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Acoustical Comfort in Primary School Classrooms in the City of Joao Pessoa, Paraiba, Brazil

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Abstract

Based on Brazilian and International normative guidelines, acoustical comfort was evaluated in 119 primary school classrooms in the City of Joao Pessoa (Brazil). A Beta Regression Model (BRM) was built, through which it was verified to what extent acoustic parameters of these rooms can affect teacher speech intelligibility. It was found that the Levels of Noise from external sources, Background Noise, Reverberation Time and the Speech Intelligibility Index are not within reference values established by the norms. Reverberation Time affects the quality of intelligibility at around 77.18%.

Keywords: Classroom; Acoustic parameters; Intelligibility

Introduction

School plays an important role in the development of people and society. It is in school, more precisely in the classroom, that the teaching-learning process takes place. This process comprehends covering the curriculum as well as disseminating good social skills, which are part of education in its broadest sense [1-6]. In Brazil, public schools are organized as follows: those for kids up to 6 years old, fundamental schools and high schools, technical or career schools, and special schools for people with disabilities. Fundamental education comprises two levels: the first corresponds to the initial years (1st to 5th year), for 6- to 10-year old students; the second (6th to 9th year), for 11- to 14-year old students.

According to the Ministry of Education, about 72000 students were enrolled in fundamental education in the city of Joao Pessoa in 2011, 60% of which in public schools. On the other hand, population growth and social programs promoted by the Federal Government resulted in the construction of several housing complexes which required infrastructure, thus building new schools.

Kowaltowski [7] highlights that environmental comfort related to productivity at work or learning depends on the building design and its suitability to the users' activities. There is, then, a strong relation between school architecture and user satisfaction concerning the quality of the environments. This is directly related to environmental comfort, which comprises thermal, visual, acoustical and functional aspects offered by external and internal spaces. Comfort issues relate to several factors, such as air quality, ventilation, verbal communication, lighting, space availability and finishing materials.

De Giuli et al. [8] state that working or studying in a comfortable environment enhances not only well-being but also satisfaction and, thus, productivity and learning rates. Consequently, it is necessary to reach a good level of comfort in school buildings considering that students spend nearly 30% of their lives in there. And, previous research has shown a link between chronic noise exposure and reading skills. Elementary school-age children are thought to be negatively affected by such exposure [9].

According to Zannin and Zwirtes [5], acoustical comfort in primary and secondary school classrooms, as well as university classrooms, has been the focus of several studies around the world [10-19]. Another focus of study mentioned by these authors is students' and professors' noise perception, as well as the influence of noise on people [17,20-22].

It can be verified that classroom quality relates to several important variables, among which those that stand as the core of environmental comfort, such as: air quality, temperature, light, sound. On these grounds one variable is directly associated to the quality of students' learning: acoustical comfort. Classrooms are designed to promote learning, not only for children but for adults as well. Classrooms have become multimedia communication environments, which increases even more the importance of classroom acoustics.

Good acoustical quality for learning using verbal communication demands low noise levels and little reverberation. When acoustics are not good both teacher's comfort and vocal health may be affected [23]. According Chiang and Lai [24], an Evaluation Model of Acoustic Environment in Classrooms to evaluate the environmental quality of elementary schools. It was found that the acoustic environment of these elementary schools is not adequate. With open windows, the noise levels at both Joint Classrooms and traditional classrooms are 20 dB (A) above the standard. The reverberation time in traditional classrooms is better, while in Joint Classrooms it tends to be longer. Klatte et al. [25] said children from reverberating classrooms performed lower in a phonological processing task, reported a higher burden of indoor noise in the classrooms, and judged the relationships to their peers and teachers less positively than children from classrooms with good acoustics. And Sato and Bradley [26] said that detailed analyses of early and late-arriving speech sounds showed these sound levels could be predicted quite accurately and suggest improved approaches to room acoustics design.

Thus, this paper aims at presenting the current acoustical panorama of classrooms in a city of the state of Paraíba, Brazil, as well as analyzing the possible relations between acoustical parameters and intelligibility in the public school classrooms that were analyzed.

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Methods and Models

This study was carried out in public schools in the city of Joao Pessoa. These schools not have a standard design and were not observed the presence of acoustic treatment in any of the schools. As our region is tropical (hot and humid), the designers only care about ventilation. All classrooms have windows and/or hollow elements and it have an average volume of 144.97 cubic meters, ranging between 72.56 and 218.40 m^3.

These schools are grouped in nine poles that respect some socioeconomic and geographic coherence, totaling 93 schools. When setting the sample, some criteria were taken into consideration to guarantee its significance and representativeness concerning the population studied. It was decided that only schools with groups from 1st to 5th year of fundamental education would be analyzed, for these initial years of education represent the most enrollments in the public school network.

During a pilot experiment it was found that older children adapted more easily to the presence of the researcher during data collection, since measurements of the equivalent sound pressure levels were done during classes. For this reason, it was decided that this study would be carried out in the 5th year groups of fundamental school.

Sixty-five schools participated in the study. The justification for not evaluating 28 schools were the following: 1) some did not have 5th year groups; 2) some were undergoing building renovation; and 3) due to some extracurricular activities (martial band rehearsals, dance groups, etc.) between morning and afternoon classes, which prevented measurements of external noise levels; or still, discrepancies arose in the data concerning sound pressure level. This way, sample had 119 classrooms, 71.26% of the total 167 5th-year groups in the city's public school network.

Evaluation of acoustical parameters and speech intelligibility

To measure Sound Pressure Level (SPL) equivalent sound levels were registered-Leq by using a calibrated sound pressure level meter, Sound Level Meter model (SL-4011) made by Instrutherm. The equipment meets the requirements of the current Brazilian legislation for the calculation of SPL for offering "A" weighting; "SLOW" response; Reference Circuit-85 dB (A); measurement range between 50 and 115 dB (A).

In Brazil the measurements of sound pressure levels follow the guidelines prescribed by NBR 10.151/2000 [27], which specifies a method for measuring noise. Indoor measurements (as in classroom) shall be made at a minimum distance of 1 m from surfaces such as walls, ceilings, floors and furniture. The sound pressure levels in the indoor environment is the arithmetic mean of the values measured in at least three distinct positions (P_i) and the distance between (P_i) is around 0.5 m, according to figure 1. Measurements were conducted during daylight classes (morning and/or afternoon). SPLs were collected at each one of the five previously specified spots of the classroom. In addition, five consecutive measurements were done at each spot, with intervals of 30 seconds between them, in rooms in use (during classes). After that, SPL was calculated by using equation (1), meeting the requirements set by NBR 10151/2000 [27].

$$Leq = 10\log\left[\frac{1}{n}\sum_{i=1}^{n}10^{\frac{Li}{10}}\right] \quad (1)$$

Where Leq is the equivalent sound pressure level, in dB (A); Li is the sound pressure level measured at each moment "i", in dB (A); N is the total number of measurements.

In the evaluation of SPLs coming from outside sources (REXT), the same procedure as stated before was used, but under different conditions. In this case, classrooms were empty and schools were not active. These measurements were done at the same day when sound pressure level was measured, between morning and afternoon classes.

Reverberation Time (RT) was calculated based on room volume, on the area of materials that compose internal surfaces (walls, ceiling and floor), room occupation (people, furniture and objects) with their respective absorption coefficients (α). Equation (2) was used according to NBR 10179/1992[28], provided that this equation takes into consideration an average absorption coefficient below 0.30.

$$RT = \frac{0.16.v}{\sum S_i\alpha_i} \quad (2)$$

Where v is the room volume in m^3; Si is the surface area in m^2; αi is the absorption coefficient; RT is reverberation time in seconds.

According Müller and Swen Mediro [29], Farell-Becker found the equation (3) that evaluates the relation between %AlCons and STI.

$$\%AlCon = 170.5405e^{-5.419STI}, \%AlCons \in [0,100] \quad (3)$$

On the other hand, according Valle [30]

$$\%AlCons = \frac{200.D^2RT}{V.Q}\%; D \le DL \quad (4)$$

Thus, by equations (3) and (4) we obtain STI (5).

$$\frac{200.D^2TR}{V.Q} = 170.5405.e^{-5.419STI}$$

$$\frac{200.D^2.RT}{170.5405.V.Q} = e^{-5.419STI}$$

$$\log\left(\frac{200.D^2.RT}{170.5405.V.Q}\right) = -5.419STI$$

$$STI = \frac{-\log\left(\frac{200.D^2.RT}{170.5405.V.Q}\right)}{5.419}; D \le DL \quad (5)$$

Where D is the distance between listener and sound source, V is the room volume, Q is sound source directivity and DL is critical distance. This latter is the maximum distance where sound intensity - due to

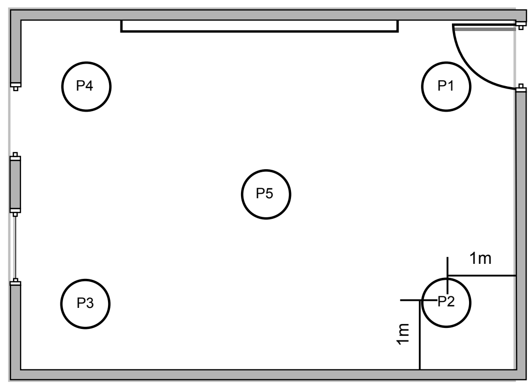

Figure 1: Noise levels measurement spots.

the direct sound of the sound source - is equal to the intensity of the reverberant field, according to equation (6).

$$D_L = 0.141 \cdot \sqrt{Q \cdot A} \quad (6)$$

Directivity of a sound source at any spot of the room is expressed through the so-called directivity factor Q. This factor depends on the relation between the sound pressure level produced by the sound source in the considered direction and the level that would be achieved if the source were not directive. The higher the SPL in one specific direction, the bigger will be Q value in this direction.

For the current study, since sound source is the teacher's voice, a typical value of Q = 2.5 for human voice was used, according to Valle [30].

Data analysis

Analyses were carried out to examine the relationships between acoustical parameters and speech intelligibility based on one descriptive-correlational study. Also, association hypotheses were verified, by establishing more definite relations based on the observation of the nature of the relations between them.

Descriptive analysis of acoustical parameters and speech intelligibility: By using descriptive analysis of parameters such as sound pressure level (SPL), Levels of noise coming from outside sources (REXT), Reverberation Time (RT) and speech intelligibility (STI), the objective was to learn their characteristics, as well as compare the results found to the standards set by current legislation.

In order to describe the main characteristics of the found data, descriptive statistics were applied with the use of the R software. Such analysis allowed knowing better the investigated variables, through the observation of how the data was organized and summarized based on charts and measurements of central tendency and dispersion.

Analysis of the ratio between acoustical parameters and speech intelligibility: The analysis of the relation between the acoustical parameters SPL, RT and REXT and STI was conducted in two phases, as follows: Phase 1 – Analysis of Correlation; and Phase 2 – Beta regression modeling.

Results And Discussions

Descriptive results

Sound pressure levels (SPL) measured ranged between 56.5 and 84.6 dB (A), average 71.5 dB (A) and standard deviation 6 dB (A), which indicates little dispersion, that is, data are near the average. It was observed that 25% of the recorded values for SPL in classrooms are below 67.2 dB (A), whereas 75% of SPL are below 75.4 dB (A). This way, interquartile range (Q3-Q1) will be 8.2, which means that 50% of SPLs are around the median, 71.4 dB (A).

Regarding parameters set by NBR 10152/1987 [31], values found are over those set in the norm, which sets values around 40 and 50 dB (A) for classrooms. Such finding can be seen in figure 2. Sound levels coming from external sources (REXT) ranged between 42 dB (A) and 66 dB (A), average 52.7 dB (A) and standard deviation 4.8 dB (A), which indicates little dispersion, that is, numbers are near the average. It was observed that 25% of the Sound Pressure Level in classrooms are below 55.7 dB (A). This way, interquartile range (Q3-Q1) will be 6.3, which means that 50% of the SPLs are around the median, 52.7 dB (A).

Regarding parameters set by NBR 10151/2000 [27], around 75% of the values found are over those set by the norm, which must be of 50 dB (A) during the day in strictly urban areas, also around hospitals and schools, which can be seen in figure 3. Reverberation Times (RT) ranged between 0.43 and 0.92 seconds, average 0.6863 seconds and standard deviation 0.1082516 seconds, which indicates little dispersion, that is, number are near the average. It was observed that 25% of the reverberation times are below 0.61 seconds, whereas 75% are below 0.76 seconds. This way, interquartile range (Q3-Q1) will be 0.15 seconds, which means that 50% of the RTs are around the median, 0.69 seconds.

Regarding parameters set by ANSI S12.60/2002 [32], only 18.33% of the values found are within the acceptable range set, which must be between 0.5 and 0.6 seconds. This finding can be seen in figure 4. Speech Transmission Index (STI) found ranged between 0.1980 and 0.3377, average 0.2540 and standard deviation 0.03070982, which indicates little dispersion, that is, numbers are near the average. It was observed that 25% of the indexes are below 0.2316, whereas 75% are below 0.2540. This way, interquartile range (Q3-Q1) will be 0.0417, which means that 50% of the STIs are around the median, 0.2496.

Regarding parameters set by IEC 60268-16/2003 [33], only nine rooms, 7.5%, presented indexes in the 0.3-0.45 range, which means

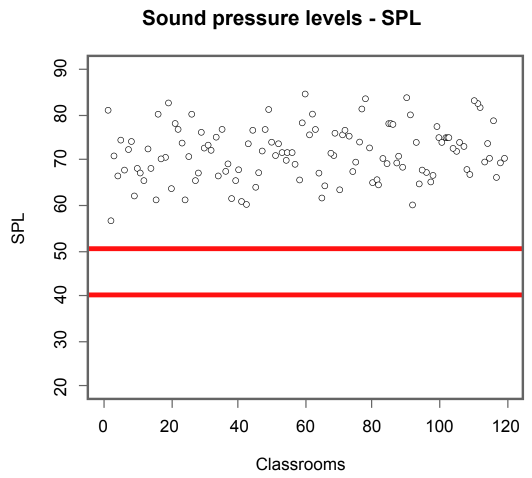

Figure 2: Sound pressure levels measured in classrooms.

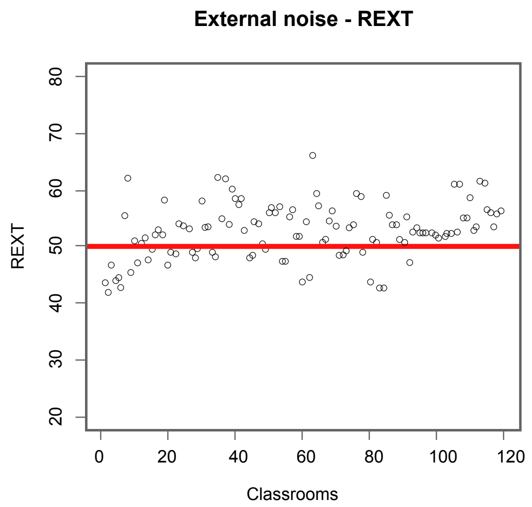

Figure 3: Sound levels coming from external sources.

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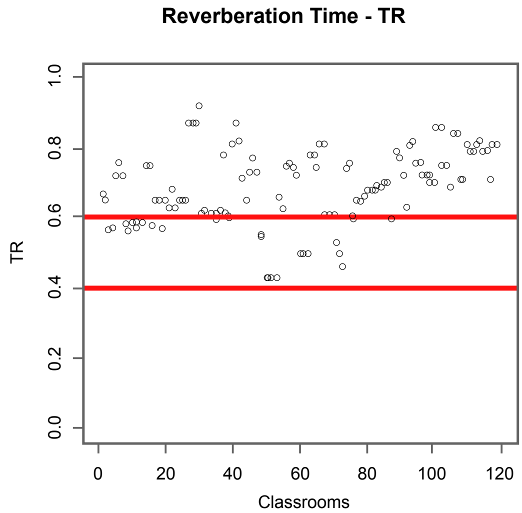

Figure 4: Reverberation times calculated in classrooms occupied.

poor intelligibility. The remaining ones presented indexes in the 0 a 0.3 range, which means bad intelligibility. This finding can be seen in figure 5.

Mathematical modeling

In order to evaluate the relationship between SPL, REXT, RT and STI parameters, a correlation analysis was conducted. Table 1 shows these correlations, highlighting the strong association between STI and RT.

The strong correlation that can be seen between STI and RT parameters, r=–0.99373916, is expected since, according to equation (5) STI is a function of RT. However, there is a correlation between the remaining parameters, which led to the following question: Provided that the distance between the listener and the source in each room is not the same; and the volumes of these rooms are different; and provided that the relation between STI and RT is extremely strong, then how probable is it that RT can affect the quality of intelligibility? This question led to the construction of a mathematical model based on beta regression modeling, for STI (0,1), where STI is the dependent variable and RT is the independent variable.

Be Yi the observations so that for each independent value of y we have a value of STI (0,1) with distribution and average μi, and unknown parameter; be variable X observations so that for each independent value *x* we have a value of RT; thus, the model for predicting STI will be written in the form of equation (7).

$$g(\mu_i) = \beta_0 + \beta_1 RT + \phi(error) \qquad (7)$$

Model coefficient estimates and their respective standard errors, values of Z (number of standard deviations of about the mean) and probabilities are described in table 2. It can be seen in this table that the error, value of Z and Pr (>Z) validate the coefficient estimates of intercept and RT coefficients. Representative value of pseudo R^2 ratifies the efficacy of the model as it relates STI and RT. Thus, based on the information of the estimates presented in table 2, the mathematical model for predicting STI as a function of RT is presented in equation (8).

$$STI = \frac{e^{-0.069322-1.477769RT}}{1+e^{-0.069322-1.477769RT}} \qquad (8)$$

Based on equation (8) the odds ratio can be estimated, by analyzing to what extent variable RT affects STI. The estimated value $e\beta_1 = e^{-1.477769} = 0.228146$ is odds ratio associated to RT. Thus, there is a chance of about 22 times of occurring loss in the quality of speech intelligibility if RT rises each second. That is, under the conditions evaluated classrooms are when compared to those in the acoustical comfort control, there is a 77.18% probability that RT will affect speech intelligibility. This finding can be seen in figure 6, observing that 81.67% of RT measured in classrooms are over the 0.6 seconds, as can be seen in figure 4, which represents an STI variation between 0.19 and 0.27.

Conclusions

The objective of this study was to analyze the influence of acoustical parameters on speech intelligibility in classrooms of public schools in Joao Pessoa. For this, 119 classrooms were analyzed; those that offered 5th-year fundamental school classes, considering that these groups have a more representative student sample, for these are the oldest students in the first phase of fundamental school.

For starters, the study aimed at measuring acoustical parameters SPL, REXT and RT, which represent the absence (or presence) of acoustical comfort in, nearly, all classrooms. SPLs were all over the values set by NBR 10152/1987 [31], which establishes values in the 40 - 50 dB (A) range. Around 75% of the classrooms presented REXTs over those established by NBR 10151/2000 [27], which recommends 50 dB (A) during the day in strictly urban areas, and those around hospitals or schools. Regarding RT, only 18.33% of the classrooms presented values considered acceptable by ANSI S12.60/2002 [32], which sets the

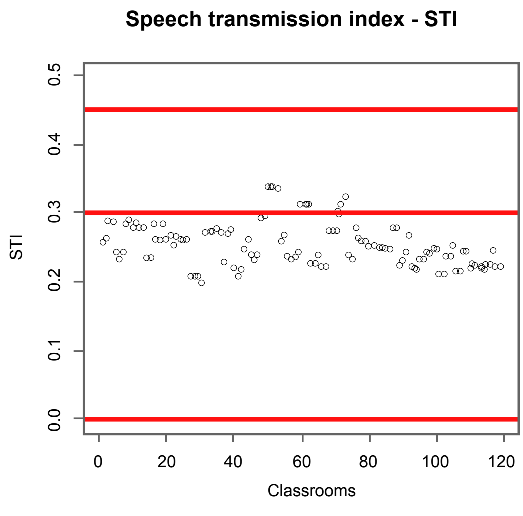

Figure 5: Speech transmission index measured in classrooms.

	SPL	REXT	RT	STI
SPL	1.0000000	0.10007630	- 0.14933457	0.16221662
REXT	0.1000763	1.00000000	0.19389128	- 0.17564388
RT	-0.1493346	0.19389128	1.00000000	- 0.99373916
STI	0.1622166	- 0.17564388	- 0.99373916	1.00000000

Table 1: Correlation matrix between considered variables.

Coefficient	Estimate	Standard Error	Z Value	Pr(>Z)
Intercept (β_0)	-0.069322	0.006178	-11.22	2. 10^{-16}
RT (β_1)	-1.477769	0.008997	-164. 24	2. 10^{-16}
Pseudo R^2	0.995600			

Table 2: Model coefficient estimates and corresponding standard errors.

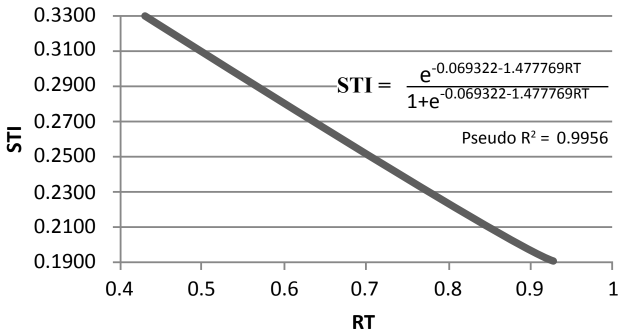

Figure 6: Mathematical model for predicting STI as a function of RT.

0.4-0.6 second range for classrooms.

A worrying factor was speech intelligibility in classrooms, measured based on the Speech Transmission Index STI. It was verified that in 92.5% of the classrooms this index was in the 0.3-0.45 range, representing poor intelligibility according to IEC 60268-16/2003 [33]. This situation deserves special attention since intelligibility reflects the degree of understanding of the words inside environments and it is considered a determinant factor since communication is essential in a classroom. Among acoustical parameters measured, it was verified that Reverberation Time (RT) and Speech Intelligibility (STI) were strongly correlated (r=-0.99373916), which demonstrates that the quality of intelligibility lowers when reverberation time rises. This result ratifies studies that show that good speech intelligibility levels, even in small classrooms, are related to the adequate predicted reverberation times. Based on these data, it is considered pertinent to build a beta regression model to analyze the risk run by quality of intelligibility as RT is raised by a unit. Mathematical modeling presented an elevated consistency, value 0.9956 for pseudo R^2; variable "Reverberation Time" (p value = 2×10^{-16}) was the most representative, odds ratio of 0.228126, demonstrating that this variable affects the quality of intelligibility at about 77.18%.

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