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Speech Intelligibility Test for Polish Language – Relation to the Acoustic Properties of Classrooms and Comparison to Other Languages

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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. The aim of the study was to recognize the possibility of applying some international guidelines for room acoustics developed on the basis of adult studies to classrooms in Polish schools. This paper presents a 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. The 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 word test are similar to results of English tests (Anderson, Kalb, 1987; Jacob *et al.*, 1990).

Keywords: speech intelligibility; classrooms; schools; room acoustics.

1. Introduction

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 (Koszarny, Jankowska, 1995; Augustyńska *et al.*, 2010; 2011). 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 (Augustyńska *et al.*, 2010). It also negatively affects teachers' subjective assessment of their own health. Reasons 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 (Radosz, 2012; Mikulski, 2013). The acoustic properties of classrooms are particularly important in primary schools where, due to the pupils' age, the best possible conditions for the transmission of verbal content should be ensured (Yang, Bradley, 2009; Melo *et al.*, 2013).

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 (Steeneken, Houtgast, 1980; 2002). One of the issues which has not been fully examined 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. Recently published national standard (PN-B-02151-4:2015) introduced new requirements for different spaces including classrooms. Evaluation scales for parameters of room acoustics have been adopted from several different international guidelines. However, those guidelines were developed on the basis of studies of adults and for different languages. 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) involving children to assess possibility of applying the new standard. 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 (Jianxin, Chengxun, 2010; Sommerhoff, Rosas, 2012). Therefore, research hypothesis states that Polish language and age of respondents affect the results of speech intelligibility tests.

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) (Steeneken, 1992; Steeneken, Houtgast, 2002; Sato *et al.*, 2008; Sato, Bradley, 2008). There are several types of linguistic materials used in speech audiometry: isolated words (consonant-vowel-consonant CVC and consonant-consonant-vowel-consonant CCVC structures), sequences of numerals, pseudowords and sentences.

According to the HEARCOM D-7-1 report, 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) (Versfeld *et al.*, 2000; Wagener *et al.*, 2005; Ozimek *et al.*, 2009; 2010). In the case of the Polish language there are expressive word articulation tests (CVC and CCVC structures) and PLOMP and MATRIX sentence type tests (Pruszewicz *et al.*, 1994; Ozimek *et al.*, 2009; 2010). Guidelines have also been created for sentence tests for children, but their final version has not been developed yet (Ozimek *et al.*, 2010).

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: pseudowords of the CVC structure (CVC pseudowords) in Danish (Houtgast, Steeneken, 1985), pseudowords of the CVC structure in Spanish (CVC-Logatoms$_{\text{Spanish test}}$) (Sommerhoff, Rosas, 2012), CVC nonsense words with equal distribution of phonemes (CVC$_{\text{EQB}}$) from the revised STI model of Steeneken and Houtgast (2002) and phonetically balanced monosyllabic words conforming to ANSI S3.2-1989 (%PB-ANSI) (Jacob *et al.*, 1990). In these studies, the results of subjective tests were referenced to the values of the speech transmission index (STI) (Fig. 1), which has been developed, among others, on the basis of studies by Steneeken and Houtgast. The studies were conducted on adults. Articulation lists were played through speakers in acoustically different rooms or via headphones, using appropriately modified sound samples. 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" (phonetically balanced PB words) and sentence tests (based on SRT – Speech Reception Threshold) (Jacob *et al.*, 1990; Versfeld *et al.*, 2000; Wagener *et al.*, 2005) (Fig. 2). The largest differences between

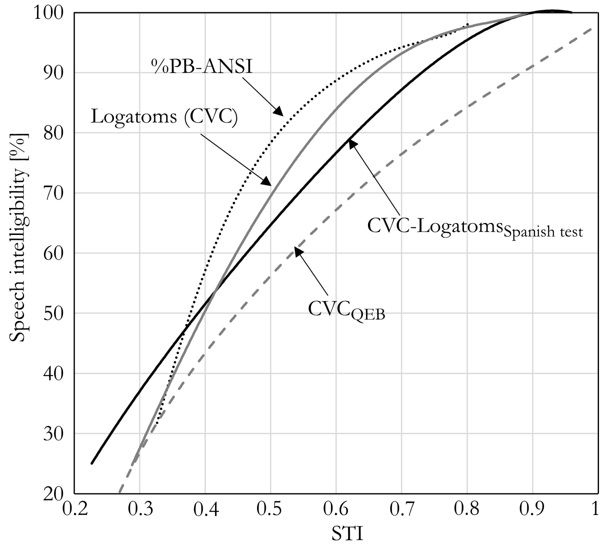

Fig. 1. Comparison of results of the relationship between subjective speech intelligibility and speech transmission index STI (Sommerhoff, Rosas, 2012).

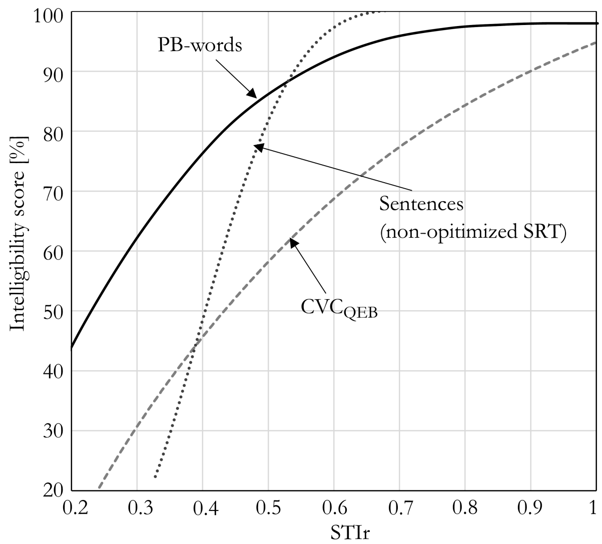

Fig. 2. Comparison of results of the relationship between subjective speech intelligibility and speech transmission index STI (Yang, Bradley, 2009).

tests with words and sentences can be seen when STI < 0.6. Differences between the articulation tests were also observed when comparing results of tests for English and Chinese with respect to acoustic parameter U_{50} (Jianxin, Chengxun, 2010) which is a ratio of usable energy of the speech signal compared to the unusable energy (Fig. 3). Differences in speech intelligibility for English and Chinese reached 30% for the same acoustic conditions.

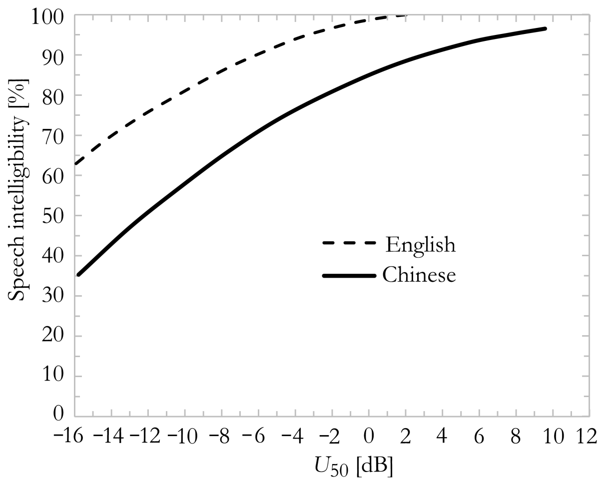

Fig. 3. Relationship between objective parameter U_{50} of room acoustic evaluation (1 kHz) and subjective speech intelligibility for English and Chinese (Jianxin, Chengxun, 2010).

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 (2009) 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.

3. Method and apparatus

3.1. Tested rooms and the test group

41 classrooms were selected for the studies. Selected classrooms have a conventional rectangular shape (volume from 160 m^3 to 200 m^3) and varied decoration and equipment (different sound absorption). 20 pupils (age from 10 to 12 years old) were selected based on an interview with a school nurse or hygienist.

3.2. Studies of acoustic properties of rooms

Reverberation time (T_{20}) was measured in accordance with PN-EN ISO 3382-1 and PN-EN ISO 18233:2006 in octave bands in the range of 125–8,000 Hz, while speech transmission index STI was measured in accordance with PN-EN ISO 18233:2006 and PN-EN 60268-16. Room acoustic parameters were derived from impulse response measurements in unoccupied classrooms. Two sound sources were used – the omnidirectional source of Brüel & Kjaer type 4296 for the reverberation time, and the mouth simulator of Brüel & Kjaer type 4227 for the STI. Acoustic parameters were measured with PC and WinMLS 2004 software. Filtered MLS signals were used for measuring STI and swept sine signals for measuring reverberation time.

3.3. Speech intelligibility test

In order to conduct speech intelligibility studies in classrooms, a word test developed by Pruszewicz and Demenko (1994) was used. The test consists of 10 letters of 20 words and consists of the most common single-syllable nouns in Polish. Lists are balanced phonetically, semantic and structural. 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 ($L_{\mathrm{Aeq}} = 60$ dB – normal speech level according to ISO 9921:2005) at a distance of 1 m from the source.

4. Results and discussion

4.1. Room acoustics

Reverberation time T_{mf} in the tested rooms was in the range of 0.5–1.6 s (Fig. 4). The results were varied and no significant departure from normality was found with 95% confidence (Shapiro-Wilk test: $W = 0.962$, $p = 0.197$). Speech transmission index STI, in turn, was within the range of 0.54–0.76 (Fig. 5). Similar to T_{mf} distribution it can be concluded with 95% confidence that the STI data are normally distributed (Shapiro-Wilk test: $W = 0.973$, $p = 0.423$).

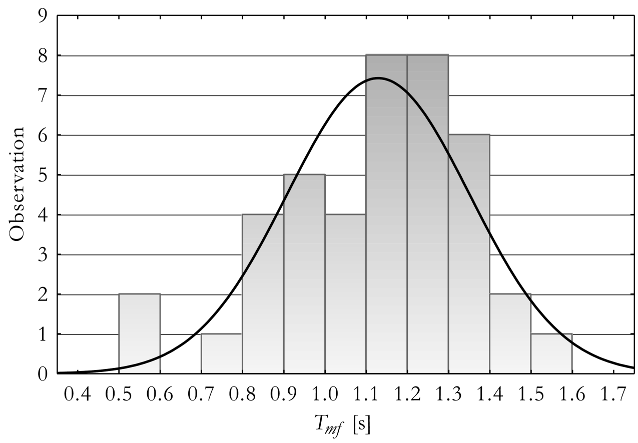

Fig. 4. Results of measurements of reverberation time T_{mf} in the tested rooms (the solid line marked matched normal distribution).

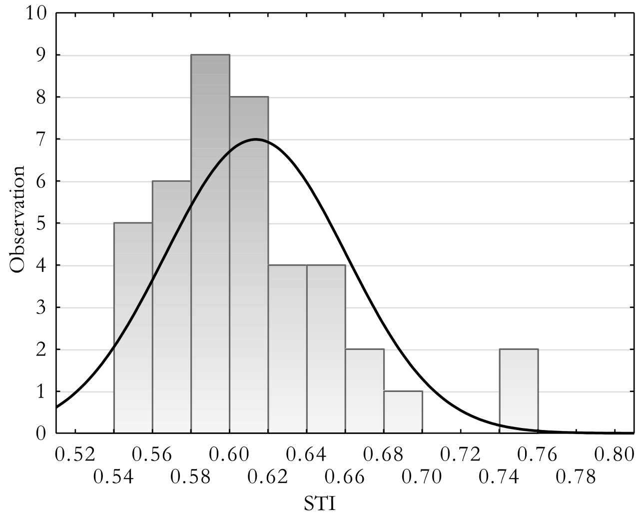

Fig. 5. Results of measurements of speech transmission index STI in the tested rooms (the solid line marked matched normal distribution).

Because tested rooms were generally of the same volume, diversity of reverberation time values and the speech transmission index STI between classrooms prove that it is caused by room equipment and school building decoration (e.g. using wood panels, wall mats, etc.). One of the tested rooms clearly differed from the rest due to the floor covering (carpet).

Range of acoustic parameters measured in classrooms is typical for Polish primary schools (Mikulski, Radosz, 2011). Most of the tested rooms have T_{mf} from 1.1 s to 1.4 s and STI from 0.58 to 0.62. It is worth noting that in Polish schools, practically there are no acoustic adaptations which is reflected in the measurement results (e.g. only two classrooms with $T_{mf} < 0.6$ s).

4.2. Word tests

Comparing the results of word test in Polish to the tests in other languages (Fig. 6), it can be noted that they are the most similar to the phonetically balanced Harvard PB word tests (Anderson, Kalb, 1987; Jacob *et al.*, 1990). Differences in speech intelligibility are less than 5% for the investigated range of acoustic parameters. Due to lack of source data from cited papers statistical tests were impossible. In case of Polish language tests a slight deviation from the above-mentioned trend curve (for STI above 0.65) was observed. It is understood that the words clarity of above 93% (PN-EN 60268-16) is sufficient to achieve satisfactory acoustic conditions in classrooms.

Regression analysis confirmed a statistically significant linear relationship between speech intelligibility and objective acoustic parameters: T_{mf} ($F = 43.38$, $p < 0.05$) and STI ($F = 86.82$, $p < 0.05$). If we look at the correlation lines (solid lines in the Fig. 7 and Fig. 8), the speech intelligibility score corresponds to speech transmission index STI of 0.72. In summary, the results of the Polish verbal test showed that the value of speech intelligibility tests of 93% can be achieved with the following values of the acoustic parameters (after rounding):

- reverberation time: $T_{mf} = 0.6$ s (Fig. 7, from the correlation line with coefficient of -0.726);
- speech transmission index: STI $= 0.7$ (Fig. 8, from the correlation line with coefficient of 0.836).

R-squared values showed that approximately 70% of the variation in speech intelligibility is predicted by STI and 53% by reverberation time T_{mf}. Results and above mentioned estimated values of the acoustic parameters values mainly resulting from limited number of tested rooms and insufficient number of rooms with

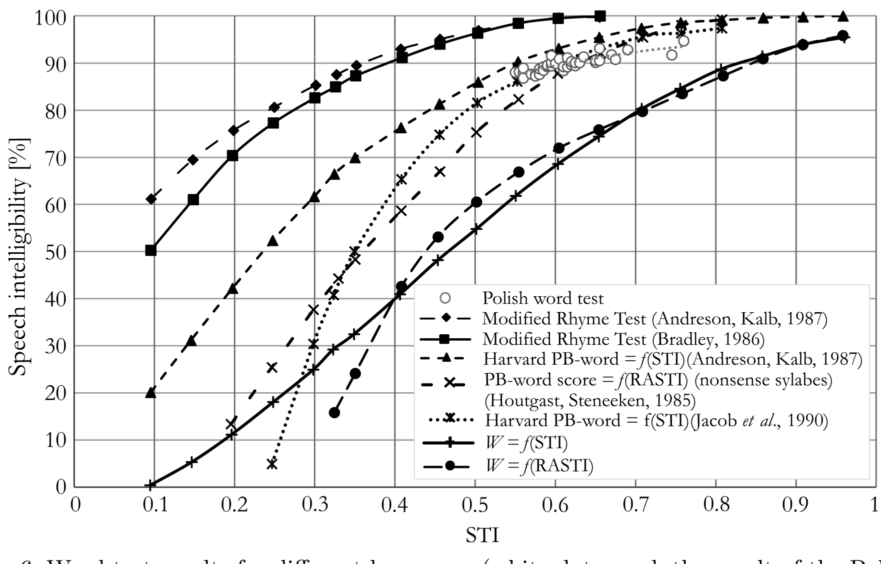

Fig. 6. Word test results for different languages (white dots mark the result of the Polish word test and the grey dotted line indicates a trend).

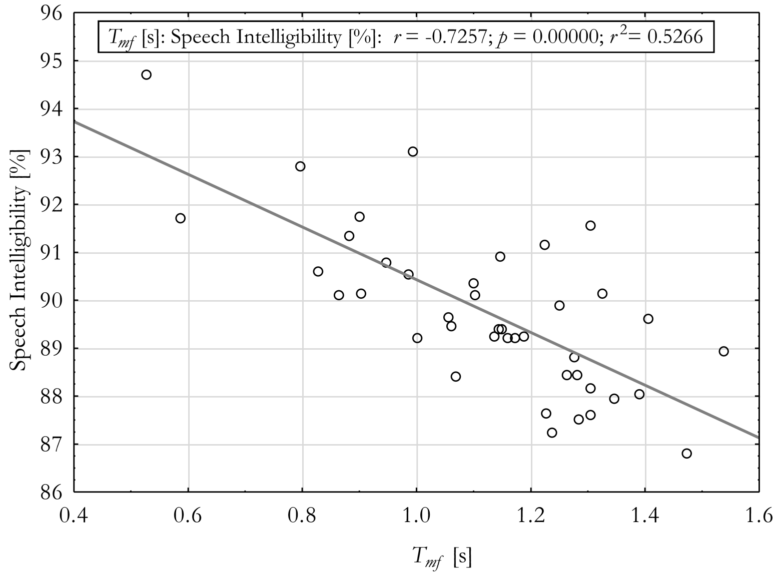

Fig. 7. Speech intelligibility score in relation to reverberation time T_{mf}.
The solid line indicates the correlation line.

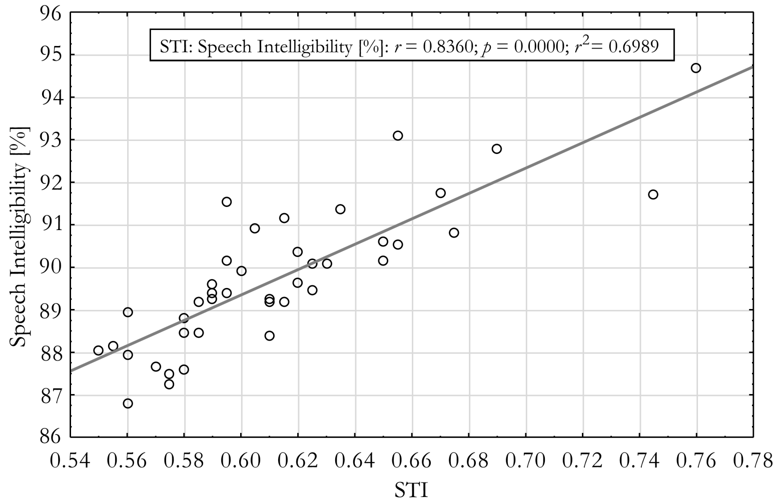

Fig. 8. Speech intelligibility score in relation to speech transmission index STI.
The solid line indicates the correlation line.

good and excellent acoustics (e.g. STI > 0.8) for better estimation of the speech intelligibility thresholds. Presented data shows that the evaluation scales for parameters of room acoustics adopted from international guidelines can be applied to Polish language and they are also suitable for children due to similarity of speech intelligibility curves (Fig. 6) for a typical range of acoustic parameters in classrooms.

5. Conclusions

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

- 41 typical classrooms selected for the studies were varied in terms of acoustic parameters.
- Regression analysis showed that there is a statistically significant linear relationship between Polish word test results and the objective parameters: speech intelligibility STI and reverberation time T_{mf}. From the presented correlation lines the values of the objective parameters can be estimated for a given speech intelligibility. However, care should be taken due to limited ranges of acoustic parameters measured in classrooms.
- On the basis of the comparison of the graphs, results of the Polish word test are similar to the results of tests conducted for English by Anderson and Jacob, however they differ from the results of tests using CVC words for Danish and Spanish.

- The results presented in the paper confirmed conclusions from the pilot studies (Radosz, Zawieska, 2014).
- Criteria for reverberation time on the basis of Polish word tests comply with the international guidelines concerning building acoustics such as BB93, SFS 5907 or ANSI S12.60-2002; however, speech intelligibility tests have shown that the value of the speech transmission index STI = 0.6 (often taken as a criterion in international guidelines) may not be sufficient to achieve optimal acoustic properties in classrooms and for that reason values of STI ≥ 0.7 are recommended for classrooms.

This work has raised the following hypothesis: Polish language and age of respondents affect the results of speech intelligibility tests. Research hypothesis should be rejected on the basis of the presented study. As example, Fig. 6 shows that for a typical STI values for classrooms in Polish primary schools (0.58–0.62), the speech intelligibility score for Polish test on children and English tests on adults does not differ by more than 3%. This hypothesis has not been reported in previous investigations and it is a matter of further studies for its confirmation.

Results of the Polish word test conducted on children showed no considerable differences in relation to the speech intelligibility tests on the basis which some international criteria for room acoustics were defined (Anderson, Kalb, 1987; Jacob *et al.*, 1990). Correlation curves did not differ by more than 5% of speech intelligibility (Fig. 6) for investigated range of acoustic parameters (T_{mf} from 0.5 s to 1.6 s and STI from 0.54 to 0.76). Nevertheless, care should be taken with the results interpretation due to lack of possibility to perform statistical tests (e.g. a statistically significant difference between the test for different languages).

The results indicate that the evaluation scales for parameters of room acoustics in international guidelines such as BB93 or ANSI S12.60-2002 can be applied to Polish language and they are also suitable for children in primary schools.

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