euronoise 2021
25th to 27th of October
Madeira, Portugal - online

A Study on Noise Exposure in School Environments

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Abstract
It is well known that schools are subjected to several external and internal noise sources and how these can influence the acoustical perception within the school environments. This study aims at investigating students' and teachers' exposure to noise during school hours.
This research is carried out within the "BRIC 19 - ID14" Project, supported by the Italian National Institute for Insurance against Accidents at Work (INAIL), which concerns the analysis of the noise extra-auditory effects on health.
An investigation methodology in order to classify the different scenarios and choose the measurements to be carried out in the school environments was defined. Nine schools were selected as representative sample for the study. Regarding the correlation between acoustical analyses and psychoacoustic parameters, a measurement campaign was performed and different questionnaires were submitted to students and teachers. The first results of the Project are shown in the paper.

Keywords: noise exposure, school environments, acoustical analyses, subjective assessment.

1 Introduction

During the last decades, we have seen ever more awareness of environmental problems and their challenges. Environment Sustainability is a vast problem: it concerns many different scientific-field-related problems as well as no-scientific ones and only a multidisciplinary approach can raise the challenge to solve them. One of the less evident problems concerns sound. Sound is a physical entity that surrounds our daily life since our birth, and it can be limited but never completely cancelled. Human activities generate sounds that oftenbecome noise. Noise pollution deeply affects the animals' life in different ways; according to the occupational safety and health limits, it can cause hearing loss if daily noise exposition overflows 85 dB; it

can affect vital parameters like heart bit or breath frequency: it can cause perception's disorders due to masking effects or even lead to change survival activities like migrations. Humans are part of the animal kingdom, and we are not immune from noise pollution's effects.
Furthermore, W.H.O. published in 2018 general guidelines to observe and summarize the problem [1] and stated that anthropic noise pollution is the second most dangerous cause of health problems [2]. Auditory problems related to lengthy noise exposition's physical damages at the auditory system for human beings and extra-auditory problems linked to psychosomatic issues have been categorized. This last aspect is represented by annoyance [3], defined as the physiological and psychological irritation caused by a specific sound. It appears during chronical noise exposition [4,5], and it can interfere daily life activities as the coping skill, a quality that allowed humans to adapt to any external signal [6]. Like for the other animals, annoyance causes a wide variety of problems like behavioural disorders for human beings (anxiety, stress, headache, impotence), even neurological disease [7], endocrine system problems [8,9] or cardiovascular disease [10,11] (Figure 1).

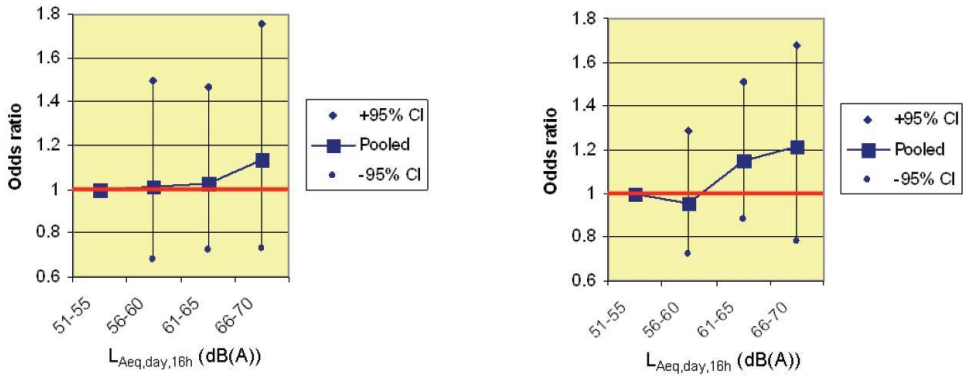

Figure 1. Exposure-response curve for road traffic noise and the prevalence of myocardial infarction (left) and all ischaemic heart diseases (right) from [11].

Since annoyance is a common problem in urban areas [12], anyone is potentially exposed. Urban noise can be caused by anthropic activities as well as by human beings themselves. High-capacity urban facility institutions are an interesting combination of these phenomena. Schools are places where external noise pollution affects an indoor environment already disturbed by the occupants' noise. It is well studied how children face learning and concentration difficulties that can evolve into anxiety, headache, aggressively and lower school achievement due to noising and long reverberant classrooms [12,13, 14, 15]. The problem is highlighted in young children since they are not already provided with any stress management skills, and issues can arise easier [16]. High background noise forces teachers to speak louder, even 10-15 dB over the normality [17], and this routine leads to voice-related problems [18]. Although these phenomena are well-known, there is still little evidence of correlation between extra-auditory effects of noise and recognized health damages and responsibililities in Italy, and there is no significant reference literature apart from W.H.O. guidelines. The extra auditory effect has recently been introduced as the cause of damage in legal disputes, and the school classification as sensitive receptors dates back to 1995 (National Framework Law non Noise pollution L.447/95).
On the contrary an extensive literature on environmental noise pollution is present, also referred to school environments. Outdoor noise pollution has been widely studied for different sound sources, from the most common road traffic noise [19] to aircraft noise [20] produced by planes and even helicopters [21]. Many European countries have introduced thresholds for the façade noise (Table 1) [22].
The social context is also considered [23,24] as well as the different indoor architectural organization of the schools (open space or not) [25].
This wide variety of knowledge about extra-auditory issues and the extensive literature on the characterization of indoor and outdoor noise sources in school environment give evidence to the need of reducing the forensic gaps on the subject. At the same time, scientific literature suggests that solutions have

to be found to reduce noise and annoyance in school, saving the school achievements of future generations and the health of children and their teachers. Here the "BRIC 19 – ID14" Project comes on the scene.

Table 1. National thresholds for external façade noise (from [22])

Nation	A-weighted sound pressure levels LAeq
Belgium	30 dBA
Germany	30 dBA
Sweden	30 dBA
Portugal	35 dBA
Italy	36 dBA
France	38 dBA
Great Britain	40 dBA
Turkey	35 dBA

2 Aim and Scope

"BRIC 19 - ID14" Project, supported by the Italian National Institute for Insurance against Accidents at Work (INAIL), involves the University of Perugia – CIRIAF, and five other universities across Italy: Ferrara University, "*La Sapienza"* University in Rome, L'Aquila University, *"Roma Tre"* University, and the University of Florence.
One of the main scopes of the project is to reduce the extra auditory effects of noise exposure at work, with particular reference to the school environments.
The general project has five specific goals; three of them are related to the different auditory issues:

- A review of all the existing material concerning the extra auditory effects, the outdoor and indoor noise pollution analysis led in school contexts and the teachers' vocal tract stress during learning activities;
- the choice of selected school scenarios from a provided list of interesting existing school cases, followed by a complete architectural acoustic analysis and the characterization of the outdoor and indoor noise sources. This step yields a comprehensive view of the acoustic environment of the school and the teachers' vocal tract stress entity;
- create architectural solutions to prevent vocal stresses and extra auditory effect is the last step; this has to be completed by an awareness program on noise and its correlated extra auditory effects and by updating consistent guidelines.

3 Materials and Methods

With the aim of evaluating the acoustic quality of schools, specific survey scenarios and operational guidelines to perform the acoustic analysis were assessed.
Several findings in literature were found and different sound sources, located inside and outside the classrooms, were classified. Starting from the literature evidences, a proper survey procedure was defined, and significant case studies were selected in order to carry out the acoustic investigations.
The identification of sound sources that are responsible of noise levels increase and of auditory and extra-auditory damages to users allows to study the correlation among environmental acoustic quality, identified damage and users behavior.

3.1 Identification and characterization of the main sound sources in schools

Classrooms are typically exposed to different noise sources, located outside or inside the class or in the school building. In the first phase of the project, a deepened bibliographic analysis was carried out and

several studies related to noise in school environments were selected. These studies come from different countries, both developed and developing.
Selected papers refer to a wide time frame and highlight how in the last ten years the scientific research in this field experienced a strong development (64% of the analyzed works) [19-27].
The school buildings analyzed in literature are mainly located in densely populated urban areas and most of them are primary and secondary schools.
Starting from the literature review, the sound sources that mainly characterize school buildings, both internal and external, were identified. It is worthy to notice that the outdoor noise is mainly due to road, rail and airport traffic, when schools are located near this kind of infrastructure. Furthermore, other external sources are linked to students' activities in the school outdoor spaces: courtyards, gyms, playgrounds. In some cases, noises from casual events or nature were detected. On the other hand, internal noise sources are mostly related to the students' actions within the classrooms, such as chatter, noise of tables and chairs. Taking into account indoor noise sources, heating or cooling systems are also relevant. Also, the neighbouring environments can be considered internal noise sources that characterize the classrooms acoustic environment.

3.2 Measurement campaign and survey procedure

An investigation procedure was defined and shared among the research groups involved in the project, with the aim of choosing proper parameters able to characterize the acoustic climate of schools. The objective of this procedure is making comparable, homogeneous and complete the measurement campaigns carried out in the selected schools, located in three different cities: Florence, Rome and Perugia.
This protocol provides survey scenarios, legislative and regulatory references and some operational indications (measures and indicators, questionnaires and supplementary activities) for:
- measuring and evaluating the acoustic climate of the investigated environments, also through the soundscape approach; assessing noise levels to which workers are subjected in specific settings (classrooms, common spaces, dining halls, gyms, outdoor spaces and other spaces considered significant);
- studying correlations among acoustic and psychoacoustic parameters and classrooms geometrical, architectural and constructive characteristics (also in terms of materials), taking into account the construction year;
- quantifying teachers' vocal effort and verifying a possible correlation between vocal effort and acoustic climate of schools, as well as audiometric test results.
The protocol defines parameters, measurements and some notes about critical issues related to the context, including the current health emergency due to Covis-19. More in detail, the protocol is divided into four categories, regarding each survey to be carried out (Table 2).

3.3 The selected case studies and scenarios

The selected case studies were chosen among 29 schools, divided in 8 kindergarten, 9 primary schools, 12 middle/high schools. Each school was investigated by the authors, who inspected the possible survey scenarios by filling the specific descriptive form. In all the three cities, at least one school typology was identified. In order to carry out the acoustic investigations included in the protocol, seven representative school scenarios were identified.
In particular, for each school the following scenarios were selected and analyzed (if present):
S1 - Teaching room
S2 - Laboratory (teaching and experimentation)
S3 - Auditorium
S4 - Gym
S5 - Common space (break or other activities)
S6 - Dining hall
S7 - External space

Table 2. Structure of the survey procedure.

Typology	Survey	Description
MEASUREMENTS AND INDICATORS	Measurement in UNOCCUPIED environment	Acoustic climate/outdoor environmental noise
		Normalized acoustic facade insulation
		Environmental noise level
		Internal noise from neighboring internal environments
		Plant noise
		Reverberation time
		Room Criteria
	Measurement in OCCUPIED environment	Acoustic climate/indoor environmental noise under regular rooms usage
		Direct measurements, recordings, dosimeters and processing
	Vocal effort	(**)
QUESTIONNAIRES	Questionnaires administration	Impact of noise on speech comprehension and perception of the intelligibility disorder
		Elements to fully understand the disturbance characteristics, well-being and sensitivity related to noise: sources identification, sensitivity to noise, subjective characteristics, relationship among sensations (light matrices, ergonomics, thermo-hygrometric comfort) and acoustic perception
		Outdoor and indoor soundscape perception
SUPPLEMENTARY ACTIVITY	Studying of speech transmission in specific conditions (according to COVID-19 emergency procedure)	Studying the effect of masks and other individual and collective protective devices on speech transmission in schools: hearing difficulties, intelligibility problems, which are increased by the inability to see the lip movement, voice reduction in terms of amplitude and at the critical frequencies
SOUNDSCAPE MEASUREMENTS	Psychoacoustic measurements and questionnaires administration in schools outdoor environment.	Questionnaires administration
		Psychoacoustic measurements development

Each case study was described through a scheme including the following data:
- school typology (kindergarten, primary, middle, or high school);
- place and address;
- outdoor acoustic climate, i.e. low, medium, high environmental noise, indicating the presence of any sources characterizing the soundscape (e.g. infrastructural, industrial, plant engineering, etc.);
- construction period, before 900, 1900-1950, 1950-1975 (before DM 18/12/75), 1975-1998 (before DPCM 5/12/97), 1998-2017 (before Minimum Environmental Criteria – in Italian CAM), after 2017;
- building and construction typology (e.g. courtyard or compact buildings, load-bearing masonry, reinforced concrete frame, etc.);
- presence of acoustic interventions or mitigation ones, indicating them if relevant, both internal and external ones (e.g. noise barriers, sound-absorbing asphalts, sound-insulating frames, indoor sound-absorbing treatments, etc.);
- environmental characteristics and any additional information regarding the urban context.

The descriptive sheets were furnished with images of the urban setting, plans and photos relating to the different survey scenarios; an example is provided in Figure 2.

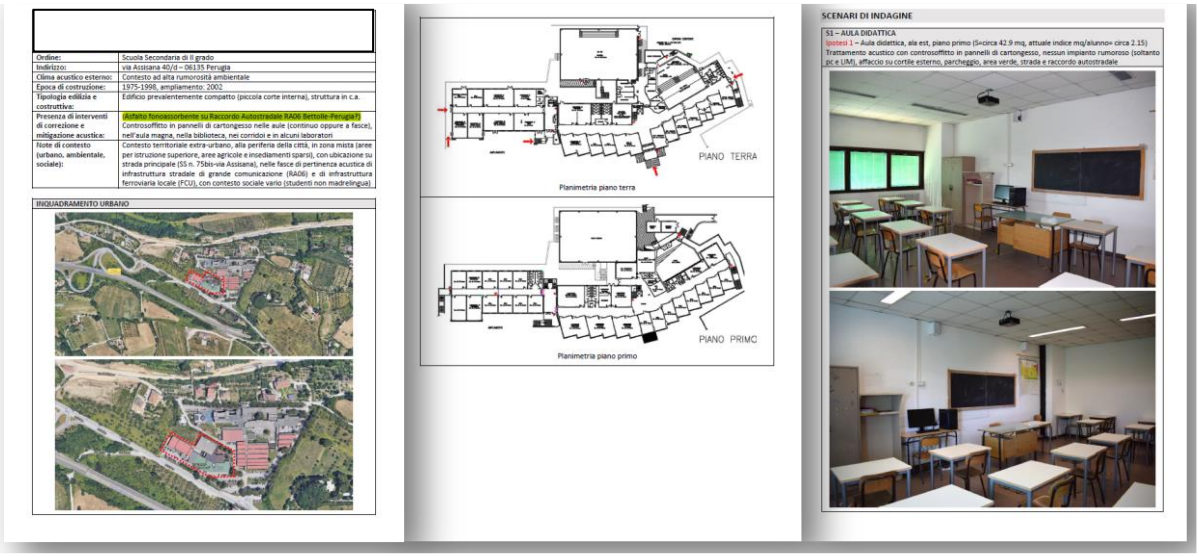

Figure 2. Example of school descriptive sheet.

Starting from the aforementioned selection criteria (urban and environmental context, outdoor acoustic climate, construction period and typology, external or internal acoustic mitigation interventions and presence of the defined survey scenarios), the choice of the case studies for each city depended on the variety of schools' characteristics, contexts and acoustic climate, in order to have a representative sample of the Italian schools.

3.4 Questionnaires

The acoustic perception depends on many factors, which were investigated in order to correlate the results of the acoustic analysis with the overall comfort perception of users – students and teachers – and other possible involved aspects – e.g., age, sensitivity to noise, etc. –. Questionnaires administered to children and teachers for investigating acoustic comfort and noise exposure in classrooms were analysed [28-30]. The cited studies were carried out in Germany, Sweden and Denmark and involved primary and secondary schools' users. They aim at identifying auditory and extra-auditory effects from exposure to noise in classrooms.
Starting from the abovementioned studies, together with the material provided by INAIL and the University of Ferrara, three typologies of questionnaires were defined, according to the parameters to be investigated in the acoustic measurement campaigns and to the specific acoustic characteristics of the scenarios under investigation. The acoustic measurement campaigns will be carried out both in empty and occupied environments.
The three questionnaires - Questionnaire 1, Questionnaire 2, and Questionnaire 3 - were drawn up considering the target audience for the questionnaire and the selected scenarios. The questionnaires will be administered to primary, secondary/high school students and to preschool, primary and secondary/high school teachers.
They examine the impact of noise on speech comprehension and the difficulties on speech intelligibility, the elements for a complete understanding of disturbance, well-being and sensitivity related to noise. They aim at identifying noise sources, emotional state of the subject and interaction of the various elements - lighting, ergonomics, thermo-hygrometric comfort - with acoustic perception. A summary of the features and contents of the questionnaires is shown in Table 3 and Table 4.
In each scenario, significant acoustic variables will be measured, computed, and correlated to the given answers for determining the relationship between well-being and classroom acoustics. The questionnaires will be distributed to students and teachers during the school year 2021/2022, according to the project timetable.

Table 3. Target and sample for the three questionnaires

Questionnaire	Target	Sample to be investigated
Questionnaire 1	Investigated classroom's students: - students aged 8-11 years (primary school sample) - students aged 12-16 years (secondary/high school sample)	120-150 students (20-25 students per each primary and secondary/high school)
Questionnaire 2	School students: - students aged 8-11 years (primary school sample) - students aged 12-16 years (secondary/high school sample)	120-150 students (20-25 students per each primary and secondary/high school)
Questionnaire 3	Preschool, primary and secondary/high school teachers	135 teachers (5 teachers who works in the S1 scenario + 10 other teachers: 15 teachers per each preschool, primary and secondary/high school)

Table 4. Contents and structure of the three questionnaires

Questionnaire	Contents	Structure
Questionnaire 1	The questionnaire is related to the classroom scenario (S1), which is subject to acoustic measurements.	The questionnaire is divided into the following sections: 1. *General data*: general information, perception of noise in life outside of school, and personal sensitivity to noise. 2. *Sounds and noise within the classroom*: perception of noise in the classroom when doors and windows are closed, related extra-auditory consequences - e.g., fatigue, loss of concentration, headaches, anger, boredom, greater ease of crying-. 3. *Sounds coming from outside*: external sound sources which impact on school activities when windows are open. 4. *Sounds coming from nearby environments*: perception of sound sources in the surrounding environments of the one under investigation, disturbing sound sources. 5. *Sounds generated within the classroom*: perception of classroom sound sources - e.g., students' chattering, dragging of furniture, falling objects, equipment-. 6. *Listening to the teacher*: analysis of a specific listening context considering a reference teacher (Italian language teacher). The questions concern the perception of the teacher's voice with closed doors and windows. 7. *Comfort in the classroom*: aspects of the perception of the overall quality of the environment - e.g., thermo-hygrometric comfort, air quality, light comfort, ergonomics -.
Questionnaire 2	The questionnaire is related to scenarios from S2 to S7 (laboratory, auditorium, gymnasium, common area, canteen, outdoor area), which are subject to acoustic measurements.	The questionnaire is divided into the following sections: 1. *General data*: general information, perception of noise in life outside of school, and personal sensitivity to noise. 2. *Sounds and noise in the classroom* (*): perception of noise in the classroom when doors and windows are closed, related extra-auditory consequences - e.g., fatigue, loss of concentration, headaches, anger, boredom, greater ease of crying-. 3. *Sounds and noise in the laboratory*: perception of noise in the laboratory when doors and windows are closed, related extra-auditory consequences, typology of perceived sounds and noise, overall assessment of the laboratory. 4. *Sounds and noise in the auditorium*: perception of noise in the auditorium when doors and windows are closed, related extra-auditory consequences, typology of perceived sounds and noise, overall assessment of the auditorium. 5. *Sounds and noise in the gymnasium*: perception of noise in the gymnasium when doors and windows are closed, related extra-auditory consequences, typology of perceived sounds and noise, overall assessment of the gymnasium. 6. *Sounds and noise in the common area*: perception of noise in the common area when doors and windows are closed, related extra-auditory consequences, typology of perceived sounds and noise, overall assessment of the common area.

		7. *Sounds and noise in the canteen*: perception of noise in the canteen when doors and windows are closed, related extra-auditory consequences, typology of perceived sounds and noise, overall assessment of the canteen. 8. *Sounds and noise in the outdoor area*: perception of noise in the outdoor area, related extra-auditory consequences, typology of perceived sounds and noise, overall assessment of the outdoor area.
Questionnaire 3	The questionnaire is related to all the investigated scenarios.	The questionnaire is divided into the following sections: 1. *General data*: general information, years of teaching, subject of teaching. 2. *Main working environment*: perception of acoustic quality in the main working environment, disturbing sound sources, use of voice. 3. *Secondary working environment*: perception of acoustic quality in the main working environment and, use of voice. 4. *Risks from noise exposure*: consequences on phonatory and hearing systems from noise exposure. 4. *Perception of discomfort*: fatigue during school activities with and without face mask. 5. *Additional information*: general perception of noise, and overall assessment of the outdoor area.

Note: (*) This section has been added as a repetition of the classroom's context analysis as not all the students who fill in Questionnaire 2 spend their time in the scenario S1. In this case, the investigation of the classroom perception is needed as a comparison with the other school spaces.

4 Results and Discussion

4.1 Questionnaires

In order to verify the easy understanding and clarity of contents of the questionnaires, the latter were distributed to students (17-18 years old) and teachers of a pilot high school class in Florence. Twenty-two students and three teachers were asked to fill in respectively the two questionnaires for students and the questionnaire for teachers.

After explaining the aim of the study and illustrating the contents of the questionnaires, the pilot class was asked to write down the time taken to complete them, to highlight any observed critical points - unclear questions, repetitions, typing errors - and to make comments on the questions they considered most significant or peculiar.

The small sample of teachers is homogeneous in terms of age, type of employment, experience and working environment. It can be observed that the main source of disturbance encountered by the teachers are pupils and dragging in desks and chairs in the same classroom or neighbouring ones. However, teachers resort to vocal effort regardless in an attempt to be heard and understood. The assessment of the school environment is positive or not negative at least. In fact, although acoustic aspects are considered important for teachers, there is a lack of perception of poor acoustic characteristics of the environments in which they work. Teachers believe that professional activities increase the risk of damage to the phonatory system, whereas no one complains of disturbances to the vocal system. Both with and without a face mask, teachers complain of high vocal effort leading to physical and mental fatigue. In their careers, teachers had the perception of not being able to manage the class due to noise levels.

The sample of students is mainly composed of native Italian speakers (65% speak Italian at home, while 35% speak Italian and another language) who are on average sensitive to noise. The students declare that they live in a context in which they feel mostly satisfied and happy.

Students report that they hear "well" and "quite well" what the teacher says in class. Noise in classroom does not significantly affect fatigue, boredom and anger, but on average it leads to loss of concentration, more effort on a task and tiredness at the end of the lesson. School activities that are most disturbed by noise are reading and calculating with numbers. In general, it is observed that noise does not influence extra-auditory effects in school environments. Most students do not identify a significant presence of noise from outside

such as cars, motorbikes, planes, or trains. This is also due to the location of the school building. From nearby environments, students are mainly affected by dragging of desks and chairs and people chatting in the corridor, both of which are considered to be disturbing on average. Noise from the same classroom is mainly attributable to falling objects and rubbing of desks and chairs, but these are not considered particularly disturbing. The classrooms are considered bright and there is significant thermo-hygrometric comfort, with frequent air changes. The students took about 15 minutes to complete the questionnaire and found the questions related to global comfort as peculiar if correlated with auditory aspects.
In the laboratory, where mainly frontal teaching activities take place, no disturbing noises are perceived and, consequently, no extra-auditory effects from noise exposure are found. In general, the main sources of noise are the dragging of desks and chairs in the laboratory, the chattering inside, the noise of vehicles and the dragging of desks and chairs from neighbouring rooms. The teacher is, however, heard "quite well", "well" and "very well" by all subjects. There is also a general feeling of well-being. In the gymnasium, noise is mainly attributable to shouting from students inside the room and to noise produced by sports activities, although the presence of particularly noisy ventilation systems was observed. Although the students state the voice of the speaker in the gymnasium is reverberating, they report that they can hear the teacher quite well. In the common area, the main noise sources are the chattering of peers and, in second place, the noise of vehicles. Noise in the canteen is instead attributable to classmates and dishes, however, it allows to hear quite well what is said by the companions and does not generate extra-auditory effects. In the outdoor area, the main sources of noise are the shouting of classmates and the noise of vehicles, which in any case does not affect the psychological and physical well-being of the students.
In conclusion, noise generated within the classroom is considered disturbing for teachers whereas it is not for students, although the latter highlight difficulties during school activities.

5 Conclusions

With the aim of identifying the typical environments for specific school activities, which are comparable among each other in Florence, Rome and Perugia, a survey protocol was defined and proper scenarios were chosen.
In the schools selected as a representative sample the measurement campaigns and the acoustic climate evaluation were carried out. Furthermore, the correlation of acoustic and psychoacoustic parameters will be performed, to which users will participate by filling questionnaires and taking part to other activities.
The use of face mask strongly influences the communication between students and teachers, which become more difficult as they are forced to speak louder. The current condition will be investigated in the light of the pandemic situation that will not be over during the acoustic measurement campaign that will be held in autumn 2021.
The preliminary study on questionnaires showed that the questions are understandable, and it takes a short time to fill in the questionnaires (15 minutes), although the the questionnaires' length. Moreover, it was considered appropriated to take into account the presence of students with learning disabilities, that will be reported by teachers. Considering the significant number of learning impaired students, their effect will be evaluated in relation to the total amount of the investigated sample.

Acknowledgements

The authors would like to express many thanks to the Department of Medicine, Epidemiology, Occupational and Environmental Hygiene (INAIL) and the Department of Engineering (University of Ferrara) for the precious contribution in drafting the three questionnaires.

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