Problems of Noise in School Settings: A Review of Literature and the Results of an Exploratory Study

Problèmes de bruit en milieu scolaire: état des connaissances et étude exploratoire

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Abstract

The article sums up the current state of research on the detrimental effects of noise in elementary and high school settings. It deals in particular with the annoyance experienced by teachers, interference with speech, and effects on pupils' attention span and learning as well as their health and well-being. The results of an exploratory study in Québec schools are also reported. A questionnaire survey indicated that a high proportion of teachers consider noise to be detrimental to their work; in particular, it interferes with speech. Furthermore, acoustic measurements were taken in 50 classrooms in 6 different elementary schools. Results show that for a majority of classrooms, the level of background noise and the reverberation time do not correspond to the optimal conditions for speech intelligibility. Open-plan schools, in particular, have very serious problems of background noise, and classrooms without insulation or sound-absorbing surfaces have problems of excessive reverberation. Measurements taken during 35 physical education classes in 4 elementary schools and 4 high schools also revealed very serious noise problems associated with teaching in gymnasia. The study demonstrates the importance that speech and hearing specialists should attach to the acoustic environment in educational settings.

Résumé

Cet article résume les connaissances disponibles concernant les méfaits du bruit en milieu scolaire primaire et secondaire. Il traite en particulier de la gêne exprimée par des enseignants, de l'interférence avec la communication verbale, des effets sur l'attention et sur les apprentissages ainsi que sur la santé et le bien-être des élèves. Les résultats d'une étude exploratoire en milieu scolaire québécois sont également rapportés. D'une part, une enquête par questionnaire montre qu'une forte proportion d'enseignants jugent que le bruit est nuisible à leur tâche et, en particulier, qu'il interfère avec la communication verbale. D'autre part, des mesures acoustiques dans 50 classes appartenant à 6 écoles de niveau primaire ont été effectuées. Les résultats montrent que, pour la majorité des classes, le niveau de bruit ambiant et la durée de réverbération ne rencontraient pas les conditions optimales d'intelligibilité verbale. Les écoles à aires ouvertes posaient, en particulier, de trés sérieux problèmes de bruit ambiant tandis que les locaux de classe dépourvu de traitement acoustique posaient des problèmes de réverbération excessive. Des mesures faites durant 35 cours d'éducation physique donnés dans 4 écoles primaires et 4 écoles secondaires ont en outre mis en évidence de très graves problèmes de bruit pour l'enseignement dans les gymnases. Cette étude démontre l'importance que les professionnels des troubles de la communication devront accorder aux ambiances sonores des milieux éducatifs.

There are no formal standards for the acoustic design of classrooms in Québec, and the same seems to be true of the other Canadian provinces. It is therefore reasonable to assume that noise is a frequent problem in the school environment, interfering in particular with speech and thus communication. In such a situation, noise in all likelihood has a negative impact on well-being, behaviour, and learning.

This article reviews the literature on the effects of noise as observed in educational settings, and reports on the results of an exploratory study carried out in Québec schools. The authors hope the paper will help professionals in the field of communication disorders to focus on the importance of the acoustic environment in school settings.

Review of the Literature

Noise Problems Reported by Teachers

The results of several recent studies indicate that acoustic conditions are unsatisfactory for teachers in some elementary and high schools (Crook & Langdon, 1974; Ko, 1979, 1981; Sargent, 1980). The work of Ko (1979) is particularly interesting in this respect: this study evaluated replies from 1297 teachers in 47 schools, corresponding to 66% of the total teaching staff in these schools, in which measurements were taken with sound-level meters. Results show that aircraft or vehicle traffic noise, as well as the noise related to school activities, is associated with reactions of discomfort, interference with speech and teaching, fatigue, and tension. The level of discomfort rose systematically with the noise level when the noise, present for at least 10% of the time (L_{10}) reached 50 dBA. It should be kept in mind that L_{10} corresponds approximately to the time average of the sound level for the duration of the measurement period, an average that is also referred to as the equivalent continuous sound level (L_{eq}).

Interference with Speech Intelligibility in Classrooms

There have been many studies of the effect of noise on speech intelligibility, leading to the adoption of standards for various situations (see ANSI S3.5-1969, R1978). For instance, it can be assumed that even unfamiliar words will be 100% intelligible with a signal/noise ratio (S/N) of +15 dBA (Webster, 1978). In a teaching situation, however, we have to take into account the fact that the sound is propagated in a closed space, which means taking account of the effects of the room's reverberation on speech intelligibility. By convention, reverberation time (RT) is defined as the interval of time corresponding to a decline of 60 dB in the sound level after the source of the sound ceases. With a constant S/N ratio, the percentage of intelligibility is inversely proportional to the reverberation time (Moncur & Dirks, 1967; Houtgast & Steeneken, 1973; Finitzo-Hieber & Tillman, 1978; Houtgast, 1981; Nabelek & Robinson, 1982; Neuman & Hochberg, 1983; Bradley, 1986; Yacullo & Hawkins, 1987). Bradley (1986a) conducted a study on more than 200 pupils ages 12 and 13 in 10 schools with various layouts and in various environments. The results indicate that the minimum reverberation time that does not affect intelligibility is 0.4 seconds in the octave band centred at 1 kHz. Beyond this value, intelligibility as measured with the Fairbanks rhyme test declines by 14% for each additional one second of RT. Since the effects of S/N and RT are cumulative, we can identify an S/N of +15 dBA and an RT of 0.4 seconds as a minimal criteria for ensuring speech intelligibility.

However, the younger the children appear to be less able to distinguish words against background noise (Elliott, 1979; Elliott et al., 1979; Nabelek & Robinson, 1982; Neuman & Hochberg, 1983). Elementary-school children need a S/N ratio closer to +20 dBA. Taking into account the sound level of the speech of a female speaker who does not raise her voice and the distance that normally separates a teacher from the pupil, Bradley (1986a) concludes that the background noise level should not exceed 30 dBA in the classroom, with the RT limited to 0.4 seconds. Bradley notes that in all the classrooms visited for his study, the background level definitely exceeded this limit.

Children with a hearing loss are very sensitive to the influence of background noise and in particular reverberation (Nabelek & Pickett, 1974; Finitzo-Hieber & Tillman, 1978). Even with an S/N of more than +20 dBA, intelligibility with an RT of 0.4 seconds is not as good as it is with an RT of 0 seconds. The acoustic design of classrooms for children with hearing impairments should therefore conform to very strict standards (see Anon, 1984). Unfortunately, this does not seem to be the case; to the best of our knowledge, government authorities have not adopted any policy on this. We do not have quantitative data on the situation in Canada. Recent research in Great Britain indicated that the average level of background noise in classrooms in specialized schools for deaf children varied between 40 and 55 dBA (Markides, 1986). In the best cases, estimated S/N ratios did not exceed +12 dBA. The situation was similar for hearing impaired children integrated into regular classrooms. These observations suggest there is reason to be concerned about the conditions imposed on hearing impaired children in Canadian school settings.

Finally, children whose mother tongue is not that of the teacher are in a similar situation to that of hearing impaired children. The impact of background noise and reverberation is probably comparable for both groups. Consequently, the optimal conditions for speech intelligibility identified above constitute a minimum to be met.

Effects of Noise on Attention and Learning

The influence of background noise on the performance of school-age children can be all the greater when the task being carried out is complex and requires concentration (Ando & Nakane, 1975; Dixon, 1976; McCroskey & Devens, 1977; Koszarny, 1978). The effect has been observed even when the noise does not include any distracting information. When the background noise level in a room rises to levels higher than those favourable to speech, there is a statistically significant drop in children's performance. Despite the precautions taken by the authors of the studies mentioned above, the observations could be tainted by a certain Hawthorne Effect, that is, a bias attributable solely to the manipulation of the environment of the children participating in the experiment. It is nonetheless very plausible that noise levels varying over time, such as those caused by passing aircraft or heavy vehicles, do have an influence on concentration.

Conversely, a reduction in noise through the acoustic upgrading of the classroom seems to encourage concentration tangibly (Moch-Sibony, 1981; Lehman & Gratiot, 1983). For example, adding insulation to the windows and doors of the classroom, reduced the noise level to 30 dBA or less from a previous 35 to 45 dBA. Systematic observations were made of each pupil's behaviour before and after acoustic alterations in four classrooms — two kindergarten classes and two Grade 6 classes. After the noise level was reduced, there was a significant improvement in attention and participatory behaviour lasting for an entire half-year of school, especially in oral courses (Lehman & Gratiot, 1983). These results corroborate the statements made by teachers questioned about the relationship between student behaviour and a noisy environment (Ko, 1979, 1981; Lukas et al., 1981; Lecocq, 1985).

Noise can have a negative influence on academic performance simply because the teacher is frequently forced to interrupt the lesson while an airplane or heavy vehicle goes by, for example. This effect has actually been reported and even quantified in studies on the detrimental effects of these two kinds of noise (Crook & Langdon, 1974; Kyzar, 1977). Time lost may add up to a considerable disadvantage in the long run.

A number of studies have looked explicitly at the influence of intrusive noise, and in particular air traffic noise, on the academic performance of elementary school children (Bronzcraft & McCarthy, 1975; Cohen et al., 1980, 1981; Lukas et al., 1981; Green et al., 1982; Bronzcraft, 1981; Moch-Sibony, 1981). Since these are cross-sectional studies especially liable to selection bias, the results should be interpreted with caution. Nonetheless, after controlling for the factors of educational and socio-economic level, and racial and cultural background, in each case the authors came up with a statistically significant correlation between exposure to noise and indices of academic performance: mainly slowness in learning to read, but also less sustained attention and more frequent helplessness behaviour. For example, results on standardized reading skills tests for all pupils from Grade 1 to the last year of elementary school for 362 schools in New York City from 1972 to 1976 were analysed for the following factors: level of outside noise, children's socio-economic status, racial and ethnic background, teacher-pupil ratio, teachers' experience and qualifications, frequency of absences as well as the rate of admissions and departures (Green et al., 1982). Taking into consideration the influence of the various different factors, a multiple linear regression analysis showed that exposure to noise alone accounted for between 50% and 75% of the lags of one year or more in reading skills. It is noticeable that, in all the studies indicating a correlation between low academic performance and exposure to noise, the upper sound levels exceed the thresholds at which interference with speech begins.

Here again, certain subgroups of children are likely to be affected more than others. For example, the effects on attention span and concentration seem to be accentuated for children with high anxiety levels (Koszarny, 1978). Similarly, with a sample of 10 year old children, introducing a background noise while an academic task was being performed had more effect on the ones who scored lower on an intelligence test (Johanson, 1983). Intrusive noise in classrooms is therefore detrimental not only to the transmission of knowledge, but also to attention and concentration and, consequently, to the activity of learning itself.

Effects of Noise on Children's Health and Well Being

Noise is also considered to be a source of psychobiological stress (Jansen & Gros, 1986) either directly, by acting on the general activation level of the organism, or indirectly, by requiring an additional effort to perform certain tasks. This aspect of the problem led a group of researchers to include biological indicators of stress in their cross-sectional and longitudinal study of the effects of aircraft and traffic noise on school populations (Cohen et al., 1980, 1981). Their findings included a significant correlation between blood pressure and the level and duration of noise exposure. Levels were certainly very high for the most exposed students, ranging between 63 and 70 dBA. It is a very disturbing indication of the potential damage risk of noise in this context.

In the course of the same study (Cohen et al., 1980), researchers questioned pupils about their perception of the environment and the educational situation. The students most exposed to aircraft traffic noise reported significantly more annoyance problems due to noise, as well as problems in understanding the teacher. Essentially the same results were obtained when the study was repeated one year later with two thirds of the original sample of 262 pupils.

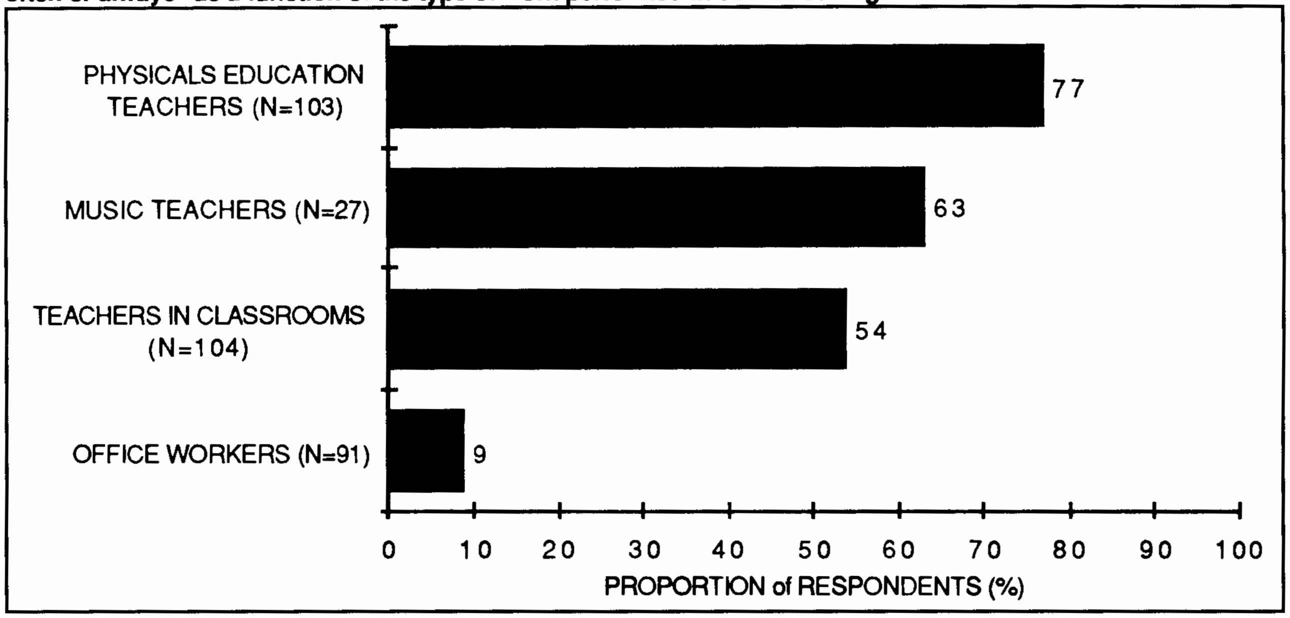
Noise can influence the behaviour and well being of students indirectly as well. Cohen et al. (1980), for example, report more frequent "learned helplessness" behaviour towards complex tasks among the children most exposed to noise. This kind of observation suggests that it would certainly be worth analysing in depth the reactions of children to intrusive noise in a teaching situation.

In short, we already know that noise can be annoying and detrimental in an educational setting. The most predictable and best known effect is interference with speech. It is noteworthy that when acoustic conditions preventing any interference with speech are met, no other undesirable effect of noise is observed. We have very little information, however, on the actual situation in our schools.

Study of the Québec School Environment

Preliminary research was undertaken to assess the importance of the problem of noise in Québec school settings. The study

Figure 1. Proportion of respondents considering that noise at work causes communication problems "quite often, often or always" as a function of the type of work performed in school settings.



was basically descriptive, including a questionnaire survey of a sample of staff working in the elementary and high schools of Québec's public school system, plus direct observation and acoustic measurements in a certain number of elementary and high school settings.

Questionnaire Survey

The questionnaire survey, carried out simultaneously in local unions in different regions of the province, netted more than 900 respondents. Replies were not processed unless they came from unions in which more than 51% of the members took part in the survey. The final sample retained included 405 respondents, representing on the average more than 80% of the total number of members in their local union doing the same kind of work in a school setting (Truchon-Gagnon & Hétu, 1988a; nota: copies of the questionnaire in French and in English are available upon request).

A majority of respondents (61%) reported that sound levels that were "uncomfortable" or "detrimental to their work" were either a frequent or a permanent feature of their workplace. Some 72% of a total of 257 teachers reported that noise at work was an "average," "important," or "very important source of problems" for them during the current school year; the corresponding percentage for support staff was 45% (N: 148).

The following problems were significantly more severe for teachers reporting uncomfortable acoustic conditions: difficulties in communicating; voice problems; less patience, availability, and effectiveness than they would like; stress; malaises. These replies coincide with the effects noise can be expected to have on people who are teaching. As Figure 1 shows, noise is blamed for communication problems by a substantial proportion of classroom teachers and by the vast majority of physical education teachers.

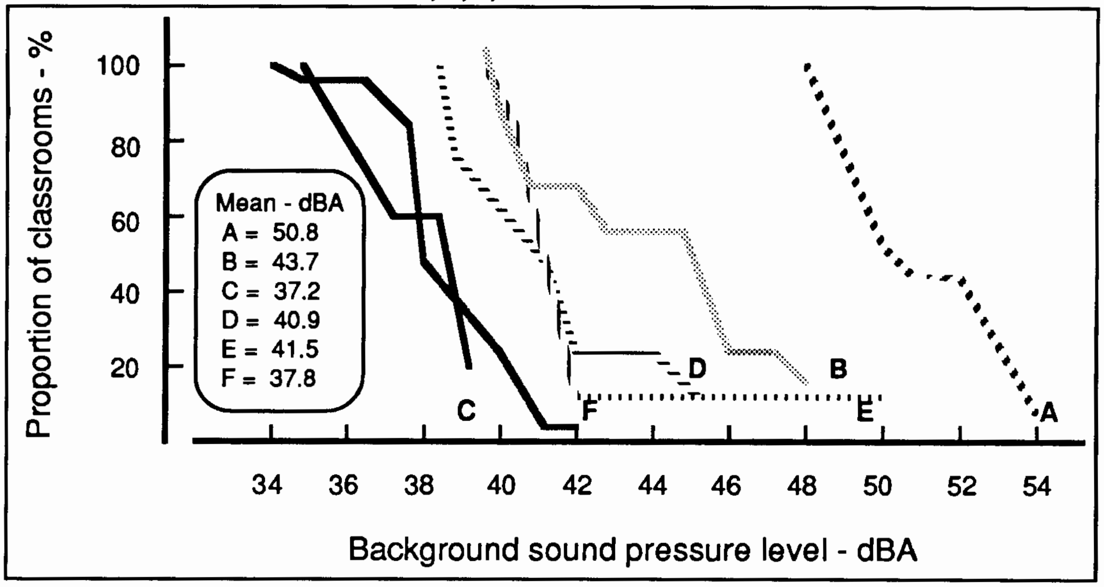
These results suggest that the acoustic environment of some Québec classrooms is not optimal for teachers' well being and the performance of their work; they also imply that pupils may be directly or indirectly affected via the ill effects of noise on their teachers and on communication within the classroom. These findings guided our exploratory gathering of acoustic data in school settings.

Acoustic Measurements and Observations

Classrooms

Acoustic measurements were taken in 50 classrooms in 6 elementary schools on Montréal Island identified in the present account as school A, B, C, D, E, and F. The schools were chosen to reflect a maximum range of different layouts and exposure to outside sources of noise. The sample included two recently built open plan schools (A and B) and one school (D) that was more than 60 years old. These three were all, in the opinion of their principals, located close to heavily used traffic arteries while the other three (C, E and F) were not but one (E) was located in a flight corridor. Only one school (C) served a high socio-economic population, as de-

Figure 2. Cumulative distribution of the background noise levels measured in the various classrooms of each of the six schools under investigation. Schools A and B were open plan; classrooms were closed in schools C, D, E, and F.



fined by the school board. The size of the schools ranged from 235 to 550 children.

Three kinds of data were collected in each school: (1) teachers' comments on acoustic conditions in their classrooms and the design and construction of the room; (2) observations concerning the visible characteristics of the walls, floors, and ceilings and the design and construction of the room, as well as sources of audible noise; and (3) measurements of the level of background noise, reverberation time, the size of the rooms, and maximum distances between the teacher and pupils (for details of the methodology, see Bilodeau & Hétu, 1988).

To avoid the effects classroom activity on measurements of background noise, the measurements were conducted in optimal acoustic conditions, that is, while children were out of the room but normal teaching activities were taking place in adjacent classrooms. Although these were optimal conditions, the level of background noise exceeded 35 dBA in nearly all the classrooms visited, as can be seen in Figure 2. It should be kept in mind that the results of the research on speech intelligibility in classrooms discussed above suggest a recommended limit of 30 dBA (Bradley, 1986a). In the separate, closed classrooms of two schools (D and E), the level exceeded 40 dBA in a majority of classrooms. As could be expected, the situation was even worse in the open plan schools (schools A and B). In school A, the level of background noise ranged from 48 to 54 dBA, depending on the teaching area. Although the data were gathered in a limited number of schools, they show clearly that noise frequently interferes with speech in elementary school settings. The factors statistically correlated with a high level of background noise were the open plan design, audible ventilation, and road traffic noise.

As well, the reverberation time at 1 kHz shown in Figure 3 were clearly excessive for the three schools with closed classrooms. These were classrooms where the ceilings were not covered with acoustic tiles.

Using Bradley's data (1986b), we estimated speech intelligibility by combining the effects of the signal/noise ratio and the reverberation time (See Bilodeau & Hétu, 1988 for details of the calculations). This estimate is valid for children 12 years of age or older with unimpaired hearing. The results are given in Figure 4. It can be seen that only one school meets the conditions for optimal intelligibility (school F). Schools B, C, D, and E have an intelligibility rating hovering around 90%, and school A less than 75%. This means that the teacher's words are not always comprehensible for a substantial proportion of pupils in the majority of classrooms in the schools visited. It would be surprising if our sample had taken us by chance to the schools with the poorest acoustic arrangements, with one exception. In other words, although this is an exploratory study, the data gathered corroborate what the survey questionnaire indicated: namely that acoustic conditions are often unfavourable to speech in classrooms.

Gymnasia

As mentioned above, the most severe noise problems were reported by physical education teachers; consequently, de-

Figure 3. Cumulative distribution of the reverberation times measured in the octave band centred at 1 kHz for the various classrooms of each of the six schools under investigation (identified as A to F).

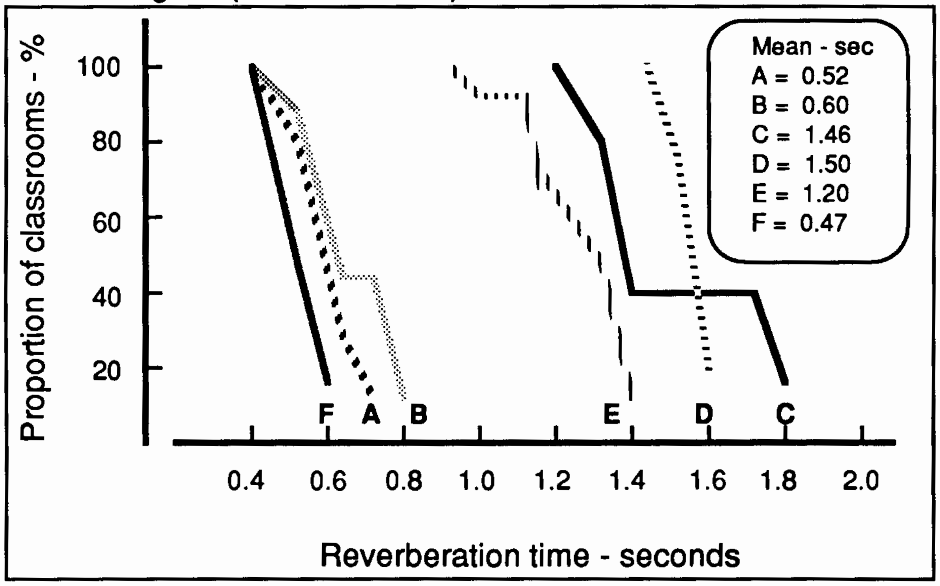
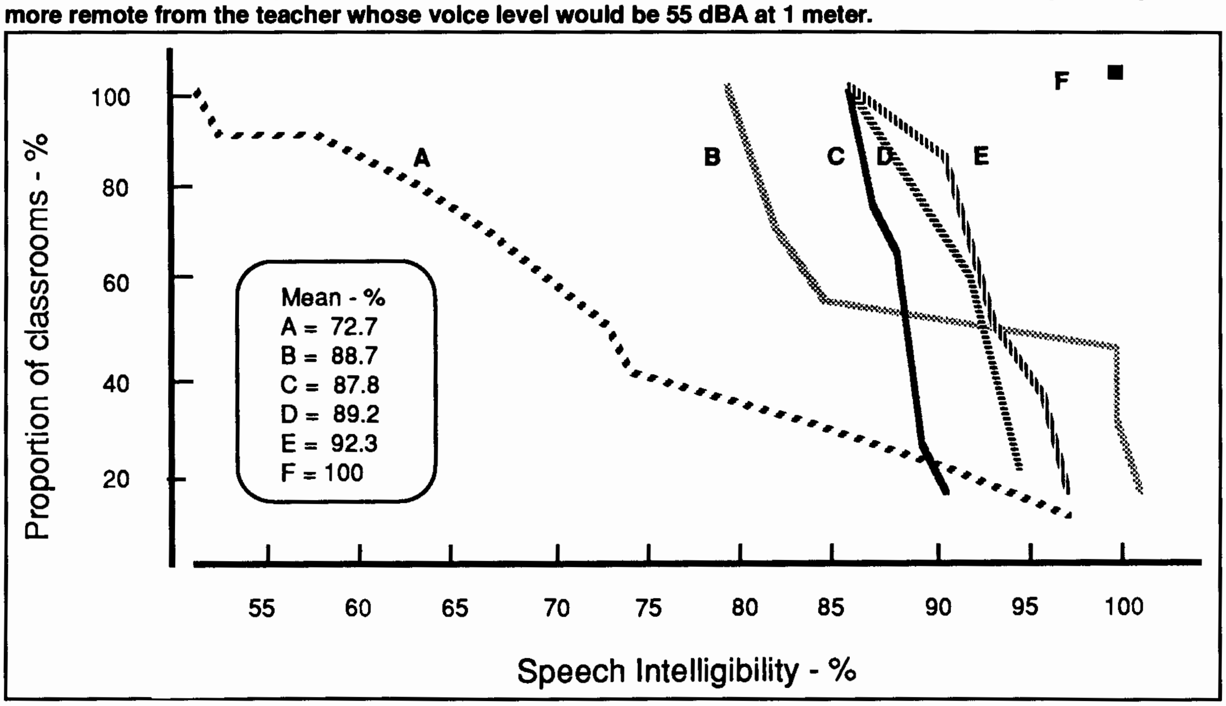


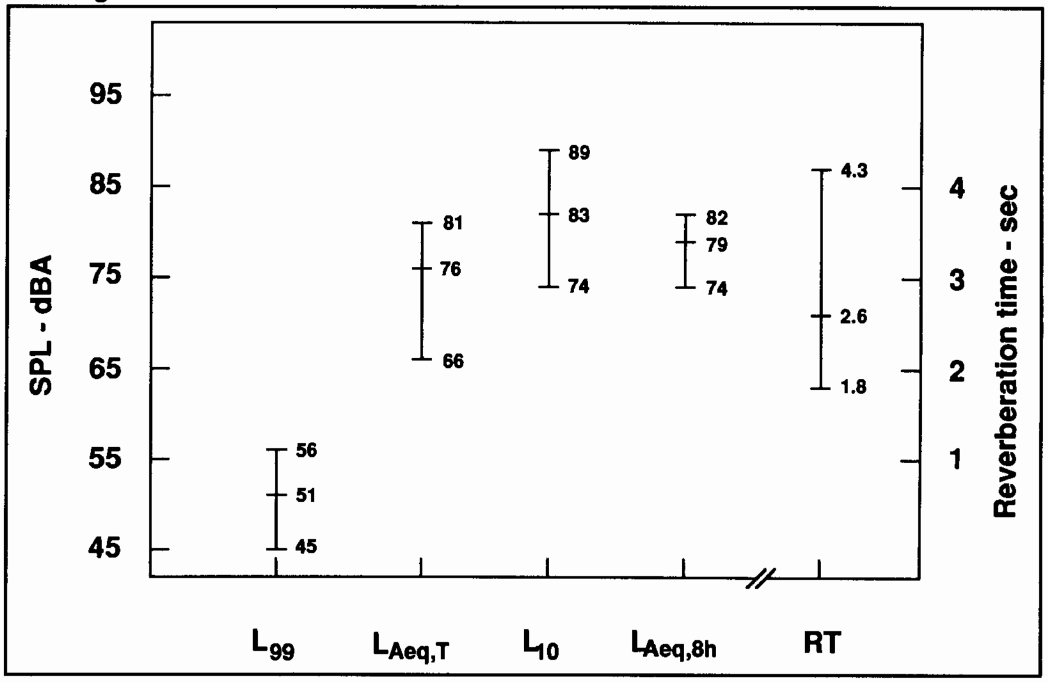
Figure 4. Cumulative distribution of intelligibility scores in the various classrooms of each of the six schools under investigation (identified as A to F) as predicted from the background noise level and the reverberation time: the index of intelligibility refers to the percentage of words that would be understood by the pupils the more remote from the teacher whose voice level would be 55 dBA at 1 meter.



tailed measurements were taken in gymnasia. A total of 35 physical education classes were monitored in 4 elementary and 4 secondary schools (Truchon-Gagnon & Hétu, 1988a).

Sound pressure levels were measured using a Bruel and Kjaer 2231 sound level meter. For every 5 minute interval during the full duration of a physical education class, 3 consecutive measures of $L_{Aeq,60s}$ (A-weighted equivalent contin-

Figure 5. Sound pressure levels (minimum, mean and maximum) measured during 35 physical education classes in 8 gymnasia. $L_{Aeq,T}$ refer to the A-weigthed equivalent continuous sound pressure level for the whole duration T of a class. The distribution of the reverberation time (RT) measured in the octave band centred at 1 kHz is depicted according to the rigth hand ordinate.



uous sound level for a 60 second interval) and 1 measure of maximum peak pressure level over 60 seconds ($L_{pAmax,60s}$) were collected. Systematic observation using a checklist was conducted for each 60 second interval of noise measurement. The checklist comprised the possible noise sources that could be heard, as well as the type of activity and the number of participants. Room size and reverberation time also were measured.

Figure 5 depicts the results of the noise measurements in 8 gymnasia. The background noise (L_{99}), generally produced by the ventilation, is loud enough to interfere with speech intelligibility and to require a voice effort from the teacher. The reverberation time alone also is a strong source of speech interference, even in the case where it was shortest, namely 1.8 s. Results from measurements taken during a total of 35 classes showed that the prevailing sound level is definitely a major source of communication problems. The lowest L_{Aeq} for the whole duration of the class was 74 dB, the median being 83 dB. Maximum peak levels also were very high. Peaks as high as 115 dBA were frequent for certain activities involving hard balls hitting hard surfaces or screaming in these reverberating rooms. This confirms that the noise can be a strong source of annoyance for the physical education teachers. The 8 hour overall exposure is high enough to be a source of excessive fatigue and stress if one considers that the task to be performed (transmitting instructions through speech communication) is constantly impeded by the sound environment.

The most severe conditions were met in multiple gymnasia in which two or more teachers were running different classes at the same time. In such cases, the volume of the room was extremely large, the reverberation time ranged up to 4.3 s, and the sources of noise were numerous and uncontrollable by any one teacher.

For all the physical education classes involved in the measurements, it was observed that the teacher almost constantly taught with a raised if not strained or shouted voice, having to compete with the sound produced by other voices and by the ongoing activities. Despite this vocal effort, the observer was frequently unable to understand what the teacher was saying. This means that the pupils are likely affected by the noise in such a setting, at least in terms of speech intelligibility.

The above data confirm that noise and speech intelligibility problems may exist in a number of school settings in Québec; the learning, behaviour, and well being or social and emotional adjustment of many children may be affected. These problems may be magnified for children with special problems. The results are sufficient to warrant a broad descriptive study of sound conditions in the teaching environment in elementary and high schools with a view to correcting the situation. Meanwhile, the results provide valuable pointers for people who are not specialists in acoustics for identifying inadequate acoustic conditions, at least in classrooms (Bilodeau & Hétu, 1988): namely the lack of acoustic tiles on ceilings and the presence of audible ventilation noise. Of course, open plan settings are not at all suited to speech communication in a teaching situation.

Conclusions

To sum up, noise in an educational setting has many detrimental effects that may have significant psychological and physical impact. They affect both the children and the teachers. Noise problems may be even more acute for people with special problems, be they perceptual, socio-emotional, or cognitive.

In the current state of knowledge, some of the harmful effects of noise in an academic setting are predictable and quantifiable: namely, interference with speech. The acoustic comfort criteria favourable to speech in class are known. The same criteria are also favourable to interpersonal relations and the overall needs and tasks of both pupils and teachers. Moreover, enforcing these criteria would forestall the emergence of other kinds of ill effects of noise, thus contributing positively to the development of pupils with special needs, such as hearing loss, learning a second language, learning problems, socio-emotional problems, and intellectual impairment.

As we observed for day care centres (Truchon-Gagnon & Hétu, 1988b), the acoustic environment in school settings is far from ideal. The situation is due less to a lack of scientific knowledge than to a lack of awareness on the part of all concerned, from architects to schoolboard managers to parents, and including specialists in speech and hearing problems.

For day care centres, an acoustic design guide is now available to prevent and correct noise problems (Melançon et al., 1989). Since the same design and construction techniques are applicable to classrooms, a similar guide could be developed to outline solutions for school settings. In the case of large spaces like gymnasia, where noisy activities are carried on regularly, further research is required to develop valid noise acceptability criteria for this setting, as well as the corresponding principles of acoustic design.

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