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Influence of classroom acoustics on the reading speed: A case study on Italian second-graders

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Abstract: The need of tuning into speech in noisy and reverberant classrooms is a challenge for good speech communication and literacy development at school. Reading development can be compromised if children are exposed to inadequate acoustics, especially those with poor neural processing in speech discrimination. This work reports preliminary results on the influence of classroom acoustics on the reading speed of 94 Italian second-graders. Speech clarity (C50) was found to be significantly correlated with all the investigated reading tasks, while no significant correlations were found with reverberation time.

[NX]
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1. Introduction

Learning experiences often occur in adverse sonic situations where children need to tune out competing sounds to tune into speech, which is an essential process for literacy development. This is true for normally developing children as well as for children with potential reading disorders, which are likely to be due to impairments in the phonological processing that is caused by an interaction of genetic (50%–80%) and environmental risk factors (20%–50%) (Cutini *et al.*, 2016). According to the “rise-time theory,” phonological impairments are due to difficulties in processing the amplitude modulation of the speech sound structure. This may turn into a deficit in discriminating the speech amplitude envelope rise-time (i.e., the time to reach a speech peak), degrading speech rhythm and prosody detection (Cutini *et al.*, 2016). Good classroom acoustics preserves the speech amplitude modulation from the teacher to the pupil at different linguistical temporal rates (i.e., phonemes, syllables, and phrases) enhancing the auditory processing at the basis of reading. If children with poor neural processing in speech discrimination are exposed to bad acoustics, they may fall behind their peers in reading development. Also, as the neuroplasticity of the auditory cortex is high until ≈8 yrs (Cardon *et al.*, 2012), the effectiveness of good acoustics may be greater up to the 2nd-grade of school.

To the authors’ knowledge, few works have studied so far the effects of classroom acoustics on the learning abilities of children. Shield and Dockrell (2008) found negative correlations between noise levels and achievement tests. Ronsse and Wang (2013) found negative correlations between background noise levels and language and reading scores for 5th-graders.

This work is a primary attempt to investigate the relationship between classroom acoustics and the reading abilities of pupils at an early stage of education. Particularly, it aims at obtaining pilot results on the influence of classroom acoustics on the reading speed scores.

2. Methodology

2.1 Participants

Tests were administrated to assess the reading abilities of children of the 2nd-grade of primary school. They were delivered during the school-hours between May and June 2016, and only the children whose parents signed an informative consent were involved

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in the experimentation. In total, 94 pupils (45 female, 49 male) whose mean age was 7.9 yrs (±0.3 yrs) participated in the study. Teachers and families were asked to report any information about known learning or hearing impairment, since such losses may affect the results. The head teacher of a school plexus that included three primary schools in Torino (Italy) (five 2nd-grade classes) participated in the study. The schools had differences in urban location and architectural characteristics, but they had a similar socioeconomic status to reduce the inter-class variability. Schools A and B were built in the late 20th century. They are located on the hills around Turin, in quiet areas with low vehicular traffic. None of them had acoustic treatments of any kind. The classroom of school A (A1) has a floor with ceramic tiles, flat plastered ceiling, three lateral walls finished in concrete, and a windowed wall. The classroom of school B (B1) has a floor with ceramic tiles, sloping plastered ceiling, three lateral walls finished with plaster, and a windowed wall. School C dates back to the late 19th century. It is placed in a residential area in the city center, facing a low vehicular traffic road. Three classrooms were selected (C1, C2, and C3), they have floors with ceramic tiles, ceilings with a pavilion vault in plaster finishing, and lateral walls with perforated plasterboard panels placed at a 7.5 cm air-gap from the rear walls.

2.2 Acoustic measures

The acoustic measures were collected at the end of the school year in the rooms furnished only with desks, chairs, and shelves. Measurements simulated the room occupancy using 100% polyester panels that absorbed ≈0.35 m^2, as to replicate seated young pupils according to Puglisi *et al.* (2017). Reverberation time (T30, s) and speech clarity (C50, dB) were measured according to ISO 3382-2 (2008) and ISO 3382-1 (2009), respectively. For T30, an impulsive signal was generated using a clapper, i.e., two wooden boards hinged together, and was acquired evenly at a calibrated class-1 sound level meter (SLM, model XL2 by NTi Audio, Schaan, Liechtenstein) at 1.1 m from the floor. Results were averaged spatially and in frequency in the 0.25–2 kHz range, according to DIN 18041 (2016). For C50, a TalkBox (by NTi Audio, Schaan, Liechtenstein), which has the diagram of energy distribution of the human voice, was used as the sound source being placed at the desk at 1.5 m from the ground. A 5 s exponential sine sweep signal was generated, three repetitions of the signal were recorded, processed, and averaged. A frequency averaging in the 0.5–1 kHz range was applied according to ISO 3382-1 (2009). To establish a relationship between classroom acoustics and reading abilities, the TalkBox should have been used for T30 measurement also. However, apart from the lowest octave bands of 125–250 Hz, no significant differences were found in the T30 measurements with an omnidirectional source, to which a clapper can be associated (Sumarac-Pavlovic *et al.*, 2008), from a source with human speech directivity (Astolfi *et al.*, 2008).

As C50 is a source-to-receiver distance-dependent parameter, it should be measured in each position or in regular areas of the room. However, pupils in Italian schools do not have a fixed position for the entire year, so a perfect comparison with the individual reading scores cannot be done. Being this is a pilot study and the rooms are geometrically different, C50 was acquired in the central position of rooms with the SLM placed at 1.1 m from the ground, as to replicate a child seated in the central row of desks. This approach might not be properly coherent with the research purpose, as a spatial C50 mean across positions in the classroom would have brought to values more related to the average children listening context. However, according to Astolfi *et al.* (2018), who measured C50 in five to eight positions, among which the central one, in 11 primary school classrooms, the spatial average of C50 in each room differed from the central value by less than 1 dB, which is a C50 just noticeable difference according to ISO 3382-1 (2009). Also, considering that measured T30s were above 0.7 s (Table 1), small variations are expected among positions. A difference of less than 0.5 dB was found between the average value of three positions in the rooms along the main axis (i.e., first, central, and last rows) and the value at the central position, applying the Barron and Lee theory (Barron and Lee, 1988) for C50 calculation, which considers a decrease in the reverberant diffuse sound energy with increasing source distance, unlike the classical theory. This fits well with C50 (Secchi *et al.*, 2018) and speech level (Astolfi *et al.*, 2008) decrease with the distance from the source in small classrooms.

Noise levels in a simulated occupied condition were acquired to characterize the rooms' noisiness during the measurements. The only contribution of real background noise was considered to avoid the effects of involuntary noise events, i.e., the

Table 1. Dimensional and acoustic parameters measured in the classrooms, divided for each school and with the reference of optimal range. The parameter "r" refers to the distance from the blackboard wall at which the SLM was placed for C50 measurements. The mean values of each measured acoustic parameter are reported per several frequency ranges averaging, and the standard deviation is indicated in brackets when available (otherwise: NA). The values highlighted in bold represent the cases of compliancy with the reference standard.

		T30 (s)					C50 (dB)			
Classroom	V (m^3)	0.125–0.25 kHz	0.5–1 kHz	0.5–2 kHz	0.25–2 kHz	r (m)	0.125–0.25 kHz	0.5–1 kHz	0.5–2 kHz	L_{A90} (dB)
A1	176	1.0 (0.06)	0.8 (0.04)	0.7 (0.03)	0.8 (0.04)	3.4	−1.5 (0.07)	**2.4** (0.26)	2.8 (0.25)	27.1 (NA)
B1	166	2.0 (0.12)	1.3 (0.01)	1.3 (0.06)	1.4 (0.06)	3.7	−5.4 (0.08)	−0.3 (0.23)	−0.3 (0.16)	22.6 (NA)
C1	241	0.9 (0.09)	0.8 (0.03)	0.8 (0.04)	0.9 (0.05)	4.2	−1.6 (0.12)	**1.6** (0.22)	1.7 (0.29)	25.7 (NA)
C2	194	0.9 (0.05)	0.9 (0.03)	1.0 (0.03)	1.0 (0.03)	5.0	0.4 (0.29)	**2.8** (0.39)	3.1 (0.33)	23.7 (NA)
C3	260	1.0 (0.05)	0.9 (0.07)	0.9 (0.06)	1.0 (0.05)	4.7	−0.2 (0.36)	**4.0** (0.35)	3.6 (0.30)	27.3 (NA)
Optimal range	—	—	—	—	0.5–0.6	—	—	≥0	—	—
Reference	—	—	—	—	DIN 18041	—	—	DIN 18041	—	—

A-weighted statistical level that was surpassed for 90% of the measuring time, L_{A90}, was evaluated.

2.3 Reading measures

The reading tests were designed for the present study, starting from existing and standardized ones that were shortened (Sartori *et al.*, 2007). The test administration was performed in one-to-one sessions by trained experimenters. Each pupil was taken by an experimenter to a quiet room of the school for the test duration, which was about 30 min. The reading abilities were measured in terms of reading speed in syllables per second (syll/s) and of number of errors per each task to evaluate the reading accuracy. Each experimenter was trained to report the same information about reading speed and the number of errors, so it has been possible to reduce the inter-experimenter variability making it negligible for the subsequent analyses.

The reading tests included several tasks. The reading of words (RWs) aimed at reading aloud four lists of words. The lists were divided based on the familiarity-to-image ability ratio, which is the ratio between the familiarity with a specific word and the ability of the specific word to evoke a sensory mental image. The reading of non-words (RNWs) was based on two lists of 2- and 3-syllabic words without semantic meaning. The reading of sentences (RSs) aimed at reading sentences with a structure so that the second half of it had an opposite meaning with respect to the first. The reading of a short text (RT) aimed at reading a text with syntactic and semantic meaning. Analyses were done averaging together the reading speed of the four lists of words and of the two lists of non-words to obtain a single value of RW and RNW speed.

3. Results

3.1 Classroom acoustic parameters

Table 1 shows the results of T30, C50, and L_{A90} measurements, respectively, per each classroom. The DIN 18041 (2016) standard specifies the optimal values of reverberation time for teaching in occupied conditions, which is a function of room volume and frequency. None of the classrooms complied with the optimal values. C50 agrees with the DIN 18041 (2016) recommendations in all cases except one, that is, classroom B1. Table 1 reports T30 and C50 values averaged on other frequency ranges that were considered for subsequent analyses also, since different frequencies contribute differently to the speech discrimination (Houtgast and Steeneken, 2002), which is strictly related to reading development (Cutini *et al.*, 2016).

3.2 Reading tasks scores

The normality test of Shapiro–Wilk revealed that most of the reading speed distributions class-by-class and task-by-task were normal, that is, 77% of the cases. Therefore,

Table 2. Correlation matrix between 94 pairs of reading speed scores (syll/s) and the number of reading errors for all the administrated reading tasks (i.e., RWs; RNWs; RSs;, RT). ** *p*-value < 0.01.

		Number of errors			
		RW	RNW	RS	RT
RW (syll/s)	Spearman coefficient	−0.43**			
	Pearson coefficient	−0.50**			
RNW (syll/s)	Spearman coefficient		−0.34**		
	Pearson coefficient		−0.35**		
RS (syll/s)	Spearman coefficient			−0.56**	
	Pearson coefficient			−0.56**	
RT (syll/s)	Spearman coefficient				−0.51**
	Pearson coefficient				−0.50**

to make the analyses comparable, non-parametric statistic tests were then used. Considering the number of errors, their distribution in the different trials was non-normal in 70% of the cases.

The base the hypothesis of this work is that good classroom acoustics increases the reading speed. To exclude that the increased reading speed implies a higher number of errors, Table 2 reports the correlations between errors and reading speed, showing a negative and statistically significant relationship task-by-task. Due to the high number of pairs (i.e., 94), the correlation coefficients are low but significant (p-value < 0.05). In addition, the average number of errors was overall low with respect to the number of items that the children had to read task-by-task, which allows assuming that those who read faster also perform accurately. Then, to understand if any differences across reading speed scores and the number of errors exist class-by-class, the Kruskal–Wallis test was applied to the distributions of data task-by-task. Neither the reading speed scores nor the number of errors were found to be different (p-value > 0.05).

A descriptive analysis of the reading speed scores was performed to compare means and standard deviations to the available reference values for the Italian language. Figure 1 shows the reading speed scores averaged class-by-class and task-by-task based on increasing C50, compared with the upper and lower threshold standardized for the "sufficient performance" in reading of Italian 2nd-graders at the end of the school year (Cornoldi *et al.*, 2010) that is equal to 1.55–2.86 syll/s. The speed of RT resulted in normally distributed scores, with mean values in the sufficient performance level being in the range 2.04–2.61 syll/s. RW and RS tasks were also found within the suggested threshold, whereas the RNW exhibited lower means, suggesting a greater reading difficulty. Overall, higher speeds task-by-task were found for higher C50s.

3.3 Relationships between reading speed scores and classroom acoustics

Data of all children were considered independent to increase the sample size (e.g., each pupil's reading score corresponds to an acoustic measure that is unique per each classroom). It could not be stated *a priori* if a linear dependency of reading and acoustics exists, so both the Spearman and Pearson coefficients were calculated. Table 3 reports the correlation coefficients between the reading speed scores and C50, resulting

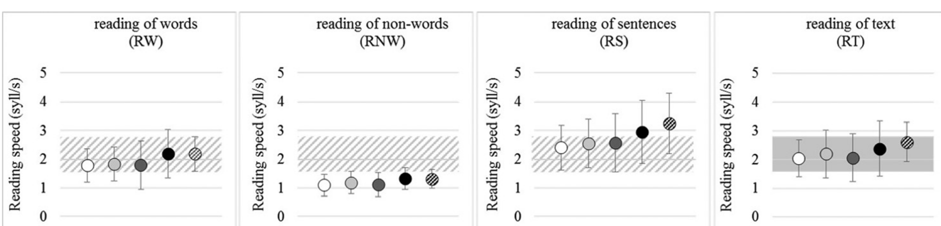

Fig. 1. Reading scores averaged class-by-class and task-by-task. Dots represent the mean value for classes B1 (white dot), C1 (light gray dot), A1 (dark gray dot), C2 (black dot), and C3 (black striped dot), which were ordered based on increasing C50. Error bars represent the standard deviation of each reading measure. The gray area on the graphs represents the upper and lower threshold standardized for the sufficient performance in reading of Italian 2nd-graders at the end of the school year according to Cornoldi *et al.* (2010). It is represented in solid color for the text reading task as it is the only standardized value; in the other tasks, the same area is reported, although not standardized (i.e., striped gray).

Table 3. Correlation analysis between clarity C50, per different frequency ranges, and speed scores of RWs, RNWs, RSs, RT. * p-value < 0.05. ** p-value < 0.01.

	All children (n = 94)					
	$C50_{0.125–0.25\ kHz}$		$C50_{0.5–1\ kHz}$		$C50_{0.5–2\ kHz}$	
	Spearman coefficient	Pearson coefficient	Spearman coefficient	Pearson coefficient	Spearman coefficient	Pearson coefficient
RW	0.24*	0.21*	0.25*	0.21*	0.25*	0.21*
RNW	0.23*	0.20	0.21*	0.19	0.21*	0.19
RS	0.25*	0.23*	0.30**	0.28**	0.30**	0.28*
RT	0.21*	0.19	0.27**	0.23*	0.27**	0.23*

congruent for all the frequency ranges, except in the case of RT at low frequencies with the Pearson coefficient. Most of the highly significant correlations (p-value < 0.01) were found with Spearman coefficients, thus allowing to assume that most of the reading scores and C50 are not linearly correlated. No significant correlations between reading speed and T30 were found for all the frequency ranges.

4. Discussion and conclusions

4.1 Classroom acoustic parameters

In rooms A1 and B1, although the volumes are small, long reverberation times may depend on the highly reflective finishing of the surfaces. In rooms C1, C2, and C3, although they all present an acoustic treatment, long reverberation times may depend on the volumes that are higher than typical. Concerning speech clarity, the pavilion vaulted ceiling of rooms C1, C2, and C3 emphasizes the early sound reflections in the central area of the classroom that are due to the teacher's speech, however different speech clarity values were measured due to the classroom layout. In the case of A1, the flat ceiling supports early reflections uniformly. In the case of B1 the longer reverberation tail determines lower speech clarity. Traditionally, reverberation time is considered to be the acoustic parameter to be measured to characterize classrooms. However, studies have argued the need to account for other parameters that consider the early reflections to enhance listening, such as speech clarity, as classrooms with similar reverberation times may present significantly different speech clarity values (Campbell *et al.*, 2015).

4.2 Relationships between reading speed scores and classroom acoustics

None of the reading speed scores resulted to be correlated with T30, supporting the results of Ronsse and Wang (2013) who studied the effects of reverberation times, in the 0.18–0.40 s range, on the achievement scores of 3rd- and 5th-graders. Although the T30s of the classrooms in the present study were higher than those in Ronsse and Wang (2013), a larger variability of reverberation time is needed to find significant relationships with the reading tasks. Statistically significant correlations were found between the reading speed scores and speech clarity, C50. Although C50 is correlated with T30, the latter considers the decay of late reflections despite the early reflections. It can thus be hypothesized that the early reflections are mostly associated with the reading abilities, more than the late ones. The importance of C50 was highlighted by Campbell *et al.* (2015), who reported the need of supporting the listening experience enhancing speech clarity, as the acoustic information that is important in the subjective perception and understanding is missed by reverberation. Therefore, it is needed to design classrooms reducing T30 and supporting C50, which aim can be achieved combining absorptive and diffusive surfaces. The proposed method will be empowered measuring C50 in several positions to consider its variability inside the room, instead of its value in the central position only. An extension of the study to more classrooms and pupils is needed to increase the sample size and the acoustic conditions. Children of different school grades of primary school will be engaged to evaluate temporal effects of classroom acoustics on the reading abilities development.

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