# A pilot study on the influence of language on the results of speech intelligibility tests in classrooms

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## ABSTRACT

Numerous studies have shown that teachers often speak louder in classrooms because of the acoustic properties of the spaces. To improve the acoustics in classrooms, it is necessary to develop relevant acoustic criteria. Existing evaluation scales for parameters of room acoustics have been developed on the basis of studies of adults for a variety of languages (e.g., Dutch and English). One of the issues still not fully recognized is the effect of the respondents' language and age on the results of speech intelligibility tests. This paper presents a pilot study of the speech intelligibility of Polish-speaking children (10-13 years old) in conjunction with parameters of room acoustics. It also compares studies of speech intelligibility for other languages. Our study confirmed a relationship between the results of speech intelligibility tests and speech transmission index STI for classrooms with varied acoustics. It also showed that the results of Polish tests are similar to Anderson's and Jacob's results for English.

Keywords: speech intelligibility, schools, room acoustics I-INCE Classification of Subjects Number(s): 51.1.4

## 1. INTRODUCTION

The largest group of educational facilities in Poland are schools (primary, lower secondary and upper secondary schools). According to the Central Statistical Office, about 32,000 Polish schools are attended by about 5.3 million pupils and students, of which 2.16 million attend primary schools (29). There are about 352,000 school rooms and schools employ about 400,000 teachers. The largest group of teachers works in primary schools (170,600) and in lower secondary schools (102,900) (29). The highest number of cases of chronic diseases of the vocal organ in Poland are found in the Education Section (24), i.e. in institutions dealing with education. According to research conducted by the National Institute of Public Health - National Institute of Hygiene (NIZP-PZH) and the Central Institute for Labour Protection — National Research Institute (CIOP-PIB) teachers, especially in primary schools, complain about the necessity of speaking in a raised voice during the lesson (1, 2, 6). This leads not only to an increased vocal effort, but also to rapid accumulation of fatigue and occupational speech organ disorders. Because during lessons it is necessary to speak in a raised voice, a significant percentage of teachers assess the conditions of their work and well-being negatively (1, 2, 6). It also negatively affects teachers' subjective assessment of their own health (1, 2). Reason for teachers speaking in a raised voice include acoustic properties of classrooms, which adversely affect the background noise resulting from student activity and other factors (9, 16). The acoustic properties of classrooms is particularly important in primary schools where, due to the pupils' age, the best possible conditions for the transmission of verbal content should be ensured (7, 25).

The acoustic properties of classrooms can be improved provided that appropriate criteria for the assessment of such rooms are developed. The existing scales for assessing the acoustic parameters of rooms have been designed based on studies of adults (22, 23). One of the issues which has not been fully examined until now is the effect of the language in which verbal content is conveyed on the relationship between speech intelligibility and room acoustics. To date, no studies on Polish speech intelligibility in connection with objective acoustic properties of a room have been conducted in Poland. There are also no national documents containing requirements, recommendations or methods

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of assessment of school room acoustics (disregarding the requirements for indoor noise and acoustic insulation of space dividers). Therefore it was necessary to undertake research on the intelligibility of speech in the Polish language related to objective room acoustic parameters, such as reverberation time and the speech transmission index (STI). Studies conducted worldwide show that the type of language in which the tests are conducted and age can have a significant impact on the relationship between objective acoustic performance and subjective intelligibility tests (5, 23).

## 2. SPEECH INTELLIGIBILITY TESTS

Criteria for acoustic assessment of rooms are established on the basis of subjective tests concerning e.g. speech intelligibility. The most widely used test method for determining the recommended values of acoustic parameters is to compare the results of objective tests (measurements) with the results of subjective tests (speech intelligibility tests) (17, 18, 21, 22). There are several types of linguistic materials used in speech audiometry: isolated words (CVC and CCVC structures), sequences of numerals, logatoms and sentences.

According to the HEARCOM D-7-1 report (30), isolated words (CVC structure) are most commonly used as stimuli in speech audiometry, however many authors suggest that the study of speech intelligibility for children should make use of more complex utterances (sentence tests) (12, 13, 25, 26). In the case of the Polish language there are expressive word articulation tests (CVC and CCVC structures) and PLOMP and MATRIX sentence type tests (12, 13, 14, 15). Guidelines have also been created for sentence tests for children, but their final version has not been developed yet. (11)

Relationships between objective room acoustic parameters and the results of subjective tests (also referred to as articulation tests) have been studied so far with respect to: logatoms of the CVC structure (CVC) in Danish (3), logatoms of the CVC structure in Spanish (CVC-Logatoms$_{Spanish_test}$) (23), ($CVC_{EQB}$) (22) and monosyllabic words conforming to ANSI S3.2-1989 (% PB-ANSI) (4). In these studies, the results of subjective tests were referenced to the values of the speech transmission index (STI) (Figure 1), which has been developed, among others, on the basis of studies by Steneeken and Houtgast (3). The studies were conducted on adults. Articulation lists were played through speakers in acoustically different rooms (4, 23) or via headphones, using appropriately modified sound samples (3, 22). When comparing the results of the relationship between subjective speech intelligibility and speech transmission index STI, significant differences between the curves can be noticed. They were also the subject of research on the verification of the STI method for English, which used a list of phonetically different words, referred to as “the Harvard list” (PB words) and sentence tests (based on SRT - Speech Reception Threshold) (4, 25, 27) (Figure 2). Differences between the articulation tests were also observed when comparing results of tests for English and Chinese with respect to acoustic parameter U50 (5) (ratio of usable energy of the speech signal compared to the unusable energy) (Figure 3).

Subjective intelligibility tests are focused mainly on adults. There are few publications concerning the question of referring objective room acoustic parameters to articulation test results conducted among children. Nevertheless, the studies of Yang and Bradley (25) show that age is important in the study of subjective speech intelligibility. Differences between the age of 5 and 13 can reach up to 20% of correct responses in word tests.

### 2.1 Tested rooms and the test group

Three classrooms for a group of early school education children and 3 classrooms for a group of older children were selected for the pilot studies. Pupils were selected from each age group based on an interview with a school nurse or hygienist. 20 people were assigned to each group (0-3 and 4-6). During the speech intelligibility test in classrooms, sound was played from directional sound source ADAM A5X with linear frequency characteristics. The tests played level was calibrated each time using a sound meter ($L_{Aeq}$ = 60 dB) at a distance of 1 m from the source.

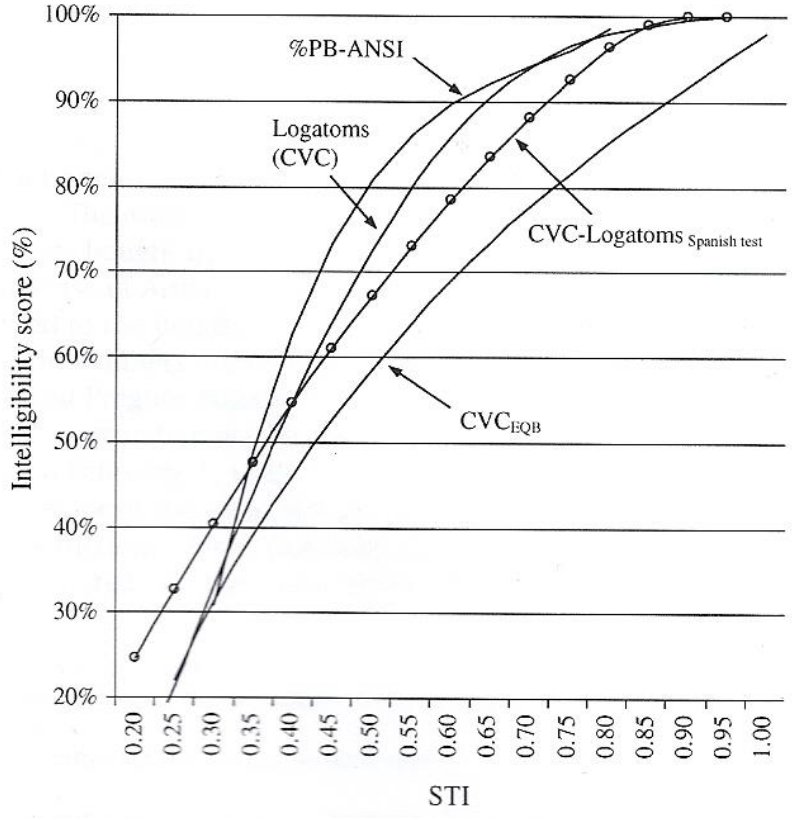


Figure 1 – Comparison of results of the relationship between subjective speech intelligibility and speech transmission index STI (23)

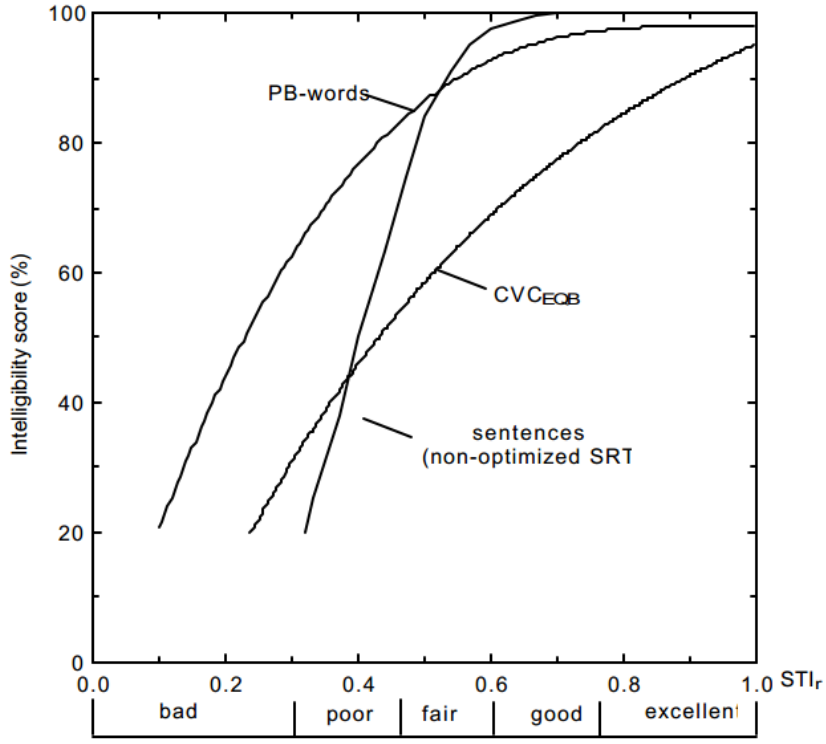


Figure 2 – Comparison of results of the relationship between subjective speech intelligibility and speech transmission index STI (27)

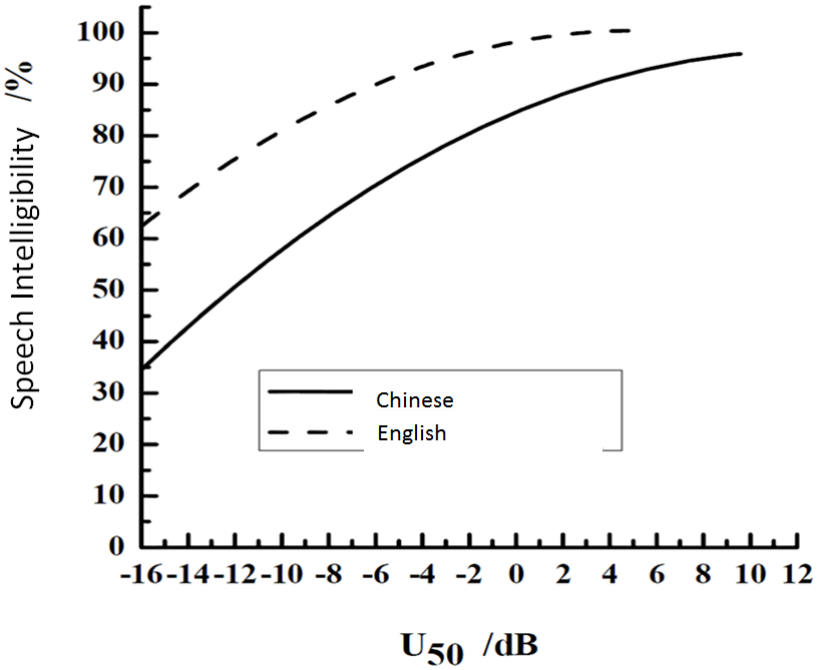


Figure 3 – Relationship between objective parameter U50 of room acoustic evaluation (1 kHz) and subjective speech intelligibility for English and Chinese (5)

## 2.2 Studies of acoustic properties of rooms

Reverberation time (T20) was measured in accordance with PN-EN ISO 3382-1 (26) and PN-EN ISO 18233:2006 (28) in octave bands in the range of 125 Hz - 8,000 Hz, while speech transmission index STI was measured in accordance with PN-EN ISO 18233:2006 (28) and PN-EN 60268-16 (27). Reverberation time Tmf in the tested rooms was in the range of 0.84 - 1.41 s (Table 1). Speech transmission index STI, in turn, was within the range of 0.55 - 0.67 (Table 2). Due to the lack of significant external noise and the position of objects (traffic noise), the background noise in rooms (from external sources) did not exceed 28.4 dB (Table 3).

Table 1 – Results of measurements of reverberation time $T_{20}$ in the tested rooms

| Item | Test group | Classroom | Reverberation time $T_{20}$ averaged from measurement points (s) | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | 125 Hz | 250 Hz | 500 Hz | 1,000 Hz | 2,000 Hz | 4,000 Hz | 8,000 Hz | $T_{mf}$[3] |
| 1. | 0-3 | A | 1.55 | 1.54 | 1.53 | 1.48 | 1.22 | 1.12 | 0.92 | 1.41 |
| 2. | | B | 0.85 | 1.05 | 1.10 | 1.08 | 1.00 | 0.93 | 0.76 | 1.06 |
| 3. | | C | 1.02 | 1.13 | 1.02 | 0.88 | 0.82 | 0.77 | 0.56 | 0.91 |
| 7. | 4-6 | D | 1.36 | 1.18 | 1.13 | 0.75 | 0.65 | 0.61 | 0.53 | 0.84 |
| 8. | | E | 1.58 | 1.29 | 1.37 | 1.27 | 1.18 | 1.08 | 0.86 | 1.28 |
| 9. | | F | 1.67 | 1.44 | 1.44 | 1.18 | 1.14 | 1.07 | 0.84 | 1.26 |

[3] $T_{mf}$ – reverberation time averaged from octave bands with centre frequencies: 500 Hz, 1 kHz and 2 kHz.

Table 2 – Results of measurements of speech transmission index STI in the tested rooms

| Item | Test group | Classroom | STI |
|---|---|---|---|
| 1. | 0-3 | A | 0.55 |
| 2. | | B | 0.61 |
| 3. | | C | 0.64 |
| 7. | 4-6 | D | 0.67 |
| 8. | | E | 0.56 |
| 9. | | F | 0.57 |

Table 3 – Results of measurements of background noise in the tested rooms

| Item | Test group | Classroom | $L_{Aeq}$ (dB) |
|---|---|---|---|
| 1. | 0-3 | A | 23.9 |
| 2. | | B | 24.0 |
| 3. | | C | 28.4 |
| 7. | 4-6 | D | 27.2 |
| 8. | | E | 27.8 |
| 9. | | F | 26.9 |

### 2.3 Word tests

Average test results were 91.8%, 89.5% and 89.6% of correct answers, respectively (Table 5). Also 9 divergent observations and one extreme observation were noted (Figure 4). The results were subjected to statistical tests for significant differences. For this purpose, the Mann-Whitney test was selected (the distribution of observations is not a normal distribution). The results showed statistically significant differences ($p<0.05$) for rooms D and E and no statistically significant differences ($p<0.05$) for rooms E and F.

Table 4 – Descriptive statistics of the word test results for three different rooms

| Descriptive statistics | | | | | | | |
|---|---|---|---|---|---|---|---|
| Room | N significant | Average value | Confidence -95% | Confidence +95 | Min | Max | Standard deviation |
| D | 20 | 91.8 | 90.45 | 93.25 | 84 | 96 | 2.99 |
| E | 20 | 89.5 | 87.97 | 91.03 | 83 | 96 | 3.27 |
| F | 20 | 89.6 | 87.95 | 91.15 | 85 | 95 | 3.41 |

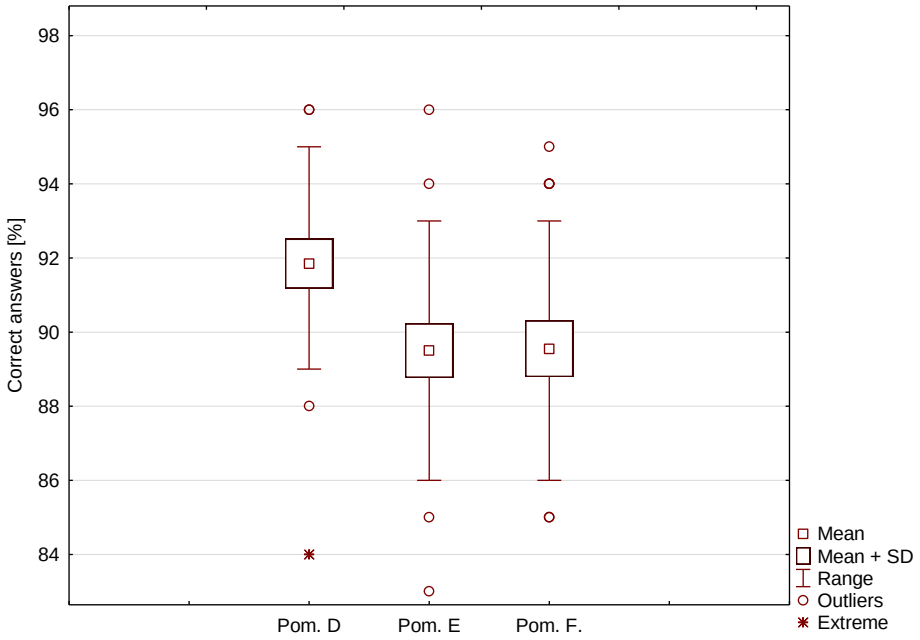


Figure 4 – Word test results for three different rooms with an indication of divergent and extreme observations

When the results of word tests in Polish are compared to tests in other languages, it can be found that they are most closely related to %PB-ANSI (4) and %PB words (27) tests. Differences do not exceed 2% for room D and 4% for rooms E and F. Significant differences between the results (up to 18%) were observed for $CVC_{EQB}$ (22), CVC (22), and CVC-$Logatoms_{Spanish\_test}$ (23) tests (Table 5).

Table 5 – Comparison of word tests with tests for other languages for the measured STI values.

| Speech intelligibility | Classroom D | Classroom E | Classroom F |
|---|---|---|---|
| STI value | 0.67 | 0.56 | 0.57 |
| Results of the Polish word test | 92% | 90% | 90% |
| $CVC_{EQB}$ (22) | 62% | 73% | 73% |
| CVC (22) | 90% | 79% | 79% |
| CVC-$Logatoms_{Spanish\ test}$ (23) | 84% | 72% | 72% |
| %PB-ANSI (4) | 92% | 86% | 86% |
| %PB words (27) | 94% | 89% | 89% |

## 2.4 Sentence tests

Average test results were 94.5%, 95.7% and 95.5% (Table 6) of correct answers, respectively. Also 2 divergent observations were noted (Figure 6). The results were subjected to statistical tests for significant differences. For this purpose, the Mann-Whitney test was selected (the distribution of observations is not a normal distribution). Due to the varied arrangement of benches in the rooms for grades 0-3, the test result is not considered dependent on the place in which it was conducted. The comparison of the sentence tests in Polish to the Sentences test (SRT) (8) did not show differences exceeding 4%, but there was no upward trend in the test result with an increase in the STI value (Table 7).

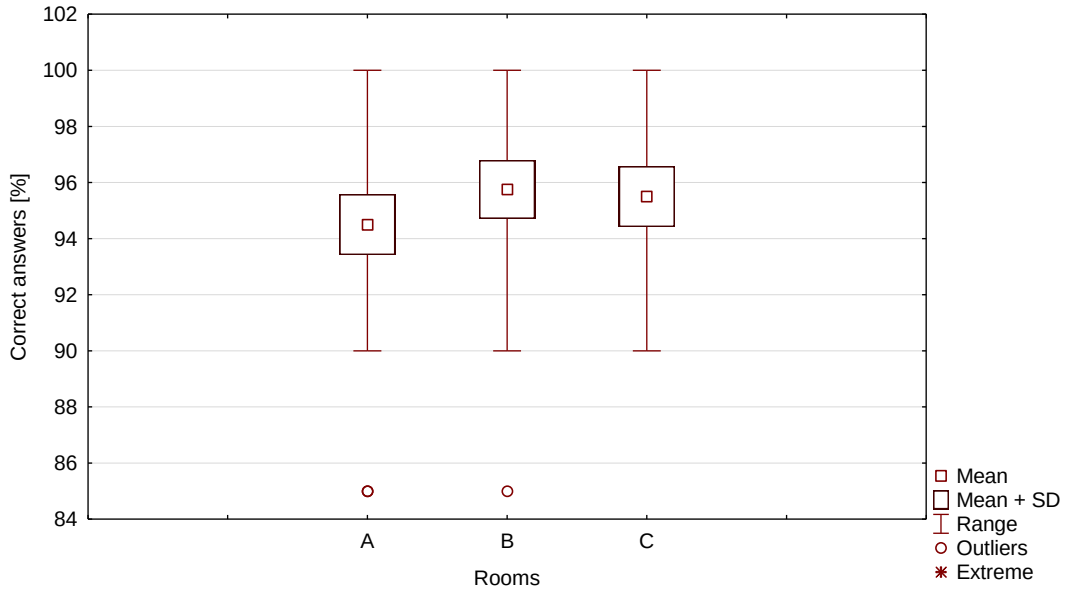


Figure 6 – Results of sentence tests for three different rooms with an indication of divergent observations.

Table 6 – Descriptive statistics of the sentence test results for three different rooms.

| Descriptive statistics | | | | | | | |
|---|---|---|---|---|---|---|---|
| | N significant | Average value | Confidence -95% | Confidence +95 | Min | Max | Standard deviation |
| Room A | 20 | 94.5 | 92.2 | 96.8 | 85 | 100 | 7.1 |
| Room B | 20 | 95.7 | 93.6 | 97.9 | 85 | 100 | 6.8 |
| Room C | 20 | 95.5 | 93.2 | 97.8 | 90 | 100 | 7.1 |

Table 7 – Comparison of sentence tests with tests for other languages for the measured STI values.

| Speech intelligibility | Classroom D | Classroom E | Classroom F |
|---|---|---|---|
| STI value | 0.55 | 0.61 | 0.64 |
| Results of the Polish sentence test | 94% | 96% | 95% |
| Sentences (SRT) (8) | 91% | 97% | 99% |

## 3. CONCLUSIONS

As a result of analysis of the studies of the relationship between subjective speech intelligibility and the parameters characterizing the acoustic properties of school classrooms, the following conclusions were drawn:

- there is a relationship, confirmed by statistical tests, between word test results and the objective parameter of speech intelligibility STI,
- results of the Polish word test are similar to the results of tests conducted for English by Anderson and Jacob,
- results of the Polish word test differ significantly from the results of tests using CVC words for Danish and Spanish,
- no statistically significant differences between test results of three different groups of respondents in the same room were found, which indicates a possibility of a higher number of groups to be surveyed in the studies,
- no relationship, confirmed by statistical tests, was noted between sentence test results and the objective parameter of speech intelligibility STI,
- numerous divergent observations and a lack of relationship between sentence test results and the objective speech intelligibility index (STI) indicate the need for recording sound levels during tests to ensure an appropriate SNR relationship,
- lack of differences in test results showed a necessity to extend the sentence lists.

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