB. This school had a higher SNR than all other schools, which had an average SNR of <10 dB. The average speech level in school 3 was 82.71 dB, which was 10 dB higher than other schools. There was no difference in the occupied background noise levels among all the schools [see Figure 7]; hence the difference in SNR is primarily due to teachers' speech level. This suggests that teachers at school 3 used raised vocal effort to maintain a better SNR value. The lowest SNR was found to be in school 1. At this school teachers mainly used sign language for teaching and employed verbal communication as a communication supplement. They did not prioritize vocal audibility.

Normal conversational level for speakers at 1 meter distance is around 60 dBA.^[34] In the current study, teachers were speaking at a higher level to compensate for background noise, particularly in school 3. This prolonged use of an excessive voice level may result in various voice disorders along with other possible health-related issues.^[35]

Reverberation time

RT varied in the window and door closed and open conditions. Such variation occurs due to changes in room absorption coefficients. Window and door absorption coefficients are 1 in an open condition. This refers to full absorption with no reflections of incident sound waves.^[36] Estimated RT was based on the absorption coefficient of open windows/doors because usually classes were conducted in this condition.

The average reverberation for all the schools' time was 0.93 second, which is higher than the recommended value, <0.4 second.^[16] There was a positive relationship seen between RT and room volume. As no acoustical treatment was present in any of the classrooms in the four schools, there were no effects related to other classroom materials (such as boards, cupboards, or walls). All the classrooms of all schools were either made of concrete walls and ceiling or had gypsum board walls and ceiling. The absorption coefficient of these

materials is close to 0, and are more reflective and therefore cause greater reverberation.

Increase in RT causes reflected sound to overlap and mask desired speech signals. The masking effect is greater for consonant perception. In English consonants will occur in word final positions and have greater chance of being masked by reverberant sound waves.^[2] In addition to teacher speech, background noise present in the classroom is also reverberated, which further impairs speech perception ability.^[2]

Current classroom scenario

The teachers and headmasters in all four schools had knowledge of the effects of high noise levels on speech perception and the need for high SNR values for better speech comprehension. However, they were not aware of the relevant standards or the classroom modifications required to reduce noise levels. Among the four schools, three schools were run by charities and children attending those schools are from low socio-economic families. Those schools provide tuition and services free of charge. Hearing aids used by these children were mostly donated items. The group amplification systems installed in two schools were also donated to the school management. These donated items did not have local dealers to provide maintenance services, nor did the school management have any expertise to provide such services. These schools focus more on student-written academic achievement than on listening and spoken language. Children in these three schools mostly use monaural hearing aids, and hence they derive no binaural processing advantages. The amplification characteristics, noise reduction strategies and overall performance of most hearing aids were uncertain. In one school, one primary classroom had an FM system facility, but teachers were not familiar with its functioning. One school attempted to reduce external playground noise by growing plants in front of classrooms to better separate them from playgrounds. At another school, doors are closed during teaching activities to reduce noise interference from adjacent classrooms.

Possible modifications

The above discussion clearly indicates that focused attention is not given to acoustical conditions in the Indian schools for children with hearing impairment that were surveyed. However, it is known that these schools require better acoustical planning than do normal schools.^[2] Some possible suggestions and modifications to improve the listening conditions in the classrooms are discussed below.

There are several ways to improve classroom environment. Actions such as physical environmental modifications to reduce background noise and the use of assistive listening devices may help, and it is generally advised to use a combination of these strategies.^[8]

External noises in classrooms could be reduced by modifications such as using exterior barriers, landscaping such as planting (with provisions to secure vegetation from

heavy rain and storms), and carpeting for deflecting or absorbing unwanted sounds from external sources.^[16] Building high compound walls will also assist in reducing external noise interference. School buildings and especially classroom walls should be free of cracks, have regular maintenance, and should have a high sound transmission loss level (STL) to attenuate external noise which could be better expressed in Sound Transmission Class (STC) rating. The recommendation from ANSI standards for STC rating is 50 between classrooms and 45 between classrooms and corridors.^[37] In this study, ceiling fans with open windows were used for ventilation purposes, and this created audible noise interference in most classrooms. Regular service maintenance, with repairs and replacement of malfunctioning units, should be scheduled.

For an optimal listening environment, ceilings should have height of <2.7 meters to avoid a high RT. With addition, acoustic ceiling tiles with a high absorption coefficient may be installed in order to achieve desired RTs. A fully suspended ceiling is more effective than absorptive panels. School 2 in this study had suspended classroom ceilings and had a reduced RT when compared to the other schools. Concerns exist in using carpet in tropical environments regarding air quality inside the classroom and allergic reactions that carpets may cause. An absorptive ceiling is more effective than carpet in reducing RT – by 0.4 second on average.^[29] However, if carpeting is installed over a pad, it is an efficient acoustic modification in absorbing the high-frequency consonant sounds reverberation and for damping noise from student movements. Reflective wall surfaces can be modified in a multiplicity of ways. Acoustic panels, and cork, felt, or flannel bulletin boards are some of the interior wall modifications that can reduce noise and RT.

To avoid noise interference from corridors and adjacent classrooms closed solid-core doors with a noise lock and double plane windows are very effective. However, in a tropical climate that is a problematical approach when air-conditioning systems are not available. Alternatively, assistive listening devices may be helpful. They help mitigate the problems caused by noise, distance from speaker, and reverberation issues that cannot be resolved with hearing aids alone. Personal FM systems will give benefit to children with severe to profound hearing loss who have word discrimination scores in quiet above 20%, as noted their attention to verbal commands has increased.^[38] However, with this method children may not hear external sounds such as alarms and visual alerting devices need to be installed.

Simple physical modifications could also support a better listening environment. These include modifying seating arrangements, appropriate lighting, and placing barriers in classrooms to avoid distractions.^[39] Dye, Hauser, and Bavelier^[40] suggested that the best seating arrangement for children with hearing impairment is one that is consistent and has minimal distractions, such as circular arrangements.

Children with hearing impairment are affected by lighting conditions. They are adversely affected by excessive as well as by insufficient environmental lighting. Excessive lighting will cause “dazzling” on whiteboards or desks which creates visual distraction.^[41] Appropriate lighting is essential for children who supplement audition with visual cues^[42] and must be considered along with acoustic factors.

CONCLUSION

A first step towards quality education or teaching is provision of a good listening environment. The present survey of acoustic listening conditions was the first in Indian schools for children with hearing impairment and one of the first in a developing country context. Studies from other countries found a widespread prevalence of high background noise, RT and poor SNR in classrooms for children with hearing loss. Results from the Chennai study align with previous studies, indicating that schools for children with hearing impairment do not meet national or international acoustic standards. Poor classroom acoustics will affect the listening and learning capabilities of children as well as teacher performance and health. Acoustic designs should be targeted at reducing unoccupied noise level and RT in order to optimize the listening environment during lessons, and this should be considered at the initial design stage of school building or before any refurbishment work is initiated.

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Conflicts of interest

There are no conflicts of interest.

APPENDIX – 1

CLASSROOM ACOUSTICAL SCREENING SURVEY WORKSHEET*

Date _____ Audiologist/Surveyor _____

School _____

1. OBSERVATION INFORMATION

Listen in the classroom and check for the following; a “yes” is an indicator of potentially excessive levels of noise

Background Noise

| Classroom features | Yes | No |
|---|-----|----|
| Ventilation system is audible | | |
| Mechanical equipment must be turned off during important lessons | | |
| Noise from playground is audible | | |
| Noise from automobile traffic is audible | | |
| Noise from air traffic is audible | | |
| With heating and ventilation system turned off, sounds from other classrooms, learning spaces, or hallway are audible | | |

| Reverberation classroom features | Yes | No |
|--|-----|----|
| A hard surface, flat ceiling without acoustical ceiling tiles | | |
| Ceiling height is over 11 feet | | |
| Acoustical ceiling tiles have been painted | | |
| Walls are constructed of sound reflective materials (e.g., plasterboard, concrete, wood panelling) | | |
| Floors are constructed of sound reflective materials (e.g. concrete, tiles, wood) | | |

Teacher to listener distance:

Nearest _____m Furthest _____m

Class room style:

____ Traditional ____ Open ____ Portable/Relocatable

Type of amplification device used:

Hearing aid/Cochlear implant monaural/binaural

Strategy is used to teach the children:

____ Personal amplification device only

____ FM system

____ Infrared system

____ Induction loop system

____ hardwire system

Primary instruction style:

____ Large group ____ Small group ____ Individual
 ____ Other (specify)

Seating arrangements:

____ Clusters ____ U shaped/round ____ Row ____ Other (specify)

2. NOISE MEASUREMENTS

Class room schematic diagram: (will be attached)

Sound level meter used:

Method

____ one hour average ____ short time ____ second average; # of time samples ____

| Condition | Ambient noise levels (dBA, dBC) unoccupied and occupied classroom | | | | Teacher voice levels (dBA): occupied classroom | |
|-----------------------|---|-----|-----|-----|--|-----|
| | 1. Unoccupied, HVAC on; 2. Occupied, HVAC on | | | | level | SNR |
| | 1 | | 2 | | | |
| Weighting | dBA | dBC | dBA | dBC | | |
| Measurement locations | A | | | | | |
| | B | | | | | |
| | C | | | | | |
| | D | | | | | |
| Average dB level | | | | | | |

3. REVERBERATION TIME: (estimated)

Room Volume (V) = _____ cubic feet

Area Floor _____ x ABS. Coef. _____ = A Floor _____

Area Ceiling _____ x ABS. Coef. _____ = A Ceiling _____

Area Side Wall 1 _____ x ABS. Coef. _____ = A Wall 1 _____

Area Side Wall 2 _____ x ABS. Coef. _____ = A Wall 2 _____

Area End Wall 1 _____ x ABS. Coef. _____ = A End 1 _____

Area End Wall 2 _____ x ABS. Coef. _____ = A End 2 _____

Total A = _____

Estimated Average RT of Classroom = .049 x _____ (V) / _____ (A) = _____ seconds

¹Adopted from Johnson ^[18].

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