ACOUSTIC SOLUTIONS FOR OCCUPATIONAL HEARING CONSERVATION IN CLASSROOMS FOR VOICE TEACHERS

Politecnico di Torino

Master Degree in
Architecture for the
Sustainability Design

ILLINOIS

College of Applied
Health Sciences

December 2018

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Supervised by
Arianna ASTOLFI
Pasquale BOTTALICO
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BACKGROUND

INTRODUCTION

Communicative disorders constitute important health problems with important socio-economic consequences.

As it has been recognized that teachers are one of the largest groups of professional voice users which develop voice disorders (Russel et al, 1998; Angelillo et al, 2009), research began to focus on the impacts of noise in schools, where students and teachers alike could be impacted by day to day activities creating noisy environments. In many studies of school classroom settings, noise levels varied greatly depending on the course being taught and the pedagogic style of the teacher.

Previous studies showed that over 38% of the teachers complained that teaching had a bad impact on their voice and 39% of those had cut back teaching activities as a result (Smith et al, 1998). In one of his studies involving comprehensive phoniatric examination Lejska found 7,1% of voice disorders among a group of 772 teachers. Voice dysfunction interferes with job with 18.3% of teachers missing at least 1 day of work per year due to voice disorders affecting financial and economic sources too (Thibeault et al, 2004).

A survey of 237 teachers found that only 1% of the teachers received voice therapy for their voice problems (Sapir et al, 1993), although more than half reported multiple symptoms of voice problems.

Within these studies, teachers of all courses were being evaluated; results indicated that among school teachers, music and sports teachers were exposed to the most intense sound levels and showed a higher risk for developing voice disorders (Thibeault et al, 2004; Morrow & Connor, 2009; Trinite, 2017).

The need of this project research is based on the fact that music teachers, and in particular voice teachers, are the largest occupational group developing voice-related problems as they are exposed to many sound sources during the course of their work activities.

It has been well documented that noise can present as a problem in occupational settings for health and overall job performance. There have been many studies done on employee noise exposure within factory type settings for having consistent and intermittent intense noise levels, as these settings are obvious in their potential harmful effects on employees (Cutietta et al, 1994; Mendes et al, 2007). It has been found that employees in noise intense environments, among other health effects, are subject to the development of noise-induced hearing loss (NIHL). This form of hearing loss is typically classified as a high frequency sensorineural hearing loss and has a characteristic "noise notch" of around 15 dB HL, with improved hearing thresholds on either side of the notch (Phillips et al, 2010).

This type of hearing loss is a caused by direct loud noise exposure over time to the hair cells that preside in the cochlea within the inner ear; it is a permanent hearing loss that does not improve but may stabilize if the noise source inducing the hearing loss is removed or dampened to safe exposure levels.

The prevalence of hearing loss in the general population has been well documented, so much so that The National Institute for Occupational Safety and Health (NIOSH) has established clear guidelines in its Recommended Exposure Limit for occupational noise exposure. However, very few studies have investigated the average levels of exposure in music education environments; music was seen as pleasant to ears, therefore not likely harmful to those exposed to it in comparison to undesirable sounds (Cutietta et al, 1994). Although, in the 1980's and 1990's, music became an area of interest for effect on hearing health, particularly for orchestral musicians and music students (Cutietta et al, 1994; Phillip & Mace, 2008; Phillips et al, 2010; Pawlaczyk-tuszcynska et al, 2017).

The intensity of vocal use and vocal load has been quantified or compared with classroom teachers using the same voice-use parameters few times and, generally, there is very little data concerning the voice-use parameters and subsequent vocal load for singing teachers.

In a study conducted by Morrow and Connor (Morrow & Connor, 2009) it has been demonstrated that music teachers present 48% more phonation time when compared with classroom teachers and, in general, they may develop voice problems more frequently than classroom teachers and have been found to seek care at voice clinics at more than four times the rate of other teachers (Fritzell, 1996).

A similar research about vocal doses pertaining to primary school teachers was conducted in 2012 by Bottalico et al in Turin: 40 primary school teachers have been monitored during some of their activity days ans the results showed a worsening of the voice quality parameters which leads to vocal diseases.

Despite that, the Bureau of Labor Statistics estimates approximately 245000 people identified as musicians/

singers/music directors/composers and yet they are often overlooked in terms of occupational safety.

Music instructors are daily exposed to occupational noise, but it is still undetermined whether this is at or above the Recommended Exposure Limit and the impact this may have on hearing (Melo et al, 2016). Choral singers can experience noise levels up to 110 dB and are often exposed to sound levels between 86 and 98 dB (Isaac at al, 2017) when the recommended limit of noise exposure for workers, according to the standard of 1972 of the Occupational Safety and Health Administration (OSHA), is 90 dB over an 8-hour time considering that for every 3 dB increase in noise exposure the limit should be halved. In 1998 The National Institute for Occupational Safety and Health (NIOSH) recommended that noise exposure levels within occupational settings should not have not exceeded 85 dB(A) averaged over an 8-hour period (Mace, S.T., 2005).

On a given day, voice instructors use voice at high intensities for long periods during their workday and can be exposed to high decibel levels for many consecutive class periods and consequently the risk of hearing loss and vocal disease may be potentially significant (Cutietta et al, 1994; Isaac et al, 2017).

In addition, results from previous studies have shown that bad acoustic quality environments and their effects upon our hearing perception contribute to the decline vocal and hearing health.

Research supports evidence that music instructors are identified as a high-risk occupation for voice disorders because they engage in prolonged periods of occupational vocally intense activities associated with poor work-related conditions. These teachers report a higher frequency of chronic voice problems and often indicate both high noise levels and high level of reverberations as main cause of vocal discomfort (Thibeault et al, 2004).

The acoustic environment, measurement of hearing change due to exposure and the demand this environment requires by the vocal mechanism are factors able to determine the effects of occupational noise.

The aim of the project research was to analyze and describe occupational risk associated with environment conditions in which teachers were leading their classes to highlight the changes on voice and hearing parameters after singing classes in the Department of Music at the University of Illinois Urbana-Champaign.

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ARCHITECTURAL ACOUSTIC OPTIMAL DESIGN OF MUSIC ROOMS

Acoustics is the most important feature for a room where music is practiced and performed. The performers are dependent on the response of the room in order to play better and to develop their skills (Standards Norway Information).

The interaction between people, rooms and activities they are leading cause different sensations related to voice production that can be associated, for example, with acoustic comfort, which can be considered strictly related to a well-being as "vocal comfort appears to decrease with the speaker's perceived fatigue and the sensation of needing to increase the voice level" (Pelegrin-Garcia & Brunskog, 2012).

Good acoustical qualities are essential in classrooms and other learning spaces; excessive background noise or reverberation in spaces interferes with a good sound quality presenting like an acoustical barrier to vocal and hearing comfort. With good classroom acoustical characteristics teaching and learning are easier and less fatiguing and stressful. Reverberation time has been found to influence voice power level and vocal intensity in continuous speech; the effects on voice power level of reverberation time and speaker-listener distance were investigated by Pelegrin-Garcia et al in 2011.

Good design and attention to detail throughout the construction or renovation process can ensure conformance to the requirements of the standards and a high-quality (ANSI 12.60-2002).

The study of music is based on the ability of listening and learning pitch differences, dynamics, articulation and equilibrium. This ability can be developed only thanks to a good learning space characterized by a correct acoustics.(AIA).

To design ideal spaces for music it is necessary to take into account sound characteristics, instruments and spaces features; a good analysis ex ante is fundamental in this process.

For several time the best solutions for music spaces have been based on subjective opinions of musicians, singers and listeners.

Italian and international standards have been taken effect during the last years to satisfy the needs of the music environment and to achieve a better quality for musicians, performers, listeners, singers.

DESIGN STANDARDS

ISO 3382:2009

The ISO 3382 is entitled *Acoustics - Measurement of room acoustics parameters* and it specifies the method that has to be used to quantify the number of room acoustics parameters. The most important parameter to define the quality of a room is the reverberation time which derives from impulse responses. The standard describes the measurement procedures and other tools to obtain techniques and information for the evaluation of room acoustical parameters.

ANSI 12.60:2002_ American National Standard; Acoustical Performance Criteria, Design requirements, and Guidelines for Schools

It is a standard that "provides acoustical performance criteria and design requirements for classrooms and other learning spaces. Information on good design and construction practices, installation methods, and optional procedures to demonstrate conformance to the acoustical performance and design requirements of this standard are included in this document [...] The aim of the standard is to provide design flexibility without compromising the goal of obtaining adequate speech intelligibility and good acoustical quality for all students and teachers." (ANSI 12.60, 2002). To be able to apply noise isolation systems minimum noise insulation for school building elements are specified to control the background noise levels and intrusive noises such as noise that intrudes into the classroom or learning space from sources outside of the school building envelope and noise that originates within the school building.

The acoustic properties of the rooms and sound strength are crucial for the interaction between the room and the musical instrument (Nijs et al).

Norwegian Standard NS 8178:2014_Acoustic criteria for room and spaces for music rehearsal and performance

Recently there have been complaints about the fact that poor acoustic conditions for music rehearsal exist and these kind of spaces are often built without setting requirements for sound conditions. In April 2014 in Norway music industries and organizations took the initiative to develop and publish the standard NS 8178 for acoustics in music rooms which contains acoustic criteria for rooms and spaces for music rehearsal and performance.

In particular, the standard sets requirements for the room depending on the type of music it is intended to be used for (amplified, soft or loud music), the room size (volume, space and height), the acoustic treatment, background noise levels and sound proofing.

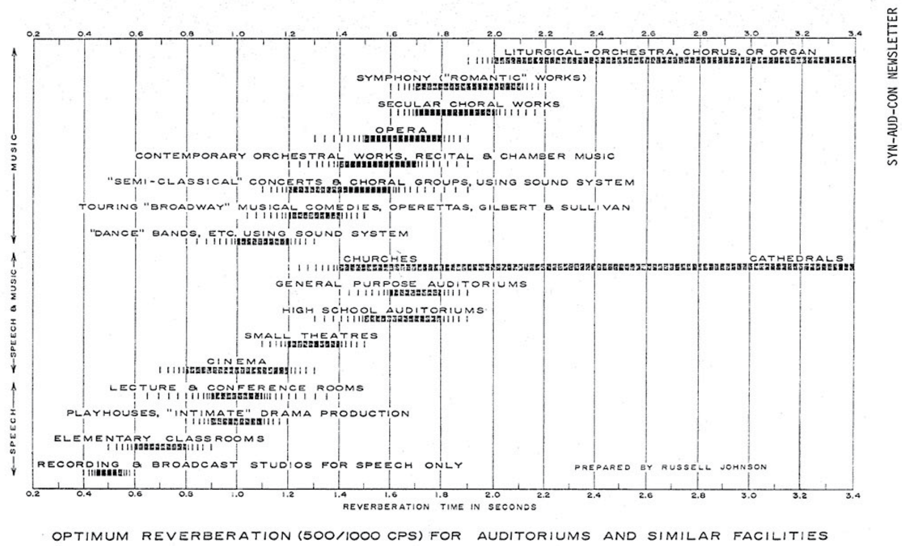
The sound level in the room is dependent on the type and number of musical instruments or singers, the style of playing or the dynamic expression, the volume of the room and the reverberation time; sound levels that are too high can sometimes increase the risk of hearing loss. The room amplification depends on the on the room volume and reverberation time.

_Reverberation Time and room dimensions

The Reverberation time (T60) is one of the most used parameters in room acoustics and it can be also an indicator to describe space quality and characteristics. It technically corresponds to the seconds a loud sound takes to have a decadence of 60 dB after being stopped or, more simply, to the time a loud sound takes to become inaudible in a space. Normally, it can be difficult to have a decay of 60 dB, that is why reverberation time can be calculated also as T30 or T20 to which correspond a decay of 30 or 20 dB.

It does not exist a perfect absolute value of reverberation time as each different activity has different needs to satisfy the acoustic comfort in a room.

In general, for as it concerns music rooms, reverberation time should be the same for each type of frequency (low, medium and high), but it is acceptable and considered ideal an increase of RT in low frequencies.



Ideal average reverberation time and room volume for different types of music and rooms (Russel Johnson, 167th Acoustical Society of America Meeting).

In 1980 Lamberty conducted some studies about room acoustics and music students: he stated that 59% preferred a "live" room (so with high reverberation times) while 11% preferred a "dead" room (with very low reverberation times) and 30% preferred something midway. The students' point of view lead to the conclusion that a "dead" room could be a room with a reverberation time of about 0.4 to 0.5 seconds and a live room could have a reverberation time of 0.8 to 0.9 seconds. The researcher asked the students to think about spaces in their own house: over 85% of the students thought that domestic bedrooms were far too dead to practice in and most all of them felt that a bathroom was too live and so almost impossible to practice in. In general, the majority was feeling the best practicing in a space with a reverberation time of about 0.7 seconds even if most students agree on the idea that it could be useful to practice in different environments so experiment variable acoustics, which would enable them to practice in different conditions, including difficult ones. For example, "dead rooms" are considered to be the worst condition to practice in; by consequence, live conditions will be lived as more pleasurable and more rewarding for those that make music.

Therefore, it can be affirmed that spaces with low reverberation times are the best to practice music; in 1955 Lane et al determined in their study the optimum reverberation times and minimum acceptable size for music teaching studios and practice rooms concluding that for small practice rooms a reasonable design for the reverberation time would be between 0.4 to 0.5 seconds.

Music Rooms	**Area m^2**	**Height m**	**Volume m^3**	**AS2107,2000**	**DfES,2002**	**BB93,2003**	**OCPS,2003**	**ANSI S12.60**
Music theory classroom	50-70	2.4-3.0	120-210	0.5-0.6	0.4-0.8	<1.0	N/A	<0.6
Ensemble /music studio	16-50	2.4-3.0	38-150	0.7-0.9	0.5-1.0	0.6-1.2	0.5-0.7	<0.6
Recital rooms	50-100	3.0-4.0	150-400	1.1-1.3	1.0-1.5	1.0-1.5	N/A	N/A
Teaching/practice room	6-10	2.4-3.0	14-30	0.7-0.9	0.3-0.6	<0.8	<0.5	<0.6
Studio Control room	8-20	2.4-3.0	19-60	0.3-0.7	0.3-0.5	<0.5	<0.6	N/A

RT for the standards AS2107,2000, ANSI S12.60, 2002, DfES,2002, DfES(BB93),2003 and OCPS,2003; the RT refers to mid-frequencies values (500Hz, 1000Hz and 2000Hz). (N/A: Not Available). (Osman, 2010).

According to the Norway standard NS 8178 the reverberation time should be adapted to the type of music and room size. If the reverberation time is too long, the sound becomes thick and unclear. However, if the reverberation time is too short, the music becomes dry and the tones lose some of their timbre and brilliance especially talking about vocals.

If the room is too small and its reverberation time is too long, the sound will be too powerful and it can become directly unpleasant or damaging to the hearing. If the room is too large and has too short reverberation time, the sound will be too quiet.

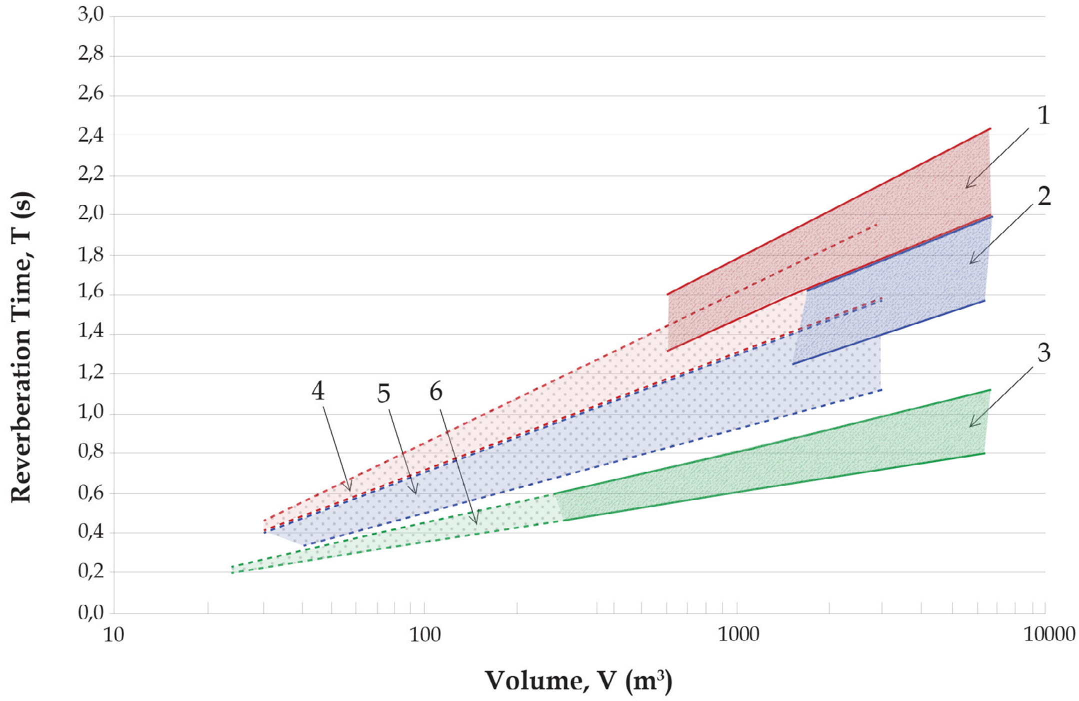
Gilford, a british researcher, stated that a space into which musical instruments are played should not have a volume smaller than 40 m^3 (Everest, 1996) as greater volumes could lead to sound intereferences and distortions caused by modal frequencies.

The table above is showing the typical dimensions and the recommended mid-frequency reverberation times for the various music rooms normally found in educational facilities.

The category in which the rooms involved in our research can be identified, following the Norwegian standard NS 8178:2014, are *Individual Practice Rooms* or *Ensemble Rooms;* individual practice rooms are designed for practice and teaching of one to two persons while ensemble rooms can be classified by size or number of people composing the group. Small and medium rooms can also be suited to group rehearsals and vocal exercises.

Rehearsal rooms for acoustical loud music		
Property	**Individual practise room**	**Small ensemble room**
Number of performers	1-2	3-12
Average net room height, *h*	≥ 2,7 m	≥ 3,5 m
Net volume, NTV	≥ 40 m^3	≥ 60 m^3; ≥ 360 m^3 (rel. to number of performers)
Net area, NTA	≥ 15 m^2	
Room geometry	Angled wall (avoid flutter echoes)	Angled wall (avoid flutter echoes)

Properties for rehearsal rooms for acoustical loud music from the Norwegian Standard NS 8178:2014.



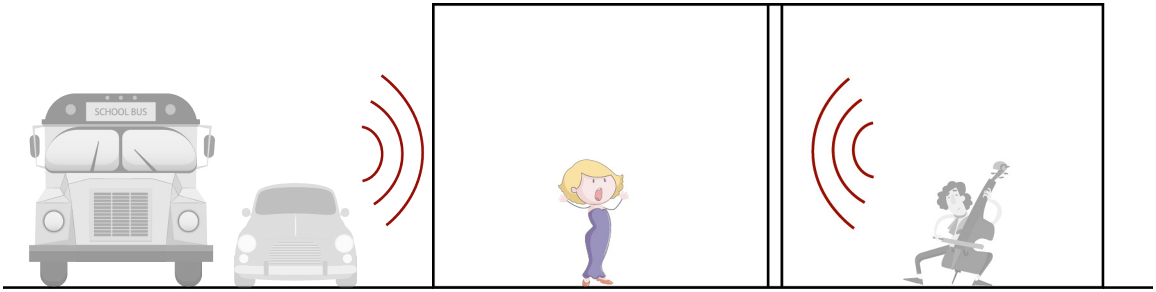
Reverberation time, T, relative to net room volume, V, for different types of music. (NS 8178:2014)

Key

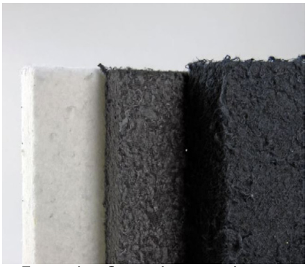
1. *upper and lower limit for quiet music in performance halls (solid lines)*
2. *upper and lower limit for loud music in performance halls (solid lines)*
3. *upper and lower limit for amplified music in performance halls (solid lines)*
4. *upper and lower limit for quiet music in rehearsal rooms (dotted lines)*
5. *upper and lower limit for loud music in rehearsal rooms (dotted lines)*
6. *upper and lower limit for amplified music in rehearsal rooms (dotted lines)*

_The Background Noise

Another important parameter that affects the quality of a space is the background noise. In 1980 Lamberty conducted a study to identify the most disturbing typologies of background noises for music students; 86% of the music students identified the most disturbing noise with that of the other students practicing, 9% identified it with the traffic noise and 4% with other kind of noises.



This research stresses the importance for music rooms to be well isolated between each other and, in general, the need for music spaces to have their own rooms and facilities as musical instruments can produce the same sound power in small rooms as in large auditoriums, leading to an uncomfortable feeling in small spaces. In small music rooms that present insufficient acoustic absorption characteristics this is considered to be the most influencing problem even because with bad room acoustics sound levels can rise and, in the long term, lead to hearing damage. Noise-induced hearing loss can affect many musicians and can be due to their extended exposure to high noise levels both from their own instruments and from others nearby.



Example of sound materials; porous absorbing material (cotton) (Adams, 2016)

The solution to obtain good quality room acoustics and to reduce sound intensities in small spaces can be the use of sound absorbing materials (Zha et al, 2002) useful also for the reverberation control, and, by consequence, for the elimination of flutter echo paths between parallel walls (Marshall et al, 1999).

The standard AS2107 of 2000 recommends a background noise level of 30 dB(A) for music studios, 35dB(A) for drama studios and 40dB(A) for music practice rooms. The standard DfES (2002) recommends the indoor ambient noise level for all school music facilities should be 30dB(A) or below. The table shows a summary of recommended maximum levels.

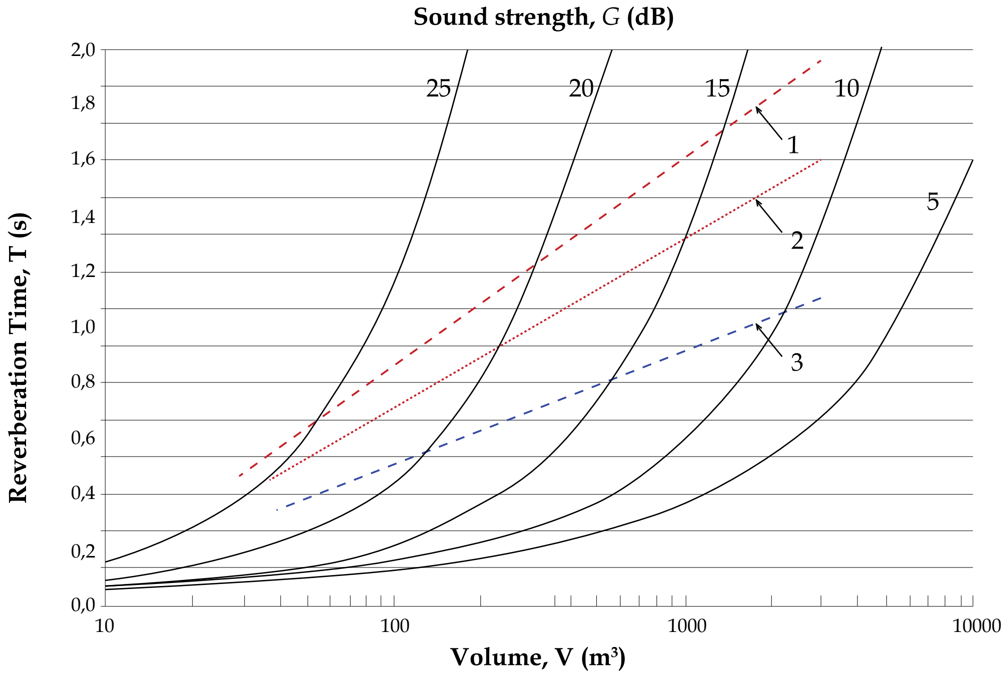
Music Activity Space	Cav. (1990)	AS2107,2000	ANSI,2002	DfES,2002	BB93,2003	OCPS,2003
Recording Studio	20 dBA	25 dBA	N/A	S/A	30 dBA	NC 15-25
Recital Hall	25 dBA	S/A	N/A	25 dBA	30 dBA	N/A
Rehearsal Room	35 dBA	35 dBA	35 dBA	30 dBA	35 dBA	35 dBA
Music Classroom	35 dBA	dBA	35 dBA	30 dBA	35 dBA	N/A
Ensemble Practice	dBA	dBA	35 dBA	30 dBA	30 dBA	35 dBA
Individual Practice	dBA	dBA	35 dBA	30 dBA	35 dBA	35 dBA
Music Listening	dBA	35 dBA	35 dBA	30 dBA	35 dBA	N/A

Summary of recommended Maximum Background Noise Levels from the standards AS2107-2000, Cavanaugh,1990, ANSI S12.60-2002, DfES,2002, DfES(BB93),2003 & OCPS,2003; S/A: Special Advice, N/A:Not Available, NC:Noise Criteria (Osman, 2010)

In order to support low values of background noise, a good sound insulation between the different rooms shall be provided. The aim should be to avoid disturbing noise from the adjacent rooms and to ensure suitability and flexibility of the rooms for their desired purpose (NS 8178:2014).

_Sound Strength, G

Sound strength specifies how many decibels the sound level in a space is above the sound level which a given sound source would produce at a distance of 10 m outdoors which means in a free sound field without sound reflections. Sound strength depends on the volume and reverberation time of the room and different combinations of volume and reverberation time will produce the same sound level for a given ensemble (Rindel, 2014).



Sound strength, G, as a function of volume and reverberation time. The dotted lines show upper and lower limits for reverberation time in rehearsal rooms for quiet and loudmusic. (NS 8178:2014)

Key

G. sound strength in dB in 5 dB steps (solid lines)

1. highest limit for quiet music in rehearsal rooms

2. lowest limit for quiet music/highest limit for loud music in rehearsal room

3. lowest limit for loud music in rehearsal room

Associazione Italiana di Acustica AIA - Guide lines for a correct acoustic design of learning spaces

The document contains a chapter dedicated to the music rooms. Noise transmission between two spaces, loud sounds generated by music instruments and an inadequate reverberation time are influencing negatively the acoustic performances of these rooms. The guide lines recommend an acoustic design focused on spaces distribution, volumes and shapes, internal acoustic treatment of rooms, sound insulation and a containment of the noise generated by the installations.

_Rooms distribution

As it has been discussed before, not only the room itself needs a good design, but also the whole architectural complex in which music classes are taught require precautions; a music building requires different musical activities at the same time, classes, individual or group rehearsals. For this reason all the rooms need to adapt and be adequate to everyone's demand. A good design of the rooms distribution is fundamental in a music building to avoid interferences between spaces dedicated to different uses. A good design can include "filter spaces" like corridors or deposits which work perfectly for spaces that need more insulation.

The position of the rooms in the building determine the quality of acoustics and its features: the insulation between overlaid spaces is more critical and more expensive compared to the insulation needed between two spaces placed on the same floor.

_Rooms dimension

For as it concern the rooms itself, architectural characteristics and furniture are essential to determine a good acoustics for each different activity.
Rooms dimensions is dependent on the activity carried on; AIA provides a table with indications related to sizing and maximum capacity of each space dedicated to specific activity.

Activities	**Maximum capacity [n. students]**	**Floor surface[m²]**
Individual practice	1	3 – 4
Private classes	2	5
Small groups practice	4	7
Medium groups practice	6	9
Groups practice and classes	15	30 to 40

Table of recommended minimum surfaces per activity and number of students in a room (AIA, 2017).

Proportions are essentials in a space for music to obtain a good distribution of the modal frequencies: if two modes overlay at the same frequency, acoustic problems could occur.

Researcher	Relative height [m]	Relative length [m]	Relative width [m]
Boner	1,00	1,26	1,59
Louden	1,00 1,00	1,40 1,30	1,90 1,90
Sepmeyer	1,00 1,00 1,00	1,14 1,28 1,60	1,39 1,54 2,33
Volkmann	1,00	1,50	1,59

Table about the ideal proportions of a parallelepiped space dedicated to music practice (AIA, 2017).

_Rooms volume

In addition to the floor surface, a proper volume is necessary for sound reflections; the first reflections need arrive to the player or singer with a time that allows them to hear all the musical tones and to feel spatial feelings. Moreover musical instruments in small rooms generate too high sound levels that can cause stress and hearing losses after long exposures and insulation problems between adjacent rooms which lead to a disturbing background noise.

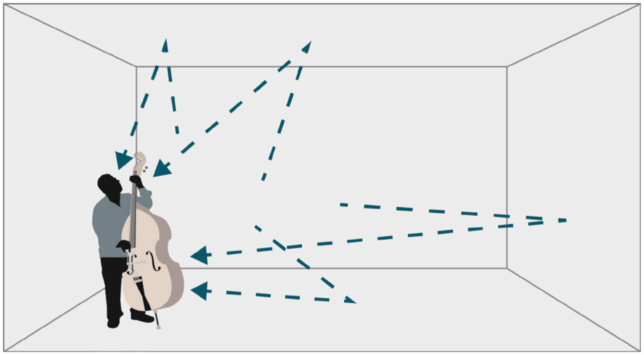
Instrument	L_{Aeq} during individual practice [dB(A)]
Violin	90
Cello	84
Double Bass	81
Drums	93

Sound levels emitted by instruments during individual practice (AIA, 2017).

More precisely, music rooms need a bigger volume in comparison to school rooms. AIA guidelines indicate a volume greater than 63 m^2 with an optimal height of 4 - 5 meters.

_Rooms shape and geometry

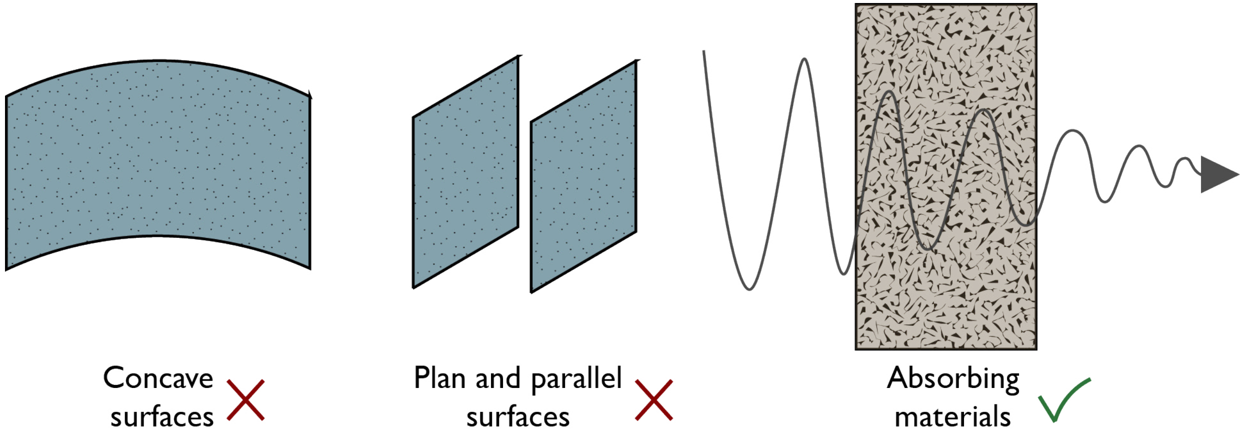
Even shapes, proportions and geometries influence sound distribution of a space: parallelepiped and cubic rooms with plans, parallel and reflective walls cause standing waves. The waves diffuse in all the directions and reflect on walls that can be parallel or with different incidence angles.



Scheme of reflecting waves.

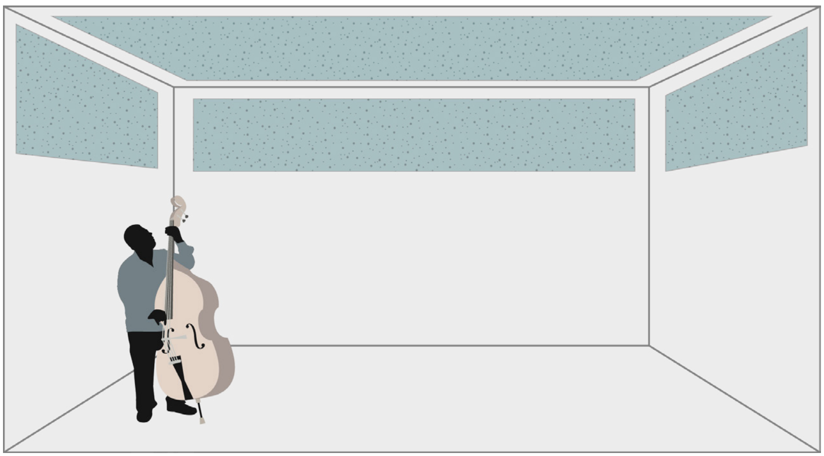
A standing wave is a wave that does not propagate, but remains in the same portion of space because the distance between two walls is equal to a multiple of a wave half-length or because of particular incidence angles. The generation of a standing wave includes the vibration of a normal mode whose frequency is normal; normal frequencies correspond to the resonance frequencies of a space as when a frequency emitted in the room equals the frequency of one of the normal vibration modes, the space exalt that particular frequency determining the formation of maximum and minimum sound levels audible in the environment. The phenomenon is emphasized in low frequencies.

For a good acoustic quality of small rooms it is necessary to avoid exact numerical relationships; another way to attenuate standing waves is to add absorbing and reflecting materials and to avoid plan, parallel and concave surfaces which can cause *flutter echo* phenomena.



Scheme of surfaces shapes.

A correct distribution of absorbing and reflecting materials contributes to the optimization of the sound distribution in space and time as these kind of materials allow to regulate reverberation times.Their disposition in the room has to be uniform and placed on the ceiling or in the high portion of lateral walls as in the low part people constitute a meaningful quantity of acoustical absorption.



Example of a correct panels placement.

Convex or irregular surfaces, like geometrical elements with prominences and indentations of different depths, can have a reflective effect useful for players or singers to have higher reverberation times without compromising the signal articulation as the irregularity of geometry assures a reflection of different frequencies at different angles by maintaining a feeling of a more diffuse sound.

Low frequencies emitted by some musical instruments and voice need to be controlled to have a good acoustic response as they tend to stay in room forming standing waves distorting the correct perception of sound. The solution is to place "acoustic traps", absorbing tools for low frequencies that can be rigid perforated panels associated to an absorbing layer that constitute an Helmholtz resonator. The optimal placement of these "traps" can be at the angles of the room.

Helmholtz resonator scale at Saint-Étienne, Rhone-Alpes, cultura heritage (/patrimoine.rhonealpes.fr/)

_Sound insulation

Architectural precautions for a good insulation have to consider both the sounds from the outside and the sound generated from the inside of the environment. Double building hardwares with high performances reduce the sound waves transmission from the outside. Walls have to be characterized by partitions with a high R_w value [dB]. Doors are critical elements and need particular attention. Noises produced by impacts can be attenuated with disjunctions of horizontal and vertical elements to reduce the sound propagation by solid ways. A double envelope ("box in a box") could be the best solution as double walls cancel the later transmissions of sound.

Decreto n.26, Provincia Autonoma di Bolzano_Regulation for the construction of music schools

The order of the city of Bolzano in the North-East of Italy, dated July 7th 2008 gives indications about the construction of schools for music teaching which have to follow the rules for school building plus particular technical guidelines.

The spaces program indicates different kinds of rooms and related guidelines.

	Useful surface [m^2]	Destination	n° of students	Acoustical requirements
A1 Aula	20	Individual or group classes for different musical instruments	max 4	Generic
A2 Aula	40	Group classes for different musical instruments	5-15	Generic
A3 Aula	40	Theory classes	15-20	It should contain a piano, a blackboard, desks
A4 Aula	60	Classes of percussion musical instruments	-	Good sound insulation
A5 Aula	60	Voice, children's choir, musical theatre and dance, bands and other ensembles	-	Flexible furniture

Single description of different kind of classrooms and destinations (Decreto n.26, Provincia Autonoma di Bolzano).

_The reverberation time

The section n.6 is important for as it concerns values of reverberation time in spaces for music; "in classrooms for individual and group classes the average reverberation time must be as much as possible linearized for all the frequencies range and be included between 0,5 and 0,8 seconds, to be able to control technique and executive precision" (Decree n.26, 2008).

Instrument class	Instrument	Sound power	Dynamic max [dB]	Frequency range [Hz]	Average reverberation time value [s]
Voice	Soloist voice	High	90-95	80-15000	0.5
	Choir	High	90	80-15000	0.9-1.0

Sound power and frequency spectrum of voice and indicative values of reverberation time (Decreto n.26, Provincia Autonoma di Bolzano).

To guarantee the recommended reverberation time absorbing surfaces need to be placed regularly in the rooms and preferably on lateral surfaces as the absorption of medium and high frequencies occurs on the ceiling and, eventually, on the floor. The walls have the function to diffuse sound and to correct reverberation time absorbing low frequencies with the aid of resonators or vibrant panels.

As absorbing materials the decree provides a list of categories:

- Porous absorbing materials: mineral or organic fibers. Their absorption coefficients depends on the thickness and on the distance from the wall or ceiling. Active mainly for medium and high frequencies.

- Perforated and cracked absorbing materials: their absorption depends on the panel thickness, holes' dimension and their wheelbase, distance from the wall or ceiling. They work better for medium-low frequencies.

- Vibrant panels: constituted by panels with low rigidity and an air interspace in front of a high-mass element. Useful to absorb low frequencies.

- Membrane absorbing panels without fibers: innovative materials used to absorb all the frequency range. Constituted by micro-perforated membranes of synthetic material, metal sheet, wood.

_Sound insulation

The section n.5 is about the acoustic insulation of the spaces and it aims that music rooms requirements must be higher compared to those for the other types of room especially for what that concerns acoustic

insulation from the outside and between different inside rooms. Sound insulation have to be guaranteed both from the outside and between the rooms.
To obtain this result of good acoustic quality materials and their combinations have to be verified, structural elements have to be insulated, floating floors with a system mass-spring-mass to cancel sound propagation by solid or air way have to be built.ealization of false ceilings and walls made by drywall and placed inclined for the reflection of waves, realization of glazed walls with a thick air layer to avoid noise, placement of elements characterized by a high mass per unit surface joined to light false-walls and doors built with a high insulation technology.
One of the most important adjustment is referred to the posing during the construction works to avoid the formation of acoustic bridges mainly in presence of technological systems.

_The background noise

The order dwells on the background noise theme, which is considered fundamental in a music room design especially in room that have a natural ventilation in which windows are usually open and let the noise from the outside come into the room and be dominant; the problem does not subsist in the areas characterized by an optimal acoustic condition, while it does in environments that present a background noise level greater than 50 dB(A). In these cases attenuation sound disposals or mechanic ventilation will be needed. In common spaces a value of background noise of 40 - 45 dB(A) is considered acceptable while in rooms dedicated to classes it descends to 35 - 40 dB(A) and in studio recording spaces the values swing between 25 and 30 dB(A).

_Geometry and dimensions

An optimal geometry of the spaces indicates rectangular spaces even if a particular attention has to be guaranteed to control *flutter echo* phenomena by the placement of absorbing panels or sound diffusion elements. Concave walls or ceiling have to be avoided as much as niches and sharp angles.

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ANATOMY AND PHYSIOLOGY OF VOICE AND HEARING

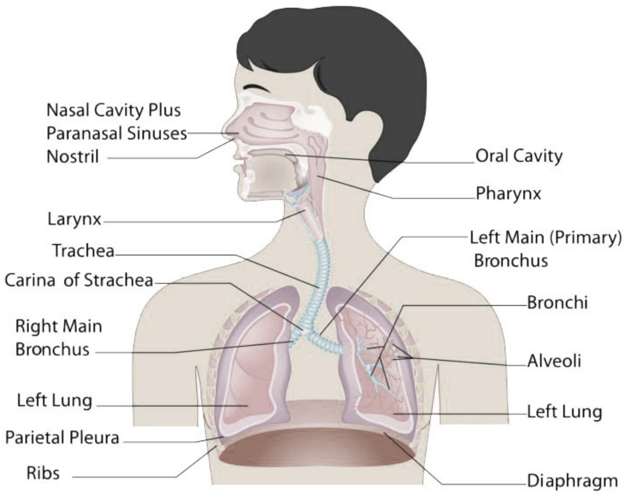
INTRODUCTION

Speech is the systematic movement of our articulators, pressures, the sound patterns we perceive, the sound waves that travel from speaker to listener. Speech is the medium people use to transmit a message and thoughts which can be expressed orally by transforming dynamic representations of chunks of speech from a buffer into audible pressure waves via a stream of coordinated movements. Most of the time articulations are visible while others can be felt and perceived in some particular parts of the vocal tract when producing a sound. For instance, anything the tongue-tip does can be felt quite clearly whereas events taking place in the back of the mouth are not as easy to feel and understand what it is happening. Speech and its sounds can be described and classified.

The respiratory system

All speech sounds require airflow from the lungs which forces the vocal-folds to vibrate in voiced sounds, so during phonation: respiratory system is a power supply.
Normal vocal-fold vibration is periodic and it is linked to articulatory movement; aperidocity may reflect vocal pathology.

The respiratory system is composed by (1) the lungs, (2) the trachea, (3) the rib cage, (4) the thorax, (5) the abdomen, (6) the diaphragm and (7) the muscles.



Anatomy of the respiratory system (www.adrenalinefatigue.com)

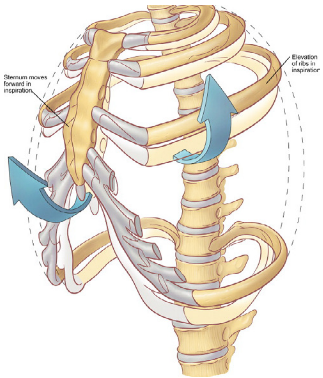
_*The breathing process*

During breathing process lungs work as an energy generator and mechanisms of pressure are established: the expansion of the chest and lungs creates negative pressure known as Boyle's law which consists in the notion that Pressure x Volume = constant. The air flows inside (inhalation) to equalize the pressure, subsequently the contraction of the chest and lungs creates positive pressure. During the exhalation, when the air flows out, the exhaled airflow is modified to produce speech sounds. This process can be compared to the idea of rarefaction and compression.

So the air-stream of our breath moves from high to low pressure regions: the pressure in the lungs is reduced while breathing in, letting the air flow in, and it is increased while breathing out.

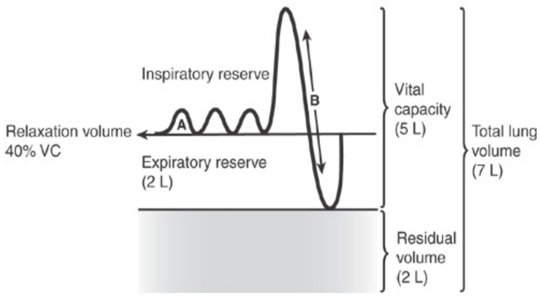
The pressure variability increases or reduces the lungs volume simultaneously with the pressure. The volume variation of the lungs is possible thanks to the lowering or raising of the diaphragm and the rib-cage.

The rib-cage is part of the structure of the respiratory system, with the vertebral column and the sternum, which, with accessory muscles (neck, chest, abdomen and back), is responsible of the flexibility of dimensions of the thoracic cavity that allows to increase or decrease lungs volume.



Thoracic cavity movement

During speech or singing activities a greater quantity of air is inhaled than in quiet breathing and there is a voluntary and conscious control of the breathing process; during the expiration the respiratory muscles relax and allow the lungs and the rib cage to recoil, the pressure increases, the air flows out, the volume return to a resting status and the whole respiratory system collapses when the vital capacity (VC), the amount of air exchanged in maximum inspiration-expiration (normally it oscillates around 5 L), is at about 40%.



Scheme about the respiratory volumes of air.

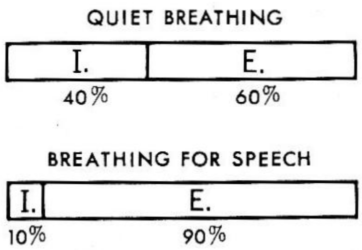


Figure 4.22. Comparison of the inspiratory (*I*) and expiratory (*E*) proportions of the respiratory cycle for quiet breathing and speech.

Comparison of the inspiratory (I) and the expiratory (E) proportions of the respiratory cycle for quiet breathing and speech.

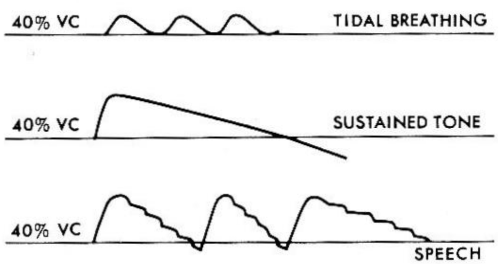
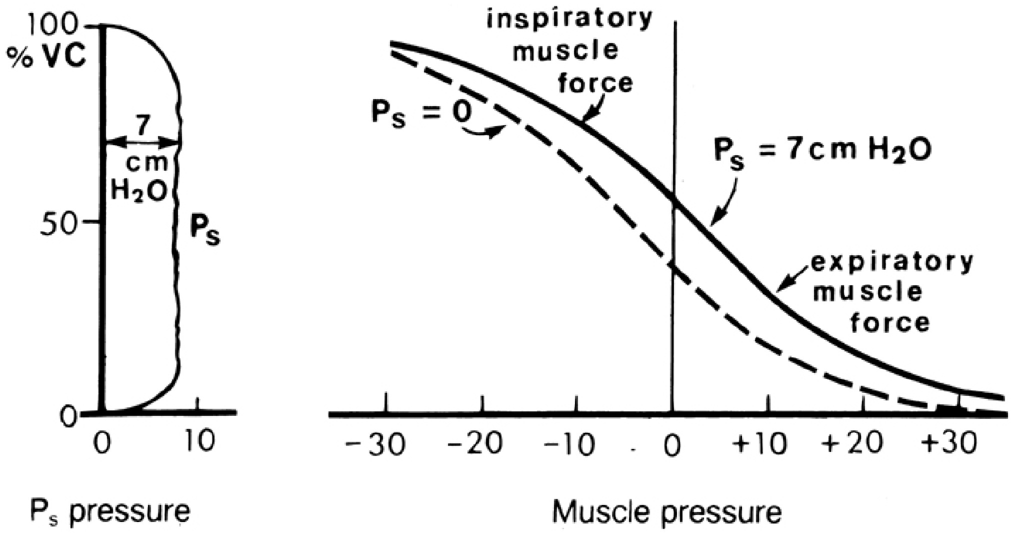


Figure 4.30. Lung volume as a function of time for various respiratory conditions.

Lung volume as a function of time for various respiratory conditions.

_Active expiration: speech and singing

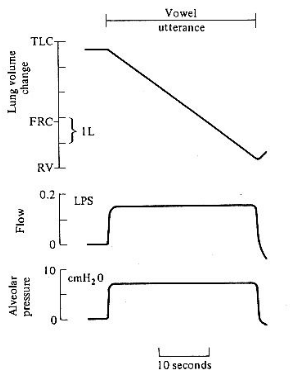
During speech or singing activities muscles counteract the passive collapse of the respiratory system and lead it into a compressed state; the inspiratory muscles maintain lungs in expanded state so that expiration can be slow and longer during exhalation phase thanks also to expiratory muscles which compress thorax and abdomen.



Relation between muscle activity during inspiration and expiration and pressure.

From the graph it is clearly visible that an increase of the subglottal pressure (Ps) leads to an increase in intensity (I), in fact I = Ps3 or Ps4: that means that increasing Ps a little involve a great increase of I.

To sum up, both inspiratory and expiratory muscles are active most of the time during breathing and the balance between them changes continuously. The pressure in the respiratory system is constant during speech activity and there are small variation of intensity.



Lung volume change (liters), flow (liters per second) ad alveolar pressure (centimeters of water) during an isolated vowel utterance produced throughout most of the vital capacity.

Intensity is directly correlated with loudness and, during speech, it increases directly proportional with the airflow. A changing in the airflow implies changes in the relation volume-velocity and it is caused by a changing of pressures within the lungs. The diagram shows then how constant flow is the corollary of constant over-pressure expressed as the number of centimeters of a water-column supported by a certain pressure. The result is a steady decrease in the lungs air volume.

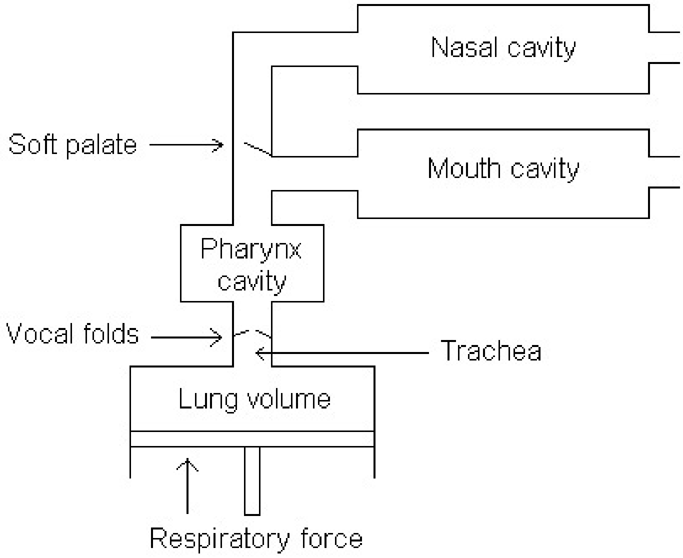
The control of speech production goes along with the control of loudness in speech which implies a consciously changing in pressure and air flow.

The vocal tract

The vocal tract in an acoustic tube that transform the positive pressure arriving from the lungs into negative pressure to make vocal folds sustain their oscillation. During the closing of the glottis the airflow begins to decrease, but the air that is above the glottis continues to move with its same speed because of inertia. This phenomena creates a region just above the vocal folds where the air pressure decreases. Pressure builds up below the glottis, causing them to open; at this time fluid pressure against the walls is greater than when the vocal folds were close together. The result is an asymmetry of driving force (air) that sustains oscillation.

_The laryngeal system

The laryngeal system is physically placed in the vocal tract and it is part of the respiratory system.



Scheme that shows how the vocal tract is part of the respiratory system.

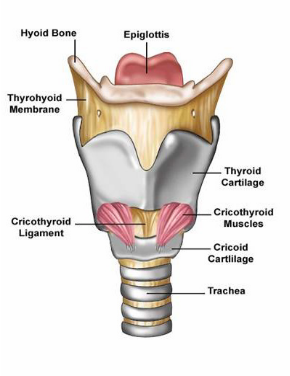
The diagram of the vocal tract shows the energy generated by the lungs. Above the vocal folds there are multiple cavities that can be modified in size and shape to change the sound quality of speech sounds during phonation.

The larynx is the continuation of the trachea and it is composed by

- Cartilages (thyroid, cricoid, arytenoid): they are highly specialized and rotate and tilt to affect changes in vocal folds;

- Muscles (extrinsic and intrinsic);

- Attaches to the trachea and the hyoid bone.



The larynx and the elements composing it.

The function of the larynx is to control airflow in and out of the lungs, to protect the lungs during swallowing, to increase intra-thoracic pressure during activities like exertion or coughing and, above all, it provides sound source for speech.

The vocal folds

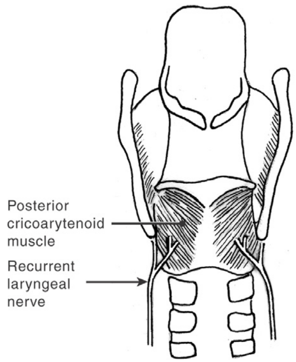
_*Vocal folds structure*

Vocal folds are characterized by a layer-structure. The cover is pliable and it is the mostly mucous membrane while the body is mostly muscled; this two elements have different vibratory properties and they are connected during phonation. The laryngeal muscles determine how tightly body and cover are connected.

To contribute to phonation vocal folds cannot work independently, but they should be assisted by the arytenoid cartilages, the vocal ligament, the thyroarytenoid muscle and the superficial mucous membrane.

The movement of the vocal folds is about abduction and adduction.

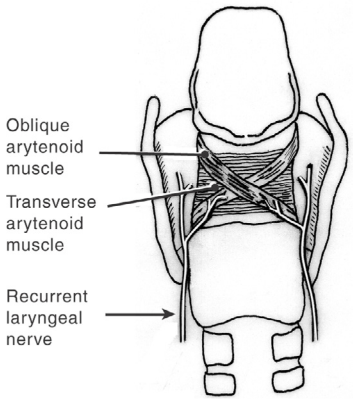
During the abduction folds are separated and in rest position to allow breathing and to produce voiceless sounds.



The muscles involved in the vocal folds movement.

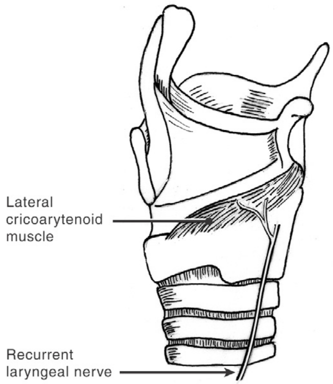
The muscles involved during the abduction are the posterior cricoarytenoid muscles attached to the arytenoid cartilages through their dorsal plates; cartilages rotate and separate vocal folds.

During adduction folds are brought together to produce voiced sounds and to be part of the phonation process; they are attached to the left and right arytenoid cartilages and the interarytenoid muscles draw cartilages together posteriorly and adduct vocal folds.



The muscles involved in the vocal folds movement.

The lateral cricoarytenoid muscles draw arytenoids forward and downward assisting in the adduction movement.



The muscles involved in the vocal folds movement.

_Myoelastic aerodynamic theory

The protagonists of the theory are muscles that adduct vocal folds and establish levels of tension and elasticity. The characteristic of elasticity allows vocal folds to stretch and to return in the original position during each cycle, aerodynamic and physical forces involve the subglottal pressure from the lungs which guides vibration and set the vocal folds into motion in each cycle.

The myoelastic aerodynamic theory states that negative pressure causes the vocal folds to be sucked together, causing a closed airspace below the glottis while a continued air pressure from the lungs builds up underneath the closed folds. Once this pressure becomes high enough, the folds are blown outward, thus opening the glottis and releasing a single "puff" of air. The lateral movement of the vocal folds continues until the natural elasticity of the tissue takes over, and the vocal folds move back to their original, closed position. Then the cycle begins again.

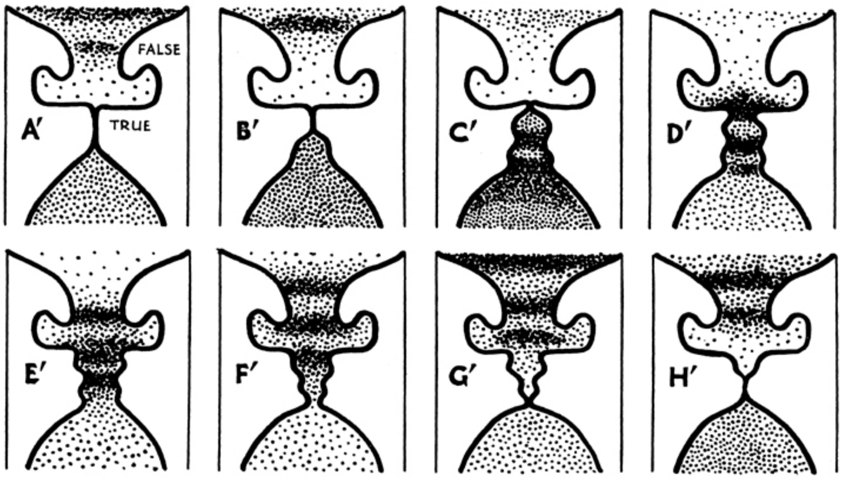
The fundamental frequency (f0) represents the number of vocal-fold cycles per second and it depends on speakers' and vocal folds characteristics: longer and more massive vocal folds vibrate at lower frequencies, tense and thinner vocal folds vibrate at higher frequencies thanks also to the cricothyroid muscle that stretches and thins the vocal folds increasing f0. Physically, a raised larynx leads to a contraction of suprahyoid muscled causing an increase of f0; a lowered larynx involves a contraction of infrahyoid muscles and it decreases f0.

Fundamental frequency varies within speakers as for men it is about 125 Hz, for women 200 Hz and for children it is higher than 300 Hz as the length of the vocal folds increases tension and decreases mass, leading to higher f0.

PHONATION

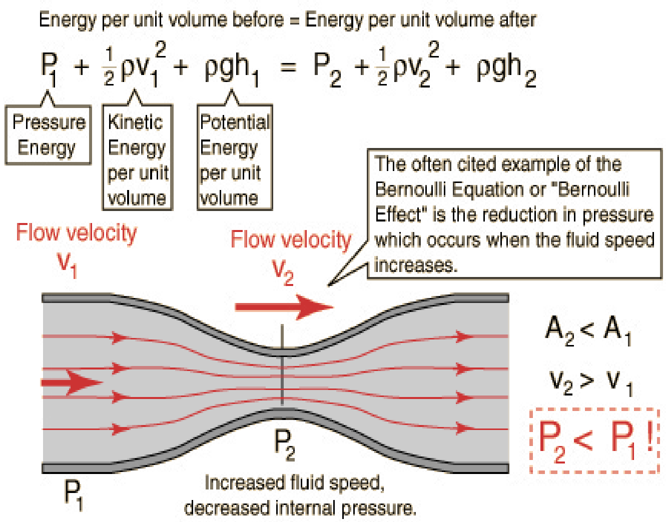
Aerodynamic forces during phonation and vocal folds behavior

The subglottal pressure Ps and intra-oral pressure are partly responsible of the vocal folds movements; the subglottal pressure, for example, have to exceed the threshold value of the pressure above vocal folds to force them apart during each cycle.

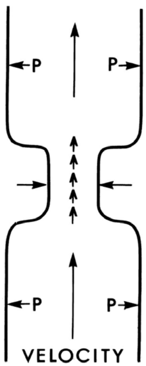


How Ps forces vocal-folds apart in each cycle

The principle of the Bernouilli effect states that an increase in speed leads to a decrease in pressure; it involves the passage of a flow through a small area that could be, for example, the glottis, and it yields a pressure drop, while inward pressure helps closing vocal folds in each cycle.



Bernoulli's principle; an increase in speed leads to a decrease in pressure.



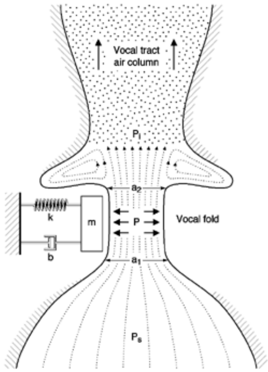
Bernoulli effect: airflow in a constriction.

Voice in general is produced through cycles of vocal folds vibration and thanks to the elastic recoil and Bernouilli effect. However, different voice qualities can be produced by adjusting the glottal aperture, tension and the superglottal pressure.

Phonation is characterized by periodic and complex cycles; in the first ones the pattern is repeated for every cycle, while in the second one multiple frequencies are produced even if it is always present the fundamental frequency f0 which is the lowest produced and on which the voice pitch depends. In complex cycles higher harmonics are whole-number multiples of f0 and as they increase the intensity decreases.

Each cycle of the vocal folds produces a single small puff of air; the resulting sound of the human voice is nothing more than tens or hundreds of these small puffs of air being released every second and filtered by the vocal tract.

The spring-mass system

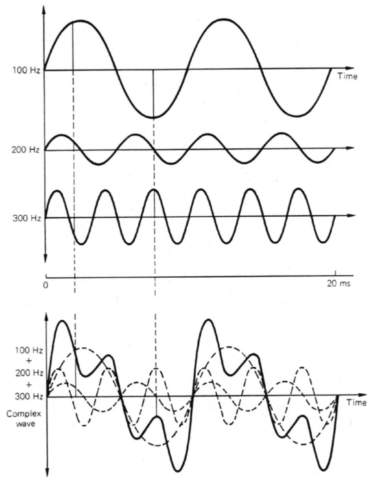


The vocal fold movemenet; each cycle produces a single small puff of air. Multiple "puffs" of air being released every second and filtered by the vocal tract constitute the sound of the human voice.

The spring-mass system is fundamental to describe vocald folds' behavior as the spring could be identified with the tissue stiffness or restoring force in the vocal fold and the mass with the vocal folds per se. The spring-mass system is characterized by an harmonic oscillator and its damping which, in vocal folds, depends on the viscosity, so the energy absorption; oscillations in the system are represented with cosine waves (sounds) whose amplitudes, in the real world, decrease with time.

Vocal folds do not move in uniform fashion, but rather in a wave-like motion from bottom to top. To sustain their oscillations folds need a combination of convergent and divergent shapes to have different pressure intensities: in the bottom part vocal folds are closer together letting the air flow converge.

This human spring-mass system lose a great amount of energy; the acoustic energy from the vocal-fold vibrations is strongly damped because of the soft walls of the body that absorb energy and because some energy flows back into trachea even if each glottal closure adds energy to the system, which quickly weakens. When the vocal folds vibrate and come together (glottal cycles), they produce an impulse with harmonic energy (harmonics) that are vibrations at every multiple of the fundamental glottal frequency.



Harmonics are the sum of all the componenet signals pressures at each point in time.

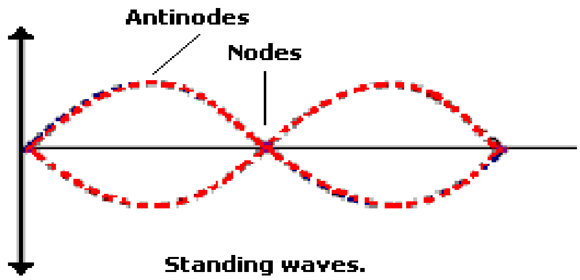
STANDING WAVES

Standing waves (or stationary waves) identify resonances in pipes. The vocal tract and the external ear can be considered an acoustic equivalent of pipe.

What is a standing wave?

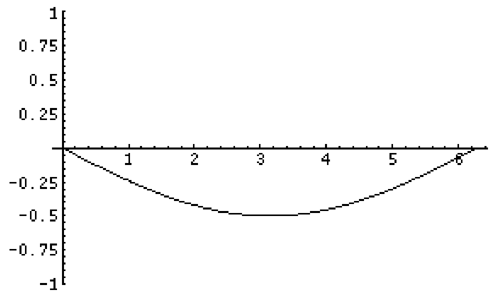
When two identical waves in frequency and amplitude, traveling in opposite directions, collide they can create a standing wave. Unlike traveling waves, standing waves appear to vibrate in place; their peaks alternate from positive to negative in place and terminate in a zero-point of displacement on both sides, but do not move forwards or backwards. Peaks are called anti-nodes and the zero-points of displacement are called nodes. The standing wave remains in a constant position.

In music standing waves are created, allowing harmonics to be identified; nodes occur at fixed ends and anti-nodes at open ends.

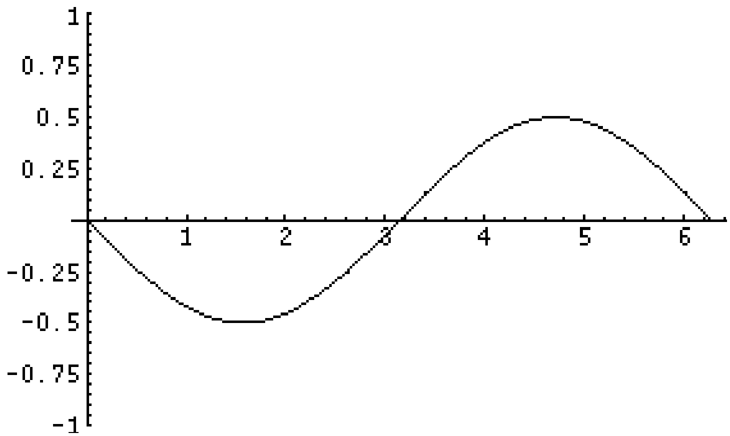


Standing waves are apperaring to vibrate in place.

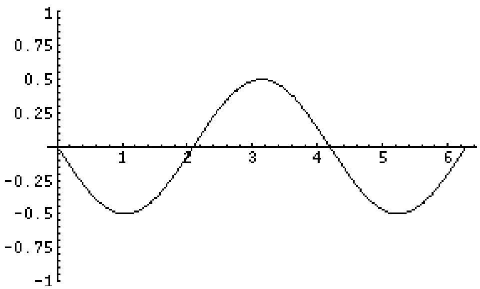
- Half standing waves are characterized by a half period, 1 anti-node and 2 nodes; their wavelength is twice the distance between the two endpoints.



- Full standing waves include 2 anti-nodes and 3 nodes and their wavelength is the distance between the end points.

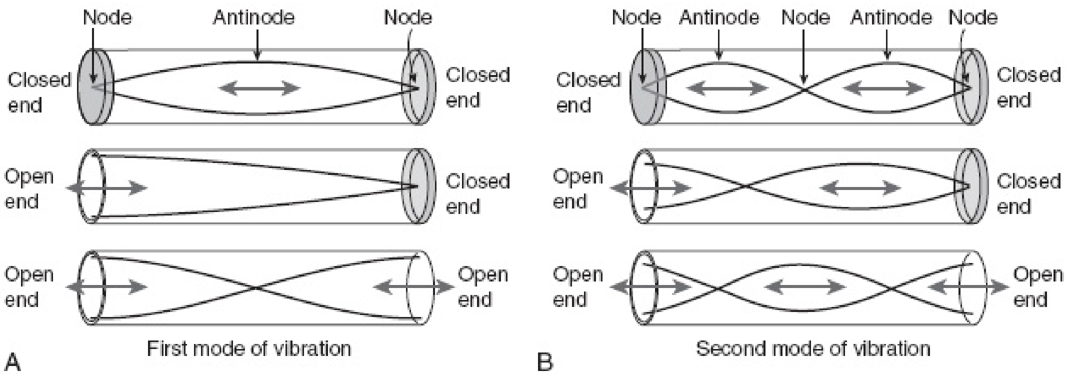


- Standing wave with three ½ cycles have 3 visible anti-nodes and the wavelength is 2/3 times the distance between the end points.



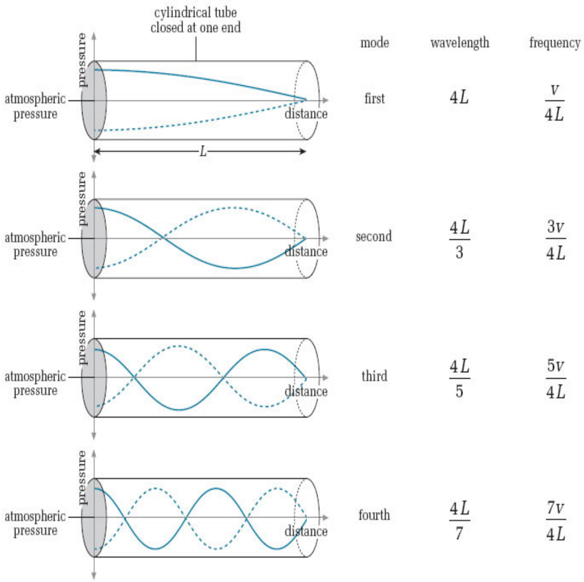
All the standing waves are sine-waves that creates themselves automatically the right frequency is found and no other shape would be possible.

Standing waves in a pipe



Vibration modes (A,B) of a tube that is closed at both ends, open at one end and closed at the other, and open at both ends.

Length is odd number of quarter waves. Allowable frequencies are f, 3f, 5f, … where f=c/ λ =c/4L for a pipe whose length is L.



Pipe closed at both ends: ½ wave resonator.

Particle displacement and particle velocity in a "closed end" standing wave are zero, standing wave has velocity zero, therefore it has a velocity node.

Resonant frequencies of pipes

Pipe may have a lot of nodes and antinodes; the more nodes number increases, the more the wavelength becomes shorter and frequency increases. The lowest possible frequency is called the fundamental frequency and all the other frequencies of the other patterns are multiples of the fundamental. The resonant frequencies of resonators are equally spaced multiples of fundamental frequencies.

Vocal tract works as pipe of air with a quarter-wave resonator: closed at one end, open at the other end.

For example, if the vocal tract is 17.5cm long, and the speed of sound(v) is 350m/s at body temperature, then v/L=2000Hz, and

F1=500Hz

F2=1500Hz

F3=2500Hz

Where its wavelengths are:

l1=4L

l2=4L/3

l3=4L/5

The vocal tract in an acoustic tube that transform the positive pressure arriving from the lungs into negative pressure to make vocal folds sustain their oscillation. During the closing of the glottis the airflow begins to decrease, but the air that is above the glottis continues to move with its same speed because of inertia. This phenomena creates a region just above the vocal folds where the air pressure decreases. Pressure builds up below the glottis, causing them to open; at this time fluid pressure against the walls is greater than when the vocal folds were close together. The result is an asymmetry of driving force (air) that sustains oscillation.

RESONANCE

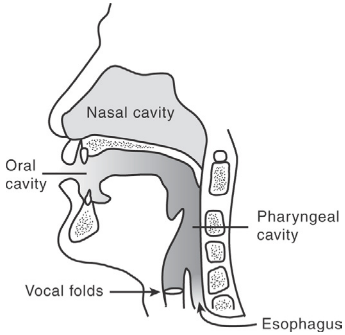
Resonance is a form of standing wave. The way our ears separate various frequencies is based on the principle of resonance which happens in the part of the inner ear called the cochlea where various parts of it resonate at different frequencies; when a particular part of the cochlea starts resonating, the nerves receptors located there pick up the signal and send it to the brain. The result is the perception of a particular pitch.

Most sounds will excite resonance in multiple areas of the cochlea at once; those sounds will be perceived as complex (containing higher "harmonics") or as musical chords. Normally, if an object is excited to vibration, the vibration will fade away due to dampening. However, all objects have a preferred vibration frequency called the resonance frequency at which vibrations are reinforced as standing waves within the object.

Resonance in the vocal tract

Resonances are the result of filtering the sound source passing through the supraglottal cavities of the vocal tract that, during speech, are shaped by the articulators.

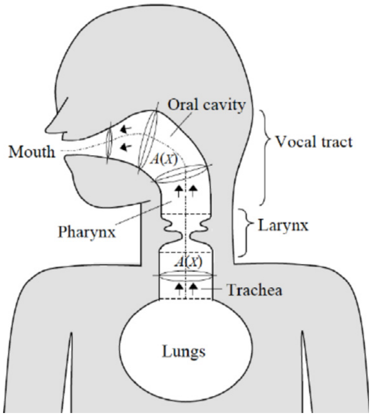
Resonant frequencies are partly determined by cavity size and they are called formants.



Cavities of the vocal tract.

The pharyngeal cavity is formed by a tube of constrictor muscles (superior, middle and inferior) that narrow the pharynx because of their contractions.

The oral cavity is formed by the space between the teeth, upper and lower jaws (maxilla, mandible), and tongue.



Tube representation of vocal tract.

The tube representation of the vocal tract shows that the region between glottis and lips can be modeled as a tube open at one end and closed at the other; glottis (with adducted vocal folds) represents the closed end while lips form the open end.

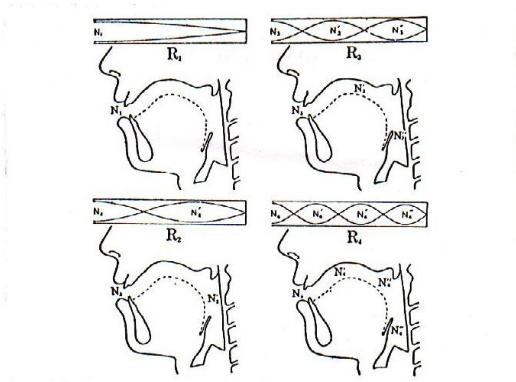
Resonance relates to the locations of air pressure and particle velocity in the tube relative to LAMBDA; in the closed end (glottis) the air pressure is at a maximum and the air particle velocity must approach zero, while at the open end (lips) the air pressure is at a minimum and the air particle velocity must be at maximum.

_Pressure velocity and changing formants

Constricting the vocal tract near a maximum pressure (minimal velocity) raises the formant value because it reduces L, decreases l and increases f, while constricting near a region of minimum pressure (velocity maximum) lowers the formant value as it increases L, increases l and decreases f.

_Resonant frequencies of the vocal tract

Resonance means favoring certain frequencies.The pressure changes of some wavelengths (1, 3, 5 etc.) fit bettertogether than others(2, 4, 6 etc.)



The resonances and formants of the vocal tract.

Resonance consists of reflecting some frequencies and their energy back into the system; this allows the oscillations at certain frequencies to continue longer being less damped. Only certain frequencies are reflected because of the length of the vocal tract. Sinusoidal waves oscillate from a positive to a negative maximum pressure passing through a zero-point pressure; when the maximum level is reached, the rate of pressure change is minimal and the reflection takes place at the lip opening which represent the open end of the tube.

Each cycle has two maximum points, one at 90° (¼ of the wavelength) and one at 270° (¾ of the wavelength) that repeats itself at 1¼ and 1¾ of the wavelength, etc.

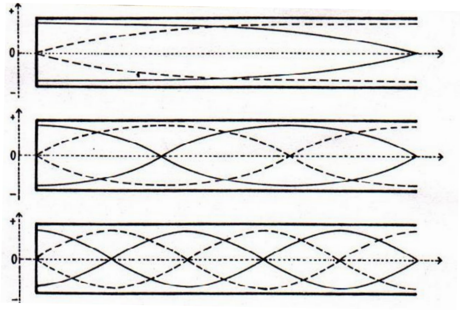
By knowing the length of the vocal tract and the velocity of the particles, so the speed of sound, resonances can be calculated.

The length of a standard vocal tract is 17 cm, so the frequency of the resonances are:

R1 = 0.25 x (340 / 0.17) = 500 Hz

R2 = 0.75 x (340 / 0.17) = 1500 Hz

R3 = 1.25 x (340 / 0.17) = 500 Hz



Resonances of the vocal tract.

Changing vocal tract shape leads to changes in the sound emitted and its fundamental frequencies; however it is possible to change the shape while keeping the pitch of the voice constant.

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AUDITORY SYSTEM

Introduction

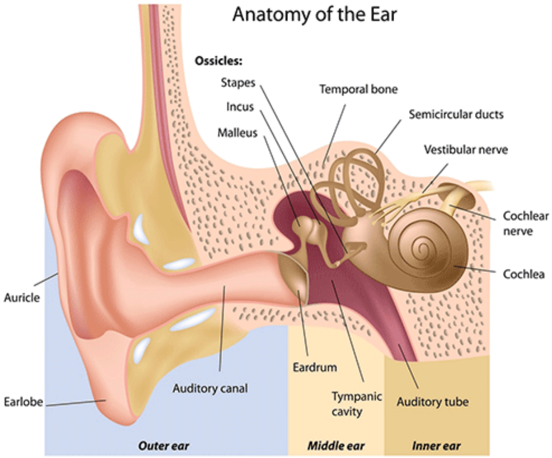
The auditory system characterizes the physiological and neurological foundation of perception: it relates the acoustic signal and the sound patterns that we perceive modifying the incoming signals that take place on its way to the brain whose structure will be recognized and decoded as a message. A complex acoustical, mechanical and neurological process takes place. The neural pathways from the auditory nerve to the auditory cortex are marked by acoustic vibrations that arrive in the ear canal and that must change first to mechanical vibrations, then to an "hydraulic" event and finally, via another mechanical transformation, to electrical impulses.

Any acoustic signal passes through the auditory system, therefore, there is need to know how the system affects the speech signal to be able to understand how speech is perceived.

Psycho-acoustics, psycho-phonetics and speech perception are part of the "Stimulus transformation" process which can be used to explain the relationship between the structure of the acoustic speech signal and the sound pattern perceived.

The auditory system analyzes sounds according to the frequency, amplitude and timing.

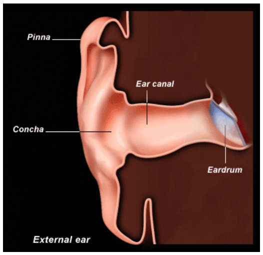
Anatomy of the ear



Anatomy of the ear.

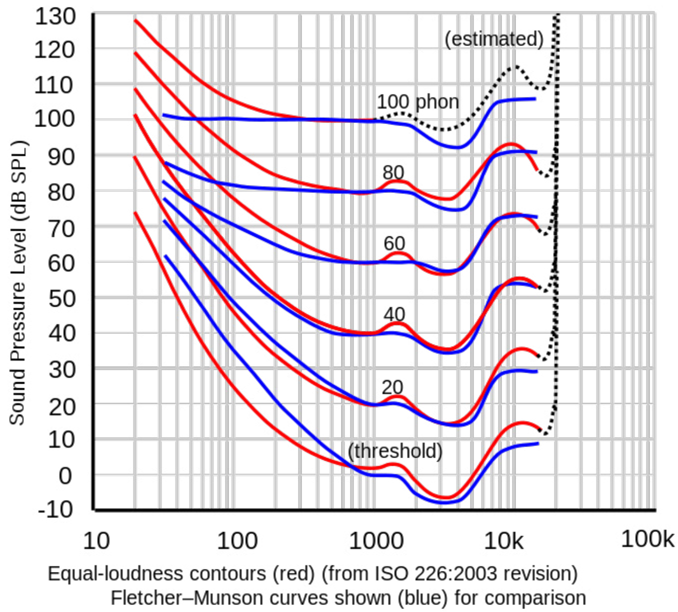
The sound, characterized by pressure waves, arrive at the outer ear, the middle ear converts pressure into mechanical vibrations, the inner ear converts vibrations into vibrations in fluid and nerve ending in the cochlea finally convert the sounds to neural impulses.

The outer ear is composed by the pinna, or auricle external cartilaginous flap, and the ear canal, or external auditory meatus (EAM) and it has a standard length of 2,8 cm.



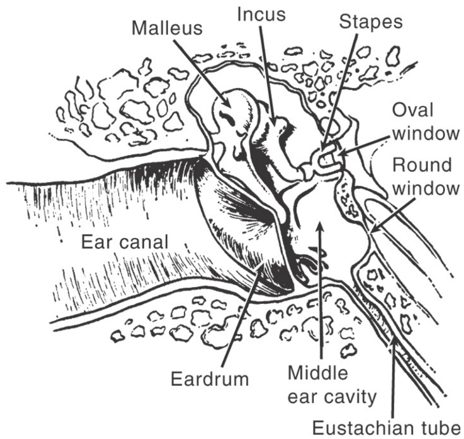
Components of the outer ear.

The pinna is made of cartilage and soft tissue and it has the function to collect sound vibrations and to guide and funnel them into the ear canal and to protect it assisting it in sound localization, while the ear canal protects the internal parts of the middle and the inner ear boosting the resonances of high-frequency sounds. The sound amplifications depends on frequency while loudness can be related to frequency thanks to the Fletcher and Munson curves.



Fletcher-Munson curves.

The middle ear is composed by the tympanic membrane, ossicles (malleus, incus, stapes), muscles, oval window (which represents the entry to the inner ear) and the eustachian tube which characterizes the ath to the nasopharynx.



Cross-section of middle ear.

The middle ear corrects the impedance mismatch between the outer ear and the fluid of the inner ear; in this process ossicles act as a lever to increase sound pressure as the size reduction from tympanic membrane to oval window increases force, muscles attenuates loud sounds and the eustachian tube equalizes air pressure variations.

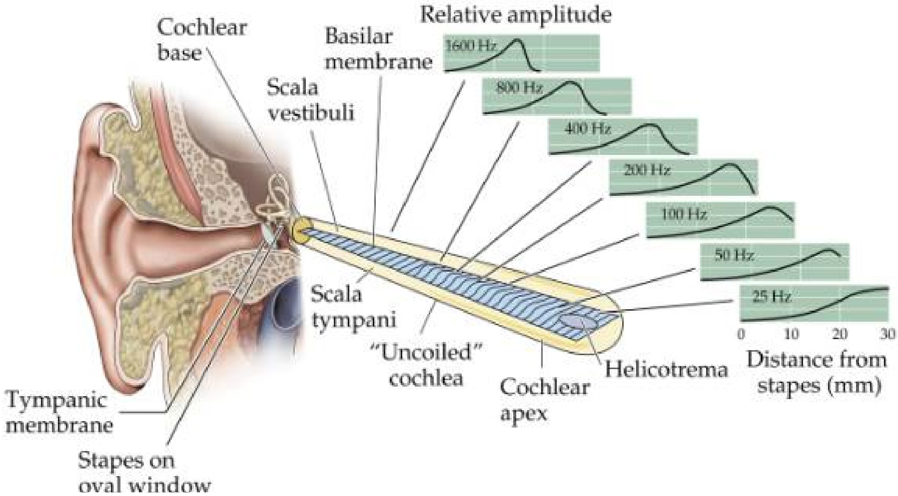
The impedance is the resistance to transmission of signals depending on the characteristics of medium; in this case, water (cochlear fluid) has a higher acoustic impedance compared to air.

Pressure is force divided by the area, so Force = Pressure x Area. The same force at the ear drum has to be transmitted to the oval window of the inner earto have the same forces on both sides.

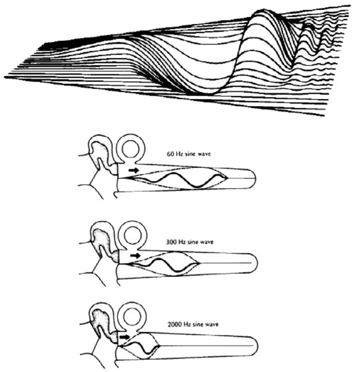
F2=F1 so P2xA2=P1xA2

The area of tympanic membrane is 0.85 cm^2 while the area of oval window is 0.03 cm^2; as area decreases, pressure increases and the amplification will be about 25 dB (0.85/0.03 ~ 28) with an increase of 5 dB thanks to the function of the ossicles so that the resulting total amplification by the middle ear will be 30 dB.

The inner ear is composed by the vestibular system that is responsible for the sense of motion and position, and the cochlea, responsible for the sense of hearing. The cochlea is a snail-shell divided into three fluid-filled parts whose two are canals for the transmission of pressure impulses and one is characterized by the sensitive organ of Corti which detects pressure impulses variations and responds with electrical impulses that travel along the auditory nerve to the brain.

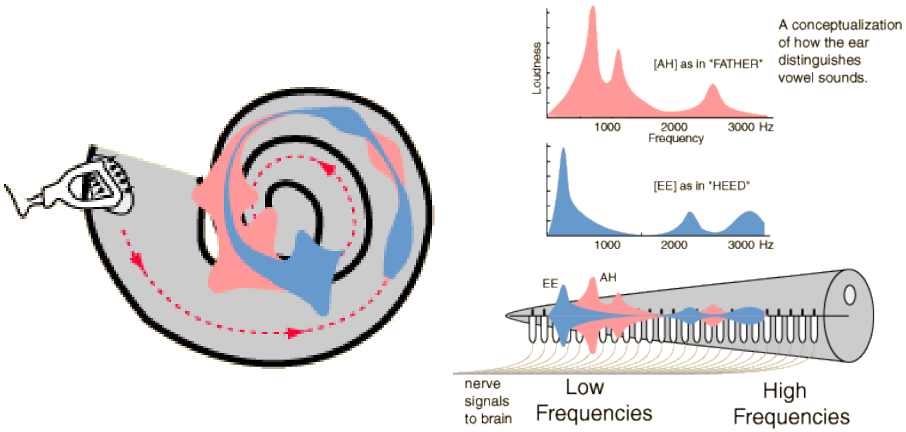


The movement of the cochlea, a snail-shell like structure.



Cochlear mechanics.

Cochlea has a particular mechanic to detect and analyzed frequencies of sounds collected and each part of the cochlea is responsible for a specific frequency.



The place theory explains how the er can recognize different sounds.

The ear can recognize different sounds, because it distinguishes pitches based on the location of maximum excitation along the basilar membrane of the inner ear. The ear acts as a sound analyzer which can detect differences in harmonic content by the different amounts of excitation at different places along the basilar membrane. Since sustained vowel sounds differ primarily in their harmonic content, this offers a mechanism by which the ear can distinguish them. Air cells at different locations along basilar membrane respond to different frequencies.

Ear dynamics

- Stapes moves against oval window causes cochlear fluid to vibrate

- Basilar membrane vibrates in response (thin, stiff base responds to higher frequencies, while ide, flaccid apex responds to lower frequencies)

- Movement of basilar membrane displaces Organ of Corti toward tectorial membrane

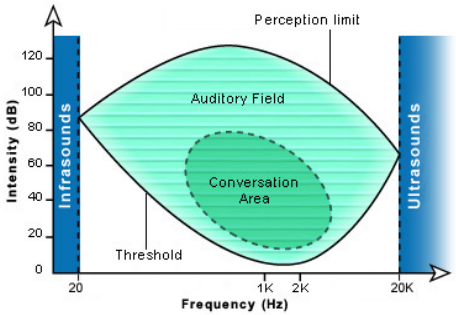
- Hair cells in Organ of Corti shear against tectorial membrane, and fire

- Impulses travel through auditory nerve.

Stable standing waves in external ear

Wavelength of sound incoming in the ear must be such that standing wave pattern matches the length of the pipe, with velocity node at closed end and antinode at open end. If the radiated sound energy has the same frequency as that of standing wave, there is resonance.

The outer ear does not work as a wave in free air, but it works as a quarter wave resonator; at the ends of pipe, whether open or closed, there are discontinuities that cause the sound to be reflected back into pipe, where the sum of incident (forward) and reflected (backward) waves creates a standing wave.



Audiometric curve for a normal hearing person.

The auditory canal in the external ear is about 25 mm long and it behaves as a quarter wavelength resonator at about 3000 Hz. Therefore the human ear has its maximum sensitivity around this frequency.

EFFECTS OF NOISE AND ROOM ACOUSTICS ON OCCUPATIONAL SAFETY OF VOICE AND MUSIC TEACHERS

The safety for workers is subject of Italian and international legislations due to the fact that noise exposure has damaging effects on health.

ITALIAN STANDARD

Decree n.81, 2008

Workers' protection against the risks of noise exposure during working time is defined in Italy by the Title VIII (Physical Agents) - Capo II of the legislation of April 9th, 2008, n.81 "Unique text about occupational health and safety". The predicted application field sets the minimum requirements to satisfy safety after a noise exposure and to reduce risks for safety and hearing (Article 187). Risk descriptors defined in the legislations are (1) peak acoustic pressure (*ppeak)*, the maximum value of the instantaneous acoustic pressure [dB(C)], (2) daily noise exposure level (*LEX,8h)*, the time-weighted average value of noise exposure levels for an 8-hours working day, (3) weekly noise exposure level (*LEX,w)*, the time-weighted average value of daily noise exposure levels for a week of 5 days per 8 hours of work.

The article 189 fixes the limit exposure value related to the daily noise exposure that don't have to be exceeded at L_{EX} = 85 dB(A) and it indicates it also as a weekly limit value:

$$L_{EX,W} = 10 \log \left(\frac{\sum_{i=1}^{n} 10^{0,1 L_{Aeq,Ti}} Ti}{T_0} \right)$$

With:

LEX,w = weekly noise exposure level [dB(A)], T0 = Reference time of *LEX,w* [2400 minutes or 40 hours],

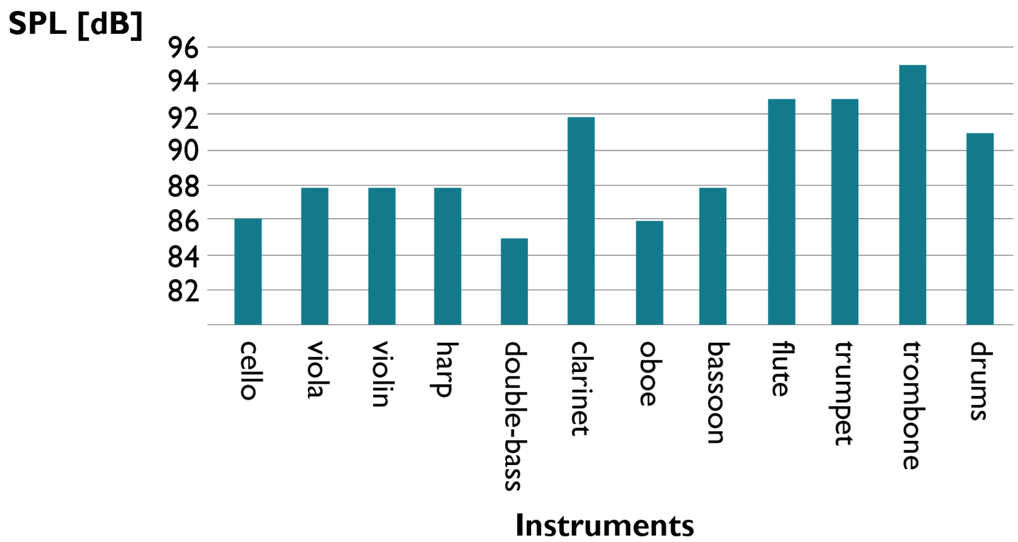
$L_{Aeq,Ti}$ = equivalent exposure level in i-th time [dB(A)],

T_i = exposure duration at the i-th L_{eq} [minutes or hours].

The employer assesses occupational noise exposure of the workers considering the level, the type and the period of exposure.

For activities that include a high fluctuation of noise exposure for workers, the employer can decide to operate guaranteeing prevention and protection measures such as individual hearing protections, formation and information and health inspection.

The annex n.2 is related to the Conference of the autonomous regions and provinces of Trento and Bolzano of 2012 which defines the *Guide Lines for the Sector of Music and Recreational Activities* applied to all the workers in the music or entertainment field for the high sound levels specifying that the more exposed people in the music field are musicians and their exposure includes also the preparatory study and rehearsals.



Typical weekly noise exposure level for orchestrals of different music instruments (Source: European Guide Lines)

Source type	Sound pressure level [db(A)]
Normal piano practice at 1m	60 ÷ 80
Singer at 1m distance	80 ÷ 100
Chamber music in a small dimensions room	75 ÷ 85

Sound levels of certain kind of music activities

Instrument	Sound power level [dB]
Singer, adult	96
Singer, boy	88
Singer, soprano	97
Singer, alto	93
Singer, tenor	95
Singer, bass	96

Sound power levels according to J. Meyer, Acoustics and performance of music (2009) and J. Burghauser, A. Spelda, Akustische Grundlagen des Orchestrierens (1971).

The census of 2010 managed by ENPALS (Ente Nazionale di Previdenza ed Assistenza per i Lavoratori dello Spettacolo) outlines the professional workers in the music field. The singers group counts 7620 people in music and 549 in theatre for a total of 8169 professional singers in Italy.

Noise exposure levels can not exceed 85 dB(A) and Lpeak of 137 dB(C).

The reduce the noise exposure there is the possibility to operate with protection, organization and information; it is possible to limit the exposure time to high sound levels by alternating the workers from noisy to more silenced areas, identifying with signals the places where the limit value is exceeding and informing workers about the risks linked to noise and the techniques of prevention to avoid or reduce these risks and providing individual hearing protectors. Where it is difficult to avoid or reduce the source sound level, it is possible to operate by augmenting the distance between the sound source and the listener, augmenting the absorbing surfaces in the space (floors, walls and ceilings), adopting music spaces of adequate dimensions and with appropriate acoustic characteristics associated, in particular, to reverberation time.

The individual hearing protectors include special and uniform ear inserts for all the frequencies to hear music with the features of natural sound. They can be silicone inserts for attenuation levels of 9, 15, 20 or 25 dB(A) and they surely need some time to be able to get used to them because of the different perception of sound.

The Agency for the Environment conducted in 1997 a cognitive survey and underlined lack and difficulties in the conduction of control activities and few technical power; for this reason a Guide Line is needed to be elaborated to clarify and simplify the application fields linked to the reality.

The limit of noise exposure for workers has been fixed to 85 dB as maximum level over an 8-hour working day above which there is the need of hearing protectors.

The legislation n.81 affirms that it does not exist a cultural concordance in recognizing the noise as an health risk so as a possible cause of damage. There is also the need to develop a knowledge about the effects of the noise related in particular to the alteration of behavioral and cognitive functions.

INTERNATIONAL STANDARD

DHHS (NIOSH) Publication Number 98-126

The National Institute for Occupational Safety and Health is part of the Department of Health and Humanc Services and, in 1998, it revised the act dated 1970 about working conditions. In this document NIOSH determines exposure limits and concentrations for various employments and their periods. The scientific and technical information in this Act are distributed to health professionals institutions and industries, government agencies and organized labor that have to respect the standards.

In 1972 NIOSH published the document *Criteria for a Recommended Standard: Occupational Exposure to Noise* which contained the basis for a reduction of the risks of developing permanent hearing loss caused by occupational noise exposure. The document of 1998 takes into account the latest scientific information and it revises some of its previous reccomendations and it has the purpose to prevent occupational noise-induced hearing loss instead of being focues on the conservation of hearing.

The limit recommended by NIOSH for occupational noise exposure is 85 dB(A) for and 8-hour time-weighted average with 3 dB of exchange rate; the limit value is currently enforced also by the Occupational Safety and Health Administration (OSHA) and the Mine Safety and Health Administration (MSHA) that, instead, still use a 5 dB exhange rate and, in general, exposures at or above these levels are considered hazardous. The exchange rate means that when the noise level is increased of 3 dB (or 5 dB) the duration of exposure of a person is cut in a half.

The 1972 criterion recommended age correction on individual audiograms while the new NIOSH criteria states that this practice is not scientifically valid and would delay intervention to prevent further hearing losses in workers whose hearing threshold levels (HTLs) have increased consequently of occupational noise exposure (Criteria for a Recommended Standard, 1998).

NIOSH provides a hearing loss prevention program (HLPP) for workers exposed to 85 dB(A) or more which includes assessments, controls, use of protectors, education and motivation. The HLPP is determined consequently to an audiometric evaluation in which significant threshold shifts have an increase of 15dB in the HTL at 500, 1000, 2000, 3000, 4000 or 6000 Hz.

The duration of exposure with the 85 dB(A) REL (Recommended Exposure Limit) is calculated by the formula

$$T=8/2^{(L-85)/3} \text{ [min]}$$

The table shows the combinations of noise exposure levels and durations that no worker exposure shall equal or exceed.

	5–10 years of exposure								> 10 years of exposure							
	Age 30		Age 40		Age 50		Age 60		Age 30		Age 40		Age 50		Age 60	
Average daily exposure (dbA)	Risk (%)	95% CI[†]	Risk (%)	95% CI	Risk (%)	95% CI	Risk (%)	95% CI	Risk (%)	95% CI	Risk (%)	95% CI	Risk (%)	95% CI	Risk (%)	95% CI
90	5.4	2.1–9.5	9.7	3.7–16.5	14.3	5.5–24.4	15.9	6.2–26.2	10.3	5.8–16.2	17.5	10.7–25.3	24.1	14.6–33.5	24.7	14.9–34.3
85	1.4	0.3–3.2	2.6	0.6–6.0	4.0	0.9–9.3	4.9	1.0–11.5	2.3	0.7–5.3	4.3	1.3–9.4	6.7	2.0–13.9	7.9	2.3–16.6
80	0.2	0–1.1	0.4	0–2.2	0.6	0.01–3.6	0.8	0.01–4.7	0.3	0–1.8	0.6	0.01–3.3	1.0	0.01–5.2	1.3	0.01–6.8

*1997-NIOSH model for the l-2-3-4-kHz definition of hearing impairment.
†CI=confidence interval.

Excess risk estimates for material hearing impairment, by age and duration of exposure.

ISO 1999:2013

The International Organization for Standardization is a worldwide federation of national standard bodies.The document about noise exposures and its risks about hearing losses is entitled *Acoustics - Estimation of noise-induced hearing loss* and it specifies the expected noise-induced permanent threshold shift in the hearing threshold levels derived from noise exposure of certain levels and durations.The Standard recommend limit values for a 8-hour working day ($L_{EX,8h}$) of noise exposure and it is related to noises at less than 10 KHz of frequency.

$$L_{EX,h} = L_{pAeq},T_e + 10 \lg (T_e/T_0) \text{ [dB]}.$$

Where:

$L_{pAeq,Te}$ is the A-weighted equivalent continuous sound pressure level for Te,

T_e is the effective duration of the working day in hours,

T_0 is the reference duration (T_0 = 8 h).

This International Standard can be referred both to regular occupational noise exposure and daily repeated noise exposure which can include not only noises to which people are exposed during working hours, but also noises at home or during recreational activities; the sum of these factors has to be evaluated in the prediction of the occurrence of hearing loss that can have legal consequences in some countries.

The International Standard constitutes a guide line for all the countries of the world even if ethical, political, economic and social factors are taken into account and can lead to a minimum difference of the interpretation of the factors present in the Standard.

The Standard needs to lean on other normative references such as *ISO 7029 (Acoustics - Statistical distribution of hearing threshold as a function of age), ISO 9612 (Acoustics - Determination of occupational noise exposure) and ISO/TR 25417 (Acoustics - Definitions of basic quantities and terms)*.

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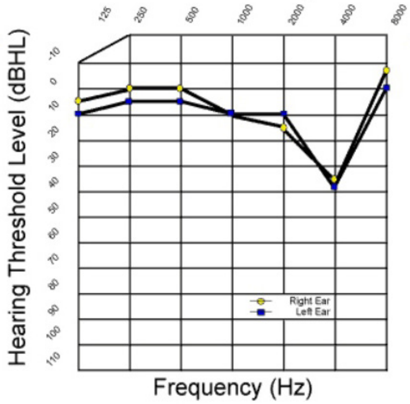
EFFECTS ON HEARING OF VOICE AND MUSIC TEACHERS

Music and voice teachers greatly rely on their ability to hear in order to perform their jobs efficiently. To teach music or voice, teachers need to be able to hear themselves as well as however many students they may have in their classroom. Because of this, these teachers are constantly being exposed to loud noise sources including themselves and their students. While closed standard classrooms have been found to measure in at an average of 65 dBA (Thibeault et al, 2004), many research studies have found the noise levels of exposure in music and voice classrooms to reach higher intensity levels. These measurements only slightly vary, with reports of 86 dB to 98 dB (Issac et al, 2017) as well as 87 dB to 95 dB (Phillips & Mace, 2008), and have been measured to be above NIOSH recommended standards for noise exposure, with mean measurements of 96.4 dB(A) and 106.9 dB(A) when measuring instrumentalists and choir singers together (Mendes et al, 2007). Some of the current literature looks into hazardous noise levels and compares to the recommendations for NIOSH of 85 dBA average for 8 hours with an exchange rate of 3 dB. For music teachers, this noise exposure often lasts throughout most of the work day. Though conductors and music teachers tend to stand in the front of the class, it is not uncommon for them to position themselves amongst the students to assess their performance better and work with them to better their sound (Zivkovic & Pityn, 2004). This puts them directly in the middle of the sound source, presenting a more direct exposure.

The noise notch

Despite a lot of studies showed that music and voice teachers are exposed to high intensities throughout the day, much of the available literature focuses mostly on the effects on hearing thresholds in music students, primarily instrumentalists (Hu & Sataloff, 2015; Isaac et al, 2017). The available literature discussing hearing thresholds for choir/voice students found that the amount of students, though exposed to noise levels above recommended by NIOSH, have varied outcomes in regards to evidence of NIHL. These studies looked for evidence of NIHL via a noise notch present at the expected frequencies of 3000 Hz – 6000 Hz (Phillips et al, 2010; Pawlaczyk-tuszczynska et al, 2017). In the study by Phillips et al (2010), it was found that the overall prevalence of NIHL was 45%, 78% of noise notches present at 6000 Hz. Bilateral noise notches were significant for students in the choir, reflecting a rate of occurrence at 18%, which was significantly higher than found in non-musical students (Phillips et al, 2010). Pawlaczyk-tuszczynska et al in 2017 found similar results. Noise notches were found 13.4% of the time in musicians and 9% of the time in non-musicians, and while hearing thresholds were poorer than the non-noise exposed control group and present noise notches were mostly noted at 6000 Hz, there was no significant difference in hearing thresholds between the two groups in the high frequencies as expected. They also noted that noise notching increased with higher measurements of noise levels (Pawlaczyk-tuszczynska et al, 2017). Both authors stated the results of NIHL present among music students is not uniform.



Hearing threshold of a person with Noise-induced Hearing loss

The findings for music teachers is variable and lacking. Cutietta et al (1994) found evidence of NIHL in both band and vocal teachers, with more severe and significant noise notches present in band teachers. Vocal teachers did show signs of notching mainly at 4000 Hz, though these teachers were over the age of forty and the authors suggest this may be due noise exposure potentially accelerating age-related hearing loss (Cutietta et al, 1994). Melo et al (2016) found that 15% of music teachers presented with a mild sensorineural hearing loss but could not be solely ascribe this to occupational noise exposure due to many of the subjects involvement in music-related extracurricular activities. Isaac et al (2017) found that 51.7% of 58 voice teachers screened positively for hearing loss with 43% screened positively for high frequency hearing loss. Age, much like in Cutietta et al (1994), and years teaching showed a weak association with the prevalence of high frequency hearing loss (Isaac et al, 2017). Overall, Isaac et al (2017) showed prevalence of hearing loss among voice teachers was significantly higher than hearing loss in voice students. This could be attributed to the many hours, days, and years spent in excessive noise exposure levels, but due to the varying results of the current literature, it is not assuredly the cause. Since NIHL is known to become worse over time and accumulation of noise exposure, it would be logical to deduce that the explanations by Cutietta et al (1994) and Isaacs et al (2017) are correct in that age and years in the profession would correlate with a larger percentage of music and voice teachers presenting with NIHL or high frequency sensorineural hearing loss. Many of the authors agreed that due to these instances of recording such high overall exposure levels, hearing conservation programs would be beneficial to instill in school/university music programs.

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Vocal effort

Vocal effort is a physiological measure that accounts for changes in voice production as vocal loading increases (Bottalico and Astolfi, 2012); it can be expressed by the A-weighted sound pressure level SPL (dB) at a 1m distance from the mouth-axis in anechoic conditions (ISO 9921, 2002). Its increase is related to the distance from the listener, the type of interlocutor (Hazan and Baker, 2011), the speaker's level of fatigue (Rantala et al., 2002; Laukkanen & Kankare, 2006), the background noise level and physical environment (Black, 1950; Pelegrin-Garcia et al., 2011).

Vocal fatigue denotes a negative vocal adaptation which occurs as a consequence of prolonged voice use; negative vocal adaptation is considered as a perceptual, acoustic, or physiologic concept, indicating undesirable or unexpected changes in the functional status of the laryngeal mechanism (Welham and Maclagan, 2003).

Speakers who use their voice for long periods and/or with increased vocal effort, such as teachers, are the group experiencing the most of vocal fatigue. In 1999 Titze identified two physiological aspects of characterizing this fatigue: laryngeal muscle fatigue and laryngeal tissue fatigue. Laryngeal muscle fatigue can involve tension in the vocal folds and it is caused by a depletion or accumulation of biochemical substances in the muscle fibers; while laryngeal tissue fatigue concerns non-muscular tissue layers (epithelium, superficial, and intermediate layers of the lamina propria) and it is probably caused by temporary changes in molecular structure (Titze, 2000).

It is important to minimize the vocal fatigue in particularly when the speaker is at high risk of vocal injury, for exemple in teaching environments (Hunter and Titze, 2015) that can manifest poor acoustic conditions (Bottalico and Astolfi, 2012). Titze defines the vocal load as a prolonged voice use measured as the number of vocal fold oscillations ("cycle dose" or "Vocal Load Index") or the phonation time ("time dose") plus additional "loading factors", such as distance from listener, background noise, and other environmental acoustic parameters (Titze et al, 2003).

Vocal comfort

Vocal comfort is a psychological magnitude determined by those aspects that reduce the vocal effort. Vocal comfort reflects the self-perception of the vocal effort by feedback mechanism listed above. A sustained vocal effort can involve in voice disorders (Titze & Martin, 1998).

School teachers and music teachers

In a study comparing teachers to music teachers, Morrow (2009) found that music teachers are approximately four times more likely than standard classroom teachers to perceive vocal discomfort as well as experience objective changes in vocal qualities. When comparing standard classroom teachers and music/vocal teachers, Thibeault et al (2004) found that music and primarily vocal teachers were at a significantly higher risk of developing a voice disorder than other types of teachers; this was found to be because of extreme voice use patterns that are involved with loud talking and singing. These patterns could ultimately lead to vocal fold tissue injury (Schiller et al, 2017).

When objectively measuring voice quality, there are voice characteristics that are measured to determine if a subject has the potential to develop a voice disorder. These characteristics include vocal load, vocal intensity, cycle dose, distance dose, phonation time, and fundamental frequency (Thibeault et al, 2004; Morrow & Connor, 2009; Ahlander et al, 2011). Vocal load has been defined in the current literature similarly as the demand placed on the phonatory system, cycle dose as the total number of cycles /vibrations completed by the vocal folds, and distance dose as the distance covered by the vocal folds measured in meters (Thibeault et al, 2004; Schiller et al, 2017). Phonation time, fundamental frequency, and vocal intensity are important to calculate the vocal load and the cycle dose and are most often measured with the use of an accelerometer (Gama et al, 2016; Morrow & Connor, 2009). Vocal load has been identified as one of the primary causes of vocal disorder and dysfunction (Ahlander et al, 2011).

Results from the Morrow & Connor (2009) study comparing music teachers with standard classroom teachers revealed that typical vocal loads measured in music teachers are much higher than those measured in standard classroom teacher as well as a 62% greater cycle dose and 90% greater distance dose in favor of music teachers. Elevated vocal loads in music/vocal teachers has been linked with extreme voice-use patterns required based on the amount of classes taught, the content of the lesson, and the teaching environment (Morrow & Connor, 2011). Without proper time for recovery (due to the amount and duration of classes per day) and speaking over excessive background noise levels, this can result in elevated vocal intensity as well as prolonged time using an elevated fundamental frequency (as occurs when speaking over noise) (Morrow & Connor, 2011; Schiller et al, 2017). Average vocal intensity for music teachers is approximately 83 dB SPL with a phonation time of 107.86 minutes (Morrow & Connor 2011). These situations promote the development of laryngeal lesions in music and vocal teachers due to more frequent and potentially damaging collisions of the vocal folds (Schiller et al, 2017).

Vocal control can be defined as the capacity to self-regulate vocal behavior. The sensation of control relates to the ability to adjust the voice consciously. In adverse conditions, speakers try to control their voice production in order to meet the needs of listeners (Wassink et al, 2007; Hazan and Baker, 2011).

Vocal effort, vocal comfort and room acoustics

Vocal effort and vocal comfort are strictly related to the acoustical quality of the space; in a research conducted by Brunskog et al objectively measurable parameters of the rooms related to an increase of the voice sound power produced by speakers and to the speakers' subjective judgments about six different rooms with different size, reverberation time and other physical attributes have been investigated. The results showed how the increase in the voice power produced by a speaker lecturing in a room is influenced by the size of the room and the amplification of the room on the talker's perceived own voice (defined as "room gain"): teachers tend to raise the volume of their voice in rooms with a low room gain and to talk softer in rooms with a high room gain.

With a sensitivity method Pegrin-Garcia et al found that the room acoustic characteristics modify the auditory perception of the talker's own voice, leading to significant changes in voice level. Their results show that the mean fundamental frequency and its variability increase in anechoic conditions, and the Phonation Time Ratio, defined as the ratio of the phonation time to the total duration of sound emission, is higher when the talker is in a space characterized by bad acoustic conditions.

Bottalico, Cutiva and Hunter conducted a research about the vocal effort in different room acoustic conditions. The measured sound pressure levels could be representative of the different effects of room on short-term vocal fatigue; they suggested that lower vocal demands and lower magnitudes of vocal fatigue were experienced by talkers in the room in which the reverberation time was more likely to be found in a typical space (the semi-reverberant room). It could have been predicted on the basis of these results that vocal effort in the reverberant room would have surpassed that in the semi-reverberant room if the subjects had been asked to speak for a longer period. For as it concerns fundamental frequency, it was lower in the condition with a medium value of T30 than in the condition with lower T30. F0 was 0.29 Hz higher from the low (0,4s) to the high (1,3s) T30. Finally, it could be stated that higher reverberation times lead to a louder voice level and the minimum level of vocal load, associated to the fundamental frequency, was found in the condition with a T30 of 0.8s.

It has been demonstrated that voice problems can be caused by room conditions: Kob et al analyzed teachers in a secondary modern school using an interdisciplinary collection of methods. They found that conditions for this group of professional voice users could be improved implementing an optimization of the classroom acoustics acting through changes based on key parameters in order to obtain an optimized space. Other results of other researches indicate that teachers with voice problems are affected by room acoustical conditions more than healthy teachers which tend to tolerate better voice load during teaching.

A lot of studies have been led to analyze the correlation between voice acoustical parameters, voice fatigue and subjective voice complaints. Boucher (2008) analyzed the relation between acoustic parameters and estimates of muscle fatigue, observed with a technique of electromyography. He found that a brief rise in voice tremor can correspond to a critical change in laryngeal muscle tissues seen as a condition where continued vocal effort can increase the risk of lesions or other conditions affecting voice.

Vocal effort has been quantified in terms of sound pressure level (SPL); in a research conducted with the Michigan State University Bottalico et al (2016) found that SPL and self-reported effort increased in the loud style speech and decreased when the reflective panels were present in the room and when reverberation time increased. Self-reported comfort and control decreased in the loud style, while self-reported clarity increased when panels were present. The results indicate that early reflections may be used to reduce vocal effort without modifying reverberation time.

Lombard Effect

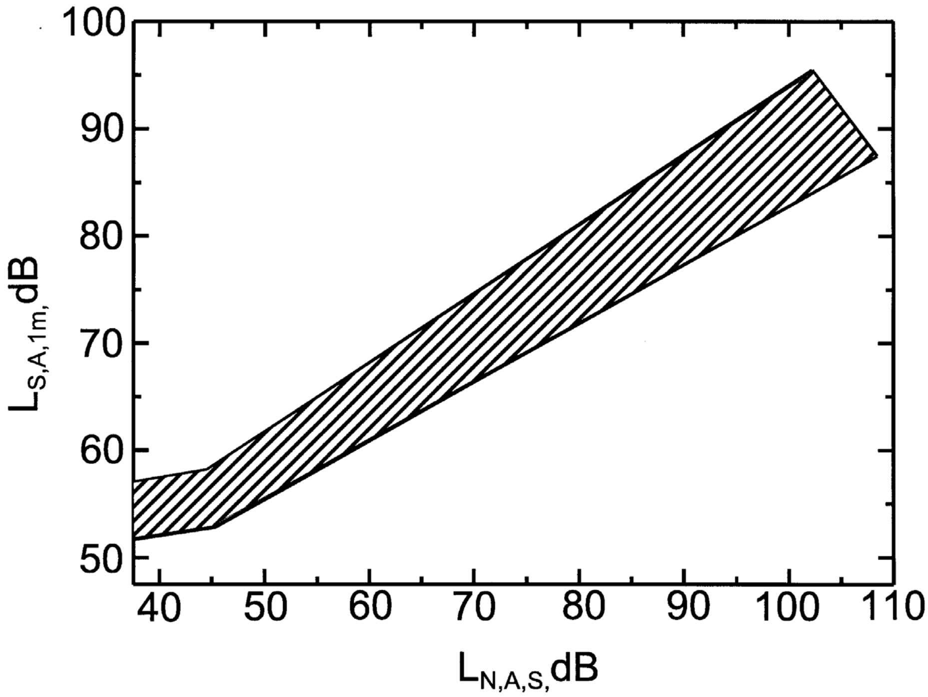
Ambient noise above a certain level influences the vocal effort and lead speakers to increase their vocal effort when their communication is disturbed by noise: this is known as the Lombard effect (ISO 9921:2002); in the presence of noise, speech can be masked and its production can be modified by what is called the Lombard effect. The Lombard effect is the so-called reflex that is evident when a speaker modifies his or her vocal effort when communication is disturbed by noise, with the vocal effort increasing as the magnitude of disturbance increases.

The Lombard effect is more present in speech communication than in singing because the common aim of people is to transmit information. Bottalico et al in 2017 conducted a research in which the hypothesized that there would be a starting point of the Lombard Effect and it would have been between 40 and 50 dB(A), based on the work of Lazarus amongst other. They finally stated that subjects started to become disturbed by noise at a lower noise level than that associated with the change-point of the Lombard effect, while the Lombard effect begins to be shown when the background noise level is 43.3 dB(A) which constitutes a sort of change-point anticipated by a noise disturbance and followed by a high level of vocal discomfort; the slope of the Lombard effect could be estimated as an increase in the voice level of 0.65 dB(A) per 1 dB(A) increase for noise levels higher than 43.3 dB(A). In another research Bottalico et al (2012) showed that during traditional classes at a primary school there was an increase of 0.72 dB in speech level per 1 dB increase in background noise level due to Lombard effect. The same result in primary school classrooms has been found by Sato and Bradley in 2008.

Lombard effect is caused by a high level of background noise, but, unfortunately, there is a lack of studies that link the influence of room acoustic parameters on speakers' voice production. One of these studies has been conducted by Brunskog et al and it was about the relation between room acoustics and the increase of the voice sound power level. They found that the power level produced by a speaker is related to the volume of the room in which he is talking and its room gain that are the reflections in that space. The result has been that a person tends to use a higher voice level in the rooms with a low room gain and a lower one with high room gain being aware of the variability of his vocal effort. Also Kob et al analyzed the effects or room acoustics on voice production in four rooms of a secondary school, but results have not been significant.

In the music field in general, reseraches have been conducted mostly on choirs; choral and solo singing are two different modes of musical performance which require different demands on the singers. In 1994, Steven Tonkinson ruled a research about the Lombard effect in choral singing. 27 singers sang *The Star Spangled Banner* twice, before and after being given instructions which consisted in resisting the increasing of vocal intensity in the moments where the choir heard from headphones increased volume. The result has been that choral singers exhibit the Lombard effect and they can consciously resist it and regulate their vocal intensity.

The Standard ISO 9921 of 2002 indicates the relation between speech and ambient noise level. The marked area indicates the variability of the Lombard effect among speakers (ISO 9921:2002).



Relation between the speech level at the speaker position ($L_{S,A,1m}$) and the ambient noise level at the speaker's position ($L_{N,A,S}$) (Bottalico, 2016).

The speech level at the listener position can be calculated as

$$L_{S,A,L} = L_{S,A,1\,m} - 20 \lg (r/ro) \text{ [dB(A)]}.$$

Where:

r is distance in meters between speaker and listener,

r_o = 1 m.

The decrease in speech level both for indoor and outdoor conditions is 6 dB for each doubling of the distance.

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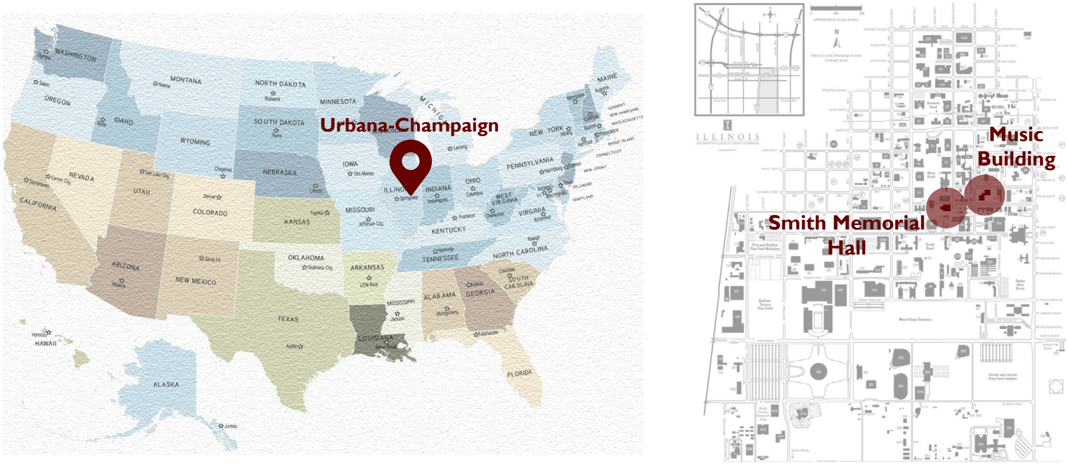
CASE STUDIES

THE MUSIC DEPARTMENTS OF THE UNIVERSITY

SPATIAL AND HISTORIC FRAMEWORK

The research has been conducted in two of the buildings that are home to the Music Department of the University of Illinois at Urbana-Champaign.

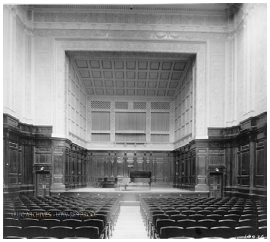


Geographic location of the town of Urbana-Champaign (/VectorStock.com/)and the music departments locations in the campus area (/illinois.edu/)

The composition of the university campus is a mix of various architects that worked on the different buildings since 1862.

Illini Union, Foellinger Auditorium, Grainger Engineering Library Information Center (/illinois.edu/)

Smith Memorial Hall, S Mathews Ave, Urbana; The Music Building, W Nevada St, Urbana


Smith Memorial Hall (/explorecu.org/)

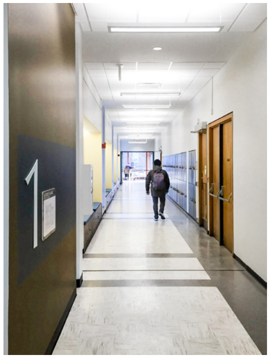
The Smith Memorial Hall is located in Urbana and it is the historical and main building that welcomes the music faculty of the University of Illinois, being listed in the National Register of Historic Places. It has been completed in 1920 by the architects James M.White and George E.Wright and it takes his name from Tina Smith, wife of Captain Thomas J. Smith of Champaign who decided to donate money to build the structure in memory of his wife.

The building is characterized by a beaux-arts architectural style and it is decorated with musical instruments and inscriptions of composer such as Bach and Beethoven.

The music building has been built with the intention to host different kind of music and performances and it has been hosting since 1920 classrooms, a concert hall and a library; it is composed by various practice rooms and studios with different dimensions and a performance hall with a total of 1100 seats and a recital hall famous for its decorations of mahogany woodwork.

The whole building has been built predominantly with stone, brick, metal and limestone.





Music Building (/music.illinois.edu/)

The Music Building is considered to be the centre of the Music department thanks to its geographic position and its dimensions spread on five levels; it is more recent compared to the Smith Memorial Hall and it hosts an auditorium, a music library, classrooms and music practice rooms.

MATERIALS AND METHOD

OBJECTIVES

The first objective of this research study was to analyze and describe teachers' voice and hearing behavior comparing their hearing thresholds and vocal characteristics before and after classes (pre and post-monitoring) associated with the voice use and noise exposure during teaching hours (voice and noise dosimetry) and the acoustics features of the space. The two areas analyzed have been (1) hearing, (2) voice and (3) space. For both hearing and voice analysis, there was a focus on two main divisions: (1) pre and post-monitoring before and after voice classes and (2) occupational monitoring and dosimetry during teachers' activity.

The second objective was to evaluate the noise exposure and the voice behavior of voice professors to explore if a hearing conservation program and/or a voice training would be necessary for the University of Illinois Urbana-Champaign Music Department as well as educate participants on the importance of hearing and voice health.

INTRODUCTION

Once the actors of the project have been defined, a questionnaire was set to be able to have a subjective point of view and describe a full overview about social characteristics, working conditions, voice symptoms and hearing problems.

To analyze the voice and hearing functioning assessment, teachers have been under hearing screening and they were asked to produce some voice samples, recorded in a sound booth, before and after each occupational monitoring.

Voice monitoring has been carried out with the Voice Care, a tool designed to allow singing teachers to walk and move freely during their occupational monitoring.

Time dose in percentage (Dt%), fundamental frequency (F_0) and vocal sound pressure level (SPL) have been the three parameters to define the occupational voice use during singing classes while the noise dosimetry provided the equivalent and instantaneous sound pressure levels and percentile levels present in the classrooms during the teaching activity. These levels are mainly generated by the piano and the voice of students singing during the lectures.

However, noise can increase if the room is not well-isolated or it borders other rooms where other classes are taught. This allows the sound generated in the other classrooms to be transmitted in the classroom where the teacher is teaching.

Finally, all collected data have been elaborated by a software that provided the information needed.

The statistical analysis consisted in three different steps:

Evaluations of the variations in the voice and hearing functioning before-after monitoring;

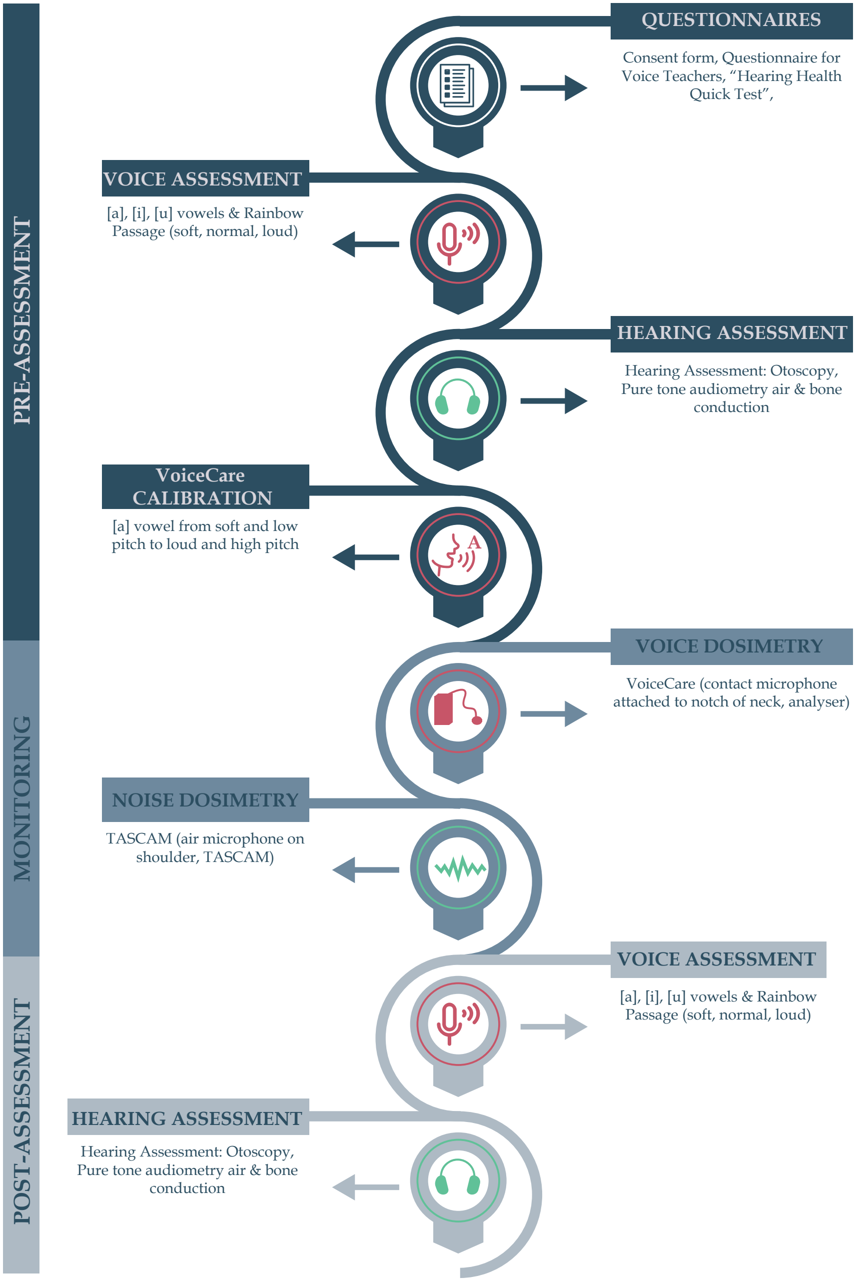
The working hypothesis is that the vocal load accumulated during the lectures will decrease the voice quality and the noise exposure could shift temporarily the hearing threshold.

Associations between those variations and the doses of voice use and noise exposure will be addressed;

The working hypothesis is that the higher vocal load will lead to lower voice quality, and that higher noise levels exposure will increase the likelihood of a temporarily shifting of the hearing threshold.

As it concerns the effects of classroom acoustics on vocal doses, the working hypothesis is that the higher reverberation times and lower sound insulation will increase the noise levels in the classroom and the vocal effort for the participants: quality can be guaranteed only if conditions are respecting certain features and if actors present a good vocal health that should be monitored and safeguarded.

DESIGN AND PARTICIPANTS



The “follow-up study” has been performed during some days of the months of March and April. Follow-up studies are designed with the aim of observing, over a period of time, a subject, a group of subjects or a population that is considered “at risk”. Their prolonged exposure to a risk and negative factors are meant to cause “outcomes” on health status or health-related variables.

The population of interest in our study was composed by 8 voice teachers at the School of Music of University of Illinois Urbana-Champaign; they have been followed during some hours of classes and assessed before and after their occupation to analyze and define changes on voice and hearing functioning related with occupational voice use and occupational noise exposure. Subjects were supposed to have some vocal and hearing tests before and after their classes while their voice and noise exposure were monitored during their voice classes whose duration depended on the availability of teachers; in general, they lasted between two and five hours. This monitoring allowed to explore changes on voice and hearing functioning that could affect teachers during their job and influence it in a negative way.

The group of subjects was composed by 5 female and 3 male voice teachers of ages from 25 to 79 that are teaching mainly opera and musical and lyric theatre voice. All the subjects had their classes in different rooms with different acoustics design.

The project consisted of three main steps:

(1) Questionnaire, Voice functioning assessment and Hearing screening at the Speech and Hearing Science clinic (before and after the in-field monitoring);

(2) Voice and noise dosimetry in classroom during the working time;

(3) Acoustic characterization of the classrooms.

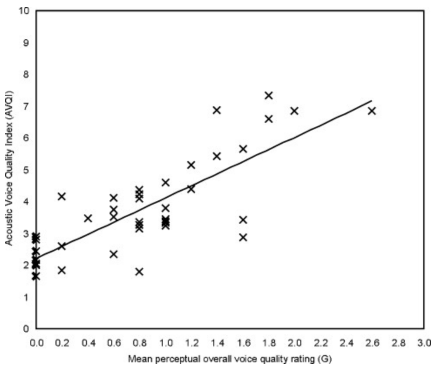
Pre and post monitoring: voice parameters

The parameters that characterize the voice assessment of pre and post-monitoring have the aim to define the quality of the voice.

(1) The **AVQI** (Acoustic Voice Quality Index) is a multivariate constructed with other parameters such as CPPS, HNR, TILT, SLOPE and Shimmer (SHDB) which are all parameters that, interconnected, are using voice analysis (mainly analyzing vowels sounds) to evaluate the voice quality.

The AVQI consists of a weighted combination of time and frequency metric and it has been developed to measure dysphonia severity (Maryn, 2013).

This parameter is taking a sample of speech and vowel; that's why to analyze it has been used only the /a/ vowel, one of the most harmonic vowels, and the *Rainbow Passage* sample.



Girbas Scale and AVQI correlation

AVQI has been created to represent the "G" of the GIRBAS Scale which is the perceptual assessment of voice quality performed by a speech pathologist; to determine the level of vocal disorder speech pathologists use the GIRBAS Scale which is composed by some parameters (Roughness, Breathness, Asteny, Strain). Listening someone's voice allows clinicians to rate the level of the overall disorders whom range varies between 0 and 3 (0 is a healthy voice without problems, 3 is high level of voice disorders).

AVQI is creating a correlation with G which is the value representing the global presence of components of dysphonia in the voice. The highest the AVQI value is, the highest the G value is which means that the voice is moving to a severe dysphonic pathology. "0" is considered normal voice without problems, so lower values of AVQI parameter mean lower values of G; lower values of G means better voice/non-dysphonic.

(2) The **CPPS** (Cepstral Peak Prominence Smoothed) is defined as a possible indicator of vocal health

status (Castellana, 2017).

CPPS is the smoothed version of the CPP (Cepstral Peak Prominence). CPP is a measure [dB] of the amplitude of the cepstral peak, normalized for overall signal amplitude by means of linear regression line calculated relating quefrency to cepstral magnitude (Hillenbrand, 1994).

In 2009 Maryn et al highlighted the relevance of CPPS stating that CPPS satisfied the meta-analytic criteria in sustained vowels as well as in continuous speech.

(3) The **HNR** (Harmonic to Noise Ratio) is an assessment of the ratio between harmonics and noise components comprising a segment of voiced speech (Murphy and Akande, 2005). This parameter measures the efficiency of speech for example, the greater the flow of air expelled from the lungs into energy of vibration of vocal folds. A high HNR value is generally associated with sonorant and harmonic voice while a low one denotes an asthenic voice and dysphonia.

(4) **SHDB** (Shimmer) is a parameter expressed in decibels [dB] and it is a time-based parameter. Shimmer is useful in describing the vocal characteristics as it relates to the amplitude variation of the sound wave measuring F_0 instability; this parameter is checking the micro-variations of the fundamental frequency in close cycles and it calculates the difference in dB. Shimmer represents how the pitch is stable.

The shimmer changes with the reduction of glottal resistance and mass lesions on the vocal cords and is correlated with the presence of noise emission and breathiness. It is considered pathological voice for values less than 3% for adults and around 0.4 and 1% for children (Teixeira, 2013).

A smaller value of SH means a more stable voice and, consequently, a higher voice quality.

(5) **SLOPE** describes the perception of overall voice quality. The spectral slope is a measure of how the amplitudes of successive components decrease with increasing harmonic number. It relates to the timbre of the sound.

The higher the slope is, the more energy is present in higher frequencies because of stronger fundamentals in that range.

(6) **PS** (Pitch Strength) is like a coefficient of relation between the signal emitted by the vocal folds and the one registered out of the mouth.
It is a perceptual attribute based on the idea that two sounds with the same pitch may vary from each other based on saliency of their pitch sensation. The study of voice pitch strength may be important in quantifying of normal and pathological qualities (Shrivastav, 2012).
Voiced speech stimuli are typically described as having three perceptual attributes—pitch, loudness, and quality. Perceived pitch is related to complex interactions among the harmonic structure, the magnitude, the phase spectra and the characteristics of the auditory system (Moore et al, 1997); "two sounds that are perceived to have the same pitch may differ in terms of the prominence or saliency of the pitch sensation that they evoke. For example, when the same note is produced by two musical instruments, such as stringed (e.g., guitar) and wind instruments (e.g., flute), the note produced from a stringed instrument typically results in the perception of a more prominent pitch than that of a wind instrument. Likewise, a 500 Hz pure tone and a bandpass filtered noise centered on 500 Hz are perceived to have the same pitch, but the band-pass filtered noise evokes a weaker pitch sensation. This perceptual attribute is called the pitch strength of the sound and is independent from pitch itself." (Shrivastav et al, 2012).
The higher the PS value is, the higher the voice quality is.

(7) **SPL mean** is an average of sound pressure levels of voice. Titze wrote that when your vocal folds are fatigued the thickness of the tissue is increasing because there's more blood etc. this lead to the fact that , to start the phonation, you need a higher minimum pressure threshold. This could be a sign of tiredness but we can't tell for sure.

(8) **SPL sd** is the range of sound pressure level used.

When the tissue of the vocal folds id fatigued, the minimum necessary pressure to start the phonation rises as an amount of air cumulates below the vocal folds until they begin their vibration; to ensure the opening of vocal folds and to start the vibration a certain amount of pressure is needed. If there is fatigue, the tissue gets bigger and it opposes more resistance to the movement so that there is the need of more pressure. By consequence, the minimum pressure threshold will be higher and the range of sound pressure level during phonation will shrink as the maximum threshold value doesn not vary.

(9) **F_0 mean** (also called first harminic frequency) constitutes the average value of the lowest frequency in a periodic waveform.

(10) **F_0 sd**

Pre-monitoring and post-monitoring: assessment

The pre-monitoring assessment was performed with the aim of characterizing the voice quality and hearing functioning before and after the occupational exposure associated with voice teaching.

This pre-monitoring assessment included three elements:

(1) Documents and surveys to fill.

(2) Voice functioning assessment (including VoiceCare calibration, production of /a/, /i/, /u/ vowels and reading of *The Rainbow Passage*).

(3) Hearing assessment (including hearing screening and otoscopy if necessary) .

_Documents and surveys

Participants were supposed to show up at the clinic in the building of Speech and Hearing Science about one hour before the beginning of their classes.

Firstly, they were asked to sign a consent form that explained the terms of the research, then two questionnaires have been given subjects to be filled;

(1) The "Questionnaire for Voice Teachers" (QVT) created by Dr. Pasquale Bottalico consisted in four sections. The first section of the questionnaire included nine questions on socio-demographics (e.g. age, gender and education), native language, and history of hearing or speech disorders; the second section contained 16 questions about working conditions (e.g. days per week of teaching, hours a day of teaching, physical conditions of the workplace); the third part contained 13 questions on the occurrence, severity and frequency of voice symptoms; he last section contained 17 questions on the occurrence, severity and frequency of hearing problems.

(2) The questionnaire "Hearing Health Quick Test" (HHQT) created by the American Academy of Audiology focused on perceived hearing health and was used to evaluate how well the participants' perception of their hearing status aligned with their measured hearing thresholds.

_Voice functioning assessment

After filling the questionnaires, the subject could go and seat in the double wall sound isolation booth to start (1) VoiceCare calibration and (2) voice assessment.

The graph obtained represents voltage values of the VoiceCare microphone and sound pressure levels values of the air microphone. The values of the VoiceCare and the ones of the air microphone are represented in two different unit measures; in order to relate the values of the contact microphone to the values registered by the air microphone the system has to convert the values of the VoiceCare, which are represented in voltage instead than dB. If this would have been imagined graphically, there would be a change of the red line from a curve to a straight line to be able to calibrate levels in dB of the VoiceCare and levels in dB of the air microphone that are going to have a linear behavior.

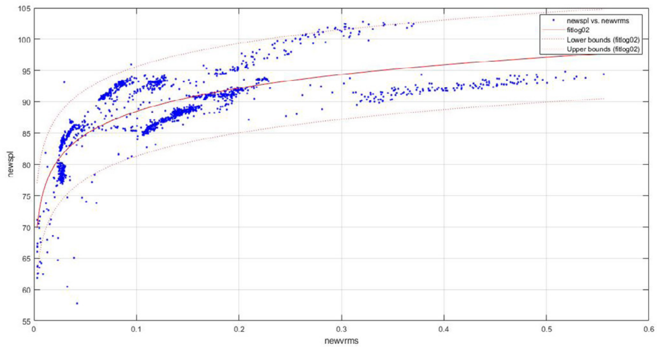
Calibration and voice assessment in the sound booth

The calibration with the two microphones allows to get two constants "a" and "b" that are included in the expression $y=a \log x+b$ which represents a log curve which relates the values in dB and the voltage ones.

The constants give a calibrated absolute value of the sound pressure level which ensure that the values measured by the contact microphone are the same as the values measured at 15 cm of distance from the mouth's subjects, where the air microphone is placed during the calibration.

The sound pressure level is calibrated and so are the sound pressure levels registered by the subject emitting sounds at 15 cm from his/her mouth.

If the value would not be calibrated it would mean that it could still be possible to see variations in the subject voice behavior, but it cannot be possible a comparison between variations of multiple subjects as each person has a different scale (Carullo et al, 2015).



Example of the VoiceCare calibration; subject 8.

The VoiceCare calibration consisted in asking the subject to do sustained /a/ vowels for at least 5 seconds each increasing both pitch and loudness, restarting from soft and low pitch /a/ when they reached their maximum, for 90 seconds, period during which the red light on the device was on. The file was saved on a SD card, that was removed to save the file in the folder with the current date containing the script files for the analysis of the previous folders.

The voice functioning assessment was done in order to characterize the natural course of acute voice symptoms and using a microphone (Microphone US-20x20) placed at 45 degrees on the left of the subject and at 50 cm of distance from his/her mouth, position chosen to attenuate distortion effects caused by the directivity of the sound.

The air microphone calibration at 94 dB is done with a calibrator, an instrument that, positioned on the top of the air microphone, emits a pure tone of 1 KHz and that references the measured sound pressure level with reference pressure p_0 equal to 20 μPa, value that corresponds to the minimum pressure audible from the human ear. After that, the subject could start the recording which consisted in the production, with three different voice levels (soft, normal and loud), of the vowels /a/, /i/, /u/ and, subsequently, the reading of the first six sentences of *The Rainbow Passage*, a phonetically-balanced speech sample equal to about 30 seconds of speaking.

The digital recording was transferred to a personal computer running Audacity Aurora.

_Hearing Assessment

During the hearing assessment, participants were asked a series of case history questions, underwent otoscopy and pure tone audiometry (air and bone) to assess hearing status before and after classes. Audiometric assessment was conducted on a clinical calibrated audiometer with supra-aural headphones and bone oscillator. Hearing assessments were completed to determine if hearing thresholds shift after time of exposure and to determine if there was hearing loss present in the subjects, particularly in the form of a "noise notch" at 4000 Hz – 6000 Hz frequencies, representative of noise-induced damage of the inner ear. Noise notches are characteristically defined by their notched appearance, formed by a decrease in hearing thresholds with an improved difference of more than 10 dB at the surrounding frequencies.

After the voice classes, subjects were supposed to come back to the clinic of Speech and Hearing department to perform a post-monitoring assessment, with the aim to determine changes on voice quality and hearing functioning associated with the occupational exposure to noise and voice during classes.

With the same procedures, subjects were supposed to repeat the voice assessment and hearing screening.

The voice quality parameters and hearing thresholds identified during the assessment were compared with post-monitoring measurements.

The purpose of this comparison was to characterize changes on voice quality associated with occupational voice use during voice classes and to identify variations on the hearing thresholds associated with the occupational noise exposure during voice classes.

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Voice and noise monitoring

_*Voice dosimetry and parameters*

One of the most fundamental issues when studying the effects of excessive or long-term vocalization is determination of the proper way of quantifying the amount of voicing: voice dosimetry has the purpose to measure and quantify vocal load centered on the concept of "vocal doses", which refer to quantifying the amount of vocal fold tissue exposure to vibration during phonation.

There are five different vocal dose measures that are used as indicators of vocal effort (Titze et al, 2003); these are obtained from the phonation time, the fundamental frequency and the sound pressure level.

The **Time Dose (D_t)**, in seconds, is the voicing time and it quantifies the total time during which the vocal folds vibrate; it is calculated as:

$$D_t = \int_0^{t_p} k_v \, dt$$

Where

t_p is the performance time (or phonation time);

k_v is the voicing unit step function (equal to 1 for voiced and 0 for unvoiced frame).

The **Distance Dose** (D_d), in meters, quantifies the total distance accumulated by the vocal folds in vibration:

$$D_d = \int_0^{t_p} k_v \cdot A \cdot f_0 \, dt$$

Where

A, in meters, is the amplitude of vibration of the vocal folds, calculated as

$$A = 0.05\, L_0 \left[\left(P_l - P_h \right) / P_h \right]^{1/2} dt \;\; m$$

The distance of vocal fold travel is calculated from vocal intensity measurement that includes total phonation time, fundamental frequency, and amplitude of vocal fold vibration (Svec et al, 2003).

The **Energy Dissipation Dose** (***D_e***) is the energy dissipated by the vocal folds in the form of heating and it is obtained by integrating the dissipated power over time:

$$D_e = \int_0^{t_p} k_v \cdot P_d dt = \frac{1}{2} \int_0^{t_p} k_v \cdot \eta \cdot \omega^2 \cdot \left(A/T \right)^2 dt$$

De is the energy dissipated by heating because the tissue of the vocal folds is viscose so when they're during the collision between each other there is a friction and so there's dissipation of heating. That energy is not positive because it is not transformed in sound and because it is making you feel the sensation of burning when you are fatigued.

The **Radiated Energy Dose** (***D_r***), in Joule, represents the quantity of energy radiated in sound out from the mouth during phonation and it is obtained by integrating the power radiated (P_r) out from the mouth during phonation:

$$D_r = \int_0^{t_p} k_v \cdot P_r dt = 4 \cdot \pi \cdot R^2 \cdot \int_0^{t_p} k_v \cdot 10^{(SPL-120)/10} dt$$

SPL, in decibels, is the overall sound pressure level at 15 cm from the speaker's mouth (SPL_{mean}) and it is calculated by averaging the individual values of *SPL* only over the voice frames:

$$SPL_{mean} = \frac{1}{D_t} \int_0^{t_p} k_v \, SPL(t)$$

The **fundamental frequency, $f_{0,\,mean}$**, in Hertz (Hz), is obtained by integrating the f_0 contours over time and dividing by the time dose:

$$f_{0,\,mean} = \frac{1}{D_t} \int_0^{t_p} k_v \, f_0(t)$$

The typical fundamental frequency for women during speech is around 200 Hz, while for singers it could be higher.

The device used in our project research for the recognition of the fundamental frequency and an estimation of sound pressure levels was the VoiceCare, developed by the Politecnico di Torino.

Voice dosimetry device; VoiceCare

The VoiceCare is a portable, wearable device designed for objectively documenting the key phonatory behaviors of an individual over a full day of normal activity.

VoiceCare can be worn easily by subjects as they go about their normal daily routine. The transducer is a small contact microphone (accelerometer) which is placed to the base of the client's neck, just above the sternal notch. A cable runs from the accelerometer to the hardware module positioned in a waist-pack that the subject is wearing. The accelerometer catches the vibrations of the skin on the neck associated with phonation.

This device provides a time history record of the entire observational period from which it is possible to calculate the phonation time (the amount of time the participants phonated, tracking the exact times when phonation occurred), the fundamental frequency, and, after a calibration, an estimation of the sound pressure level at a distance of 15 cm on-axis from the speaker's mouth. The calibration is carried out by means of a reference microphone, in order to correlate the skin acceleration level to the sound pressure level.

In 2005 Švec et al. studied how accurately sound pressure levels (SPLs) of speech can be estimated from skin vibration of the neck: the VoiceCare can't be as precise as a microphone because it is influenced and changes its way of measuring data from the type of skin, its thickness, the precise position where it is placed and that's the reason why there is the need to calibrate it with an air microphone, to ensure that the whole monitoring can register values referred with those of an air microphone placed at 15 cm from the mouth subject during calibration.

However, this device is able to measure phonation-related skin vibration to estimate vocal parameters. As such, it is relatively insensitive to other sound signals and environmental noise and, furthermore, is less influenced by supra-glottal vocal tract resonances than by using a microphone (Hillman et al, 2006).

_Noise dosimetry

Noise dosimetry is the measurement of the noise to which a person is exposed integrated over a period of time and it can be measured with the use of a sound level meter or any other tool that includes the recording of sound pressure levels (SPL).

Noise exposure is usually to comply with Health and Safety regulations such as the Occupational Safety and Health (OSHA), Occupational Noise Exposure Standard or EU Directive 2003/10/EC.

Noise dosimetry device; TASCAM sound recorder

In our case noise dosimetry measurements have been performed using a sound recorder with a microphone clipped on the shoulder approximately 15 cm from the participants' ear to measure ear-level noise levels from the voice subject and the environment.

Noise dosimeter allows to obtain a time history of values of A-weighted Sound Pressure Levels with a time step of some ms; the parameters that can be evaluated from the time history include the instantaneous SPL (dBA), equivalent (running) SPL (dBA), and noise dose percentile/occurrence.

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Occupational voice and noise monitoring

After pre-monitoring assessment and before starting their classes subjects could start their classes activities wearing two devices: (1) the contact microphone (VoiceCare) placed at the jugular notch of the neck to record voice and (2) a microphone placed on their shoulder to record noise.

Teachers have been monitored during the whole duration of their hours of voice classes and the devices on the subjects allowed them to walk, behave and sing freely as they usually do during teaching.

_*Occupational Voice Monitoring*

VoiceCare recorded voice and measured the sound pressure of the phonation without capturing the environmental.

The output of the device analyzed during the post process is a time history including Sound Pressure Level (SPL), representing the average pressure level emitted by the participants at 15 cm from the mouth and Fundamental Frequency (f_0), the average number of collision per second between the vocal folds, with a time step of 30 ms. From the time history it is also possible to calculate (1) the phonation time in percentage (D_t%), (2) the Distance Dose Normalized Level (LDd_norm), (3) the Normalized Energy Dissipation Dose Level (LDe_norm), (4) the Normalized Radiated Energy Dose (LDr_norm), (5) the Mean and the Standard Deviation of Sound Pressure Level (SPL_mean and SPL_sd), (6) the Mean and the Standard Deviation of Fundamental Frequency (f_0_mean and f_0_sd).

_*Occupational Noise Monitoring*

Noise dosimetry measurements were performed with a TASCAM sound recorder attached to the subjects with the microphone clipped on the shoulder approximately 15 cm from the participants' ear to measure noise levels from the voice teacher, students, and the environment during teaching.

The microphone worked as a noise dosimeter and it had the function to measure noise exposure that can be caused by noise from the inside of the room or noise from environmental factors outside the room. This small and light device stores the noise level information and carries out an averaging process.

The TASCAM was set to measure with a sampling rate of 44.1 kHz and a maximum input sound pressure of 115 dB SPL and it was calibrated by comparison in a soundproof test booth across mic gain levels using a 1000 Hz pure tone through Audacity software; the comparison was performed with a Class 1 Sound Level Meter (XL2 Audio and Acoustic Analyzer, NTI Audio).

The recordings performed with the TASCAM were then analyzed with the software Matlab R2016b to obtain a time history of A-weighted Sound Pressure Levels values with a time step of 185 milliseconds.

Parameters evaluated include the instantaneous dBA levels, running dBA levels, and noise dose percentile/occurrence.

The graph shows (1) the equivalent sound pressure level, which is the sound level in decibels equivalent to the total sound energy measured over a stated period of time, (2) L5 and (3) L95, values of noise dose percentile that are representing the values of sound pressure level exceeded respectively 5% and 95% of all the recording period.

Acoustical characterization of the classrooms

Acoustic measurements of the classrooms were done with the aim to be able to relate them to voice and hearing measurements.

Room acoustics directly influence voice behavior and hearing health; for this reason, measurements were done in order to assess acoustical characteristics of the space that will be used to work on the safety distance between source (students) and receiver (teacher) to decrease teachers' noise exposure.

_Preparation procedure

The first approach we had to the space has been to measure the three main physical dimensions of

the room: length, width and height, as most of the parameters that needed to be calculated (such as reverberation time) depended on the volume of the room.

Then the devices to make acoustic measurements have been set: an omnidirectional microphone was placed on a microphone stand and linked to a cable and to a recorder, the phantom power has been turned on and it has been verified on the recorder that there was as less saturation as possible.

_Impulse Response

The classroom where the participants were teaching were acoustically assessed. Following ISO 3382, the acoustical parameters have been calculated from a room impulse response (IR). The IR (Impulse Response) is a recording of how the room reverberates in response to an impulsive sound such as a balloon pop or starter pistol shot. In our case the impulsive source has been a "clap".

During the measurements microphone positions should be at representative positions of those where listeners would normally be located. Measurement positions should sample the entire space at distance of around 2 m from each position and 1 m from the nearest reflecting surface, including the floor. The height of

the microphones above the floor should be 1.2 m, corresponding to the ear height of average listeners in typical chairs. A minimum of 6 measurements is suggested. Wait few seconds after the impulse generation (at least 2 times the RT).

Following this guideline, we chose a position in the room, produced three claps using the clap being careful not to rumble; we produced the first one in a powerful way, waited about 5 seconds, produced the second one in the style of the first one, waited about 5 seconds and produced the last one in a softer way. We changed position in the room and repeated the procedure (the procedure can be repeated as many times as it's desired to be able to have enough information; in our case we did from one to four claps depending on rooms dimensions).

_Insulation

The rooms in a building have to be constructed to prevent sound from being transmitted. Insulation is the ability of a building element or building structure to reduce the sound transmission through it (Acoustic Bullettin).

A music box connected with a cable to a recorder playing pink noise has been our sound source outside the room with the door closed. The loudspeaker used in insulation measurements can be seen as a point source that generates spherical waves (Hopkins, 2007). A calibrated microphone on 94 dB connected to a sound level meter worked as a receiver. The sound power had to be sufficiently high for the sound pressure level in the receiving room to be at least 10 dB higher than the background noise level in any frequency band. The loudspeaker was placed outside the room in at least 2 different positions at 1.4 m apart. The distance between the room boundaries and the source center had not to be less than 0.5 m. Microphones position had to be at least at 0.7 m distant, at least 0.5 m from the room boundaries and at least 1 m from the source. 6

measurements for each room have been performed, three from the inside and three from the outside, lasting each at least 5 seconds.

To measure the background noise the pink noise has been switched off and the receiver has been placed in the middle of the inside of the room with as much silence as possible.

The sound pressure level SPL has been measured using one-third-octave band filters and having at least the center frequencies, in hertz from 100 to 3150. An average on an energy basis all the internal and external sound source positions, separately, was calculated and, in order to measure the level difference (D).

Starting with the level difference, the standardized level difference (*DnT*) has been calculated.

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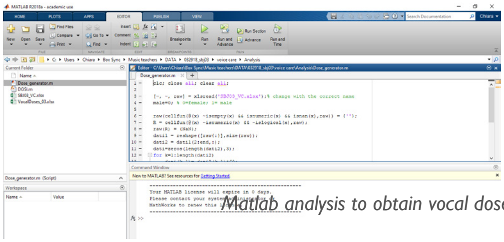
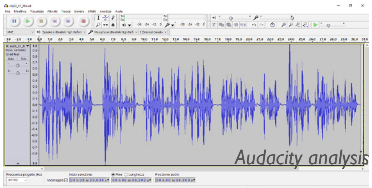
Voice analysis

MATLAB scripts were coded to analyze voice characteristics and noise exposure levels.

Voice Analysis involved segmented vocal recordings of the vowels /a/, /i/, /u/ as well as "The Rainbow Passage" in Audacity and were analyzed via MATLAB script in order to obtain vocal doses and parameters able to assess voice. A comparison of the varying intensity levels during pre-assessment and post-assessment, vowel type, male voice and female voice, were analyzed for patterns in individual SPL, f_0, SPL_{sd}, $f_{0\ sd}$, Acoustic Voice Quality Index (AVQI), Cepstral Peak Prominence (CPPS), and Pitch Strength (PS).



Matlab analysis to obtain vocal doses



Audacity analysis

Noise analysis

Noise Analysis involved running the recorded TASCAM files through a coded MATLAB script designed for noise exposure analysis; it revealed measurements of running L_{eq} in dB(A) as well as occurrence rate of exposure at varying intensity levels measured throughout the session. L_{ex} (noise exposure over an 8-hour period) was also calculated using the formula

$$L_{ex} = L_{eq} + 10\log(t/8)\ [dB(A)]$$

Where t is the duration of the exposure to the measured L_{eq}.
This formula takes into account the difference between the measured duration of exposure and the remaining hours in the workday (for a total of 8 hours). The formula assumes the remaining time not measured was spent in less harmful exposure levels, such as <70 dBA (Behar et al, 2004). This is a more conservative measurement compared to L_{eq} which is not taking into account a full 8-hour work day and the remaining time spent in less intense exposure levels. L_{eq} and L_{ex} were compared to 85 dB(A) over the 8-hour workday as recommended by NIOSH.

_R software

To have more complete statistical analysis the software R 3.5.0. has been used. This software is working using mixed effect models which are helpful when the effect that has to be analyzed includes a variable affected by different conditions. Creating a nest model it is possible to add new factors with the aim to increase the baseline and improve the model to have more significant results. The final output of the mixed effect model is a sort of summary of all the linear analysis with all the different factors that have been taken into consideration. The random effect of the model in R software indicates the variance of the data, in other words, how variable the data are from their middle point of distribution. The residual variance is a value that is giving potential error to the model. The variance can decrease adding factors to the model and improving it.
To establish if results could be significant or not, a focus has to be done on uncertainty values marked with asterisks, from 1 to 3, which indicates the grade of uncertainty.

Hearing analysis

Hearing thresholds were compared between pre-assessment and post-assessment results to check for significant thresholds shifts. Hearing thresholds were also compared to exposure levels of the individual participant to examine if a pattern was present (ie, higher noise levels and poorer hearing thresholds).
In the noise exposure analysis it has been considered the whole group of elements to which the subject was exposed; own voice subjects' was included in the noise exposure measures even if there are some studies

running that are working on the fact that the human system is adding a sort of filter to protect the earing system. There are no sources now to understand how to filter the measured value of someone's own voice; for this reason, out analysis is taking into account the whole subject's exposure measured during monitoring.

Questionnaire analysis

Voice and Hearing questionnaires were compared to assess perceived hearing and voice status to the measured hearing thresholds and voice characteristics.

Architectural acoustics

_Reverberation Time Analysis

This analysis has been done with the use of the software Audacity 2.0.5. and the Aurora Modules that allowed us to analyze the data by obtaining as output the Acoustical Parameters. Audacity 2.0.5. and the Aurora Modules have been downloaded from the website *http://pcfarina.eng.unipr.it/Public/Aurora-for-Audacity/* following the indication of the Readme.txt for loading the modules.

The selected impulse responses were opened in Audacity; from the Menu *Analyze, Aurora Acoustical Parameters Setup -> Calculate!* It was possible to obtain the Acoustical Parameters. The elements needed were T20 and T30 which, for each frequency range (from 100 Hz to 10000 Hz) represent in two different ways the Reverberation Time expressed in seconds (s). A file excel has been created in order to obtain average values and standard deviations of T20 and T30 for each frequency band and for each room.

AP_200b_SxM2_02 - Blocco note

File Modifica Formato Visualizza ?

```
Aurora 4.3 - ISO3382 Acoustical Parameter File
ISO 3382 OCTAVE BAND ACOUSTICAL PARAMETERS
Channel 1 Parameters
Filename        Frq.band [Hz]   25      31.5    40      50      63      80      100     125     160     200     250     315     400     500     630     800     1k
200b_SxM2_02    Signal [dB]     --      --      -102.362        -102.362        -102.362        84.839  83.819  98.478  97.540  104.540 99.275  100.364 93.537  93.408
200b_SxM2_02    Noise [dB]      --      --      91.831  91.831  91.831  60.464  57.163  58.128  56.412  62.295  50.245  55.304  47.725  47.814  40.107  37.564  36.944
200b_SxM2_02    strenGth [dB]   --      --      -171.362        -171.362        -171.362        15.839  14.819  29.478  28.540  35.540  20.275  23.364  93.537  93.408
200b_SxM2_02    C50 [dB]        --      --      -0.334  -0.708  -0.708  -20.902 -24.310 -15.382 -5.368  -5.398  -7.073  -4.103  -7.696  -1.169  0.326   0.711   3.237
200b_SxM2_02    C80 [dB]        --      --      11.600  5.632   5.632   -6.431  -14.182 -9.558  -2.085  2.167   -3.309  -0.337  1.095   1.850   6.131   5.263   9.558
200b_SxM2_02    D50 [%] --      --      48.079  45.936  45.935  0.806   0.369   2.815   22.512  22.391  16.403  27.995  14.529  43.309  51.878  54.085  67.816  67.625
200b_SxM2_02    Ts [ms] --      --      -2732.585       -2732.569       -2732.553       618.979 599.531 615.943 361.841 333.254 346.355 201.187 209.565 192.107 116.254
200b_SxM2_02    EDT [s] --      --      --      --      --      1.580   0.853   0.559   1.219   0.867   1.099   0.750   0.824   0.774   0.577   0.651   0.464   0.662
200b_SxM2_02    Tuser [s]       --      --      --      --      --      1.237   0.550   0.978   0.577   0.427   0.991   0.632   0.447   0.362   0.321   0.239   0.471
200b_SxM2_02    T20 [s] --      --      --      --      --      1.149   0.825   0.888   0.855   0.532   0.717   0.623   0.501   0.488   0.392   0.338   0.395   0.370
200b_SxM2_02    T30 [s] --      --      --      --      --      1.664   0.885   0.942   1.003   0.515   0.684   0.552   0.557   0.431   0.378   0.312   0.385   0.370
200b_SxM2_02    Peakiness [dB]  --      --      13.442  13.442  13.442  15.227  17.899  19.335  16.362  17.955  18.832  17.281  19.584  19.323  20.525  22.306  23.482
200b_SxM2_02    Millisecs [dB]  --      --      --      --      --      --      --      --      --      --      --      17.219  19.522  19.261  17.777  19.645  22.803
200b_SxM2_02    Impulsivs [dB]  --      --      --      --      --      --      --      --      --      --      --      13.513  14.315  13.215  13.950  14.270  15.837
200b_SxM2_02    St1 [dB]        --      --      --      --      --      --      --      --      --      --      --      --      --      --      --      --      --
200b_SxM2_02    St2 [dB]        --      --      --      --      --      --      --      --      --      --      --      --      --      --      --      --      --
200b_SxM2_02    StLate [dB]     --      --      --      --      --      --      --      --      --      --      --      --      --      --      --      --      --
200b_SxM2_02    IACC    --      --      --      --      --      --      --      --      --      --      --      --      --      --      --      --      --      --
200b_SxM2_02    IACC delay [ms] --      --      --      --      --      --      --      --      --      --      --      --      --      --      --      --      --
200b_SxM2_02    IACC width [ms] --      --      --      --      --      --      --      --      --      --      --      --      --      --      --      --      --
200b_SxM2_02    JLF     --      --      --      --      --      --      --      --      --      --      --      --      --      --      --      --      --      --
200b_SxM2_02    JLFC    --      --      --      --      --      --      --      --      --      --      --      --      --      --      --      --      --      --
200b_SxM2_02    LJ [dB] --      --      --      --      --      --      --      --      --      --      --      --      --      --      --      --      --      --
RTU = RT User (-5.0 dB, -15.0 dB)
```

Example of output for the analysis of the reverberation time

_*Insulation analysis*

The output given by the sound level meter was a text file called *Report* containing, for each measure, equivalent sound levels for each frequency band. The aim has been to use the values recorder by the sound level meter to calculate and analyze the Standardized Level Difference (Dn*T*).

```
200_in_01_3rd_Report.txt
XL2 Sound Level Meter RTA Reporting:        MyProject\2018-03-22_SLM_011_RTA_3rd_Report.txt
------------------------------------


# Hardware Configuration
    Device Info:          XL2, SNo. A2A-13055-E0, FW3.23
    Mic Sensitivity:      23.0 mV/Pa
                          (from NTi Audio M2211, SNo. 6805, User calibrated 2018-03-14  10:28)
    Time Zone:            UTC-05:00 (US/Central, DST)

# Measurement Setup
    Profile:              Full mode
    Append mode:          OFF
    Timer mode:           continuous
    Timer set:            --:--:--
    Resolution:           1/3 Octave
    Range:                10 - 110 dB

# Time
    Start:                2018-03-22, 16:25:44
    End:                  2018-03-22, 16:25:55

# RTA Results
    Band [Hz]   6.3         8.0         10.0        12.5        16.0        20.0        25.0        31.5        40.0        50.0
                [dB]        [dB]        [dB]        [dB]        [dB]        [dB]        [dB]        [dB]        [dB]        [dB]
    LZeq        57.7        55.0        56.3        52.3        45.9        38.2        38.4        39.5        36.2        41.9

#CheckSum
    0281AC80D25CBD4B0676235BB521E146
```

Example of output for the analysis of the insulation

In order to calculate this parameter, an average value of the sound pressure level measured in the inside points and one measured on the outside ones needed to be calculated.

For each frequency band, the level has been calculated with the formula

$$L=10\log *\Sigma 10^{(L/10)}/ n \quad [dB].$$

Where:

L is the sound pressure level of each frequency band,

n is the number of measurements considered.

The Level Difference *D* has been calculated by subtracting the average inside level from the outside one

$$D=L_{out}-L_{ins} \; [dB].$$

The Standardized Level Difference (Dn*T*) could be calculated departing from the Level Difference and the Reverberation Time T30

$$DnT = D + 10\log(T30/0.5)\ [dB].$$

Questionnaires

3 MALE **5 FEMALE**

SPEECH/VOICE THERAPY

Among the participating teachers, 50% reported have attended to speech or voice therapy.

VOICE COMPLAINTS

The point prevalence (current presence) of voice complaints, among the participating teachers, was 50%.

HOURS OF TEACHING

50% of the participating teachers reported to teach 5 hours per day.

VOICE DISORDERS

Around 40% of participants reported history of organic voice disorders.

DAYS OF TEACHING

Most than 60% of the participating teachers reported to teach 5 days per week.

ACTIVITY INTENSITY

More than 60% of the participating teachers reported to use their voice more intensively during teaching.

Voice teachers with voice complaints reported, in average, higher noise conditions and echo at the workplace.

Voice teachers with vocal fatigue reported, in average, higher noise conditions and echo at the workplace.

Voice teachers with history of organic voice disorders were occupationally exposed to higher background noise levels than those without history of voice complaints.

Voice teachers with vocal fatigue, and also teachers with voice complaints, were exposed to higher noise levels at the workplace compared with their pair without vocal fatigue and without voice complaints.

Voice

_Pre and post monitoring parameters

Results obtained analyzing data with R Software are represented in graphs that are showing average values and standard deviations of the pre and the post-assessment divided by the three different styles during the assessment (loud, normal, soft) and from the gender, female and male. The "p" value present in some of the graphs states the statistical significance and constitutes the risk of error; when it is indicated, it means that results can be considered statistically different.

Statistical results are shown in tables which specify also the factors used to analyze the mixed effect model. In the table column there are factors through which R analyzes the model while in row there are statistical parameters:

- *Intecept* is the constant of the equation analyzed in the R model;

- *pre.postPOST* is a factor that compares the post results compared to the pre-values;

- *genderMale* is a factor which multiply per 1 values referred to males, and for 0 the ones referred to other categories (in our case, female category). In this way this factor excludes all the elements that are not associate with the male category;

- *pre.postPOST:genderMale* is representing the interaction between the other factors.

- *Estimate* is the estimation of the coefficient associated to the factor

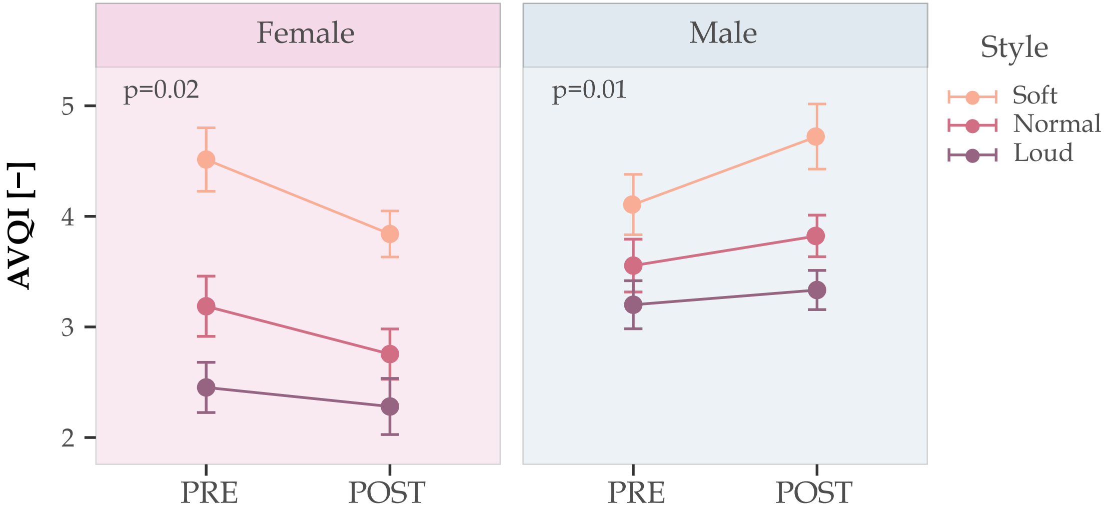
- *Std..Error* is the standard error which shows data variability. It is inversely proportional to the number of elements that are analyzed: the more elements there are, the more the error will approximate to 0 so results will be stronger;

- *df* is the degree of freedom

- *t.value* is the relation between *estimate* and *std error:* the higher it is the stronger results can be considered.

- *Pr...t..* is called "P value" and it represents the risk of error in percentage present in affirming results.

(1) AVQI

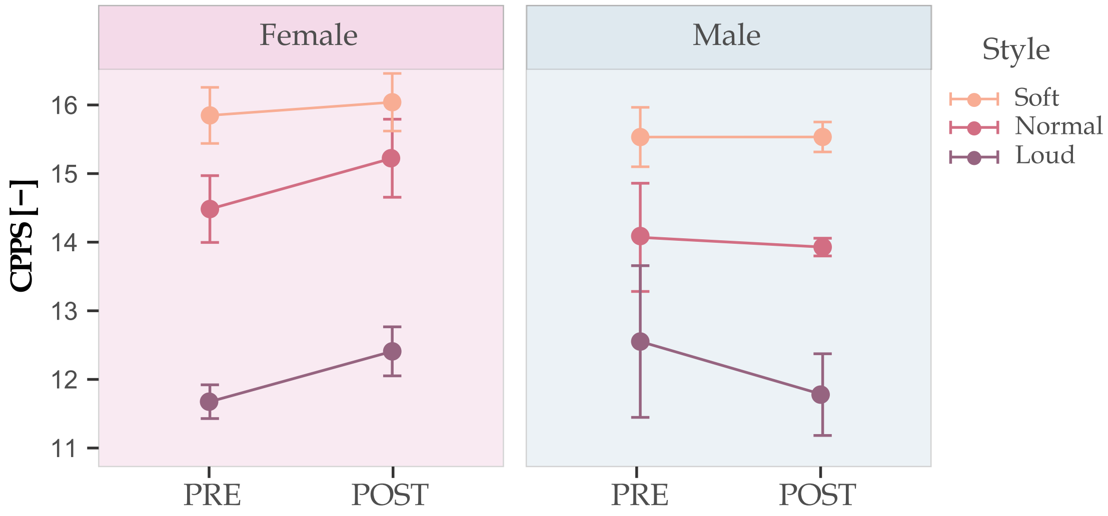


AVQI value is decreased after classes, which means that it is improving for females: the voice quality after classes is better while for males is getting a little bit worse.

The most variable value is the one concerning the soft voice style: soft voice is the more affected style in case of fatigue.

AVQI	*Estimate*	*Std..Error*	*df*	*t.value*	*Pr...t..*
(Intercept)	3.16	0.39	3	8.14	0.00219
pre.postPOST	-0.43	0.18	45	-2.39	0.02112
genderMale	0.50	0.21	45	2.42	0.01975
pre.postPOST:genderMale	0.76	0.29	45	2.63	0.01173

(2) CPPS

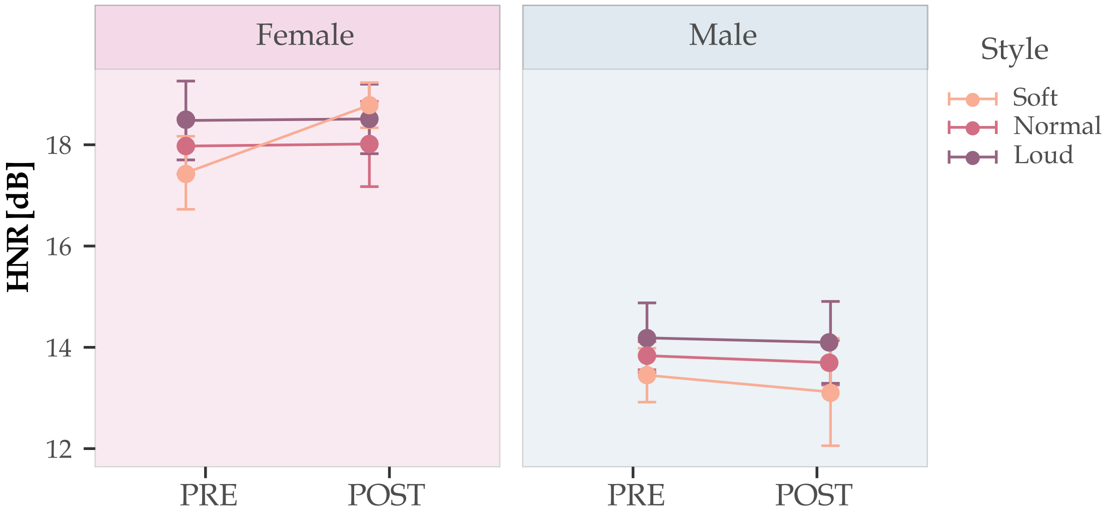


In our results "p" value is not present, which means that the difference is not statistically relevant; it is visible a tendency that can support the significant parameters analyzed.

CPPS is a parameter referred to the amplitude of the spectral peak: higher values of CPPS show more stability of the voice which leads to a healthier voice behavior.

CPPS	*Estimate*	*Std..Error*	*df*	*t.value*	*Pr...t..*
(Intercept)	14.00	0.91	3	15.39	0.0003
pre.postPOST	0.56	0.34	45	1.63	0.1108
genderMale	0.04	0.39	45	0.10	0.9191
pre.postPOST:genderMale	-0.86	0.56	45	-1.54	0.1299

(3) HNR

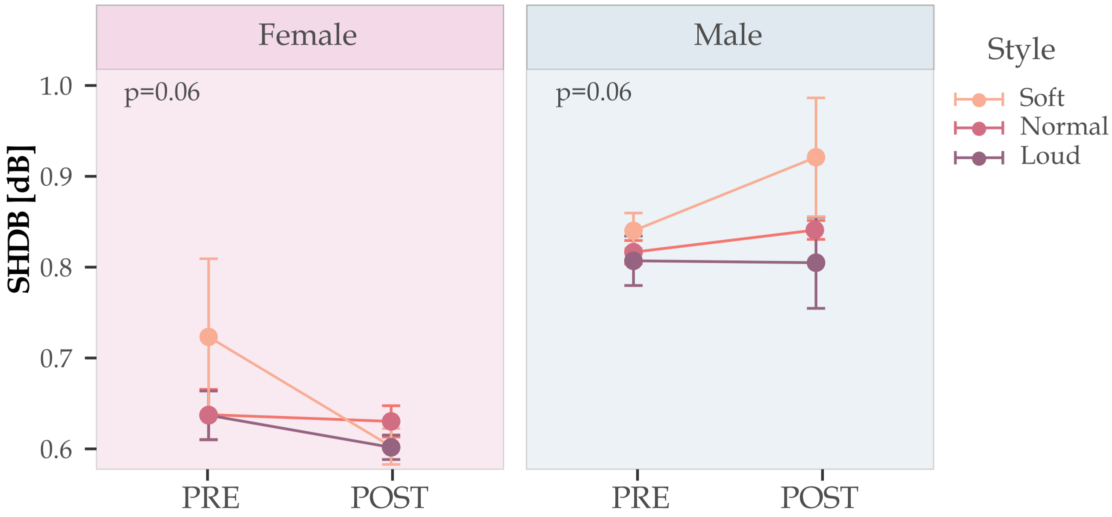


Harmonic to Noise Ratio is a parameter that refers to the harmonics of the voice; lower values are approaching to dysphonia. This is not the case of any of our subjects, but the results show that voice harmonics do not change significantly between before and after some hours of activity.

Non-significant changes can be read as a factor in line with the voice quality stability or improvement as after classes (and so after a period of high vocal load) the voice should be more fatigued and the values should decrease. As they are remaining stable, they can be interpreted.

HNR	*Estimate*	*Std..Error*	*df*	*t.value*	*Pr...t..*
(Intercept)	18.00	0.33	48	54.17	0.0000
pre.postPOST	0.47	0.47	48	1.00	0.3234
genderMale	-4.15	0.54	48	-7.66	0.0000
pre.postPOST:genderMale	-0.66	0.77	48	-0.85	0.3974

(4) SHDB



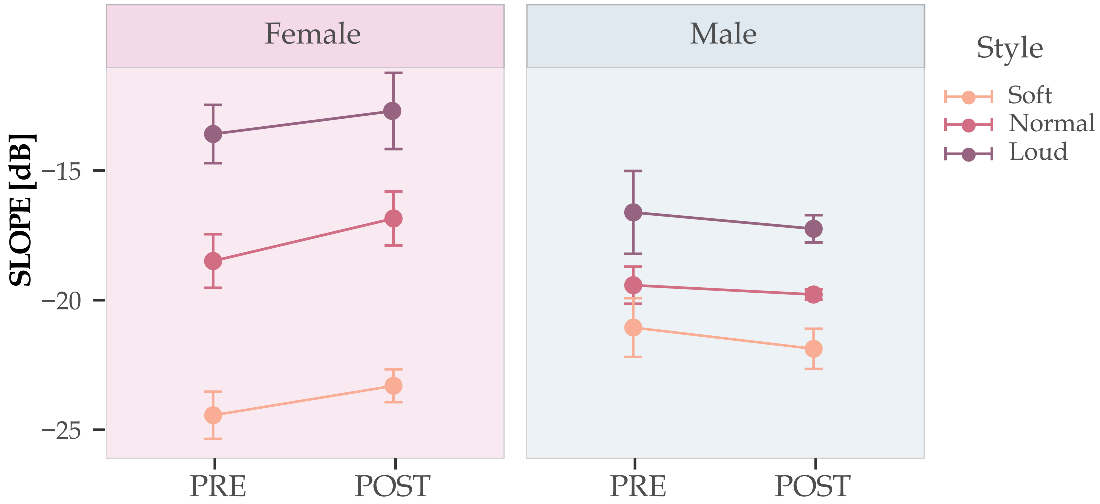
Shimmer is an indicator of F_0 instability and, in general, it can be associated to voice quality and stability. In this case results are significant.

Lower values mean more voice stability so a general increase of the voice quality while higher values refers to higher instability of the pitch.

Females tend to have a more stable voice after teaching activity while males' fundamental frequency instability is a little bit higher after classes.

SHDB	*Estimate*	*Std..Error*	*df*	*t.value*	*Pr...t..*
(Intercept)	0.67	0.02	17	31.40	0.0000
pre.postPOST	-0.05	0.03	45	-1.93	0.0601
genderMale	0.16	0.03	45	4.76	0.0000
pre.postPOST:genderMale	0.09	0.05	45	1.93	0.0602

(5) SLOPE

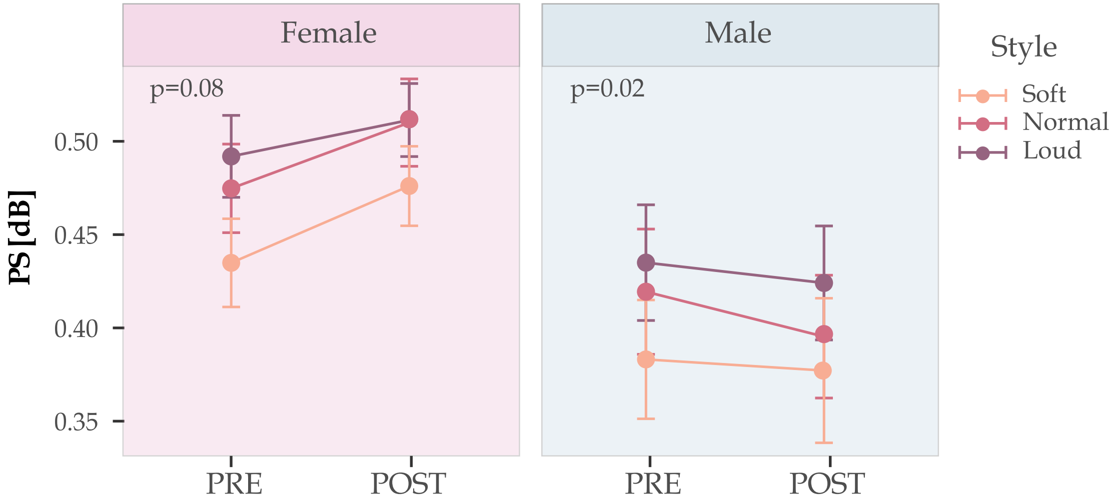


The SLOPE describes the perception of overall voice quality.

The results show that this parameter does not vary considerably, but it is in line with the other results that are supporting the fact that women's voice quality is better after classes while for men it is getting worse.

SLOPE	*Estimate*	*Std..Error*	*df*	*t.value*	*Pr...t..*
(Intercept)	-18.65	2.05	3	-9.12	0.0017
pre.postPOST	1.22	0.85	45	1.44	0.1577
genderMale	-0.19	0.98	45	-0.19	0.8464
pre.postPOST:genderMale	-1.83	1.39	45	-1.31	0.1954

(6) PS



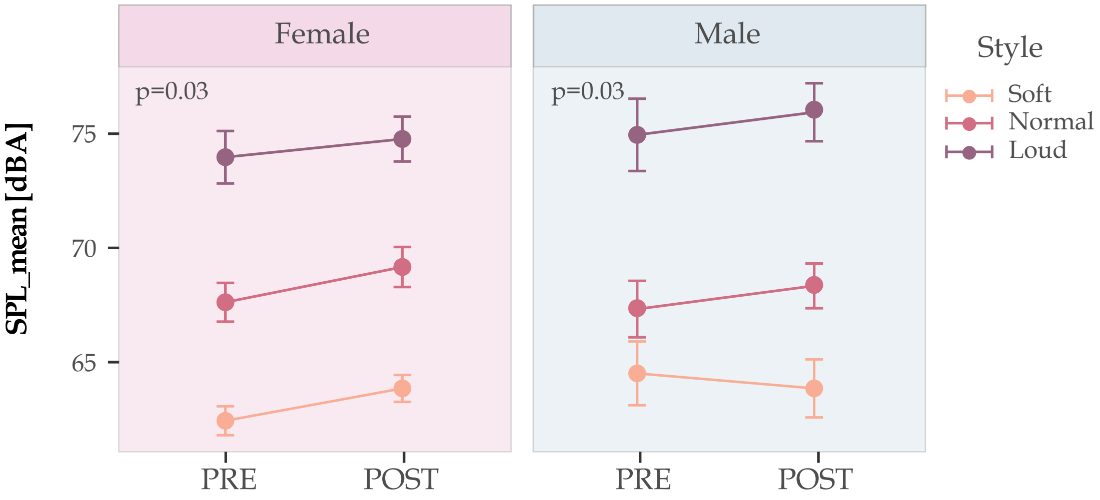
The Pitch Strength is the perceptual attribute of a sound; the higher the value of this parameter is, the higher the quality of the voice is.

Results are considered statistically significant and they are following the same interpretation of the other parameter results which shows a general

improvement for females and deterioration for males.

PS	*Estimate*	*Std..Error*	*df*	*t.value*	*Pr...t..*
(Intercept)	0.471	0.017	9	28.13	0.0000
pre.postPOST	0.032	0.019	181	1.72	0.0877
genderMale	-0.054	0.023	24	-2.35	0.0271
pre.postPOST:genderMale	-0.046	0.031	181	-1.49	0.1384

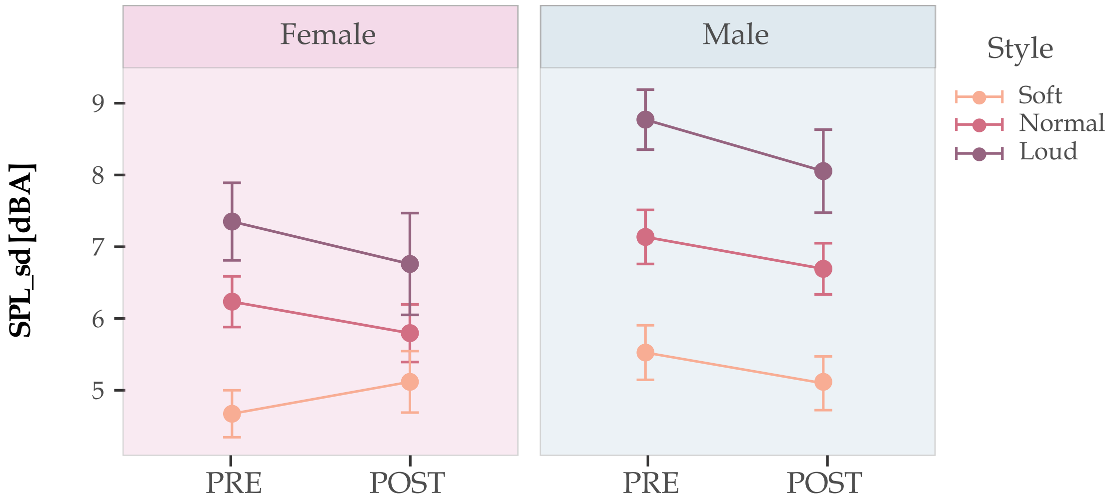
(7) SPL_mean



SPL mean is an average of sound pressure levels of voice. Generally sound pressure levels are increasing both for males and for females, but considering that voice teachers have a high vocal load during their classes hours, this fact can be considered normal because it is in line with vocal folds behavior: when vocal folds are fatigued the thickness of the tissue increases because of blood's flow and the minimum pressure threshold needed to start the phonation gets higher.

SPL_mean	*Estimate*	*Std..Error*	*df*	*t.value*	*Pr...t..*
(Intercept)	68.23	2.84	4	24.00	0.0000
pre.postPOST	0.95	0.44	175	2.18	0.0309

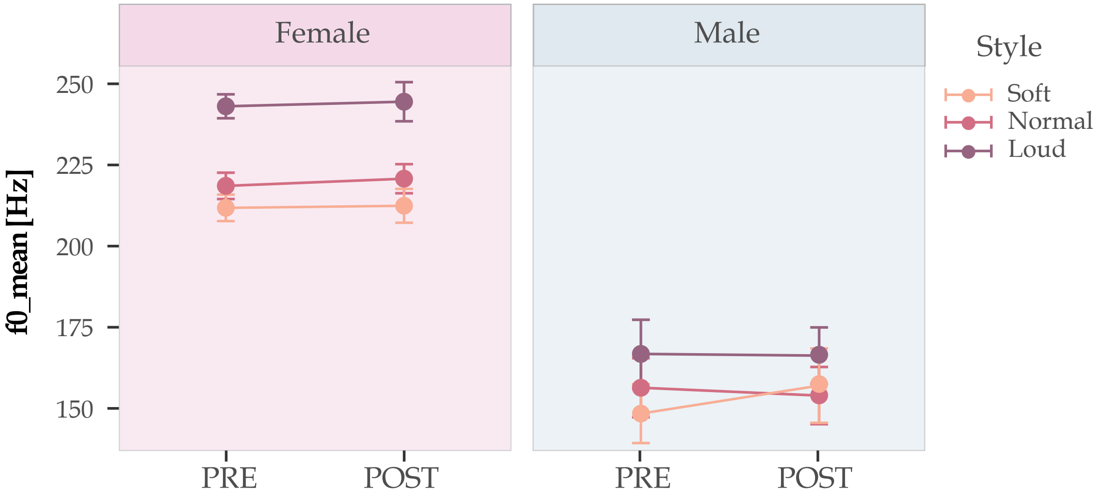
(8) SPL_sd



The sound pressure level standard deviation is representing the range of sound pressure level. Results are supporting the trend of the mean sound pressure level values: as the minim pressure threshold to start phonation raises, the range, so the standard deviation, decreases.

SPL_sd	*Estimate*	*Std..Error*	*df*	*t.value*	*Pr...t..*
(Intercept)	6.37	0.67	4	9.51	5.2E-04
pre.postPOST	-0.32	0.25	175	-1.30	1.9E-01

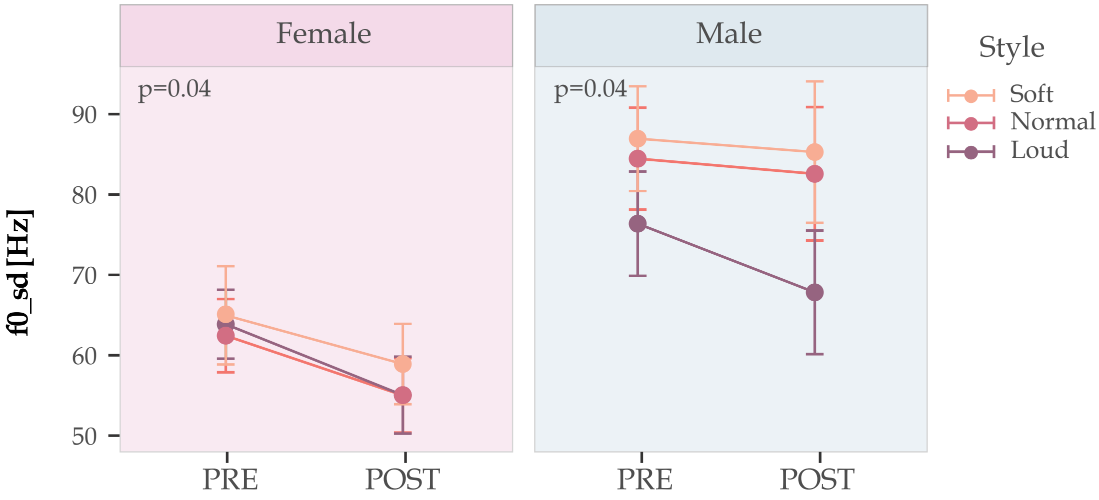
(9) F_0 mean



The reason why fundamental frequency values for males and for females meaningfully change is due to the characteristics linked to gender: females' fundamental frequency during speech is higher than males' one and for both categories, it increases while singing activities.

f_0_mean	*Estimate*	*Std..Error*	*df*	*t.value*	*Pr...t..*
(Intercept)	221.02	6.44	8	34.34	$2.0e^{-10}$
pre.postPOST	1.42	4.54	182	0.31	$7.5e^{-01}$
genderMale	-57.69	10.20	10	-5.65	$1.8e^{-04}$
pre.postPOST:genderMale	0.41	7.47	181	0.06	$9.6e^{-01}$

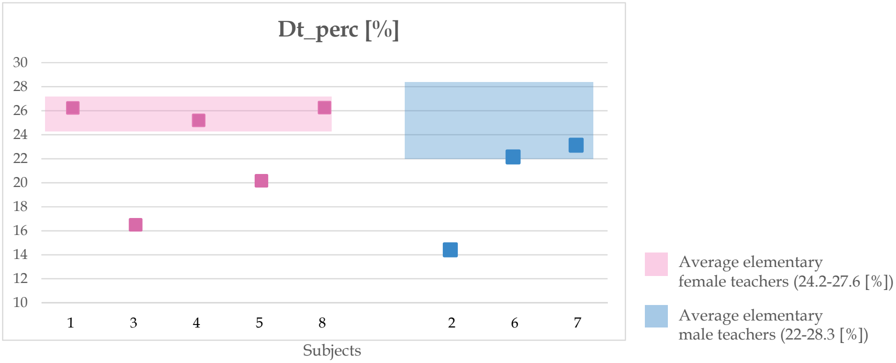
(10) F_0 sd

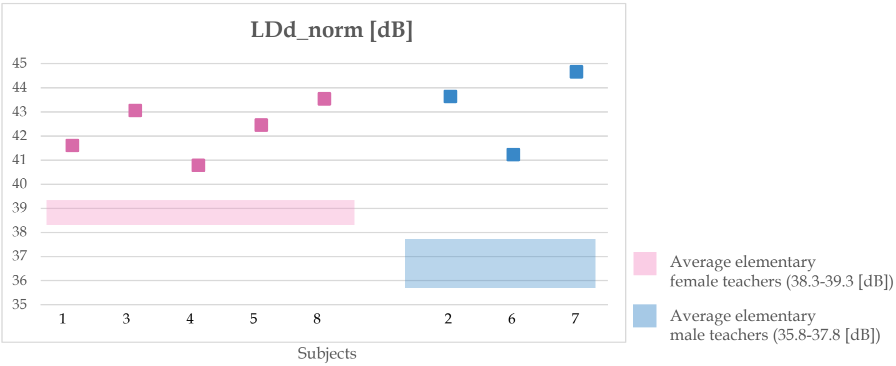


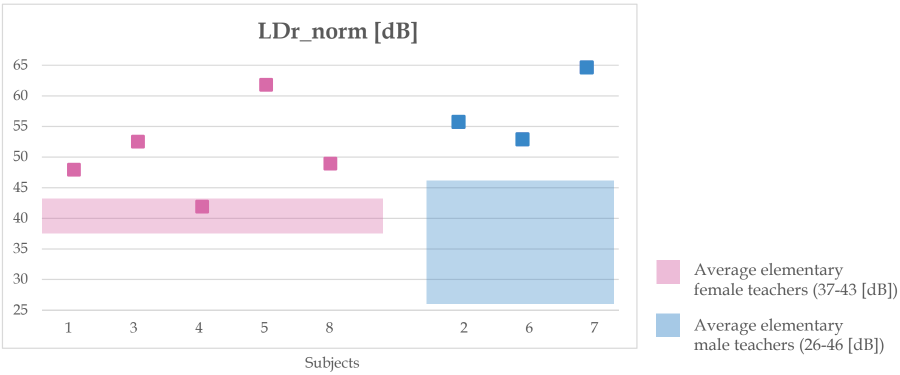
Pitch variability after activity is reduced of about 6 Hz both for females and for males. Sometimes a smaller pitch range could not be a good sign for vocal health, it can be a sign of fatigue, but in our case this parameter is not significant so it cannot mean fatigue or vocal disorders.

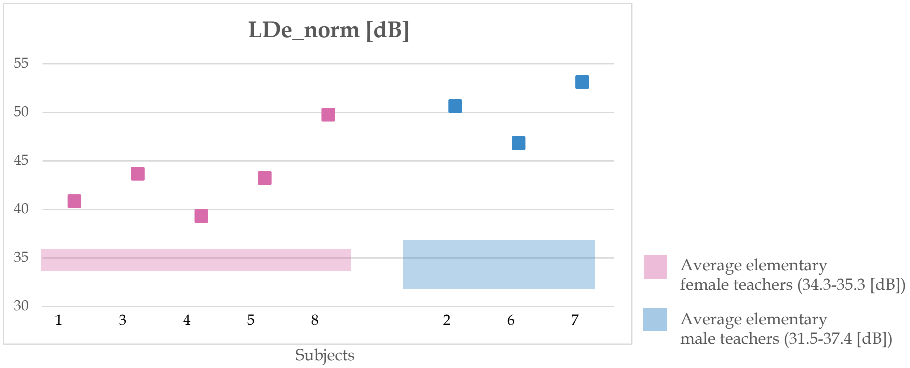
f_0_sd	*Estimate*	*Std..Error*	*df*	*t.value*	*Pr...t..*
(Intercept)	64.25	3.97	15	16.18	$9.06e^{-11}$
pre.postPOST	-7.48	4.03	184	-1.86	$6.47e^{-02}$
genderMale	17.58	6.45	16	2.73	$1.50e^{-02}$
pre.postPOST:genderMale	3.37	6.62	184	0.51	$6.11e^{-01}$

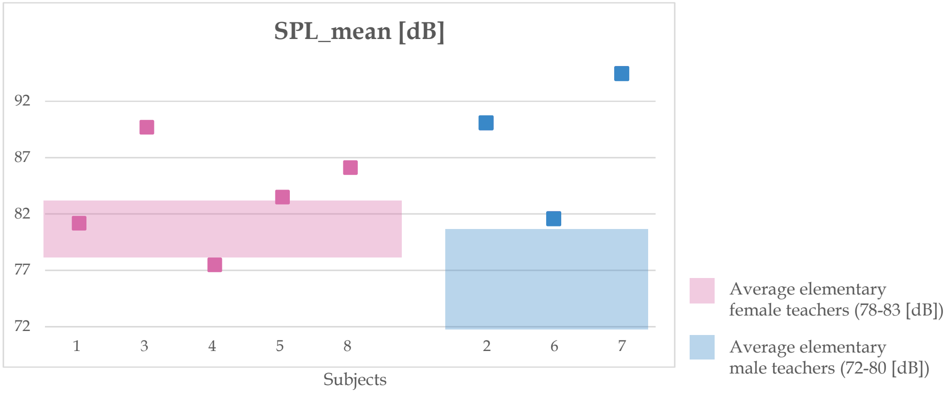
_Monitoring: vocal doses

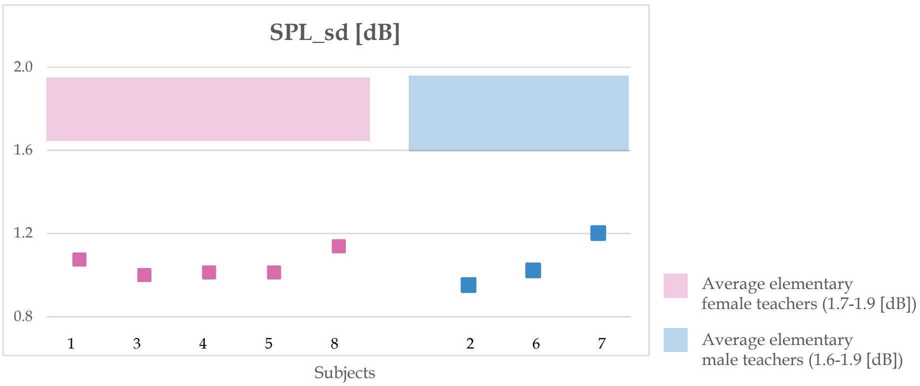


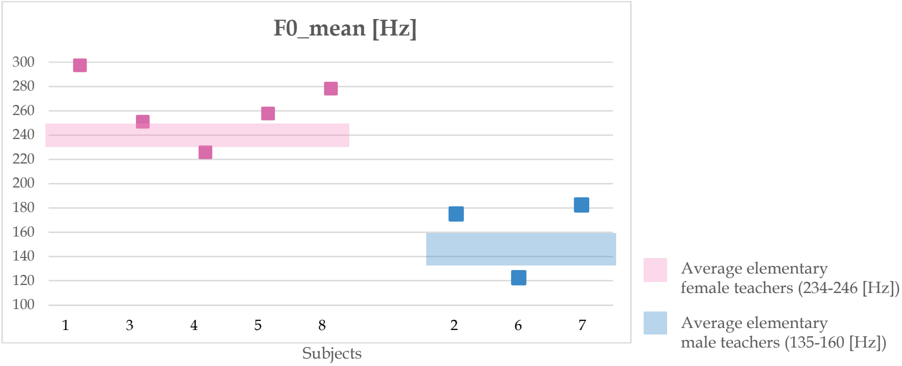


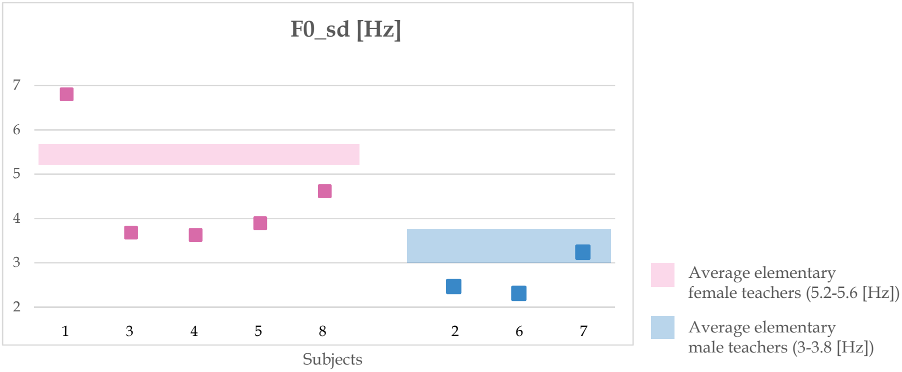



LDe_norm [dB]
55
50
45
40
35
30
1
3
4
5
8
2
6
7
Subjects
Average elementary female teachers (34.3-35.3 [dB])
Average elementary male teachers (31.5-37.4 [dB])


SPL_mean [dB]
92
87
82
77
72
1
3
4
5
8
2
6
7
Subjects
Average elementary female teachers (78-83 [dB])
Average elementary male teachers (72-80 [dB])


SPL_sd [dB]
2.0
1.6
1.2
0.8
1
3
4
5
8
2
6
7
Subjects
Average elementary female teachers (1.7-1.9 [dB])
Average elementary male teachers (1.6-1.9 [dB])





Vocal doses are the result of the occupational monitoring done thanks to the VoiceCare.

The graphs show values of females and males for voice teachers compared to the range registered among primary school teachers in the research conducted in 2012 in Turin by Dr Pasquale Bottalico and Dr Arianna Astolfi.

Time doses in percentage are all around 20/30%; a person that is speaking constantly like a monologue speaks about 50% of the time. The values take into account the voicing frame, not the speaking one.

It has to be considered also the fact that there is a difference between voicing and unvoicing: voicing is involving the vibration of the focal folds, unvoicing is a frame excluding the vibration of the vocal folds. The vowels are

all voice and they are always considered voiced as there is always the vibration of vocal folds. Consonants are divided in voicing and non-voicing: d, for example, includes vibration, t is not. All the pauses, so the breathing moments, are non-voicing.
A value of about 25/30% is typical for teachers of primary schools which have a speech range, while singing could be also more than 50 % of phonation time because singing involves the production of sustained vowels and more vibration of the vocal folds.

The Distance Dose is measuring the vibration of vocal folds in meters; both males and females among voice teachers have higher values compared to primary school teachers. The load in terms of distance is higher for voice teachers because it is a value strictly related to the fundamental frequency f0; fundamental frequency for singers is higher as they are often in the voice range, their vocal folds vibrate more and the distance dose rises.

Voice teachers are dissipating more energy (energy dissipation dose parameter) than school teachers; the radiated energy values too are higher because the power of the voice for voice teachers is more intense. The values registered concerning the Mean Sound Pressure Level are not that different from among the two categories, while the standard deviation for voice teachers, which represents the variability of the sound pressure level, is smaller compared to normal teachers and this fact can be explained because voice teachers use always their voice in a louder way as they are singing, fact that leads to a less variability in the amplitude.

The Mean Fundamental Frequency is higher for voice teachers and it is depending also on the voice style (baritone, soprano etc).
The standard deviation of fundamental frequency shows that normal teachers' pitch was less variable compared to the one of voice teachers.

The results show that the load is higher for voice teachers even if load in terms of time is not higher.

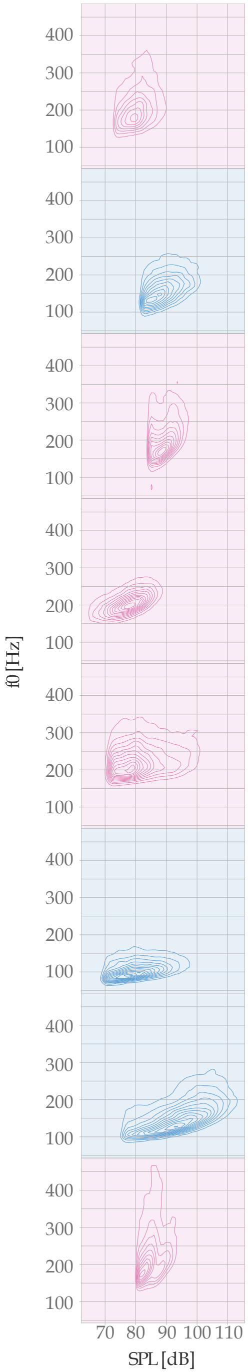
_Monitoring: voice distributions

The VoiceCare has as output a time history that is including fundamental frequencies f0 and Sound Pressure Levels SPL.

From this time history it is possible to create a visual correlation between the SPL and f0 values to better understand the voice behavior of each subject.

From these graphs about the distribution of the voice density, some areas can be recognized: both for males and females the most dense zones are placed corresponding to the values of fundamental frequency and sound pressure levels typical of the speech range.

The fundamental frequency range for women is wider than the males one as the feminine fundamental frequencies is higher.

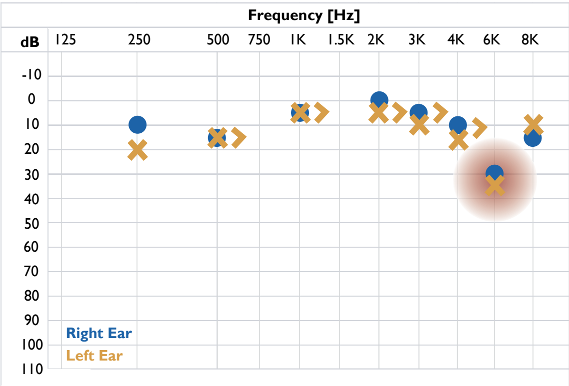


Hearing

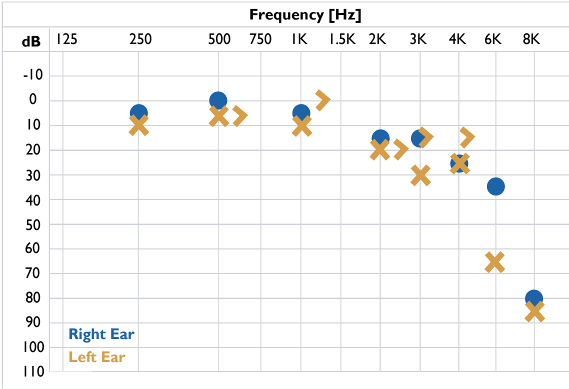
Hearing assessments pre/post class revealed no significance in threshold shift between the two measurements; however, hearing assessments showed majority of subjects with hearing loss. The typical nature of these hearing losses was in the form of sloping high frequency hearing loss and noise notches occurring at 6000 Hz, bilaterally. High frequencies are the first that are damaged as they are placed right at the beginning of the cochlea where the energy firstly arrive to decrease in the following parts of the cochlea. From the noise exposure monitoring it is possible to affirm that notches are caused by the subjects' life style.

_Hearing screenings

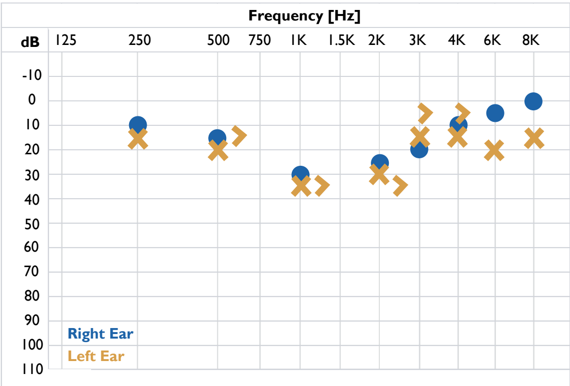
sbj_1



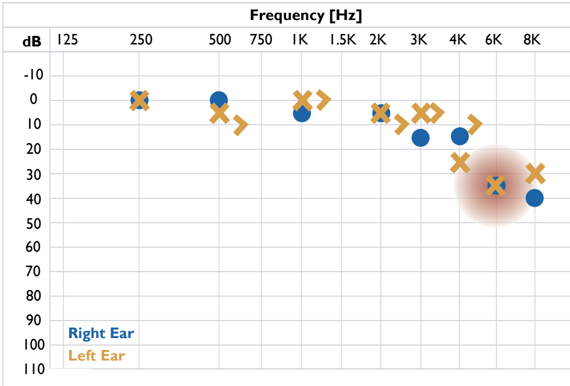
sbj_2



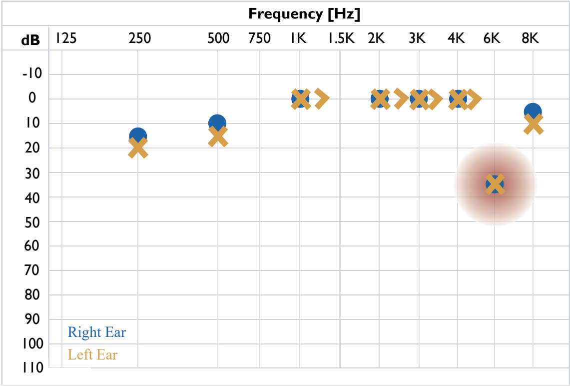
sbj_3



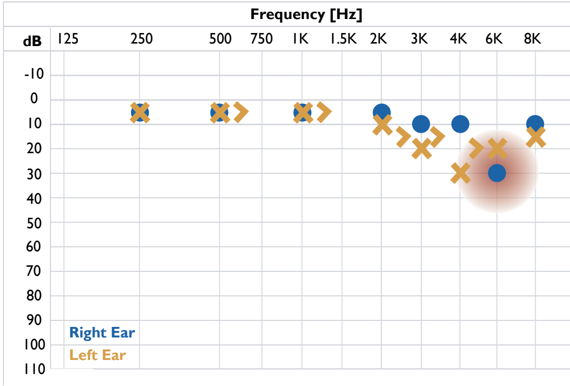
sbj_4



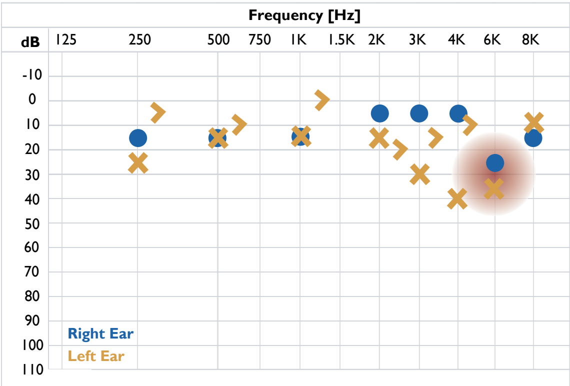
sbj_5



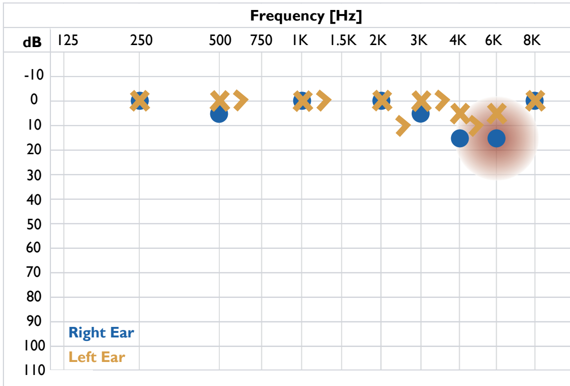
sbj_6



sbj_7



sbj_8

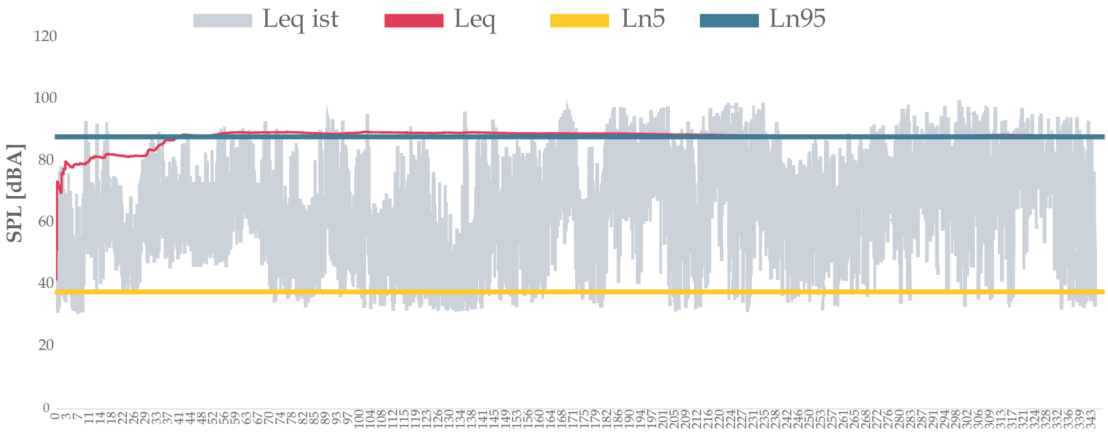


_Noise exposure

The data registered concerning the noise gave an output including a time history subdivided into periods of 185 ms, for each of them correspond information about dB(A), running, pow, L5, L95 that are percentile levels; L95 is the level exceeded the 95% of the monitoring period, while L5 is the level exceeded only 5% of the time and it can more or less precisely correspond with the background noise level of the room.

time	dBA	pow	running	min	hour	Ln5	Ln95
0.09288	33.947	2481.2	44.267	0	0	88.149	37.931
0.27864	32.994	1992.4	42.056	0	0	88.149	37.931
0.4644	35.626	3652.6	42.43	0	0	88.149	37.931
0.65016	35.323	3406.5	42.489	0	0	88.149	37.931
0.83592	31.832	1524.7	41.937	0	0	88.149	37.931
1.0217	58.574	7.20E+05	58.559	0	0	88.149	37.931
1.2074	52.602	1.82E+05	58.797	0	0	88.149	37.931

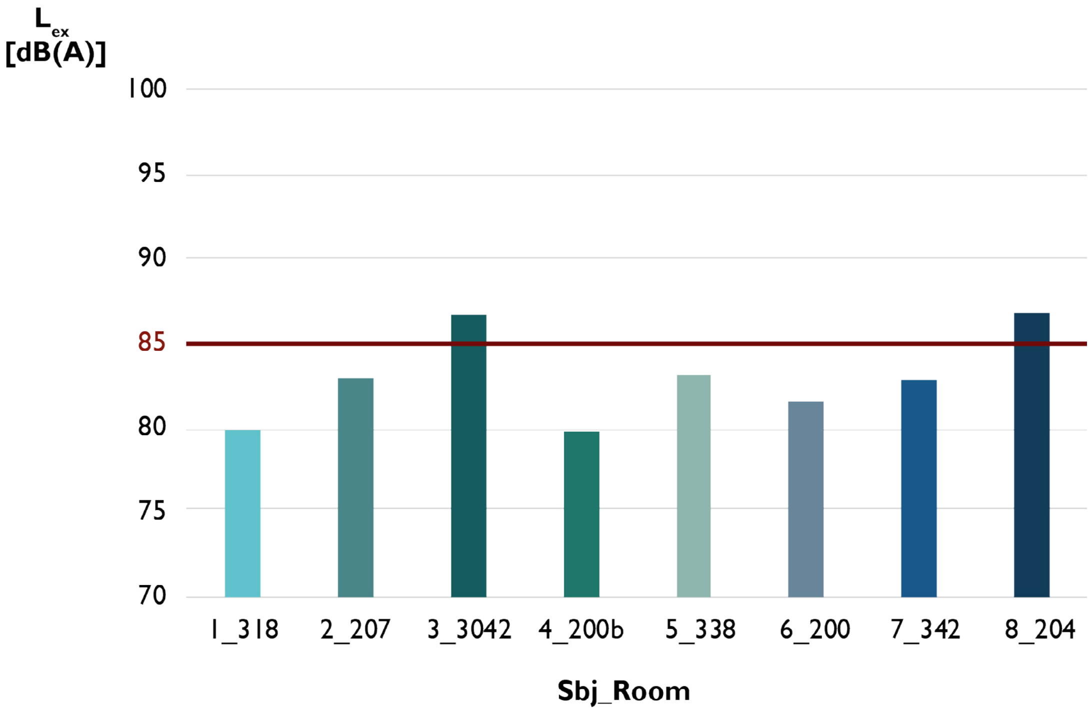
Example of time history from the TASCAM device



Noise exposure results graph from subject 8; Instantaneous level, Equivalent level, percentile levels (L5 and L95). L5 value can be associated with the background noise level of the rooms.

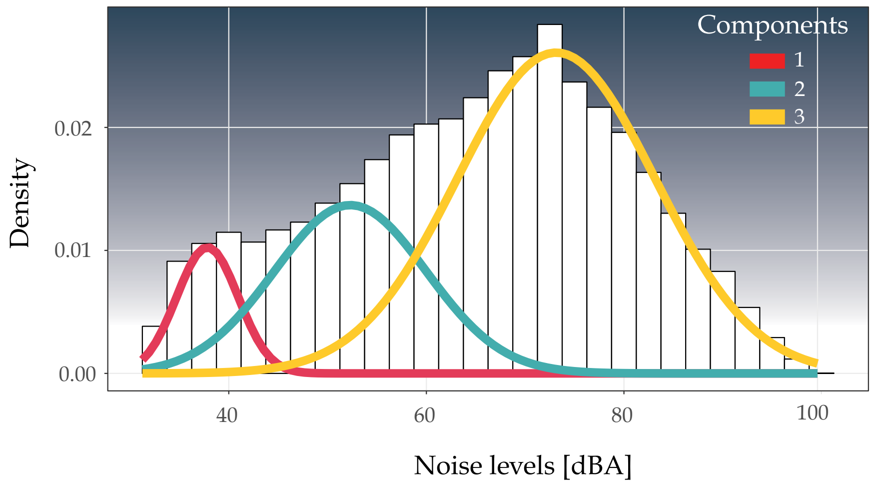
Subject [#]	Duration [hr]	Leq (running) [dB(A)]	Ln95 [dB(A)]	Ln5 [dB(A)]	Lex [dB(A)]
1	3.9	83.0	36.9	81.9	79.9
2	3.8	86.2	35.2	85.6	83.0
3	5.9	88.1	35.6	87.3	86.8
4	3.5	83.4	35.9	82.0	79.8
5	3.5	86.8	41.4	85.9	83.2
6	2.0	87.0	39.3	85.8	81.6
7	3.5	86.5	44.9	89.7	82.9
8	5.7	88.3	37.9	88.1	86.9

Example of time history from the TASCAM device and calculation of Lex to split results in a 8-hour period



Lex levels for each subject and room; it is indicated the limit threshold recommended by the standards

The results obtained from the analysis show that the noise exposure spread on an 8-hour period exceeded 85 dB(A) only in two cases, but, in general, values are really close to the standard limit of 85 dBA.



Distribution of noise levels and their occurrence; subject 8.

From the graph representing the distribution of noise levels through level values (X axis) and occurrence (Y axis) it is possible to understand the different sound sources that are present in the room. The distribution of the levels is showing three different noise components: the lowest graph curve can be reduced to the (1) background noise as it is always lower than 40 dB; the second curve can be associated with the (2) speech; and the third one with sources such as (3) music (singing voice and piano). The sum of the three curves is representing the sum of all the rectangles.

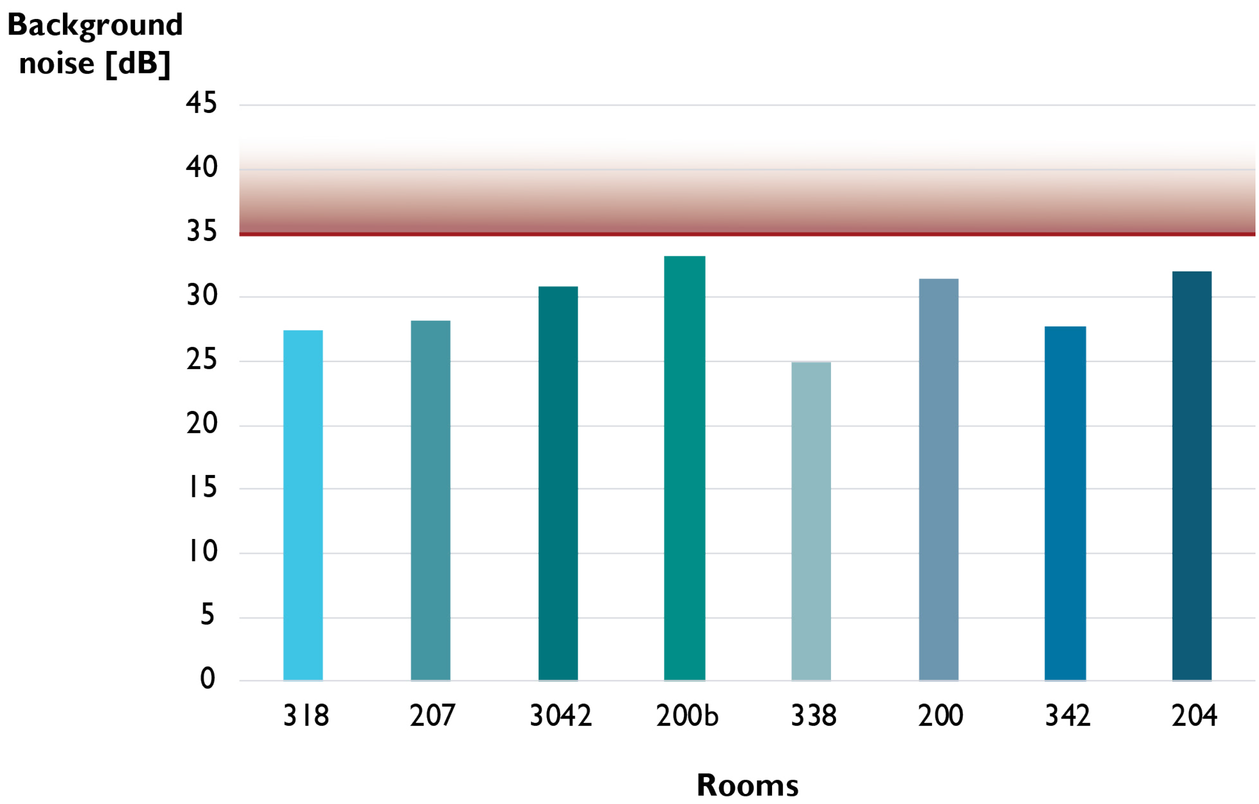
Room acoustics

Subject	Room	Building	Area m^2	Height m^2	Volume m^3
#01	318	Smith Memorial Hall	7.0	2.4	16.9
#02	207	Smith Memorial Hall	21.4	5.4	114.5
#03	3042	Music Building	15.4	2.2	33.1
#04	200b	Smith Memorial Hall	23.5	5.4	125.7
#05	338	Smith Memorial Hall	6.9	2.4	16.7
#06	200	Smith Memorial Hall	20.0	5.4	106.8
#07	342	Smith Memorial Hall	6.9	2.4	16.7
#08	204	Smith Memorial Hall	21.4	4.2	89.9

_Background noise

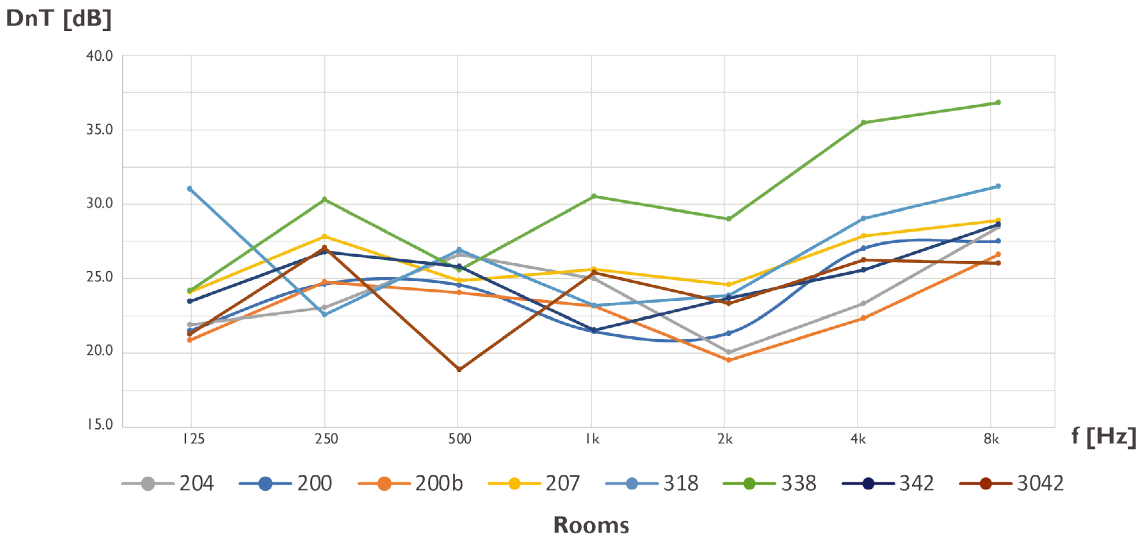
Subject	Room	Building	Area m²	Height m²	Volume m³	Background Noise (La_{eq} (dB))
#01	318	Smith Memorial Hall	7.0	2.4	16.9	27.5
#02	207	Smith Memorial Hall	21.4	5.4	114.5	28.2
#03	3042	Music Building	15.4	2.2	33.1	30.9
#04	200b	Smith Memorial Hall	23.5	5.4	125.7	33.2
#05	338	Smith Memorial Hall	6.9	2.4	16.7	25
#06	200	Smith Memorial Hall	20.0	5.4	106.8	31.5
#07	342	Smith Memorial Hall	6.9	2.4	16.7	27.8
#08	204	Smith Memorial Hall	21.4	4.2	89.9	32.1

Physical characteristics of the rooms and measured background noise levels.

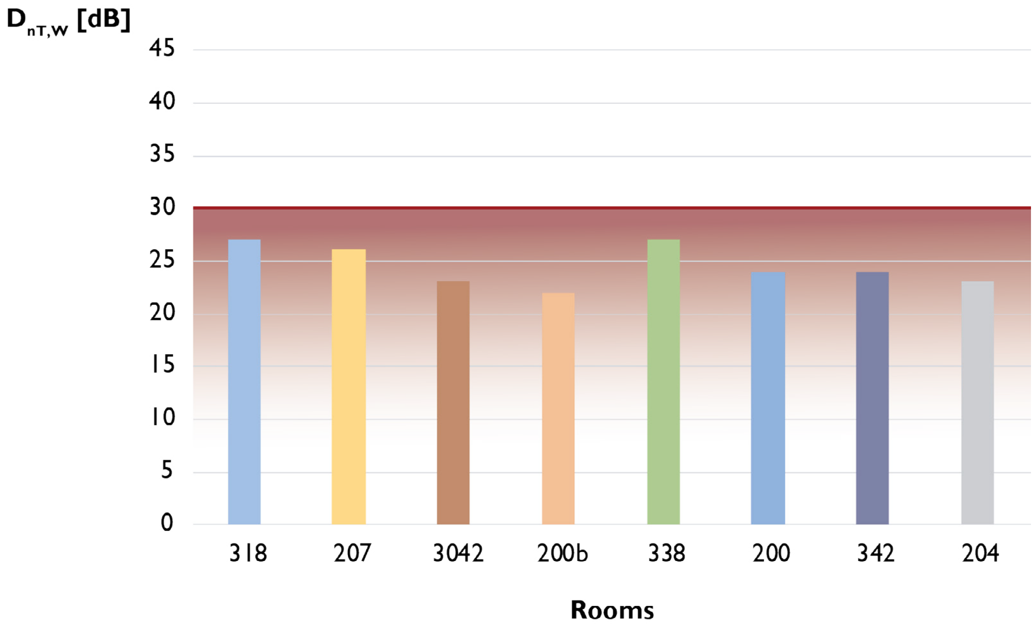


Measured background noise levels;limit value of noise pressure level of the building generated noise ≤ 35 dB; DIN 18041.

_Insulation



D_{nT} measured values.



Dnt,W measured values; limit value UNI11367, AppendixB, Acoustic normalized insulation for common spaces in buildings linked by accesses and openings to living environments. Good performance for hospitals and schools ≥ 30 dB.

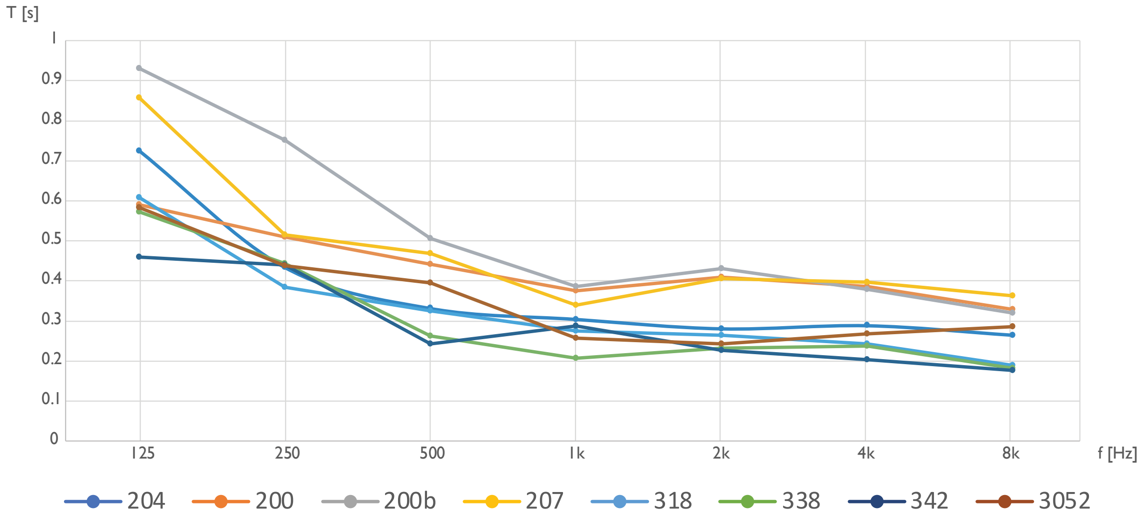
_Reverberation Time

All the classes are following the standards for classroom acoustics considering speech. As the rooms welcome voice classes practice rooms standard values have to be considered.

Concerning reverberation times values, rooms result to be very dry so they can be considered very good for speech purposes. Measured values are not the optimal values for music, but we have to consider that the higher is the reverberation time the higher is the sound produced in the space. With a very dry sound (so low reverberation times) noise levels that are exceeding the standard values have been measured; increasing the reverberation time the noise will increase too consequently. It can be affirmed that it is safer to have a dry environment considering that they are not spaces for music but they are spaces with an educational purpose. Students that learn to control their voice in the worst situation, so in a space with low reverberation, can really learn how to use their voice in the best way and it will be easier for them to sing in other environments with higher reverberation times.

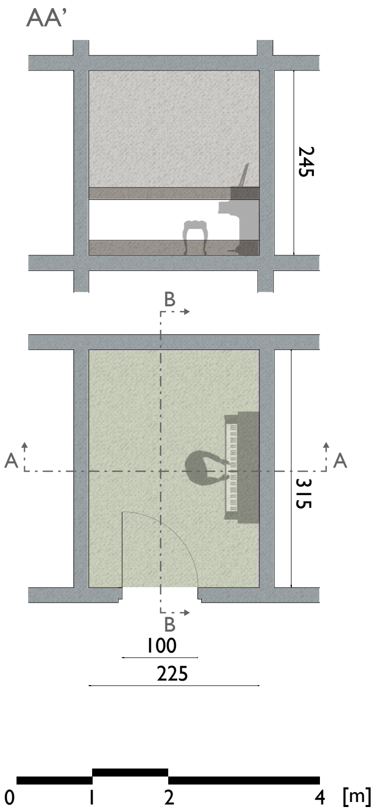
		Frequency range [Hz]						
		125	**250**	**500**	**1k**	**2k**	**4k**	**8k**
Rooms	**204**	0.66	0.39	0.30	0.28	0.26	0.26	0.24
	200	0.54	0.46	0.40	0.34	0.37	0.35	0.30
	200b	0.85	0.69	0.46	0.35	0.39	0.34	0.29
	207	0.78	0.47	0.43	0.31	0.37	0.36	0.33
	318	0.55	0.35	0.30	0.25	0.24	0.22	0.17
	338	0.52	0.40	0.24	0.19	0.21	0.22	0.16
	342	0.42	0.40	0.22	0.26	0.21	0.18	0.16
	3052	0.53	0.40	0.36	0.23	0.22	0.24	0.26

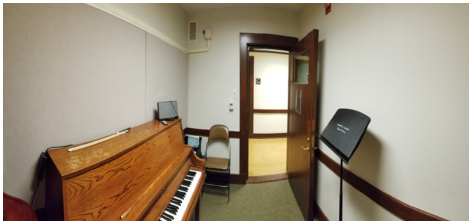
Measured reverberation times (T20) [s]



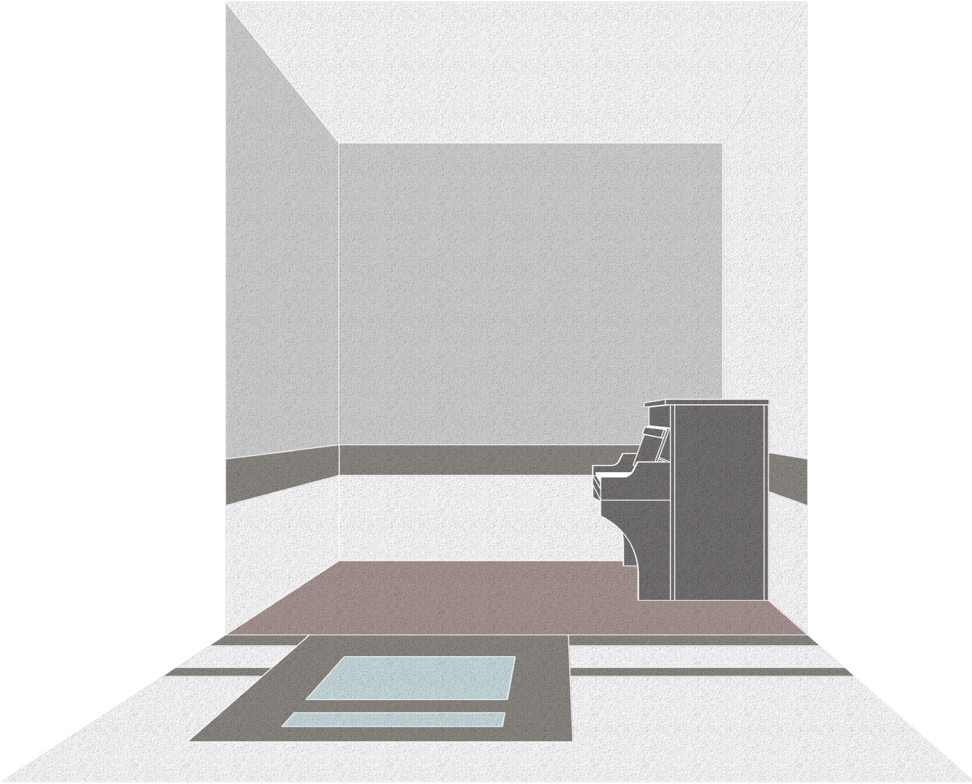
Measured reverberation times T20.

Subject#1_Room 318_Smith Memorial Hall, S Mathews Ave, Urbana





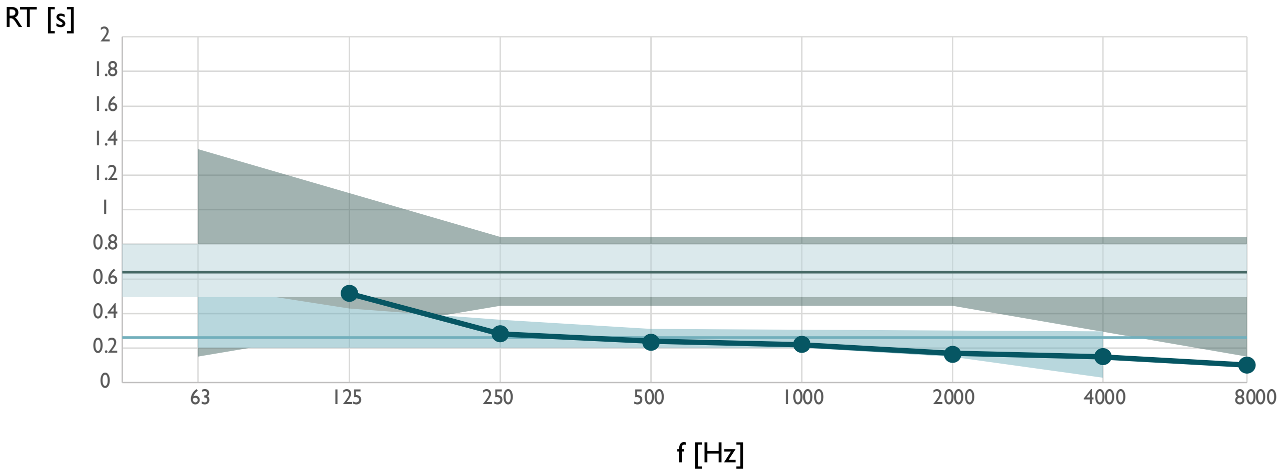
Plan and sections of the room; pictures of the room.



Materials	Frequency range [Hz]							
	63	125	250	500	1000	2000	4000	Surfaces [m^2]
Absorbing panels	0.10	0.10	0.15	0.30	0.60	0.90	0.85	9.60
Wood	0.10	0.19	0.23	0.25	0.25	0.37	0.42	3.40
Glass	0.15	0.15	0.05	0.30	0.03	0.02	0.02	0.60
Carpet	0.00	0.00	0.00	0.00	0.00	0.00	0.01	7.10
Plaster	0.04	0.04	0.05	0.06	0.08	0.04	0.06	3.75
Piano	0.20	0.14	0.10	0.08	0.08	0.08	0.08	4.10

Materials scheme; materials, absorption coefficients and surfaces.

	Frequency range [Hz]						
	125	**250**	**500**	**1k**	**2k**	**4k**	**8k**
Measured RT [s]	0.55	0.34	0.31	0.29	0.24	0.22	0.18
DIN_T_{soll} [s]	0.62	0.62	0.62	0.62	0.62	0.62	0.62
NS_T_m [s]	0.25	0.25	0.25	0.25	0.25	0.25	0.25

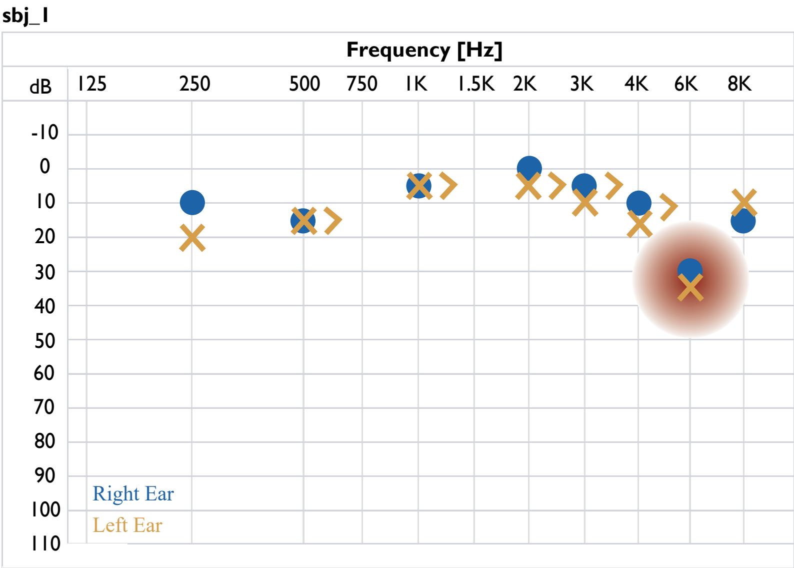


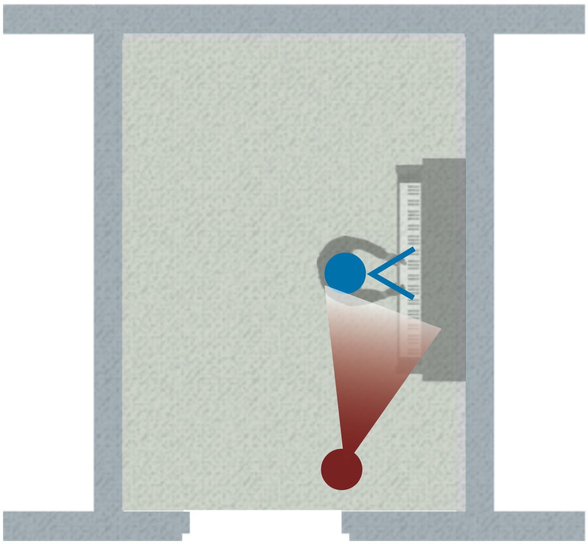
Decreto n.26, Provincia Autonoma di Bolzano. (0.5s-0.8s)

DIN 18041:2016-03. T_{soll}= 0.45lg(V)+0,07) [s]= 1.00 s.

NS 8178:2014. T_m = ($RT_{500,V}$+$RT_{1000,V}$)/2 [s]= 0.65 s.

Reverberation time and comparison with the standards.

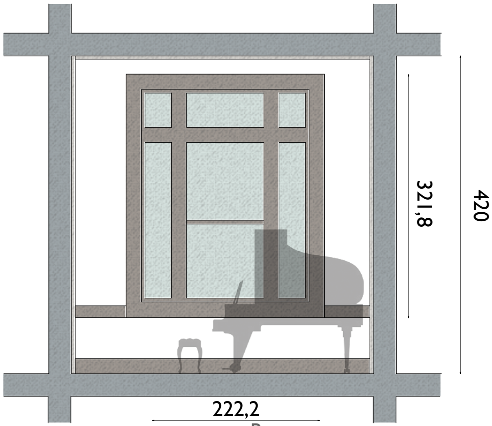




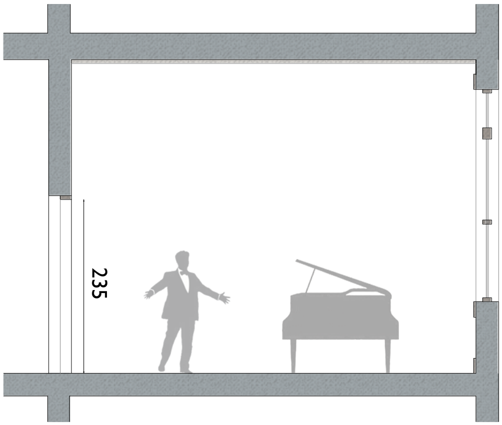
Hearing screening of the subject (receiver): possible noise notch related to the position of the student (source) in the room.

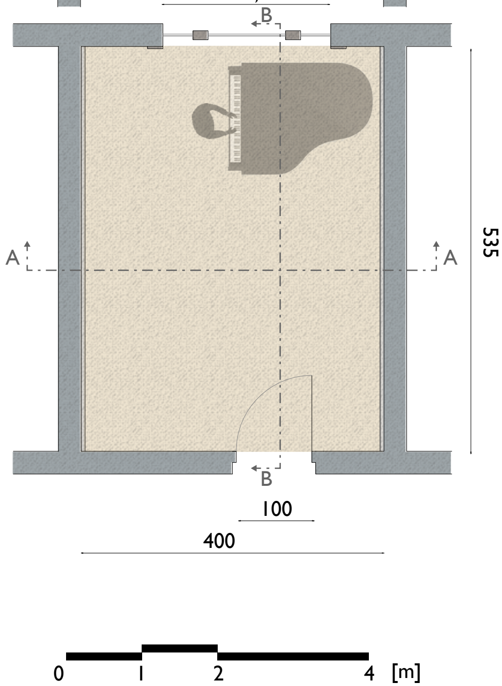
Subject#2_Room 207_Smith Memorial Hall, S Mathews Ave, Urbana

AA'

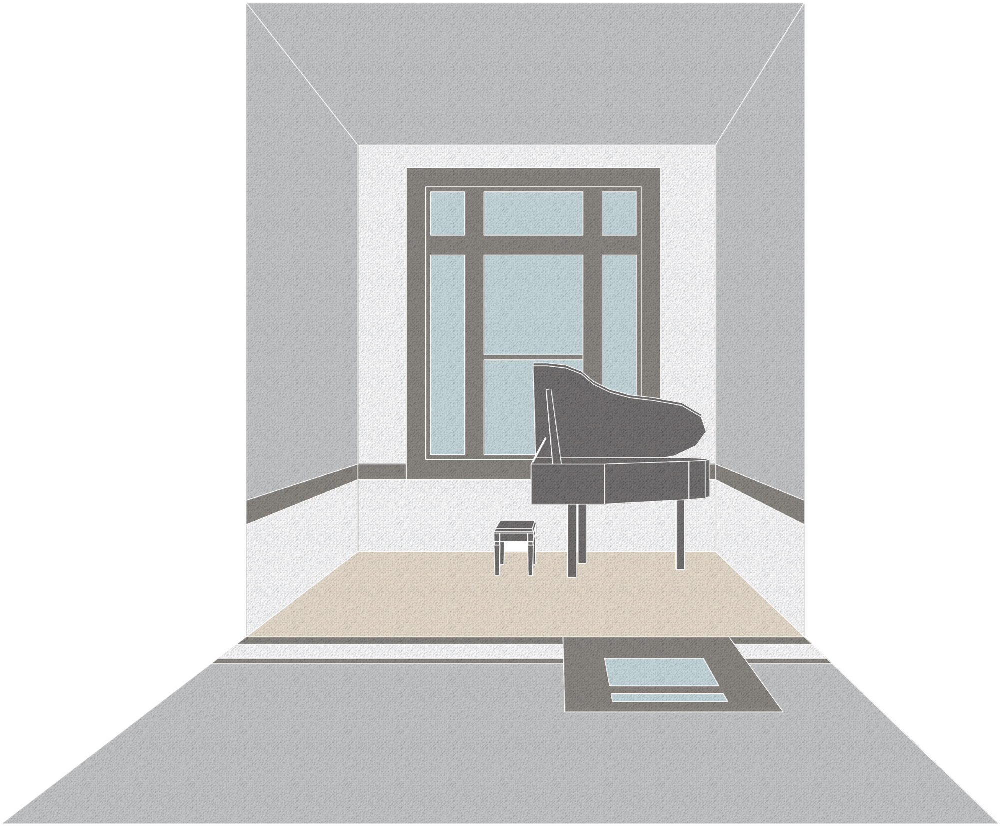


BB'





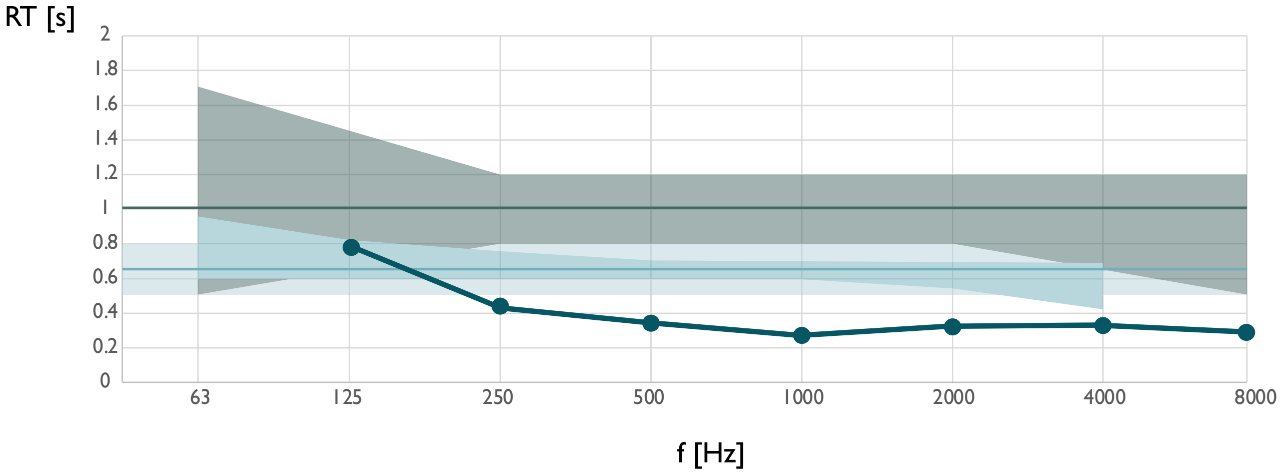
Plan and sections of the room; pictures of the room.



Materials	Frequency range [Hz]							
	63	125	250	500	1000	2000	4000	Surfaces [m^2]
Absorbing panels	0.20	0.20	0.35	0.60	0.70	0.50	0.70	65.60
Wood	0.10	0.19	0.23	0.25	0.25	0.37	0.42	8.10
Glass	0.15	0.15	0.05	0.30	0.03	0.02	0.02	4.90
Linoleum	0.00	0.00	0.00	0.00	0.00	0.00	0.01	19.80
Plaster	0.04	0.04	0.05	0.06	0.08	0.04	0.06	16.40
Piano	0.20	0.14	0.10	0.08	0.08	0.08	0.08	6.20

Materials scheme; materials, absorption coefficients and surfaces.

	Frequency range [Hz]						
	125	**250**	**500**	**1k**	**2k**	**4k**	**8k**
Measured RT [s]	0.78	0.45	0.37	0.30	0.35	0.36	0.32
DIN_T_{soll} [s]	1.00	1.00	1.00	1.00	1.00	1.00	1.00
NS_T_m [s]	0.65	0.65	0.65	0.65	0.65	0.65	0.65

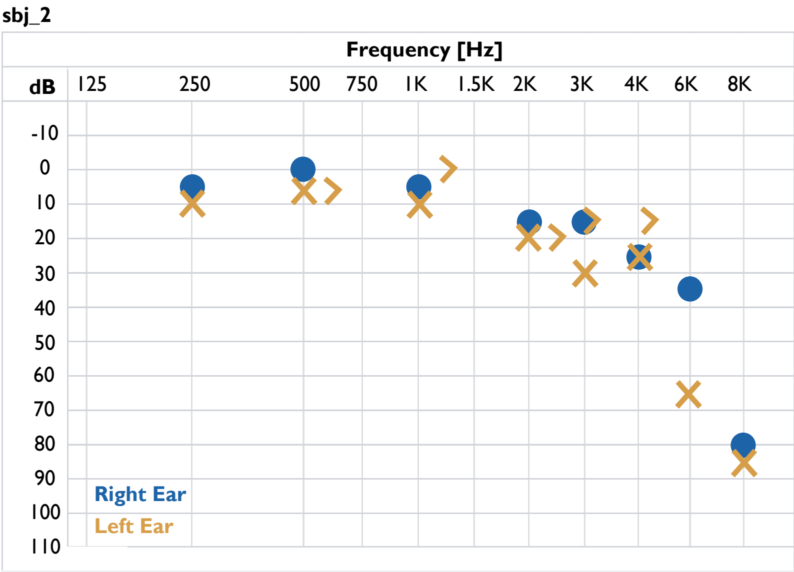


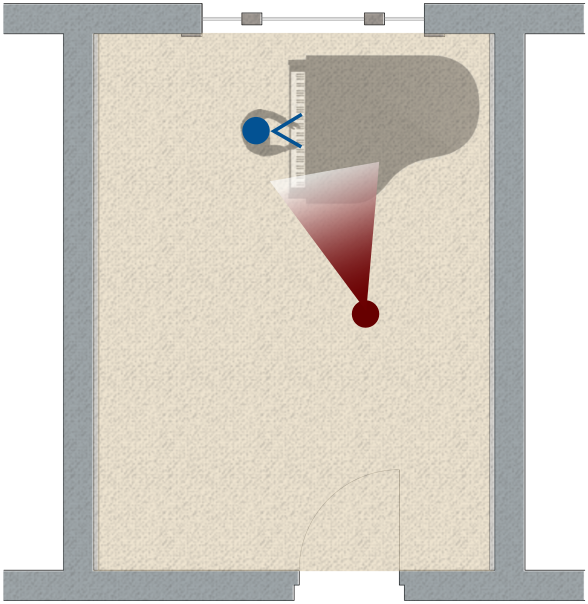
Decreto n.26, Provincia Autonoma di Bolzano. (0.5s-0.8s)

DIN 18041:2016-03. T_{soll}= 0.45lg(V)+0,07) [s]= 1.00 s.

NS 8178:2014. T_m = ($RT_{500,V}$+$RT_{1000,V}$)/2 [s]= 0.65 s.

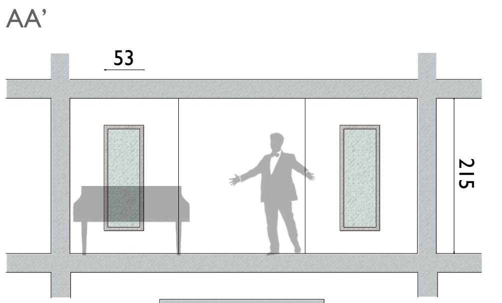
Reverberation time and comparison with the standards.

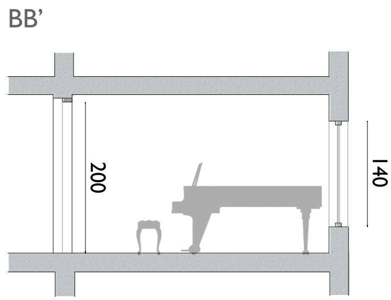


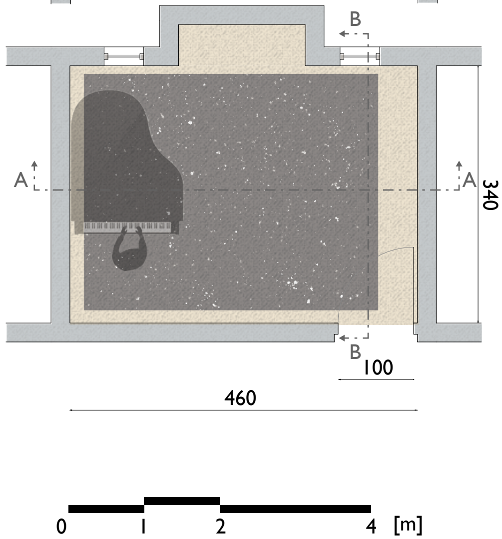


Hearing screening of the subject (receiver): possible noise notch related to the position of the student (source) in the room.

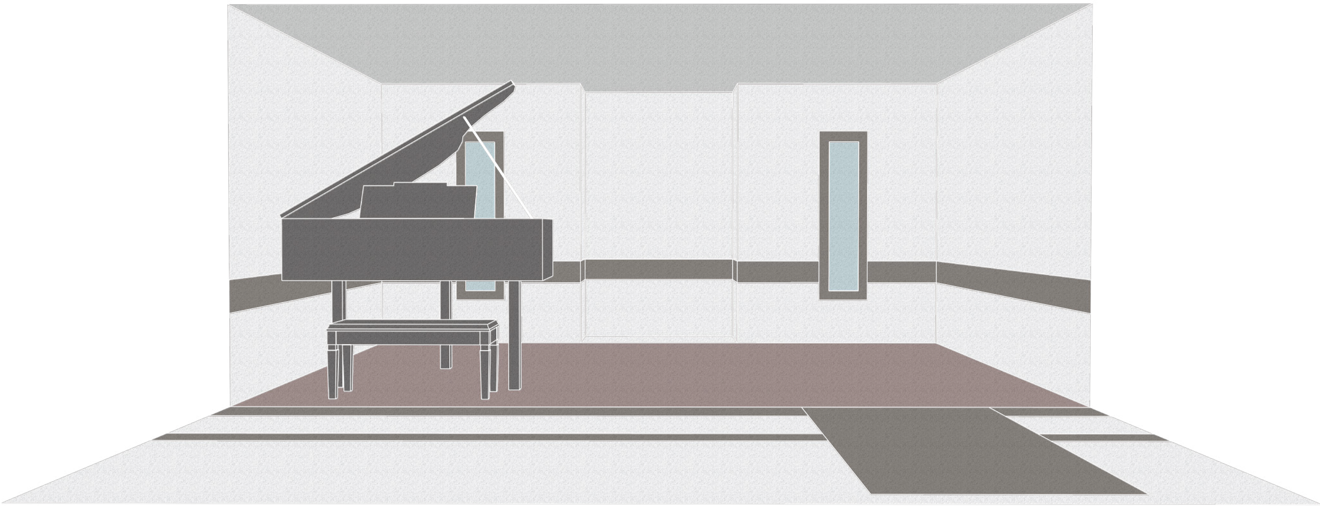
Subject#3_Room 3042_Music Building, W Nevada St, Urbana







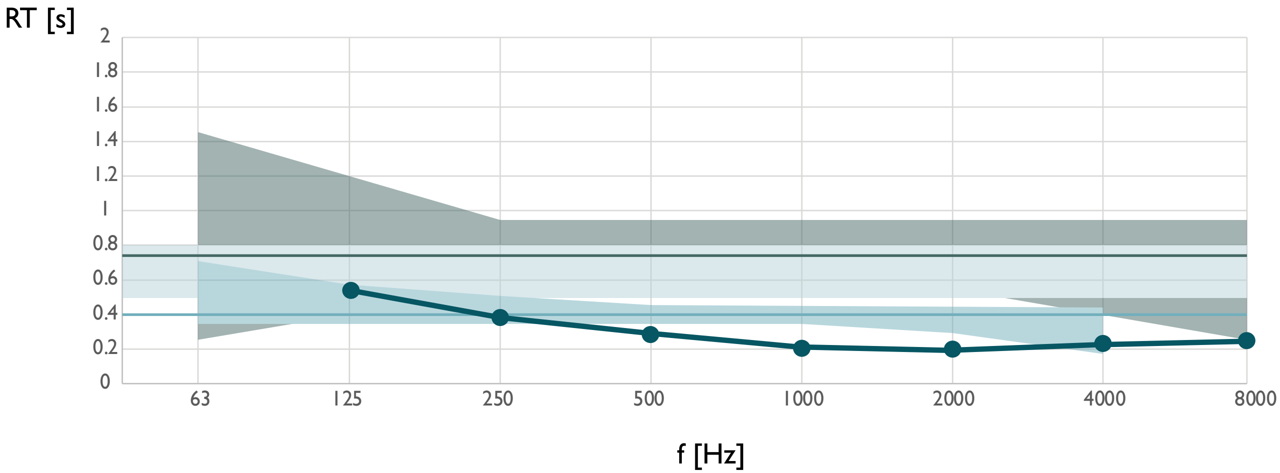
Plan and sections of the room; pictures of the room.



Materials	Frequency range [Hz]							
	63	125	250	500	1000	2000	4000	Surfaces [m^2]
Gypsum panels	0.20	0.20	0.35	0.60	0.70	0.50	0.70	16.40
Wood	0.10	0.19	0.23	0.25	0.25	0.37	0.42	2.50
Glass	0.15	0.15	0.05	0.30	0.03	0.02	0.02	0.60
Carpet	0.00	0.00	0.00	0.00	0.00	0.00	0.01	15.50
Plaster	0.04	0.04	0.05	0.06	0.08	0.04	0.06	27.10
Piano	0.20	0.14	0.10	0.08	0.08	0.08	0.08	6.20

Materials scheme; materials, absorption coefficients and surfaces.

	Frequency range [Hz]						
	125	**250**	**500**	**1k**	**2k**	**4k**	**8k**
Measured RT [s]	0.55	0.40	0.31	0.23	0.22	0.25	0.26
DIN_T_{soll} [s]	0.75	0.75	0.75	0.75	0.75	0.75	0.75
NS_T_m [s]	0.40	0.40	0.40	0.40	0.40	0.40	0.40

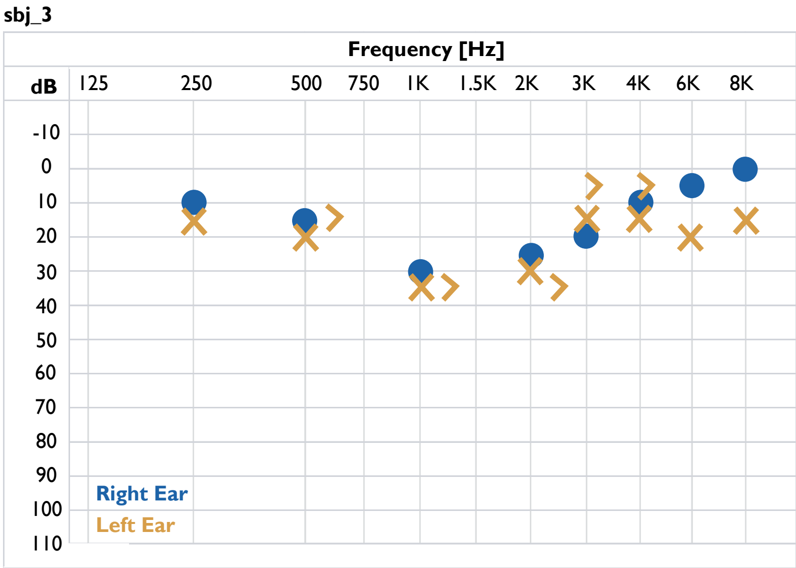


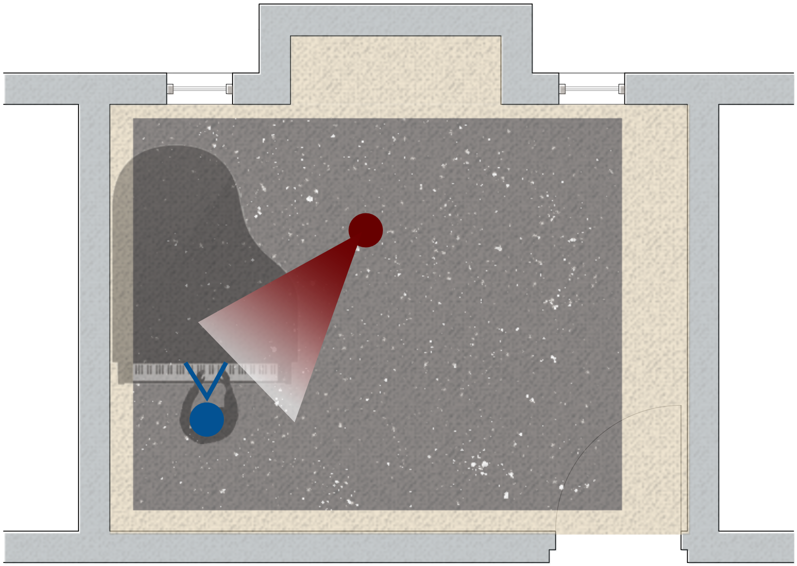
Decreto n.26, Provincia Autonoma di Bolzano. (0.5s-0.8s)

DIN 18041:2016-03. T_{soll}= 0.45lg(V)+0,07) [s]= 0.75 s.

NS 8178:2014. T_m = ($RT_{500,V}$+$RT_{1000,V}$)/2 [s]= 0.40 s.

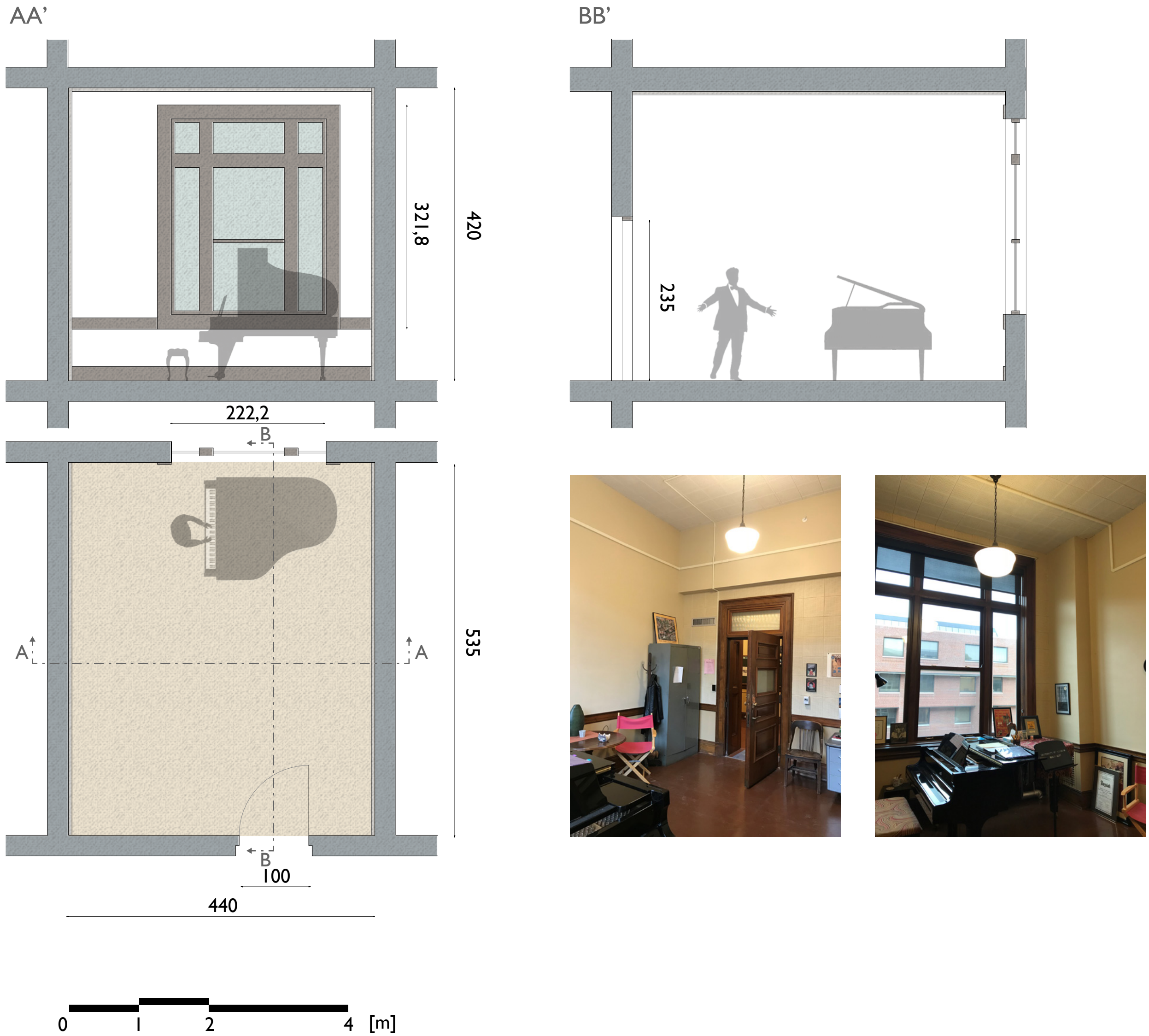
Reverberation time and comparison with the standards.



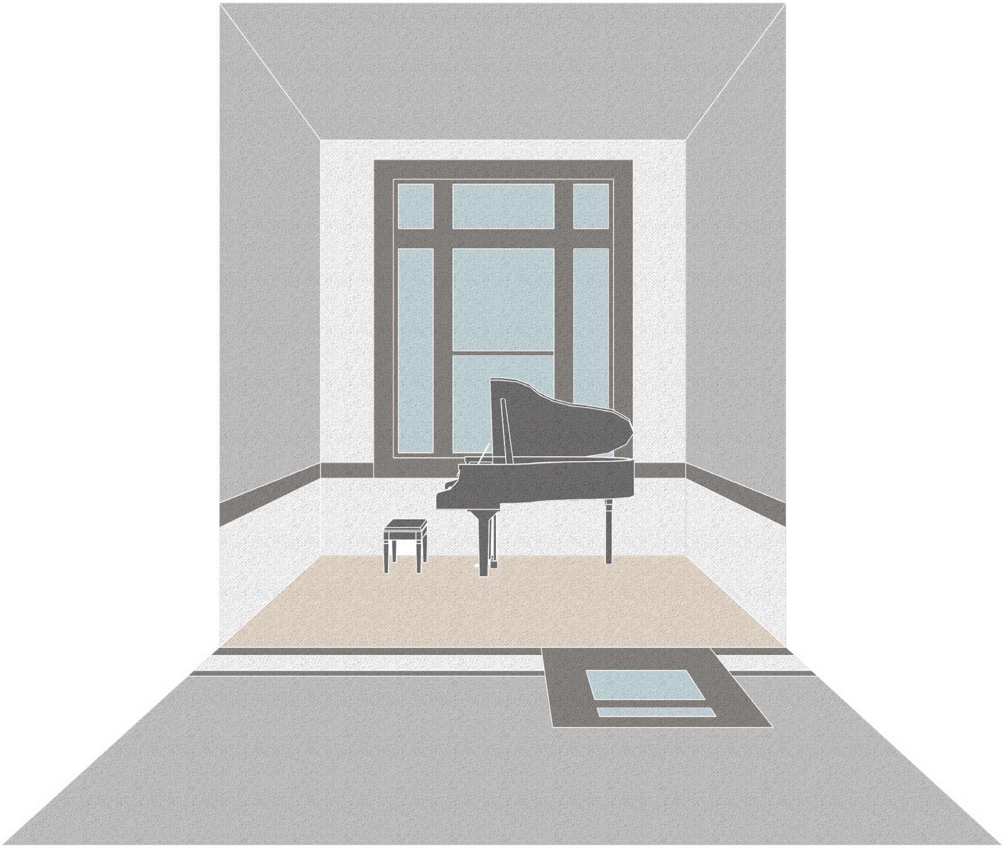


Hearing screening of the subject (receiver): possible noise notch related to the position of the student (source) in the room.

Subject#4_Room 200b_Smith Memorial Hall, S Mathews Ave, Urbana



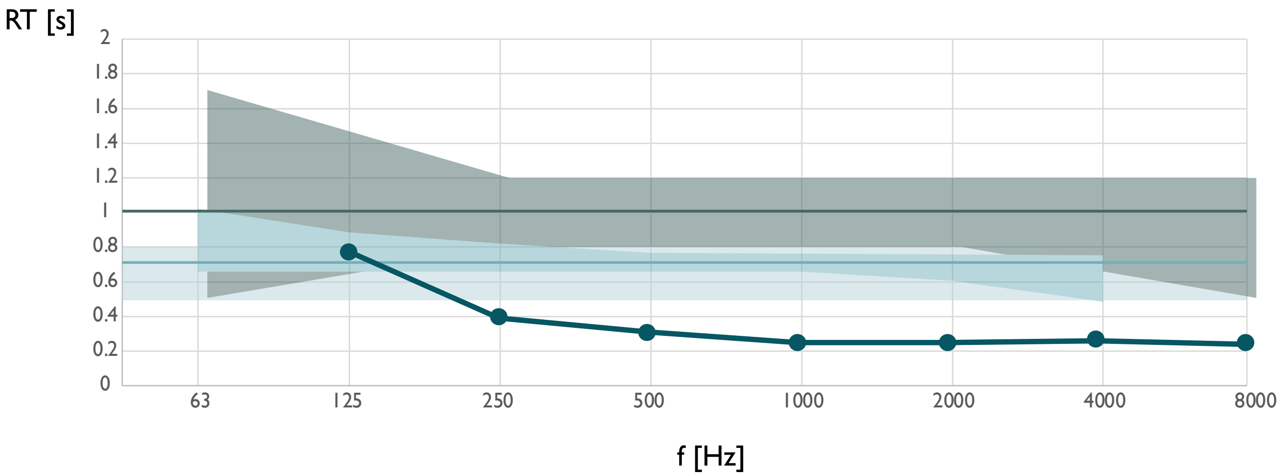
Plan and sections of the room; pictures of the room.



Materials	Frequency range [Hz]							
	63	125	250	500	1000	2000	4000	Surfaces [m^2]
Absorbing panels	0.20	0.20	0.35	0.60	0.70	0.50	0.70	65.60
Wood	0.10	0.19	0.23	0.25	0.25	0.37	0.42	8.10
Glass	0.15	0.15	0.05	0.30	0.03	0.02	0.02	4.90
Linoleum	0.00	0.00	0.00	0.00	0.00	0.00	0.01	19.80
Plaster	0.04	0.04	0.05	0.06	0.08	0.04	0.06	16.40
Piano	0.20	0.14	0.10	0.08	0.08	0.08	0.08	6.20

Materials scheme; materials, absorption coefficients and surfaces.

	Frequency range [Hz]						
	125	**250**	**500**	**1k**	**2k**	**4k**	**8k**
Measured RT [s]	0.93	0.65	0.44	0.35	0.39	0.34	0.29
DIN_T_{soll} [s]	1.01	1.01	1.01	1.01	1.01	1.01	1.01
NS_T_m [s]	0.73	0.73	0.73	0.73	0.73	0.73	0.73



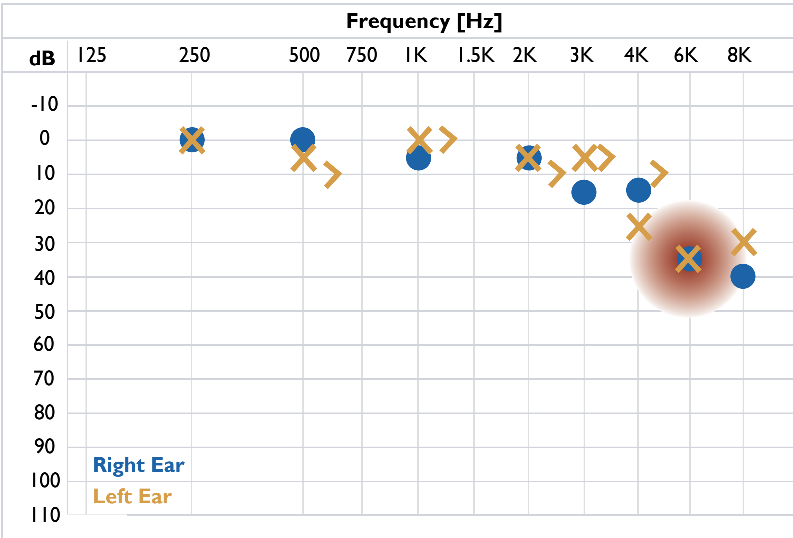
Decreto n.26, Provincia Autonoma di Bolzano. (0.5s-0.8s)

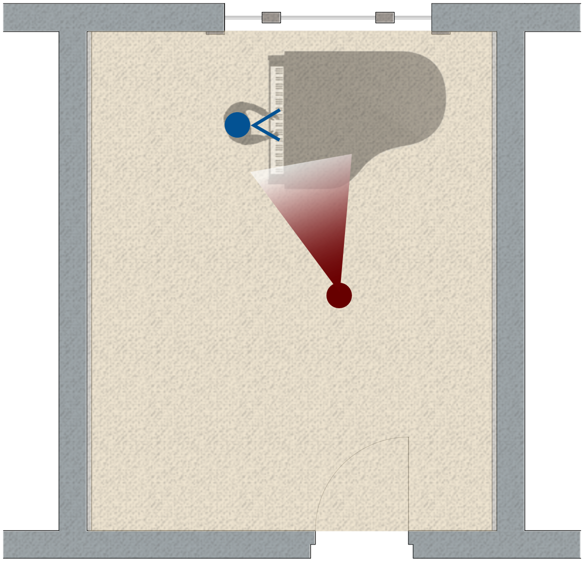
DIN 18041:2016-03. T_{soll}= 0.45lg(V)+0,07) [s]= 1.01 s.

NS 8178:2014. T_m = $(RT_{500,V}+RT_{1000,V})/2$ [s]= 0.73 s.

Reverberation time and comparison with the standards.

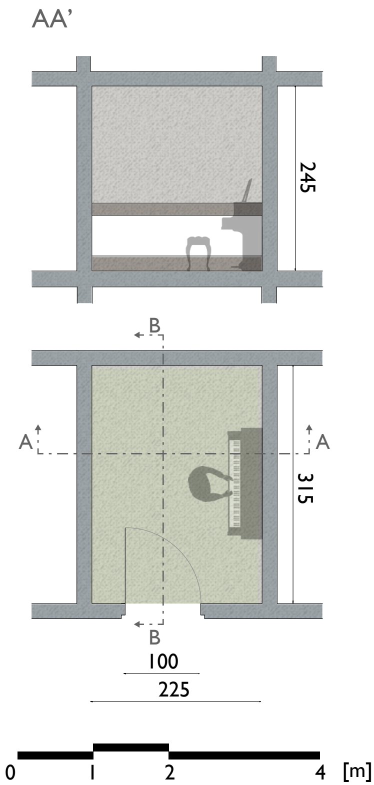
sbj_4

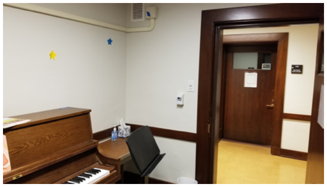


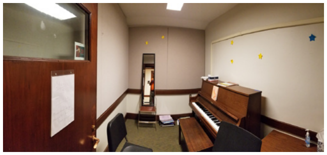


Hearing screening of the subject (receiver): possible noise notch related to the position of the student (source) in the room.

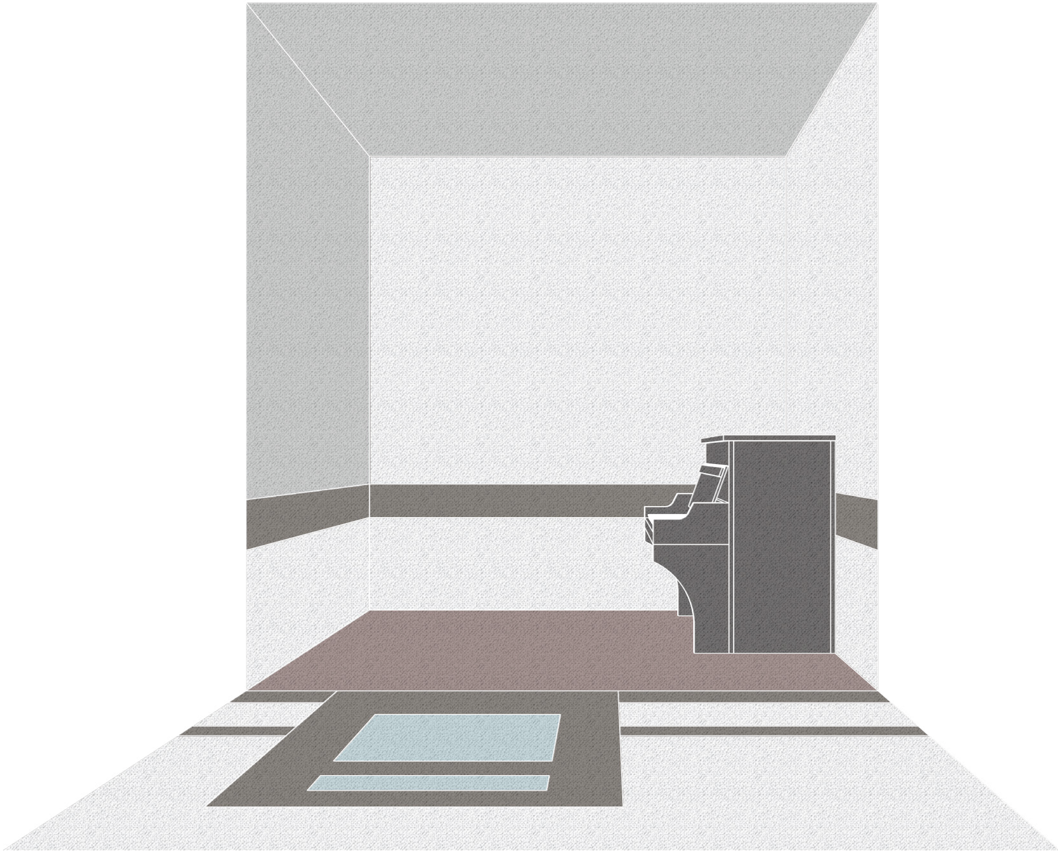
Subject#5_Room 338_Smith Memorial Hall, S Mathews Ave, Urbana







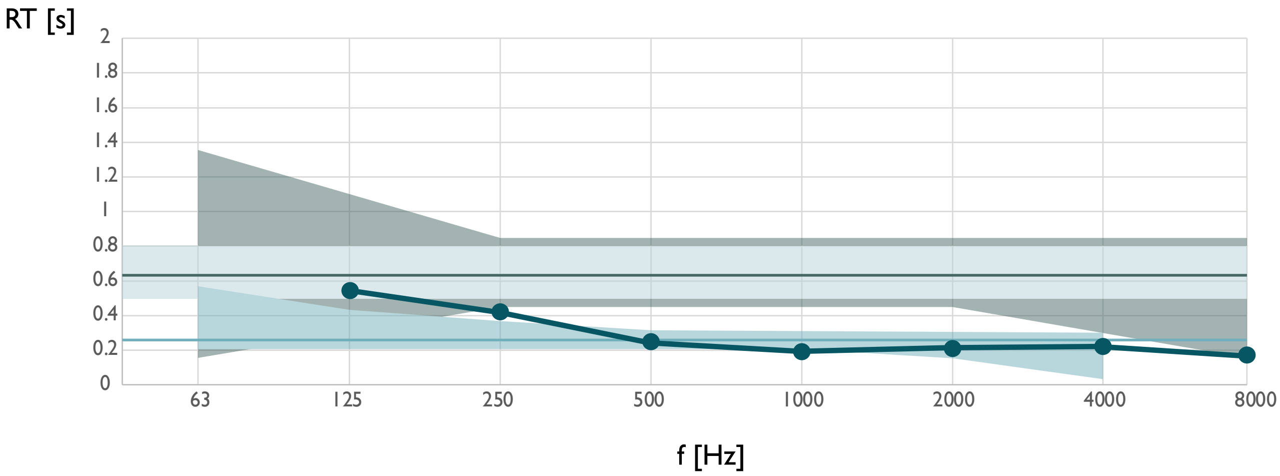
Plan and sections of the room; pictures of the room.



Materials	Frequency range [Hz]							
	63	125	250	500	1000	2000	4000	Surfaces [m^2]
Absorbing panels	0.10	0.10	0.15	0.30	0.60	0.90	0.85	9.60
Wood	0.10	0.19	0.23	0.25	0.25	0.37	0.42	3.40
Glass	0.15	0.15	0.05	0.30	0.03	0.02	0.02	0.60
Carpet	0.00	0.00	0.00	0.00	0.00	0.00	0.01	7.10
Plaster	0.04	0.04	0.05	0.06	0.08	0.04	0.06	3.75
Piano	0.20	0.14	0.10	0.08	0.08	0.08	0.08	4.10

Materials scheme; materials, absorption coefficients and surfaces.

	Frequency range [Hz]						
	125	**250**	**500**	**1k**	**2k**	**4k**	**8k**
Measured RT [s]	0.52	0.40	0.24	0.19	0.21	0.22	0.16
DIN_T_{soll} [s]	0.62	0.62	0.62	0.62	0.62	0.62	0.62
NS_T_m [s]	0.25	0.25	0.25	0.25	0.25	0.25	0.25

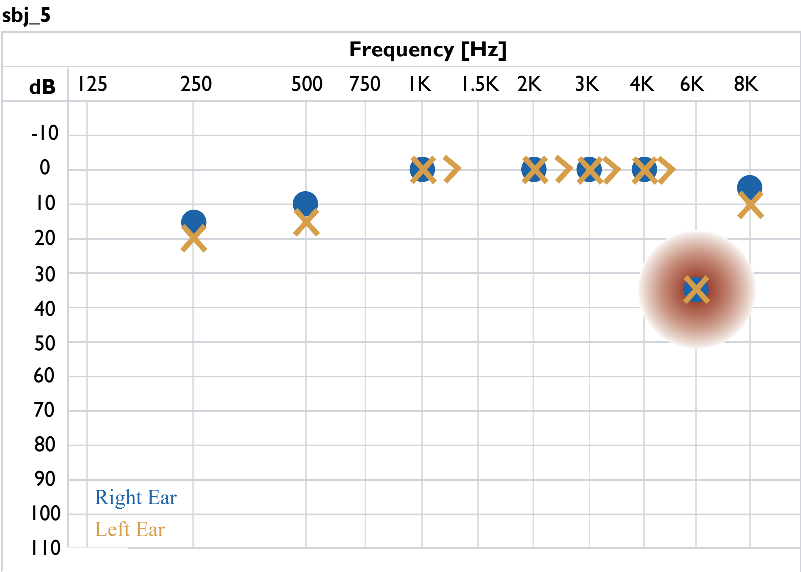


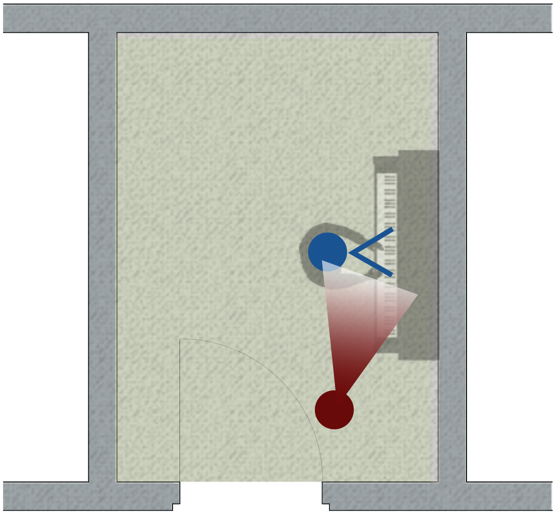
Decreto n.26, Provincia Autonoma di Bolzano. (0.5s-0.8s)

DIN 18041:2016-03. T_{soll}= 0.45lg(V)+0,07) [s]= 0.62 s.

NS 8178:2014. T_m = ($RT_{500,V}$+$RT_{1000,V}$)/2 [s]= 0.25 s.

Reverberation time and comparison with the standards.

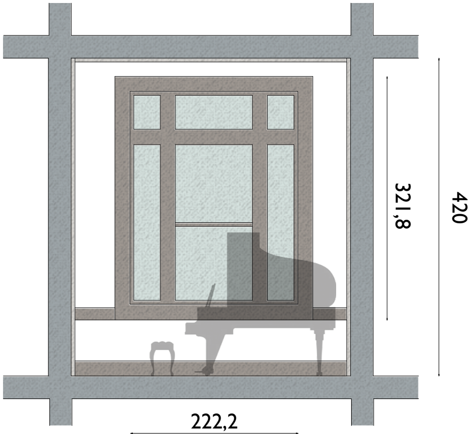




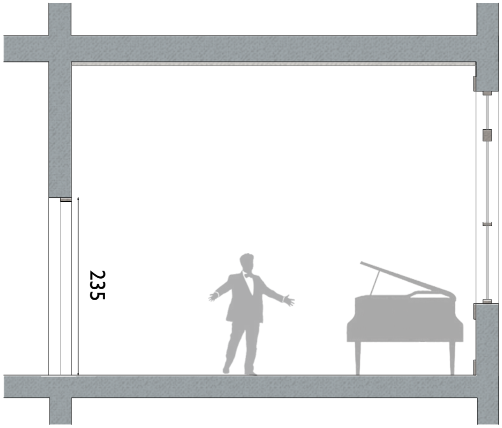
Hearing screening of the subject (receiver): possible noise notch related to the position of the student (source) in the room.

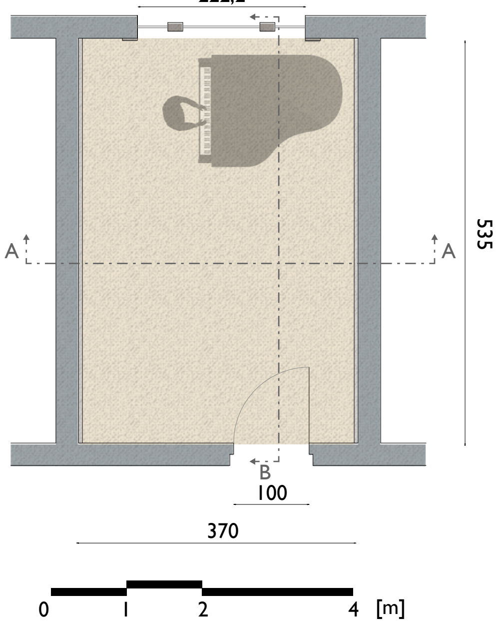
Subject#6_Room 200_Smith Memorial Hall, S Mathews Ave, Urbana

AA’

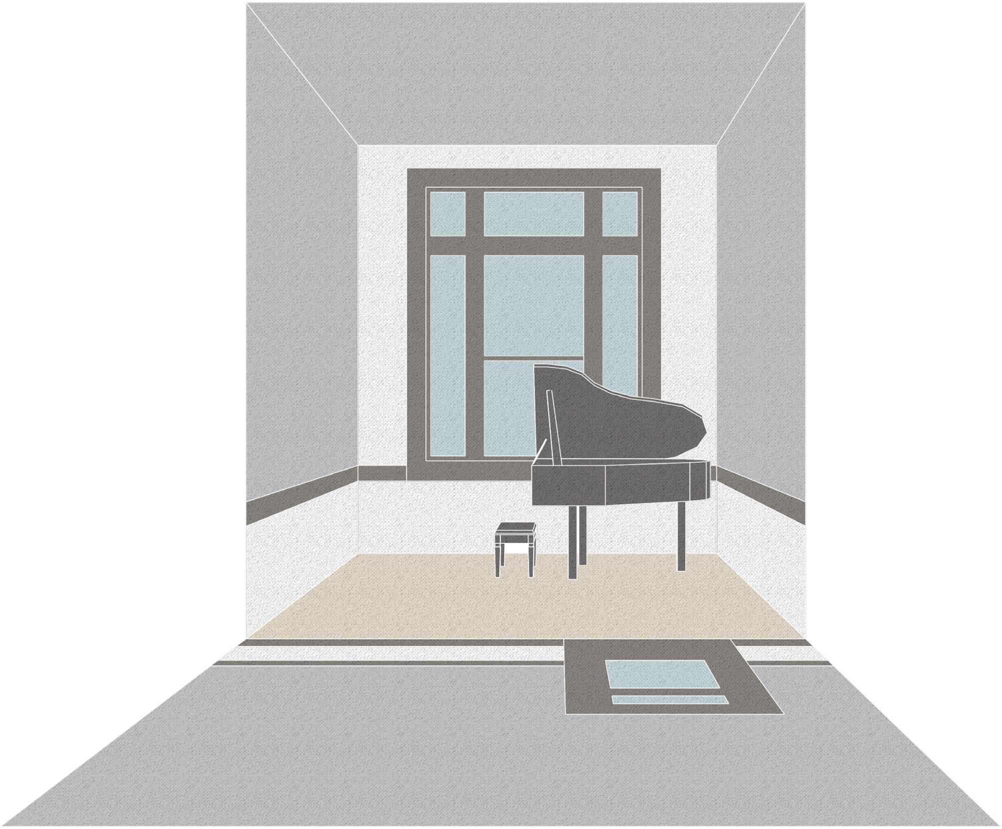


BB’





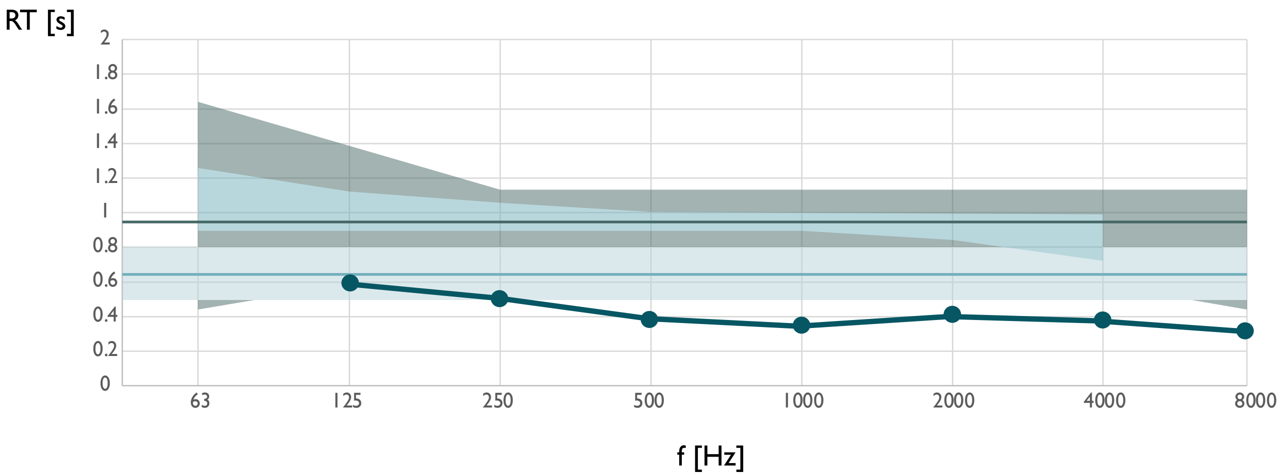
Plan and sections of the room; pictures of the room.



Materials	Frequency range [Hz]							
	63	125	250	500	1000	2000	4000	Surfaces [m^2]
Absorbing panels	0.20	0.20	0.35	0.60	0.70	0.50	0.70	65.60
Wood	0.10	0.19	0.23	0.25	0.25	0.37	0.42	8.10
Glass	0.15	0.15	0.05	0.30	0.03	0.02	0.02	4.90
Linoleum	0.00	0.00	0.00	0.00	0.00	0.00	0.01	19.80
Plaster	0.04	0.04	0.05	0.06	0.08	0.04	0.06	16.40
Piano	0.20	0.14	0.10	0.08	0.08	0.08	0.08	6.20

Materials scheme; materials, absorption coefficients and surfaces.

	Frequency range [Hz]						
	125	**250**	**500**	**1k**	**2k**	**4k**	**8k**
Measured RT [s]	0.57	0.49	0.38	0.33	0.39	0.36	0.30
DIN_T_{soll} [s]	0.98	0.98	0.98	0.98	0.98	0.98	0.98
NS_T_m [s]	0.63	0.63	0.63	0.63	0.63	0.63	0.63

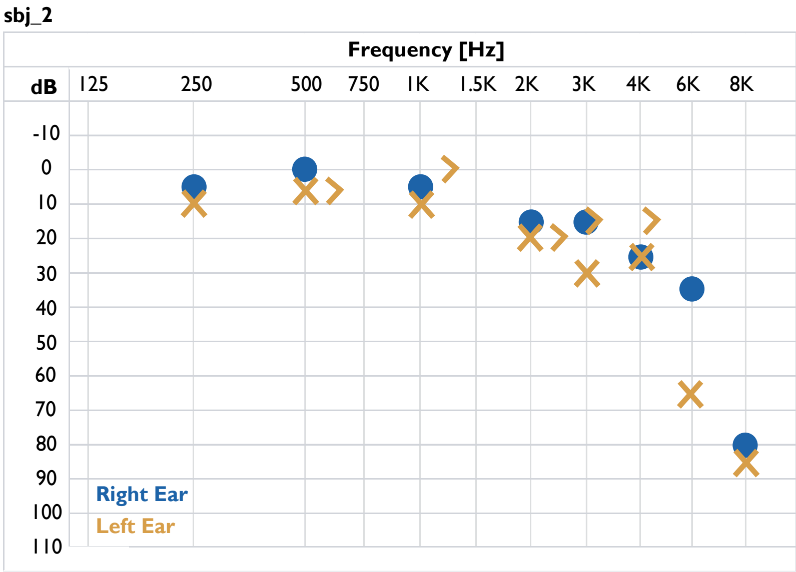


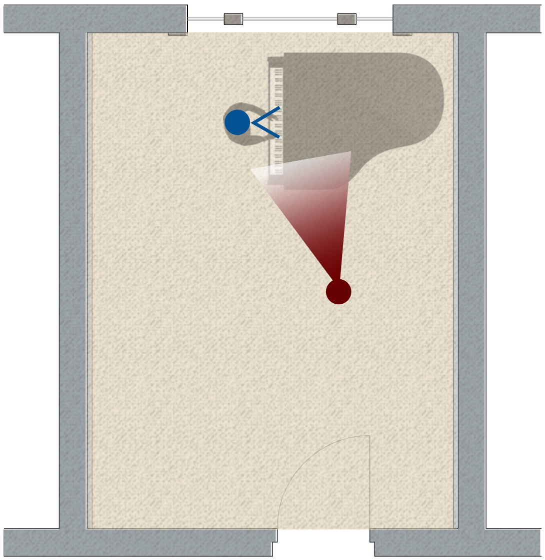
Decreto n.26, Provincia Autonoma di Bolzano. (0.5s-0.8s)

DIN 18041:2016-03. T_{soll}= 0.45lg(V)+0,07) [s]= 0.98 s.

NS 8178:2014. T_m = $(RT_{500,V}+RT_{1000,V})/2$ [s]= 0.63 s.

Reverberation time and comparison with the standards.

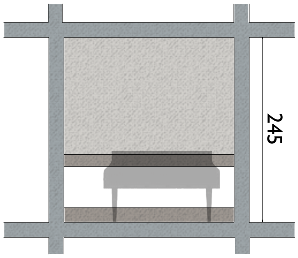




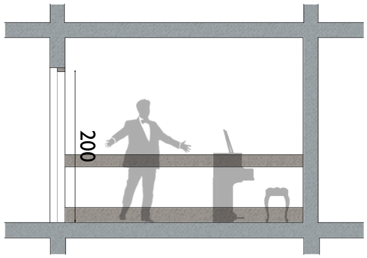
Hearing screening of the subject (receiver): possible noise notch related to the position of the student (source) in the room.

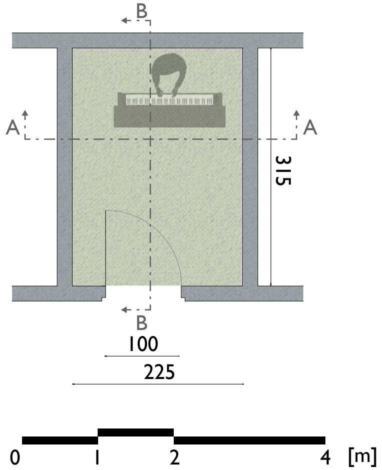
Subject#7_Room 342_Smith Memorial Hall, S Mathews Ave, Urbana

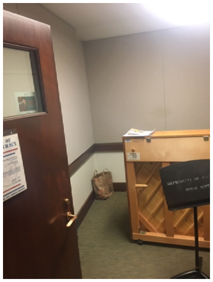
AA'



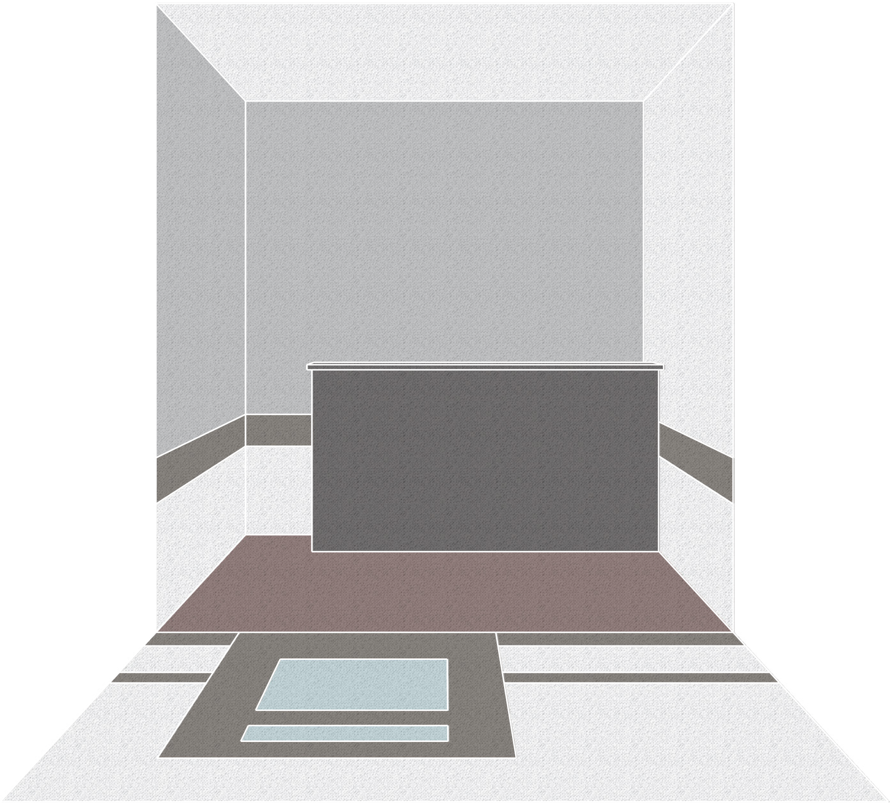
BB'







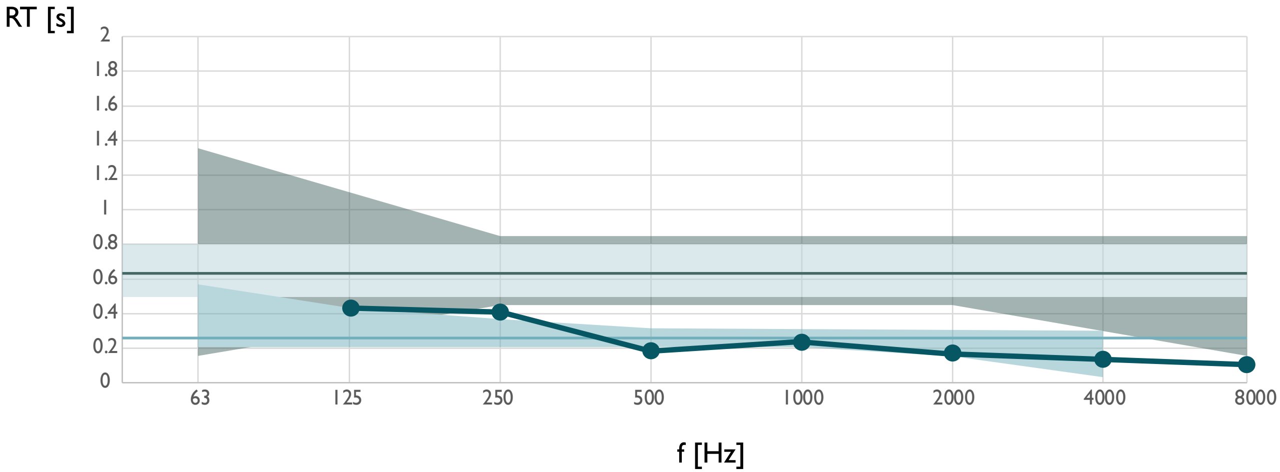
Plan and sections of the room; pictures of the room.



Materials	Frequency range [Hz]							
	63	125	250	500	1000	2000	4000	Surfaces [m^2]
Absorbing panels	0.10	0.10	0.15	0.30	0.60	0.90	0.85	9.60
Wood	0.10	0.19	0.23	0.25	0.25	0.37	0.42	3.40
Glass	0.15	0.15	0.05	0.30	0.03	0.02	0.02	0.60
Carpet	0.00	0.00	0.00	0.00	0.00	0.00	0.01	7.10
Plaster	0.04	0.04	0.05	0.06	0.08	0.04	0.06	3.75
Piano	0.20	0.14	0.10	0.08	0.08	0.08	0.08	4.10

Materials scheme; materials, absorption coefficients and surfaces.

	Frequency range [Hz]						
	125	**250**	**500**	**1k**	**2k**	**4k**	**8k**
Measured RT [s]	0.42	0.40	0.22	0.26	0.21	0.18	0.16
DIN_T_{soll} [s]	0.62	0.62	0.62	0.62	0.62	0.62	0.62
NS_T_m [s]	0.25	0.25	0.25	0.25	0.25	0.25	0.25

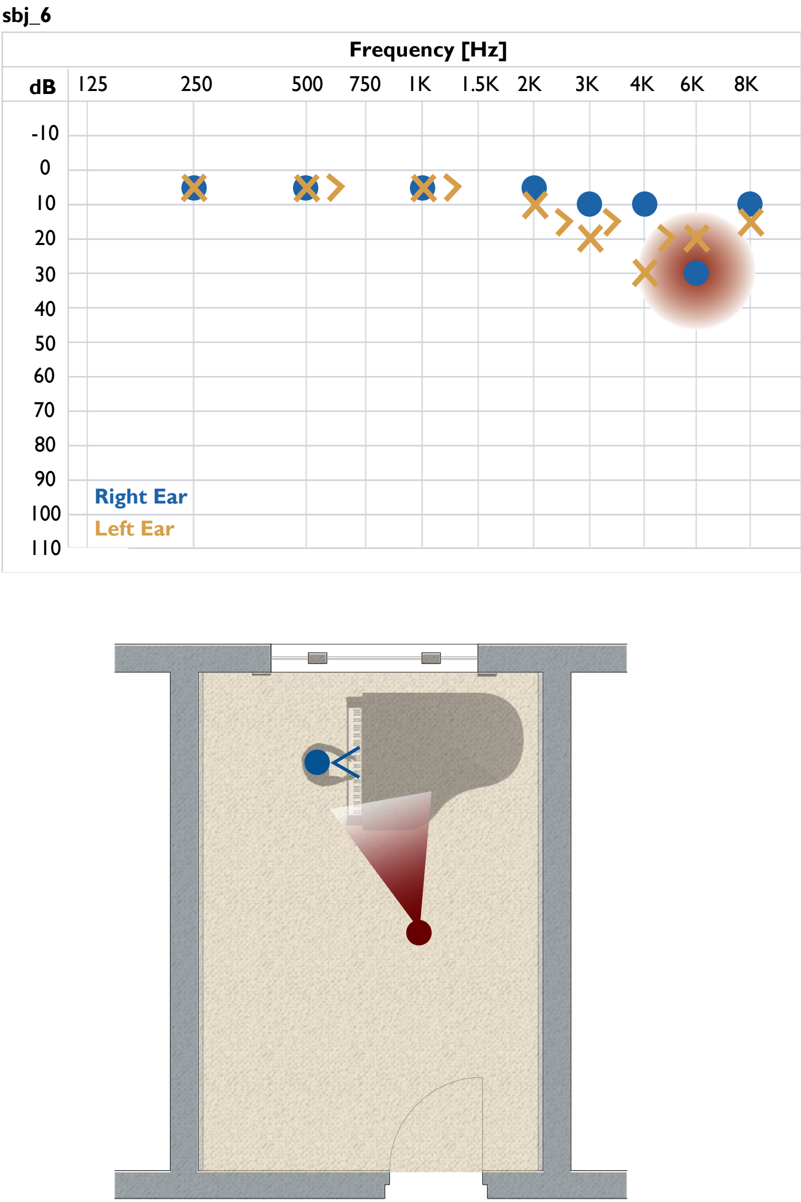


Decreto n.26, Provincia Autonoma di Bolzano. (0.5s-0.8s)

DIN 18041:2016-03. T_{soll}= 0.45lg(V)+0,07) [s]= 0.62 s.

NS 8178:2014. T_m = ($RT_{500,V}$+$RT_{1000,V}$)/2 [s]= 0.25 s.

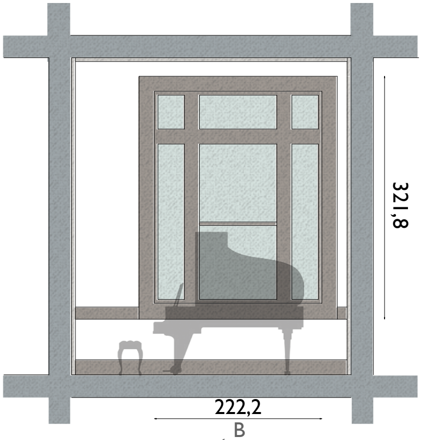
Reverberation time and comparison with the standards.



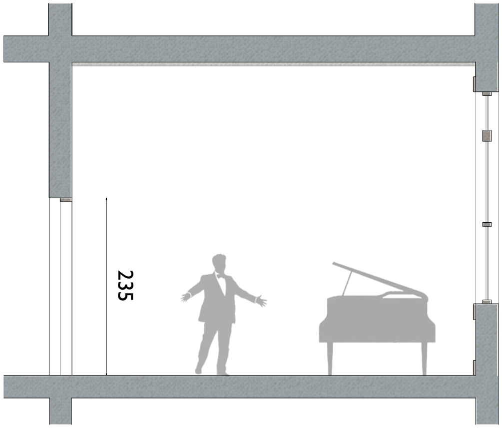
Hearing screening of the subject (receiver): possible noise notch related to the position of the student (source) in the room.

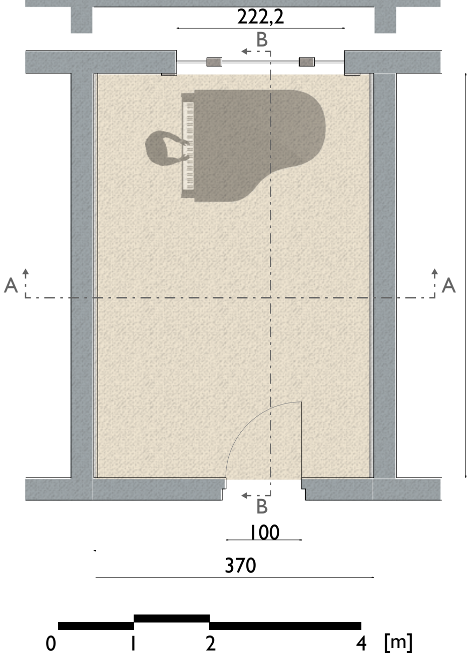
Subject#8_Room 204_Smith Memorial Hall, S Mathews Ave, Urbana

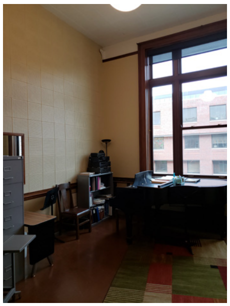
AA'

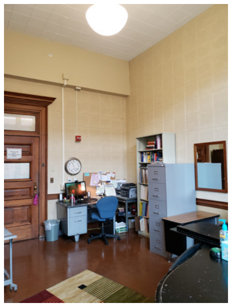


BB'

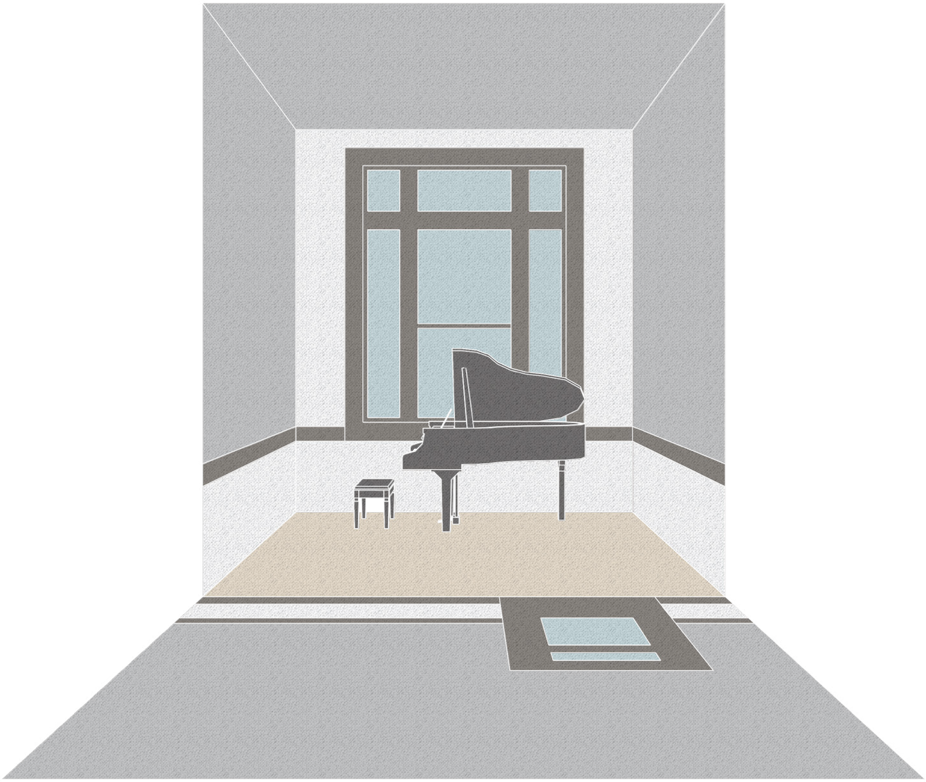








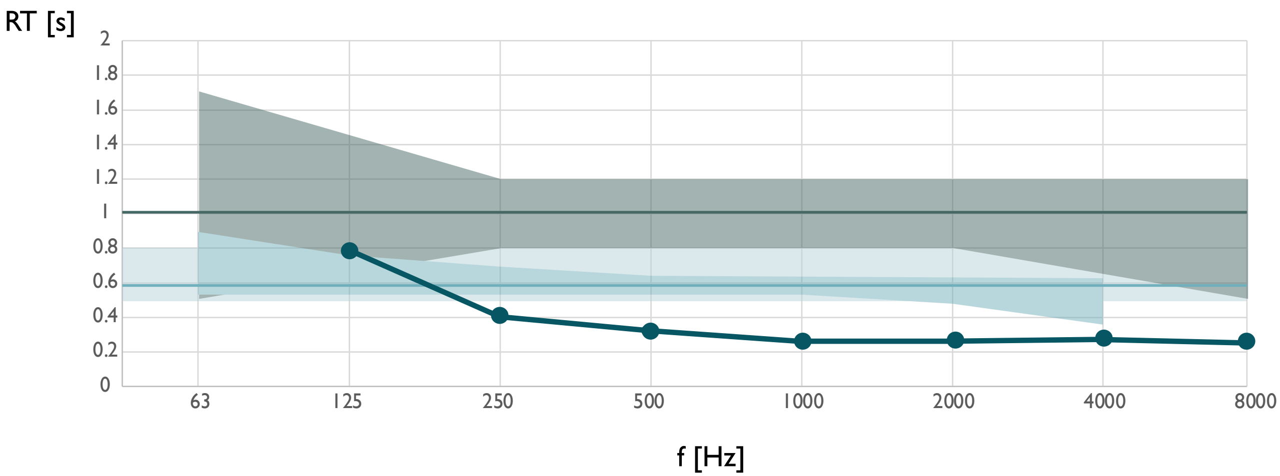
Plan and sections of the room; pictures of the room.



Materials	Frequency range [Hz]							
	63	125	250	500	1000	2000	4000	Surfaces [m^2]
Absorbing panels	0.20	0.20	0.35	0.60	0.70	0.50	0.70	65.60
Wood	0.10	0.19	0.23	0.25	0.25	0.37	0.42	8.10
Glass	0.15	0.15	0.05	0.30	0.03	0.02	0.02	4.90
Linoleum	0.00	0.00	0.00	0.00	0.00	0.00	0.01	19.80
Plaster	0.04	0.04	0.05	0.06	0.08	0.04	0.06	16.40
Piano	0.20	0.14	0.10	0.08	0.08	0.08	0.08	6.20

Materials scheme; materials, absorption coefficients and surfaces.

	Frequency range [Hz]						
	125	**250**	**500**	**1k**	**2k**	**4k**	**8k**
Measured RT [s]	0.78	0.39	0.30	0.24	0.24	0.25	0.23
DIN_T_{soll} [s]	0.95	0.95	0.95	0.95	0.95	0.95	0.95
NS_T_m [s]	0.58	0.58	0.58	0.58	0.58	0.58	0.58



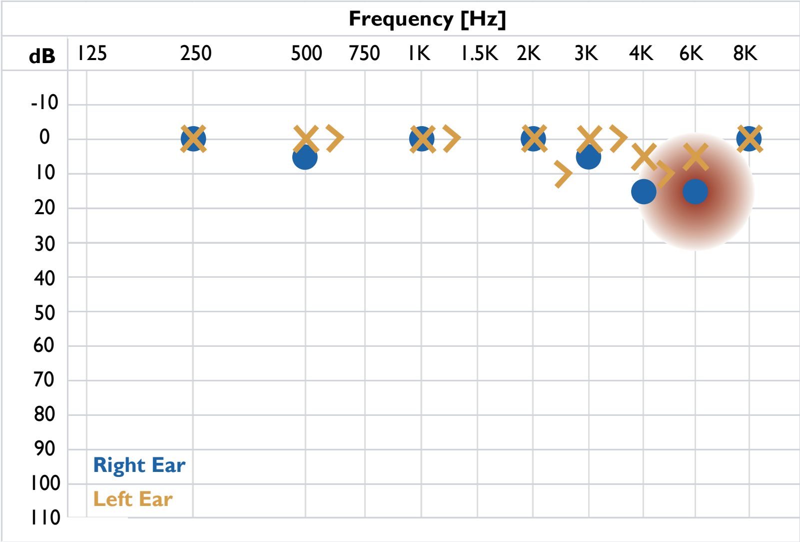
Decreto n.26, Provincia Autonoma di Bolzano. (0.5s-0.8s)

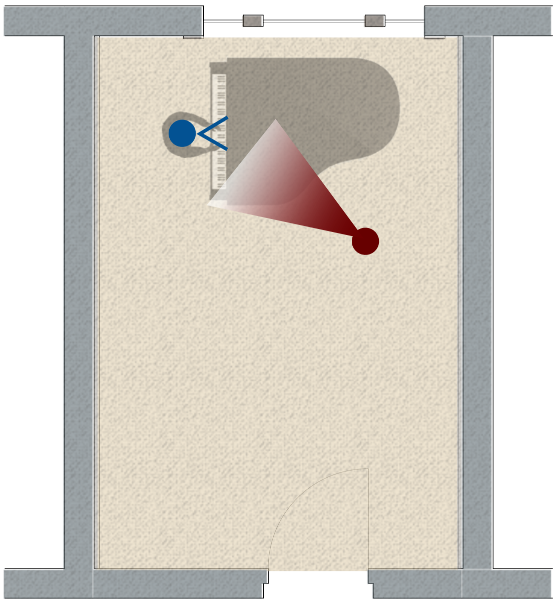
DIN 18041:2016-03. T_{soll}= 0.45lg(V)+0,07) [s]= 0.95 s.

NS 8178:2014. T_m = ($RT_{500,V}$+$RT_{1000,V}$)/2 [s]= 0.58 s.

Reverberation time and comparison with the standards.

sbj_8





Hearing screening of the subject (receiver): possible noise notch related to the position of the student (source) in the room.

As it has been explained in the Background part, the aspects analysed in the research can be linked to eachother; the software *IBM Statistica Package for Social Sciences (SPSS)* has been used to highlight the correspondances between the results, the features of the rooms and the subjects' characteristics.

Bivariate correlations have been analysed with the Pearson test; only the most meaningful correlations have been highlighted, so the results that show a P-value lower than 0.01.

The background noise is inversely linked to the sound insulation which means that the higher the background noise is, the weaker the sound insulation properties of the room are.

Volume is directly correlated to the reverberation time: the higher the reverberation time is, the bigger the volume of the room is. This result supports the Sabine formula which calculates the reverberation time as:

$$RT = (0.16*V)/A.$$

Where:

RT is the reverberation time that has to be measured [s],

V is the room volume [m^3],

A is the equivalent absorbtion area, sum of the product of $\alpha * S$ [m^2], where α is the absorption coefficient of a material and *S* is the surface it occupies in the space taken into consideration.

The last significant result is the subjects' age and their years of activity; the older subjects report to have taught for more years than the younger ones.

Room	sbj	bckg	V	T20m_DIN	T20m_NS	T20m_Bolzano	Lex	DnTW	Dur	N_N	Pos	Age	Yrs_act
318	1	27.5	16.9	0.3	0.3	0.3	79.9	27.0	3.8	2	1	45	14
207	2	28.2	114.5	0.4	0.3	0.4	83.0	26.0	3.9	2	1	79	50
3042	3	30.9	33.1	0.3	0.3	0.3	86.8	23.0	5.9	3	1	35	9
200b	4	33.2	125.7	0.5	0.4	0.5	79.8	22.0	3.5	2	1	61	28
338	5	25.0	16.7	0.3	0.2	0.3	83.2	27.0	3.5	2	3	25	1
200	6	31.5	106.8	0.4	0.4	0.4	81.6	24.0	2.0	3	1	48	18
342	7	27.8	16.7	0.3	0.2	0.3	82.9	24.0	3.5	1	3	24	1
204	8	32.1	89.9	0.3	0.3	0.3	86.9	23.0	5.7	3	1	49	20

Data introduced in the software IBM SPSS.

Correlazioni

		sbj	bckg	V	T20m_DIN	T20m_NS	T20m_Bolzano	Lex	DnTW	Dur	N_N	Pos	Age	Yrs_act
sbj	Correlazione di Pearson		.247	.081	-.113	-.294	-.160	.390	-.454	-.009	.082	.378	-.386	-.369
	Sign. (a due code)		.555	.850	.790	.480	.706	.339	.259	.983	.846	.356	.344	.368
	N		8	8	8	8	8	8	8	8	8	8	8	8
bckg	Correlazione di Pearson	.247		.691	.652	.664	.680	.118	-,887**	.195	.550	-.687	.395	.322
	Sign. (a due code)	.555		.058	.080	.072	.064	.781	.003	.644	.158	.060	.333	.437
	N	8		8	8	8	8	8	8	8	8	8	8	8
V	Correlazione di Pearson	.081	.691		,873**	,823*	,940**	-.144	-.465	-.184	.345	-.615	,827*	,800*
	Sign. (a due code)	.850	.058		.005	.012	.001	.734	.245	.663	.402	.105	.011	.017
	N	8	8		8	8	8	8	8	8	8	8	8	8
T20m_DIN	Correlazione di Pearson	-.113	.652	,873**		,946**	,962**	-.480	-.470	-.418	.148	-.524	.690	.634
	Sign. (a due code)	.790	.080	.005		.000	.000	.229	.240	.303	.726	.183	.058	.092
	N	8	8	8		8	8	8	8	8	8	8	8	8
T20m_NS	Correlazione di Pearson	-.294	.664	,823*	,946**		,934**	-.525	-.390	-.349	.202	-,714*	,767*	.693
	Sign. (a due code)	.480	.072	.012	.000		.001	.181	.339	.396	.632	.047	.026	.057
	N	8	8	8	8		8	8	8	8	8	8	8	8
T20m_Bolzano	Correlazione di Pearson	-.160	.680	,940**	,962**	,934**		-.347	-.445	-.231	.260	-.652	,825*	,774*
	Sign. (a due code)	.706	.064	.001	.000	.001		.400	.269	.581	.534	.080	.012	.024
	N	8	8	8	8	8		8	8	8	8	8	8	8
Lex	Correlazione di Pearson	.390	.118	-.144	-.480	-.525	-.347		-.275	,780*	.475	.009	-.228	-.156
	Sign. (a due code)	.339	.781	.734	.229	.181	.400		.510	.022	.235	.984	.587	.711
	N	8	8	8	8	8	8		8	8	8	8	8	8

DnTW	Correlazione di Pearson	-.454	-,887**	-.465	-.470	-.390	-.445	-.275		-.280	-.314	.320	-.085	-.049
	Sign. (a due code)	.259	.003	.245	.240	.339	.269	.510		.502	.448	.439	.842	.909
	N	8	8	8	8	8	8	8		8	8	8	8	8
Dur	Correlazione di Pearson	-.009	.195	-.184	-.418	-.349	-.231	,780*	-.280		.342	-.231	-.055	-.029
	Sign. (a due code)	.983	.644	.663	.303	.396	.581	.022	.502		.407	.582	.898	.945
	N	8	8	8	8	8	8	8	8		8	8	8	8
N_N	Correlazione di Pearson	.082	.550	.345	.148	.202	.260	.475	-.314	.342		-.655	.181	.135
	Sign. (a due code)	.846	.158	.402	.726	.632	.534	.235	.448	.407		.078	.668	.749
	N	8	8	8	8	8	8	8	8	8		8	8	8
Pos	Correlazione di Pearson	.378	-.687	-.615	-.524	-,714*	-.652	.009	.320	-.231	-.655		-,712*	-.640
	Sign. (a due code)	.356	.060	.105	.183	.047	.080	.984	.439	.582	.078		.047	.088
	N	8	8	8	8	8	8	8	8	8	8		8	8
Age	Correlazione di Pearson	-.386	.395	,827*	.690	,767*	,825*	-.228	-.085	-.055	.181	-,712*		,989**
	Sign. (a due code)	.344	.333	.011	.058	.026	.012	.587	.842	.898	.668	.047		.000
	N	8	8	8	8	8	8	8	8	8	8	8		8
Yrs_act	Correlazione di Pearson	-.369	.322	,800*	.634	.693	,774*	-.156	-.049	-.029	.135	-.640	,989**	
	Sign. (a due code)	.368	.437	.017	.092	.057	.024	.711	.909	.945	.749	.088	.000	
	N	8	8	8	8	8	8	8	8	8	8	8	8	

**. La correlazione è significativa a livello 0,01 (a due code).

*. La correlazione è significativa a livello 0,05 (a due code).

Results obtained by the analysis with the software IBM SPSS, Pearson test. In green, there are highlinghted the meaningful correlations with a P-value lower than 0.01; in light green correlations with a P-value lower than 0.05 are indicated.

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VOICE, HEARING AND ROOM ACOUSTICS

INTRODUCTION

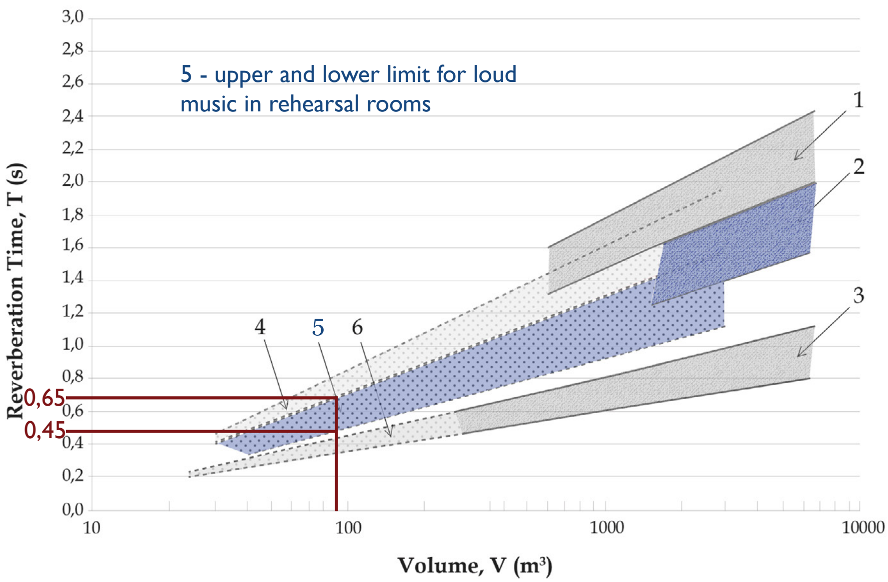
During the research, it has been demonstrated that noise exposure for voice teachers is very high compared to the standard values, both International and Italian. The equivalent level of noise exposure for teachers has been measured during one of their daily classes and, from that, it has been derived a level which corresponds to the time-weighted average value of noise exposure for an 8-hour working day.

Even if teachers do not normally work for 8 whole hours per day, their teaching conditions are not considered safe and they could be improved. How?

The room 204 and the subject #08 have been chosen as sample for this simulation considering its actual situaiton

The subject of this room is the most exposed in terms of noise and the reverberation time is low taking into account also the fact that tis room has one of the biggest volumes. From one side, its conditions are good in terms of background noise, whereas from the other, noise exposure levels result higher than expected; both the equivalent level measured during classes and the one calculated to obtain the daily noise exposure level (L_{ex}), accordingly to the Italian decree n.81 and the recommended levels given by NIOSH which both set the limit at 85 dB(A), are not satisfied.

It has to be considered also that the standards analyzed during the research provide different values as optimal reverberation times. For this simulation it has been chosen as guideline the Norway standard NS 8179:2004, *Acoustic criteria for rooms and spaces for music rehearsal and performance.*



Graph representing the recommended reverberation time value related to the room volume in the Norway Standard NS 8179:2004. The highlighted area n.5 is the one that suits the case of the room #204 and it indicates the recommended reverberation time values for the mid-frequencies.

MODEL CALIBRATION

The software Odeon has been used to simulate the room and its characteristics.

Area [m^2]	21.4				
Height [m]	4.2				
Room volume [m^3]	89.9				
Measured reverberation times [s]	**250 Hz**	**500 Hz**	**1000 Hz**	**2000 Hz**	**4000 Hz**
	0.39	0.30	0.28	0.25	0.26
Background noise (La_{eq}[dB])	32.1				
Measured L_{eq} (running) [dB(A)]	88.3				
Derived L_{ex} (8-hour) [dB(A)]	86.9				

Characteristics of the room #204.

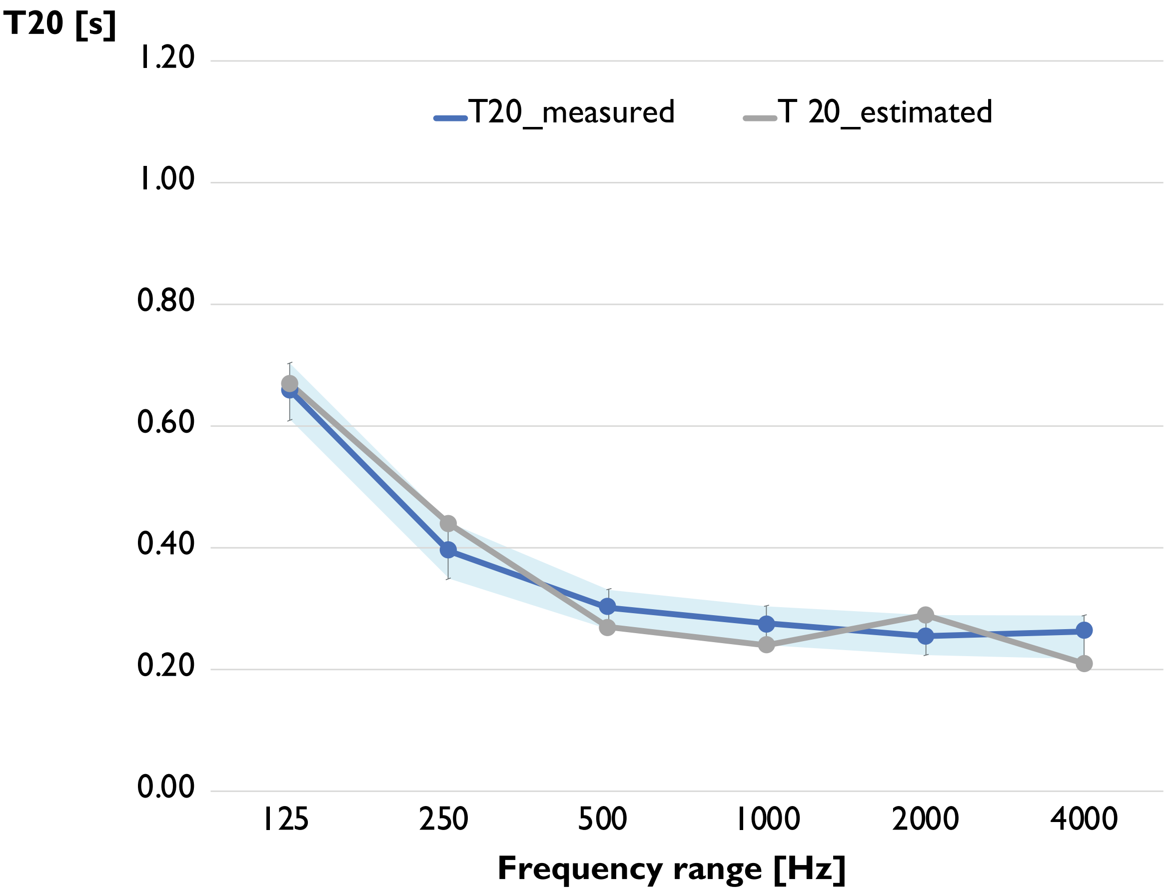
The model of the room includes only the main furniture which can be significant in the acoustical description of the room and its *.dxf* file has been imported in Odeon software.

Once the model has been imported in the software, it needed to be calibrated to match as precisely as possible the real reverberation times measured: materials and their absorption coefficients have been assigned to all the surfaces.

Materials	Frequency range [Hz]							
	63	125	250	500	1000	2000	4000	Surfaces [m^2]
Absorbing panels	0.20	0.20	0.35	0.60	0.70	0.50	0.70	58.90
Wood	0.10	0.19	0.23	0.25	0.25	0.37	0.42	11.20
Glass	0.15	0.15	0.05	0.30	0.03	0.02	0.02	4.90
Linoleum	0.02	0.02	0.02	0.03	0.04	0.04	0.05	15.00
Plaster	0.04	0.04	0.05	0.06	0.08	0.04	0.06	16.40
Carpet	0.10	0.20	0.20	0.30	0.30	0.30	0.30	3.75
Piano	0.20	0.14	0.10	0.08	0.08	0.08	0.08	6.20
Book cabinets	0.20	0.16	0.11	0.08	0.11	0.05	0.05	4.35
Metal cabinets	0.01	0.01	0.01	0.01	0.01	0.02	0.02	9.78

Materials characterizing the room and absorption coefficients (Beranek "Music acoustics & Architecture" 1962 (Odeon), Odeon, /Knauf.it/, Rockwool)

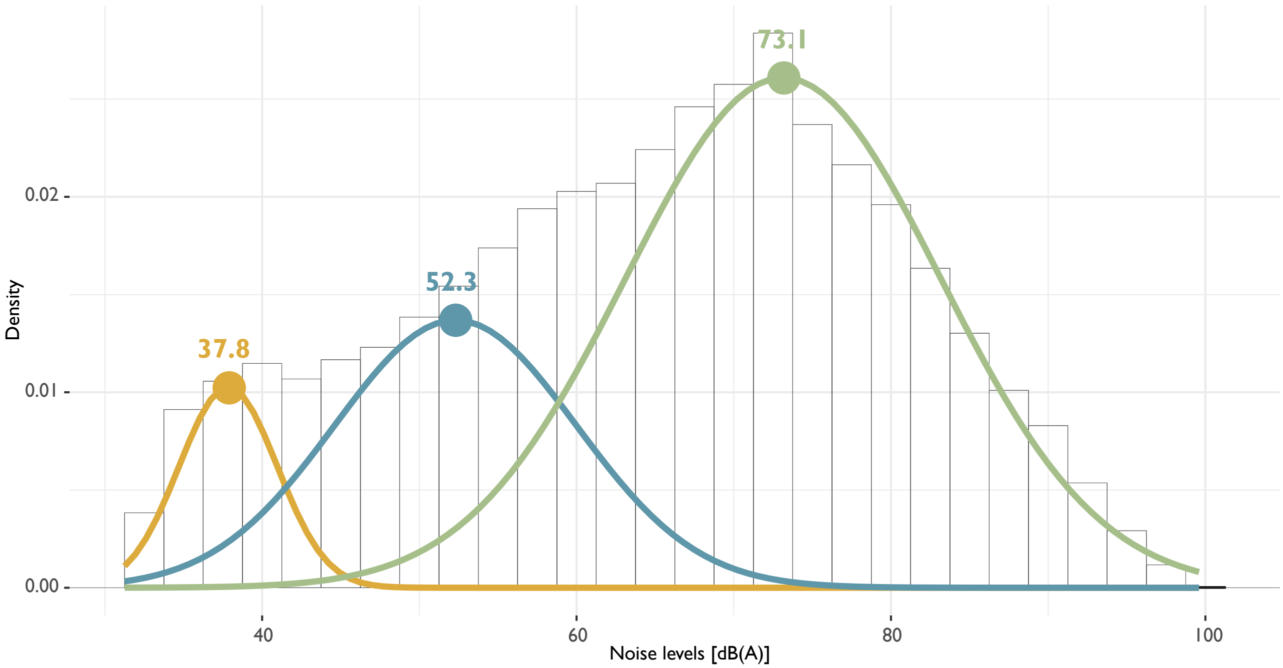
	Frequency range [Hz]					
	125	250	500	1k	2k	4k
T20_measured [s]	0.66	0.39	0.30	0.28	0.26	0.26
T 20_estimated [s]	0.67	0.44	0.27	0.24	0.29	0.21



Measured and estimated reverberation time spectrum match. The estimated reverberation time values should lay in a band of ± 10% of the measured RT values (light blue band).

As the teacher's noise exposure is due to multiple components, it has been decided to split the measured noise exposure level to be able to use only the voice component in Odeon software which is characterized by a precise source and directivity.

For both calibration and simulations only the voice component has been used in Odeon while the other components (background noise, piano and speech) have been set as constants added to obtain the whole noise expoure level.



The graph shows the occurence of each curve and element. The yellow line identifies the background noise level, the blue line the speech component, while the green one, that is the most present component of the teacher's exposure, can be associated to the music which is composed both by voice and piano.

To divide all the components, set the constant values and identify the voice component to use in Odeon software, the pitches' values of speech, background noise and music elements have been calculated with the software R and, in correspondance to the pitches, the dB(A) values have been identified with their occuerence in percentage [%].

Occurrence [%]	dB(A)
1	93.8
2	91.8
3	90.4
4	89.2
5	88.1
6	87.1
7	86.2
8	85.4
9	84.6
10	83.9
11	83.2
12	82.6
13	82.0
14	81.4
15	80.9
16	80.3
17	79.8
18	79.3
19	78.9
20	78.4
21	77.9
22	77.4
23	77.0
24	76.5
25	76.1
26	75.7
27	75.3
28	74.8
29	74.4
30	74.0
31	73.6
32	73.2
33	72.8
34	72.6
35	72.3
36	71.9
37	71.5
38	71.1
39	70.7
40	70.3
41	70.0
42	69.6
43	69.2
44	68.8
45	68.4
46	68.0
47	67.6
48	67.2
49	66.8
50	66.3
51	65.9
52	65.5
53	65.1
54	64.6
55	64.1
56	63.7
57	63.2
58	62.7
59	62.2
60	61.7
61	61.3
62	60.8
63	60.3
64	59.8
65	59.3
66	58.8
67	58.3
68	57.8
69	57.2
70	56.8
71	56.2
72	55.7
73	55.1
74	54.5
75	53.9
76	53.3
77	52.7
78	52.0
79	51.3
80	50.6
81	49.9
82	49.2
83	48.4
84	47.6
85	46.8
86	46.0
87	45.1
88	44.3
89	43.4
90	42.4
91	41.5
92	40.6
93	39.7
94	38.9
95	37.9
96	37.0
97	36.0
98	35.0
99	33.8
100	31.3

Excel file showing the registered global sound pressure levels and their correspondant occurrence in %.

	Music (piano&voice)	Speech	Background noise
Pitches' occurrence	32 %	77 %	95 %
	=32	=77-32	=100-[32+(77-32)]
Occurrence	32 %	45 %	23 %
SPL	73.1 [dB(A)]	52.3 [dB(A)]	37.8 [dB(A)]

Occurrence percentages have been spread to obtain a total of 100%; the time including speech included music too.

The sum of the components voice, piano, speech and background should give the total measured noise exposure, so 88.3 dB(A). The formula to calculate and obtain the global noise exposure is

$$L_{ex} = 10\log\left(1/t * [(10^{L_{voice+piano}/10})*(32\%)*t) + (10^{L_{speech}/10})*(45\%)*t) + (10^{L_{bckg}/10})*(23\%)*t)]\right).$$

Where

t is the duration of the class measured = 5.7 hours,

L_{speech} = 52.3 dB(A),

L_{bckg} = 37.8 dB(A).

From the calculation for the maximum duration of exposure it is possble to derive the L_{ex} (total noise exposure); NIOSH provides a formula to obtain the allowed exposure time *Ti;*

$$Ti = TC / 2^{(L-LC)/Q}.$$

With

LC=Criterion sound level,

TC= Criterion Exposure Duration,

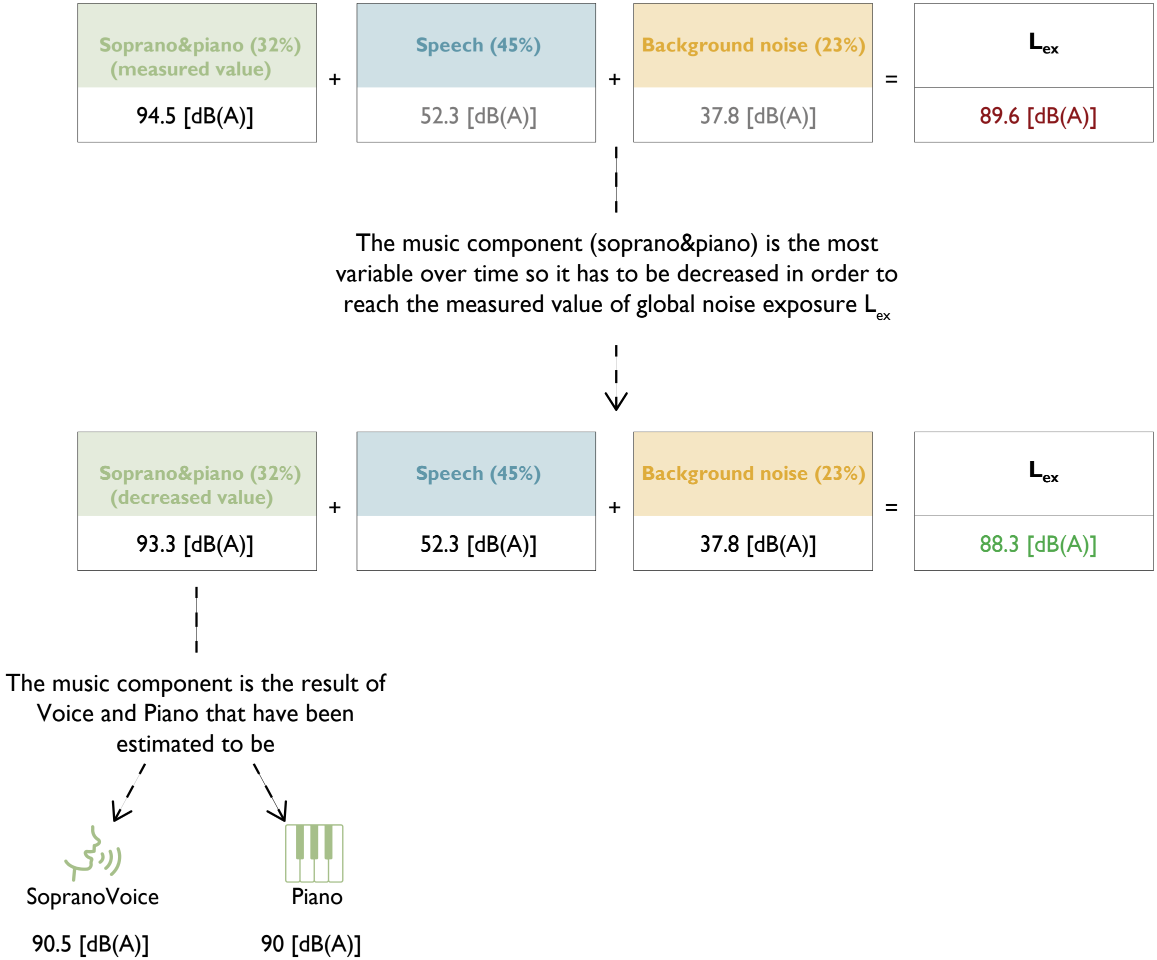
Q=Exchange rate,

L= level in dB(A).

For NIOSH the formula can be translated in :$Ti = 8 / 2^{(L-85)/3}$.

Estimation of the sound pressure levels of the music components at the receiver's point to obtain the total exposure level

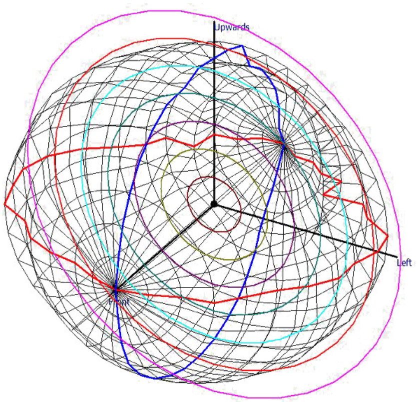
For as it concerns music a limited portion of recording of class including only piano and voice has been extrapolated and, from that, it has been obtained a measured global dB(A) level of 94.5 dB(A) at the receiver's point. This value can be considered variable as the intensities of voice and piano can vary over time. At the receiver's measurement point, which was located on her left shoulder, it is estimated to be registered:



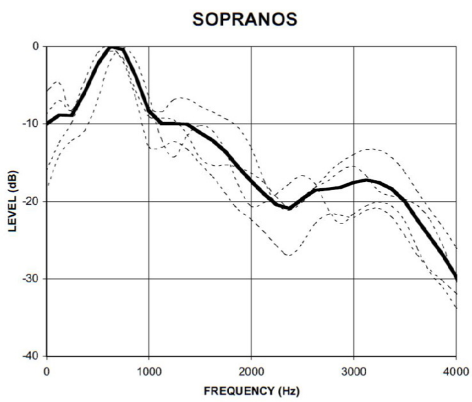
The variable component for the calculation of L_{ex}: the soprano voice

The soprano voice will be the only variable level of the simulation; the other levels (speech, background noise and piano) will be considered as fixed.

There has been placed a source identified with a Soprano voice whose directivity is automatically given by the software Odeon while its spectrum has been equalized accordingly to the research conducted by Sundberg.

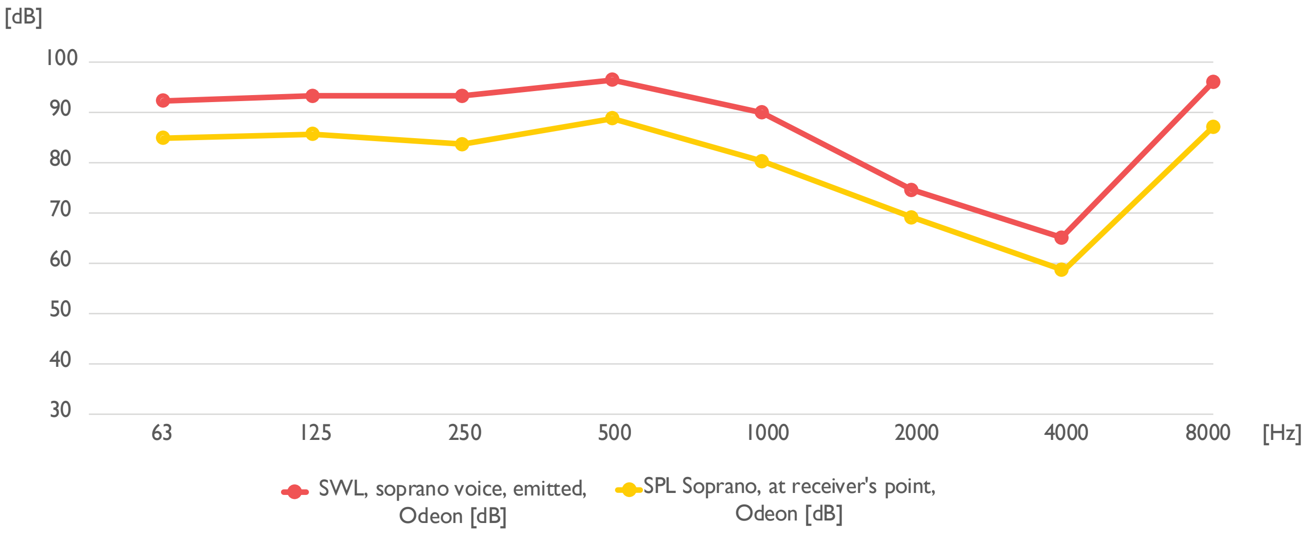


Directivity balloon in Odeon software of the source of Soprano ref. 42_NATURAL. S08 at 1000 Hz.

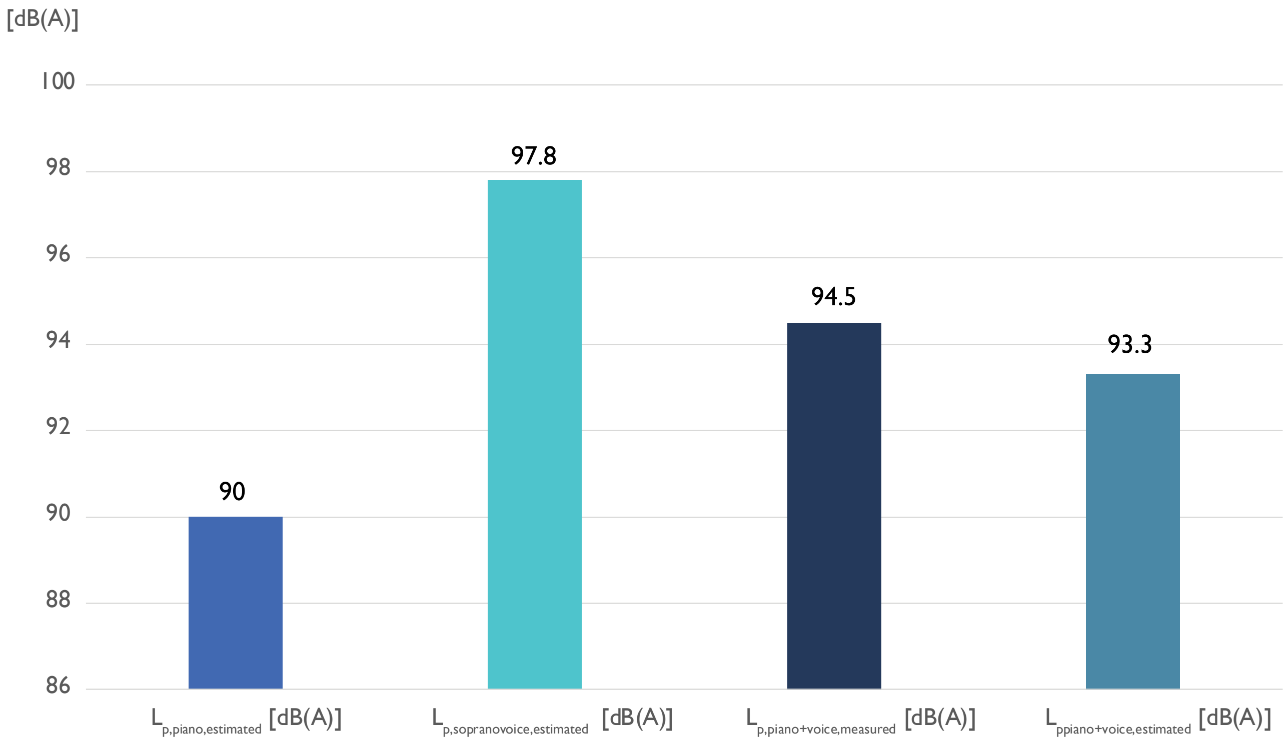


Spectrum of the source of Soprano source from the reference Sundberg,2001, Journal of Voice

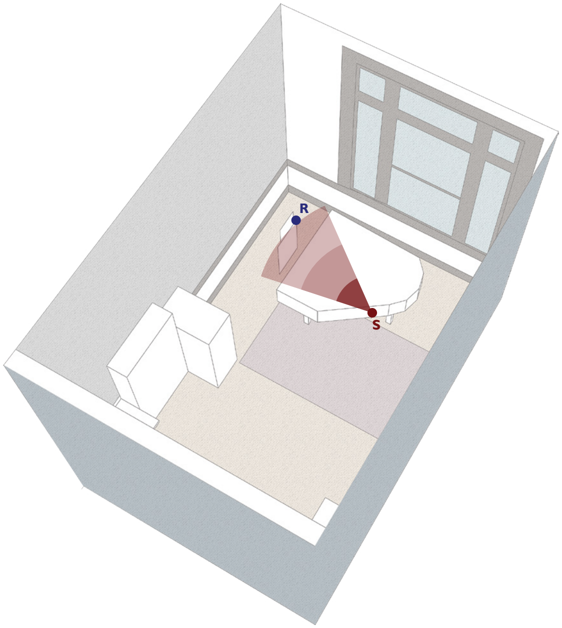
	Frequency range [Hz]							
	63	**125**	**250**	**500**	**1000**	**2000**	**4000**	**8000**
SWL, soprano voice, emitted, Odeon [dB]	92.3	93.3	93.3	96.5	90.0	74.6	65.1	95.1
SPL Soprano, at receiver's point, Odeon [dB]	84.9	85.7	83.7	88.8	80.3	69.1	58.7	88.4



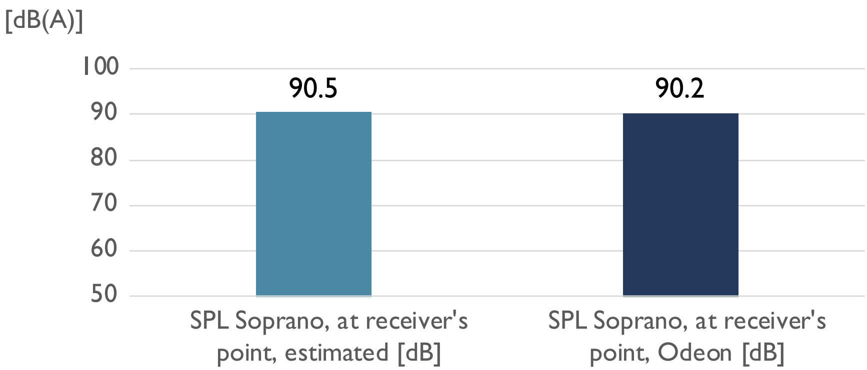
Soprano voice spectrum of the emitting source and at the reciever's point



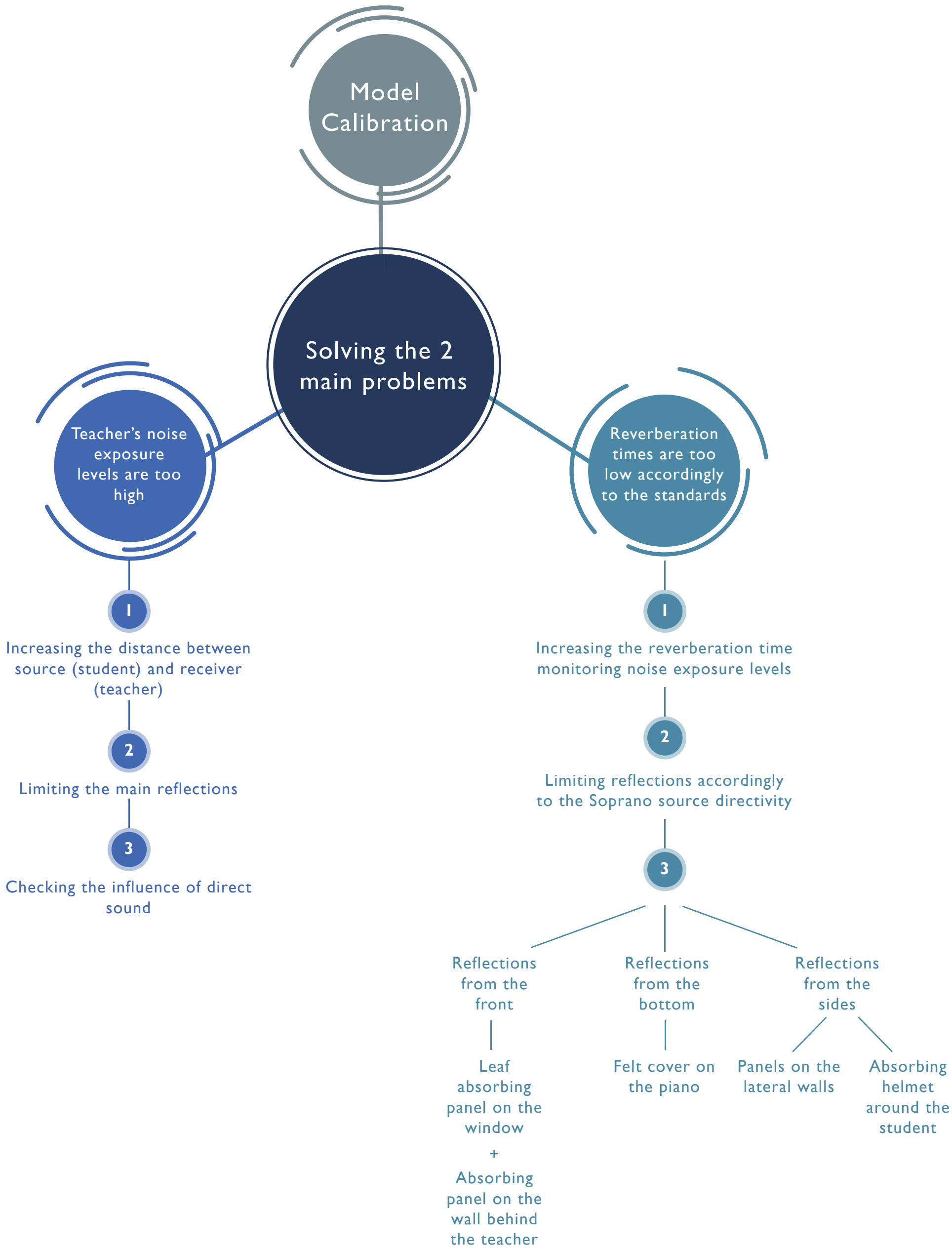
Global levels for the piano instrument, the soprano voice and the mix of these two elements, measured and estimated.



Scheme of the placement of source and receiver for Odeon calibration; the position of the two components corresponds to the real situation measured during classes.



Matching of the sound pressure level estimated and measured by Odeon software of the soprano voice at the receiver's point.



Summary diagram of the action plan on which the simulations have been based.

INCREASING THE DISTANCE BETWEEN TEACHER AND STUDENT

SIMULATION 1

The aim of the simulation is to analyze the noise level the teacher is exposed to. The receiver has been set to the piano in two different orientations: looking at the student or looking head-on. The receiver, so the teacher in this case, always maintains the same position in the room, seat on the piano playing exercises and music, while the student position can vary.

There have been set along a line 4 source points distributed at progressive distances considering the possible positions the students can occupy during classes; both teacher's and sources' coordinates will be kept the same in each simulation in order to be able to make comparisons.

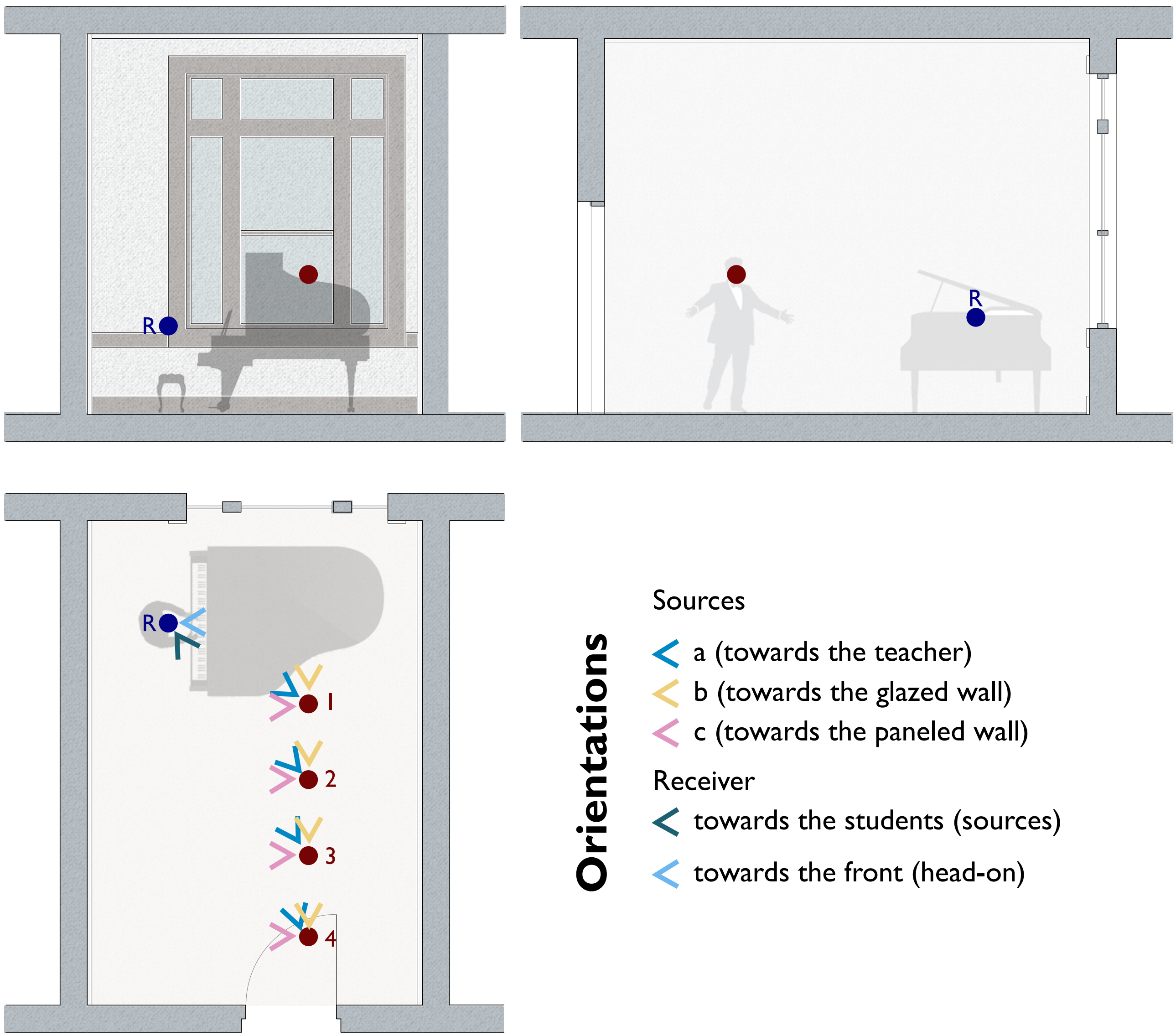
Sources in point 1, 2, 3 and 4 have been switched one by one tu understand how noise exposure at the receiver's point R (teacher's position) varies accordingly to the different student's position in the room.

Three different orientations have been set for each student's position:

a) sources towards the teacher (Rotation=0°; Elevation=0°; Azimuth=towards the teacher);

b) the sources towards the side of the windows (Rotation=0°; Elevation=0°; Azimuth= 0°);

c) the sources looking at the wall behind the teachers' position (Rotation=0°; Elevation=0°; Azimuth= 90°). The elevation always kept at 0° means that the student maintains the head straight without lowering or raising it for an educational purpose linked to a correct posture during singing.



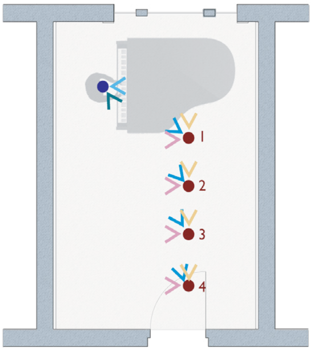
Plan and sections of the room representing the receiver's point (R, blue) and sources points (1-4, red) and their three different possibile orientations (a, b, c).

The different orientations of the sources and receiver have been useful to understand the sound influences and how its reflections were important and contributed to the global noise exposure of the teacher.
For each point the three orientations of the sources have been analyzed while the orientation of the teacher in the analysis of the total noise exposure is not taken into account as it is a monoaural exposure.

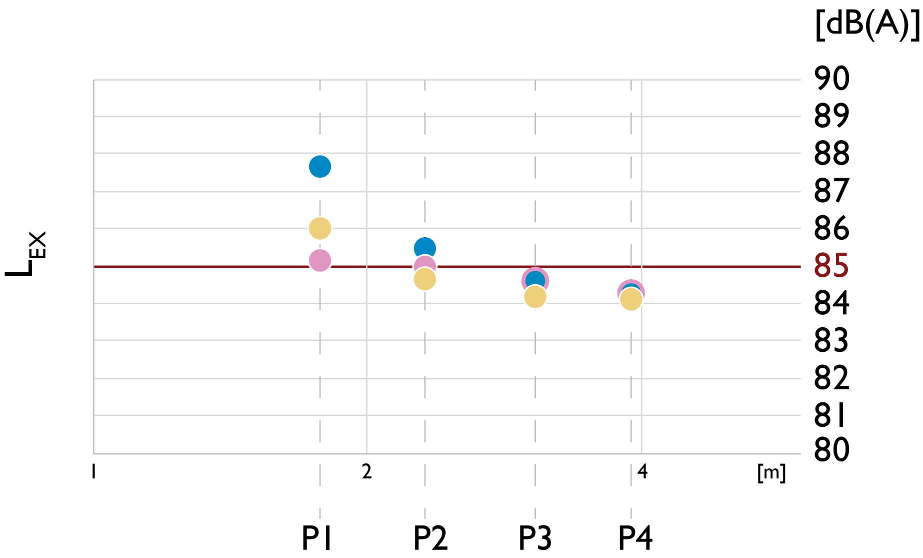
The tables below show the estimated values of the variable soprano voice during the different steps of the simulation and it shows how the obtained global teacher's noise exposure during the measured period class (5.7 hours) varies. The red line shows the limit values that has not to be exceeded in an 8-hour period which is 85 dB(A).

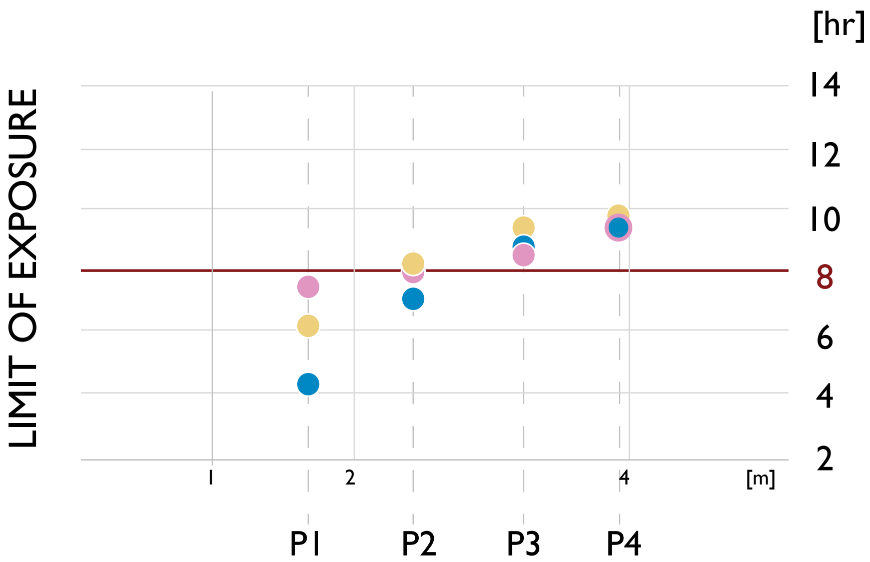
For a better understanding of the influence of sound exposure on binaural system, reflections in the room have been analysed and correlated to the single ears exposure.

NAVIGATOR



Monoaural exposure results at receiver's point												
Sources	**1**			**2**			**3**			**4**		
Orientations	**a**	**b**	**c**	**a**	**b**	**c**	**a**	**b**	**c**	**a**	**b**	**c**
SPL(A) soprano voice	92.0	86.4	88.8	87.3	85.8	85.2	84.5	84.6	82.6	82.7	82.5	81.4
SPL(A) piano	90.0	90.0	90.0	90.0	90.0	90.0	90.0	90.0	90.0	90.0	90.0	90.0
SPL(A) voice&piano (32%)	94.1	91.6	92.5	91.9	91.4	91.2	91.1	91.1	90.7	90.7	90.7	90.6
SPL(A) speech (45%)	52.3	52.3	52.3	52.3	52.3	52.3	52.3	52.3	52.3	52.3	52.3	52.3
SPL(A) background noise (23%)	37.8	37.8	37.8	37.8	37.8	37.8	37.8	37.8	37.8	37.8	37.8	37.8
Lex (A)	87.7	85.2	86.0	85.4	85.0	84.8	84.7	84.7	84.3	84.3	84.3	84.1
max duration of exposure [hr]	4.3	7.7	6.3	7.2	8.0	8.3	8.7	8.6	9.4	9.4	9.4	9.8

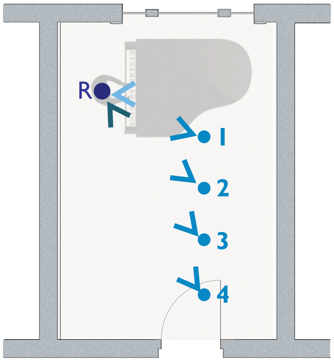


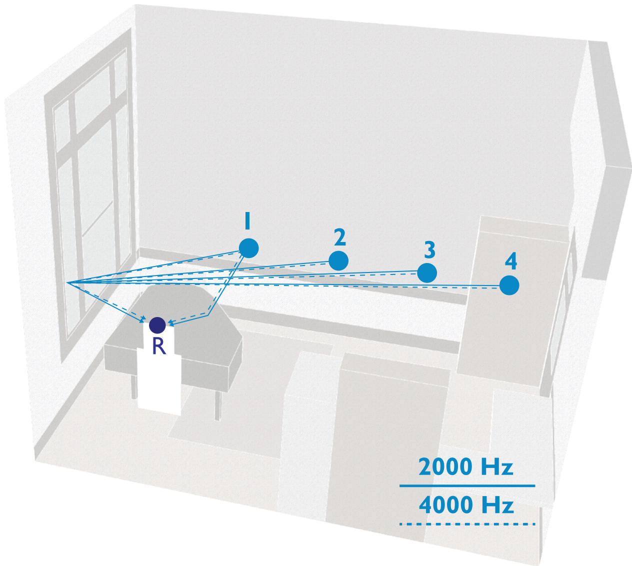


Tables and graph showing the estimated values accordingly to the 4 different possible student's positions and its 3 possible orientations.

Orientation a

Voice reflection paths





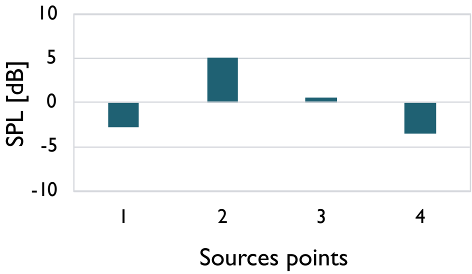
< towards the students

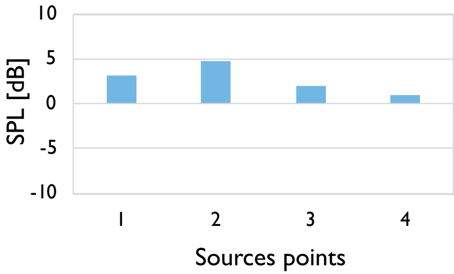
< head-on

Receiver's binaural exposure

Ears exposure [dB]				
	1	2	3	4
R	83.7	82.3	85.4	83.1
L	86.5	77.1	84.9	86.7
Differences R-L	-2.8	5.1	0.5	-3.6

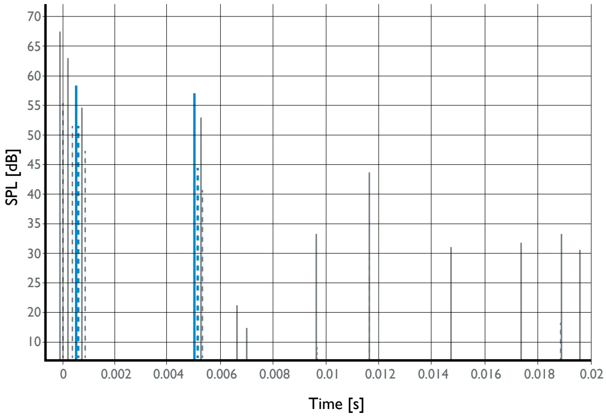
Ears exposure [dB]				
	1	2	3	4
R	84.5	84.6	80.2	80.9
L	81.3	79.9	78.2	79.9
Differences R-L	3.2	4.7	2.0	1.0



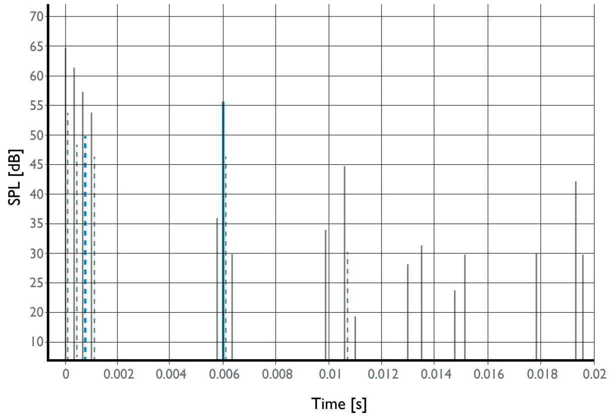


Orientation a_reflectograms

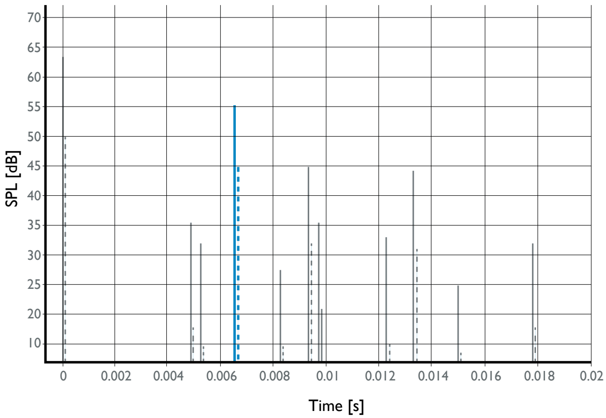
2000 Hz   4000 Hz



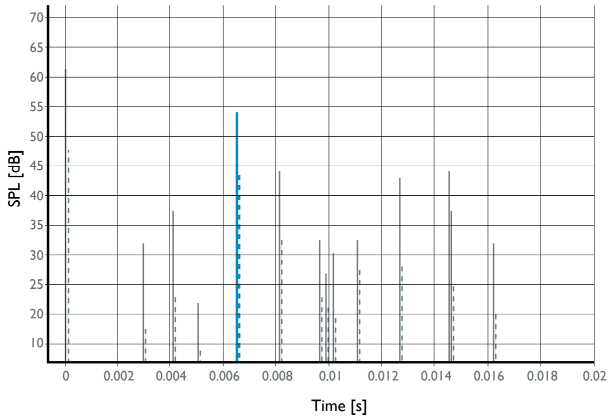
Source 1



Source 2



Source 3

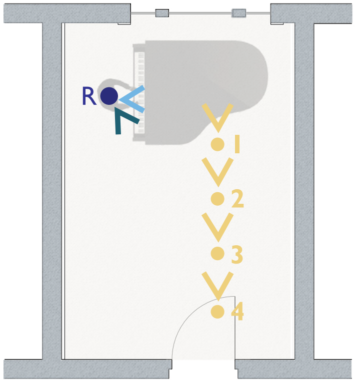


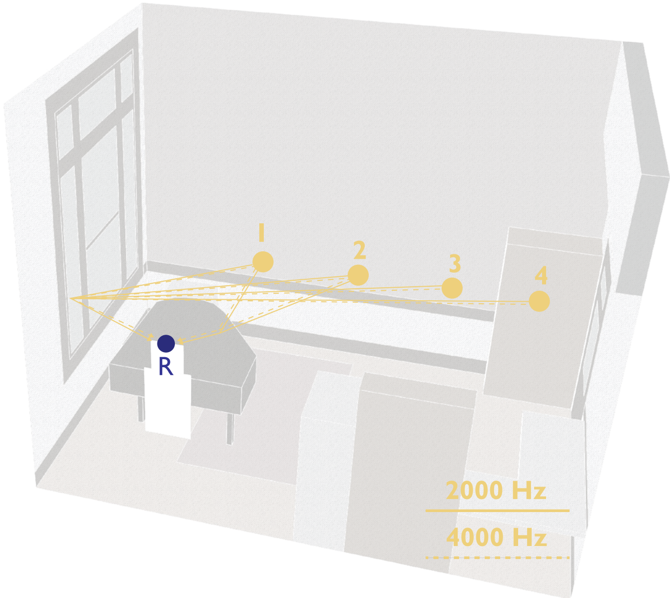
Source 4

Reflectrograms show the intensities of the sound reflections respectively at 2000 Hz and 4000 Hz.

Orientation b

Voice reflection paths



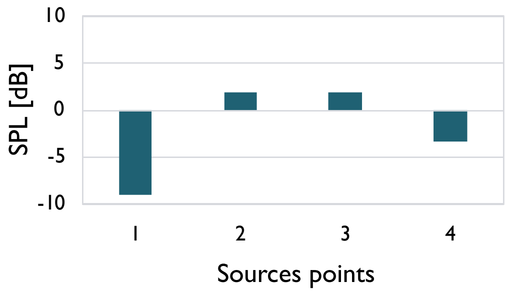


< towards the students

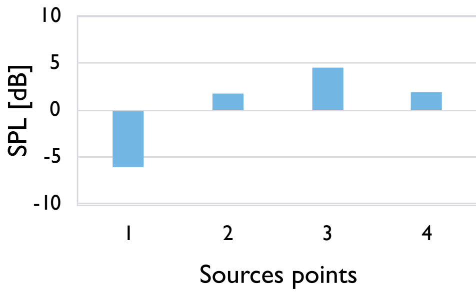
< head-on

Receiver's binaural exposure

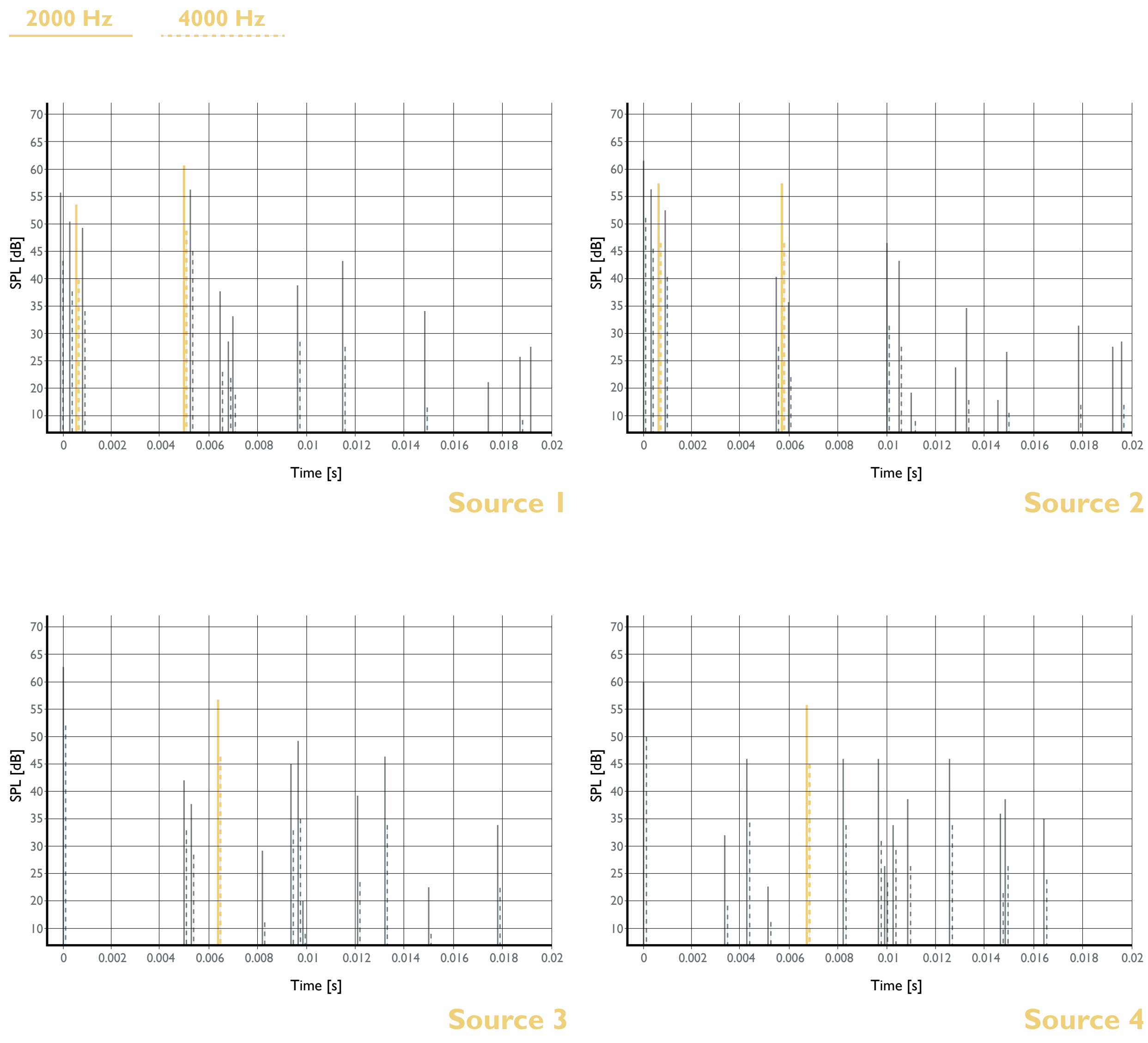
Ears exposure [dB]				
	1	2	3	4
R	76.3	81.1	85.4	82.9
L	85.3	79.3	83.5	86.1
Differences R-L	-9.0	1.9	2.0	-3.3



Ears exposure [dB]				
	1	2	3	4
R	74.7	84.5	80.2	80.8
L	80.8	82.8	75.6	78.9
Differences R-L	-6.1	1.7	4.6	1.9



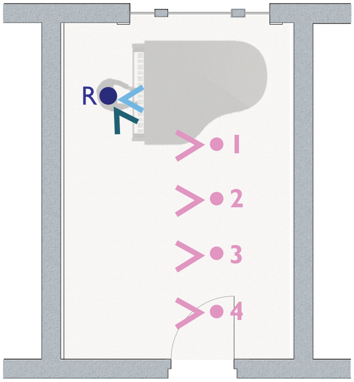
Orientation b_reflectograms

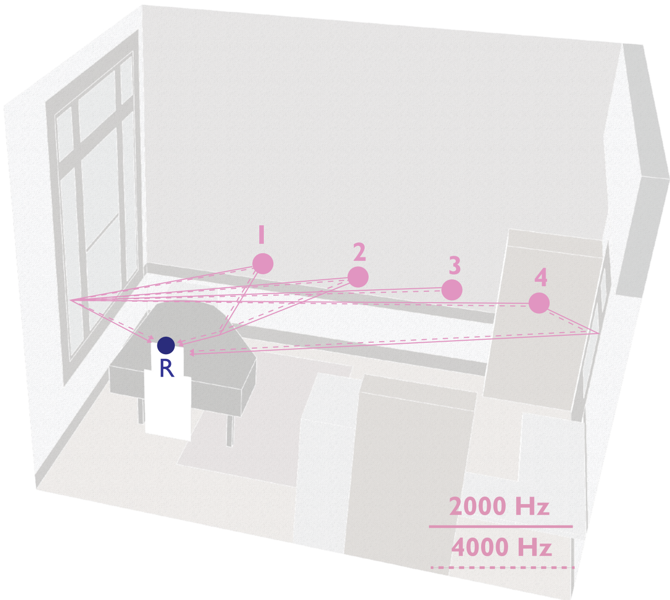


Reflectrograms show the intensities of the sound reflections respectively at 2000 Hz and 4000 Hz.

Orientation c

Voice reflection paths



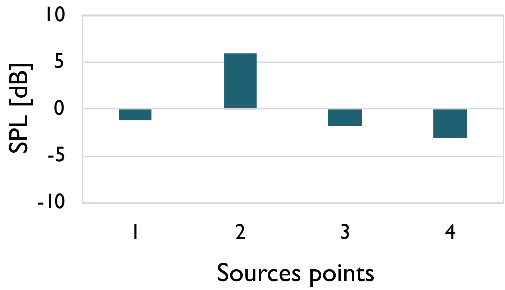


towards the students

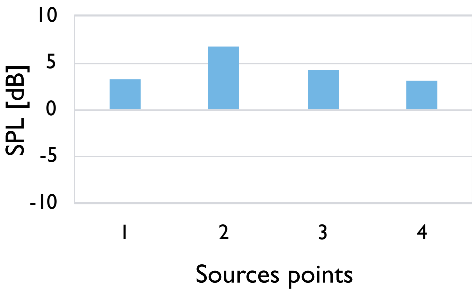
head-on

Receiver's binaural exposure

Ears exposure [dB]				
	1	2	3	4
R	83.1	82.0	84.7	86.0
L	84.2	76.0	86.5	89.1
Differences R-L	-1.1	6.0	-1.8	-3.1

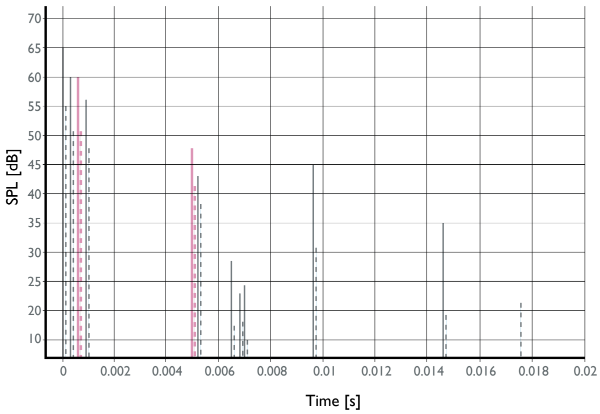


Ears exposure [dB]				
	1	2	3	4
R	84.5	84.7	80.6	83.0
L	79.0	77.9	76.3	79.9
Differences R-L	3.2	6.8	4.3	3.1

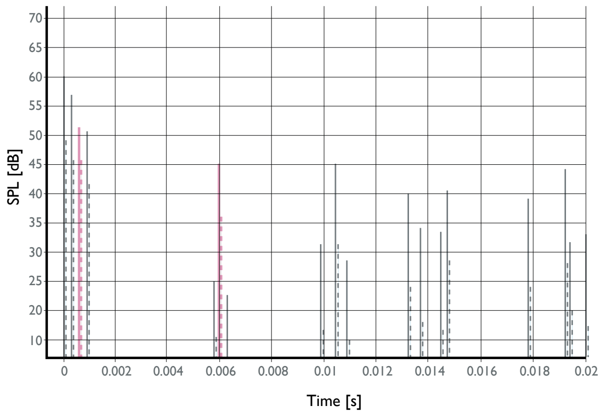


Orientation c_reflectograms

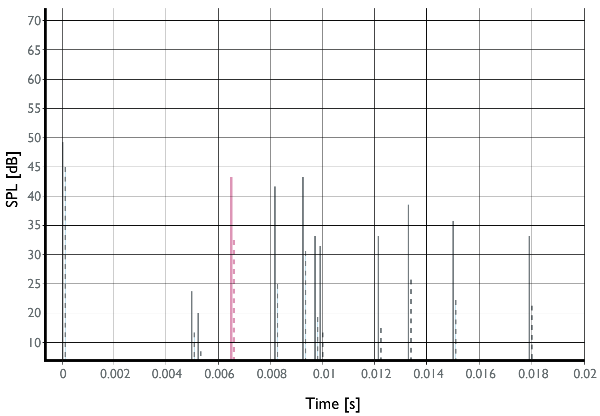
2000 Hz   4000 Hz



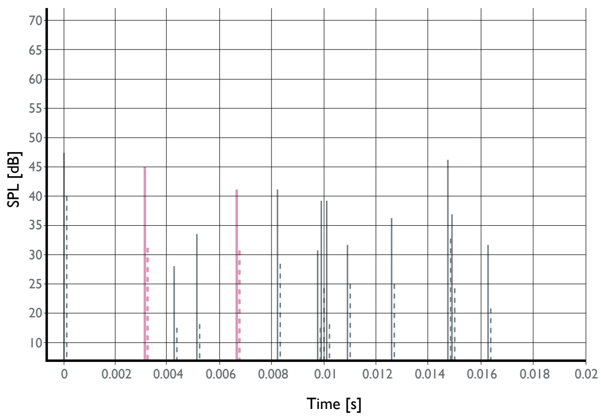
Source 1



Source 2



Source 3



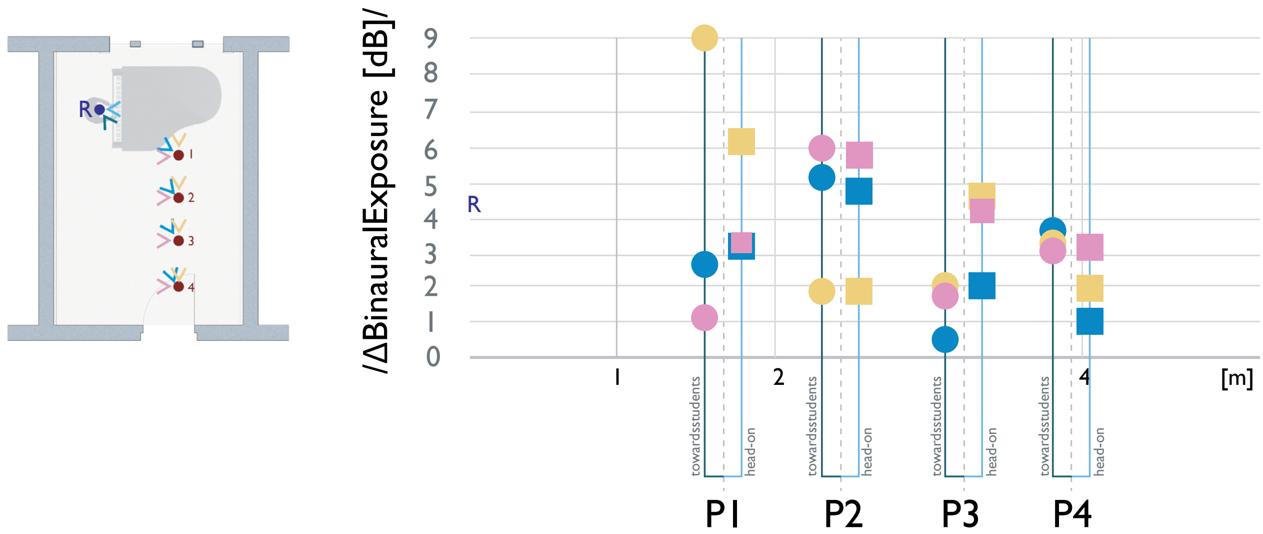
Source 4

Reflectrograms show the intensities of the sound reflections respectively at 2000 Hz and 4000 Hz.

The results showed that for Orientation a the teacher is more exposed to the source sound on her left ear, both looking at the sources and looking head-on except for point 1, which is the nearest to the receiver, in which left ear is more exposed to the reflections of sound from the glazed surface.

In Orientation b, when the source is facing the window: reflections from the window are perceived by the teacher's left ear mainly when the student is placed in point 1 and 4.

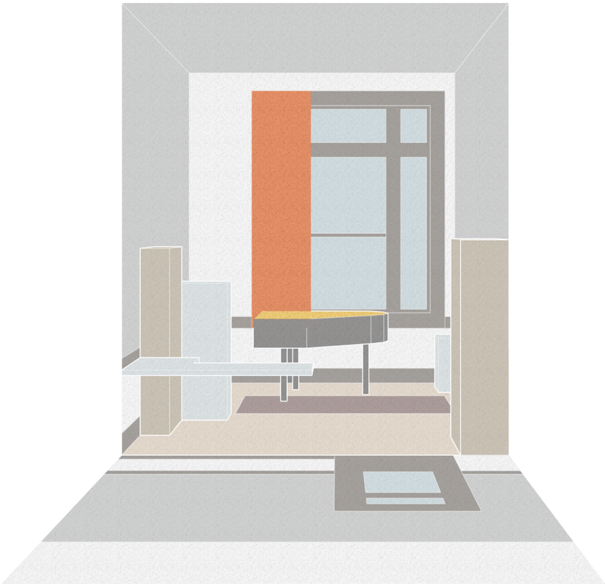
When the sources are directed towards the wall behind the teacher (Orientation c), which is composed by absorbing panels, the reflections are less intense and the right ear results to be the most exposed because of the direct sound emitted by the students (soprano voice sources).



Graph showing the difference in absolute value of right and left ear exposure.

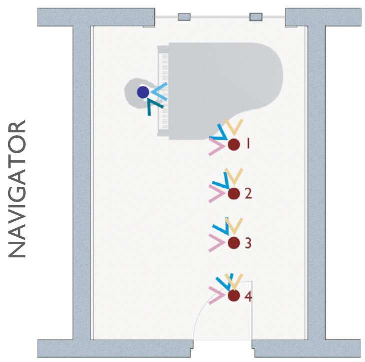
However, it is important to understand and manage the main reflections in the room to decrease the difference of exposure for the right and left ear. The Simulation 2 is reporting the actual room and materials with an insertion of an absorbing leaf panel placed on a portion of the window and a felt material placed on the piano to control reflections.

SIMULATION 2

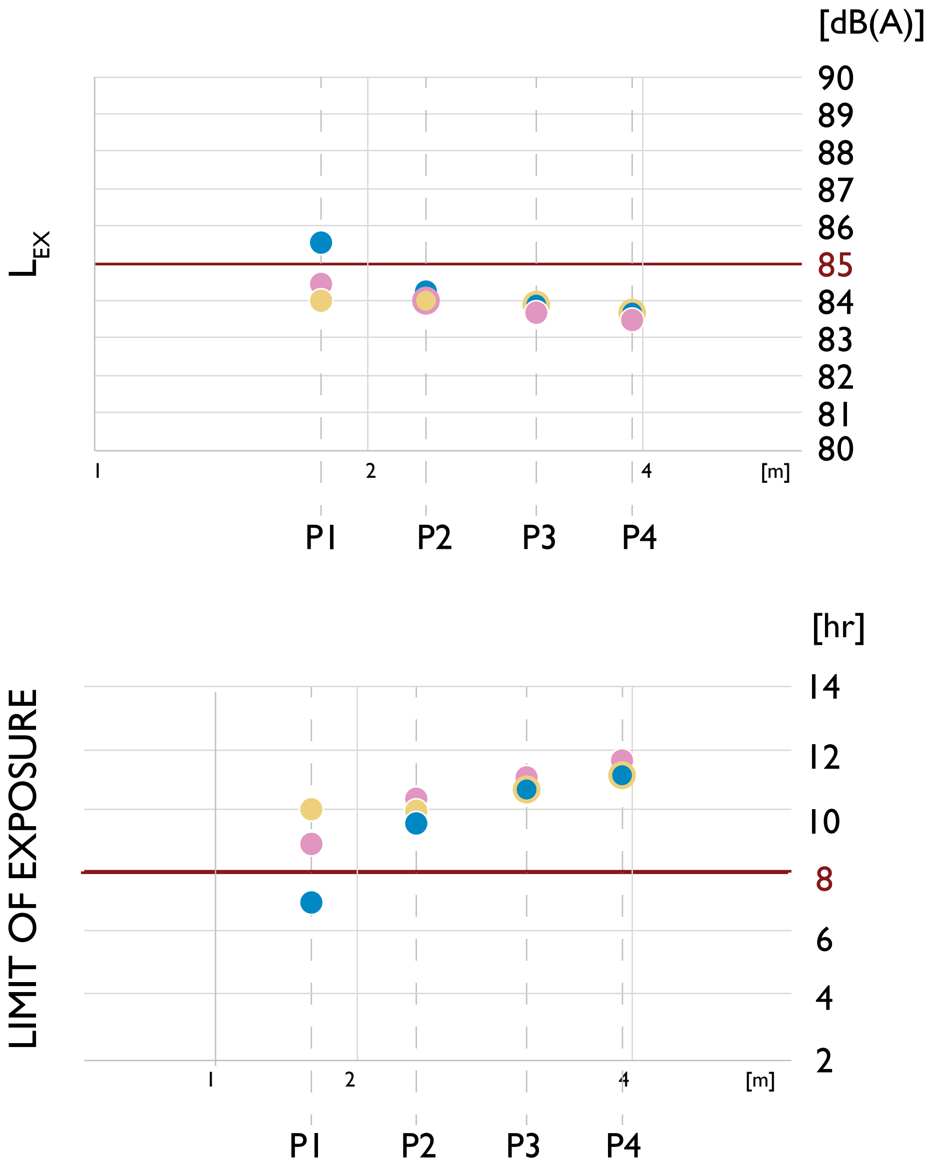


Materials	Frequency range [Hz]							
	63	125	250	500	1000	2000	4000	Surfaces [m^2]
Absorbing panels	0.20	0.20	0.35	0.60	0.70	0.50	0.70	58.90
Wood	0.10	0.19	0.23	0.25	0.25	0.37	0.42	11.20
Glass	0.15	0.15	0.05	0.30	0.03	0.02	0.02	4.90
Linoleum	0.00	0.00	0.00	0.00	0.00	0.00	0.01	15.00
Plaster	0.04	0.04	0.05	0.06	0.08	0.04	0.06	16.40
Carpet	0.10	0.20	0.20	0.30	0.30	0.30	0.30	3.75
Piano	0.20	0.14	0.10	0.08	0.08	0.08	0.08	4.25
Book cabinets	0.20	0.16	0.11	0.08	0.11	0.05	0.05	4.35
Metal cabinets	0.01	0.01	0.01	0.01	0.01	0.02	0.02	9.78
Absorbing panels	0.10	0.10	0.15	0.30	0.60	0.90	0.85	2.60
Felt	0.35	0.35	0.65	0.90	0.90	0.95	0.90	1.95

Room materials with their absorption coefficients and surfaces.

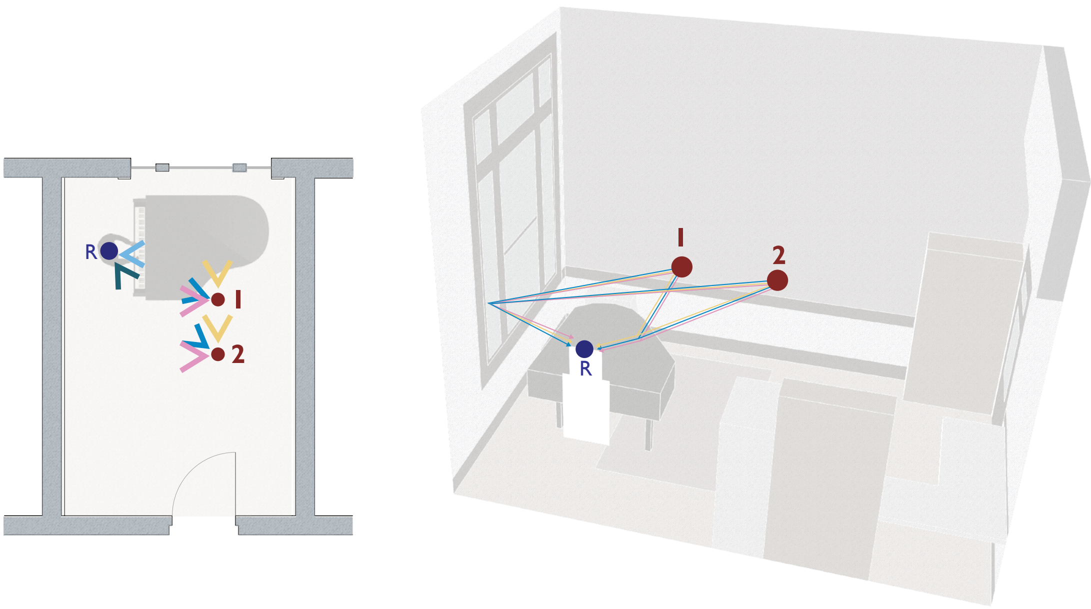


Monoaural exposure results at receiver's point												
Sources	1			2			3			4		
Orientations	a	b	c	a	b	c	a	b	c	a	b	c
SPL(A) soprano voice	90.8	85.2	88.1	87.4	85.8	85.8	83.2	83.3	81.4	81.3	81.2	80.4
SPL(A) piano	90.0	90.0	90.0	90.0	90.0	90.0	90.0	90.0	90.0	90.0	90.0	90.0
SPL(A) voice&piano (32%)	93.4	91.2	92.2	91.9	91.4	90.8	90.8	90.6	90.5	90.5	90.5	90.5
SPL(A) speech (45%)	52.3	52.3	52.3	52.3	52.3	52.3	52.3	52.3	52.3	52.3	52.3	52.3
SPL(A) background noise (23%)	37.8	37.8	37.8	37.8	37.8	37.8	37.8	37.8	37.8	37.8	37.8	37.8
Lex (A)	87.0	84.8	85.7	85.5	85.0	85.0	84.4	84.4	84.1	84.1	84.1	84.0
max duration of exposure [hr]	5.0	8.3	6.7	7.2	8.0	8.0	9.2	9.1	9.8	9.8	9.8	10.0

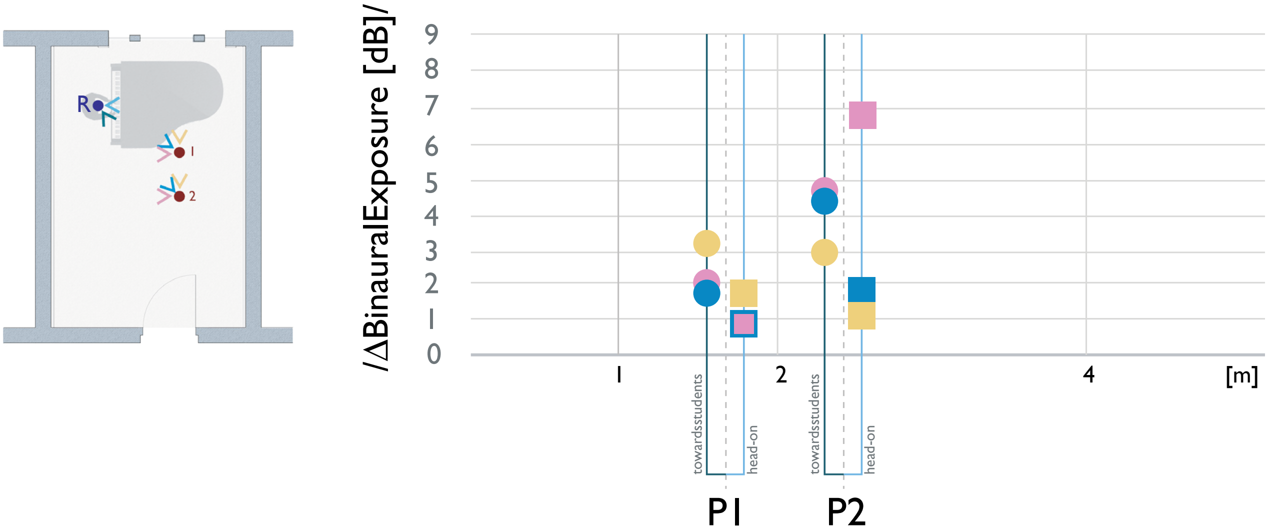


Tables and graph showing the estimated values accordingly to the 4 different possible student's positions and its 3 possible orientations.

Voice reflection paths

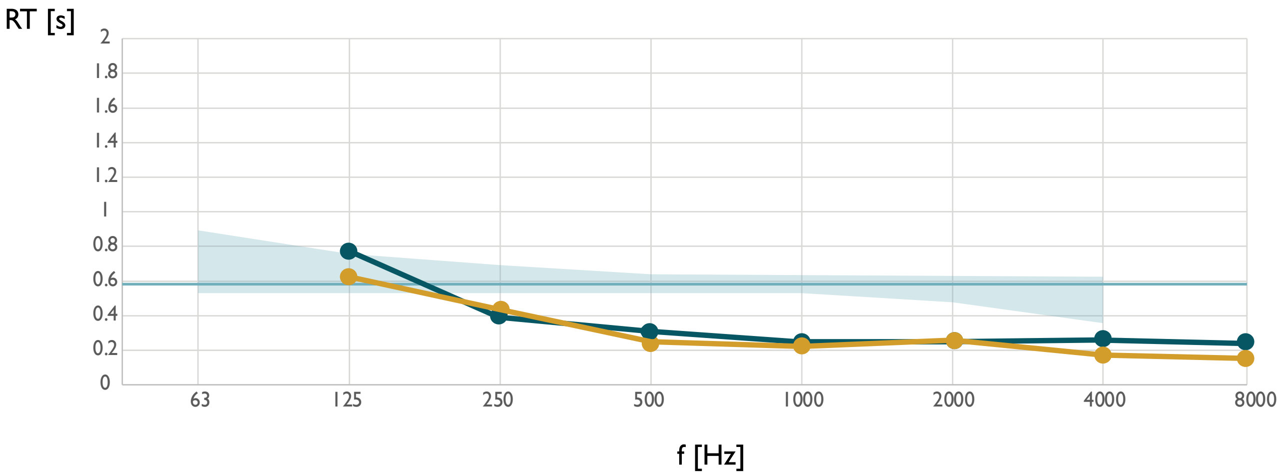


Scheme of reflections for the two most critical possible positions of the student.



Graph showing the difference in absolute value of right and left ear exposure in the most critical points 1 and 2.

	Frequency range [Hz]						
	125	**250**	**500**	**1k**	**2k**	**4k**	**8k**
RT $_{measured}$ **[s]**	0.78	0.39	0.30	0.24	0.24	0.25	0.23
NS_T$_m$ [s]	0.58	0.58	0.58	0.58	0.58	0.58	0.58
RT $_{estimated,\ Odeon}$ **[s]**	0.64	0.41	0.24	0.21	0.26	0.18	0.17



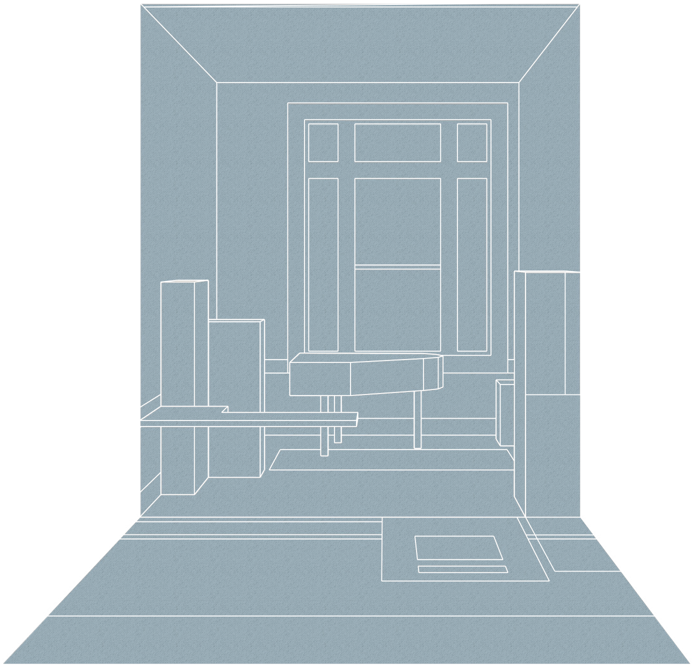
Estimated reverberation time values compared to the measured ones; measure RT (blue), estimated RT by Odeon (yellow).

The Simulation 2 shows that, controling the main reflections, noise exposure levels are not decreasing substantially even though the difference of ears exposure decreases considerably. The reverberation time values of the room, already considered lower than the standard recommendations, are even more stepping away from the optimal acoustical characterization of the room.

CHECKING THE INFLUENCE OF DIRECT SOUND: 100% ABSORBING ROOM

SIMULATION 3

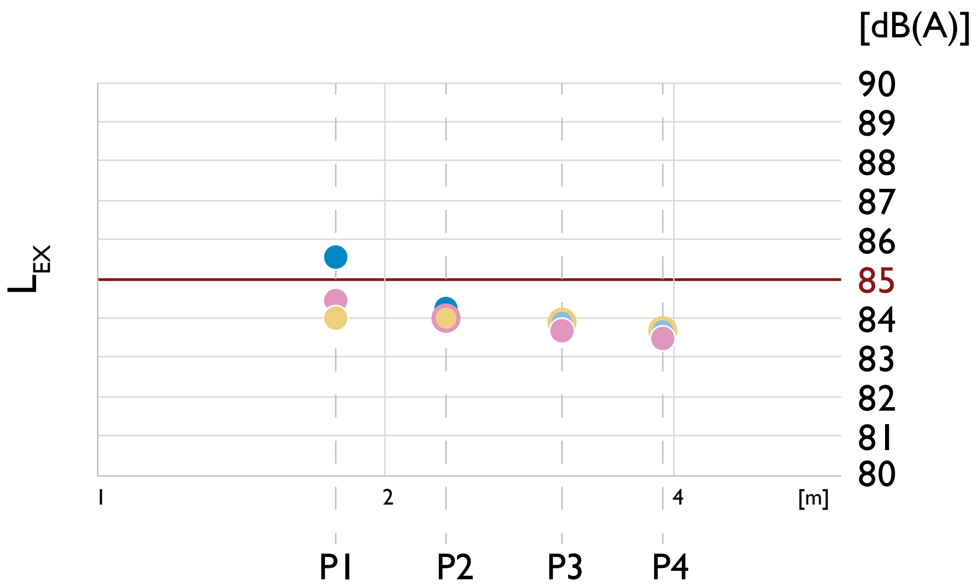
The hypothesis is that the direct sound can have an influence which cannot be managed as satisfactory by the environment. The simulation 3 speculated a 100% absorbing room where the receiver's exposure is due only to the direct sound.



Materials	Frequency range [Hz]							
	63	125	250	500	1000	2000	4000	Surfaces [m^2]
Absorbing material	1.00	1.00	1.00	1.00	1.00	1.00	1.00	130.50

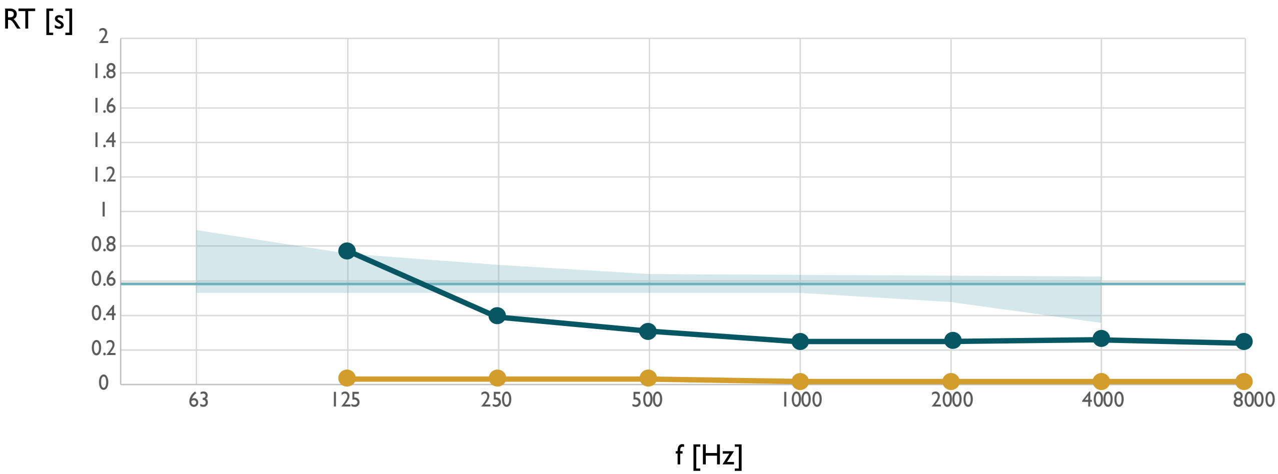
Room materials with their absorption coefficients and surfaces.

Monoaural exposure results at receiver's point												
Sources	1			2			3			4		
Orientations	a	b	c	a	b	c	a	b	c	a	b	c
SPL(A) soprano voice	87.5	80.2	83.7	81.7	80.2	79.5	79.2	79.0	77.2	77.0	76.5	74.6
SPL(A) piano	91.9	90.4	90.9	90.6	90.4	90.4	90.3	90.3	90.2	90.2	90.2	90.1
SPL(A) voice&piano (32%)	93.4	91.2	92.2	91.9	91.4	90.8	90.8	90.6	90.5	90.5	90.5	90.5
SPL(A) speech (45%)	52.3	52.3	52.3	52.3	52.3	52.3	52.3	52.3	52.3	52.3	52.3	52.3
SPL(A) background noise (23%)	37.8	37.8	37.8	37.8	37.8	37.8	37.8	37.8	37.8	37.8	37.8	37.8
Lex (A)	85.5	84.0	84.5	84.2	84.0	84.0	83.9	83.9	83.8	83.8	83.8	83.7
max duration of exposure [hr]	7.1	10.0	9.0	9.7	10.0	10.2	10.3	10.3	10.5	10.6	10.6	10.8



Tables and graph showing the estimated values accordingly to the 4 different possible student's positions and its 3 possible orientations.

	Frequency range [Hz]						
	125	250	500	1k	2k	4k	8k
$RT_{measured}$ [s]	0.78	0.39	0.30	0.24	0.24	0.25	0.23
NS_T_m [s]	0.58	0.58	0.58	0.58	0.58	0.58	0.58
$RT_{estimated, Odeon}$ [s]	0.02	0.02	0.02	0.01	0.01	0.01	0.01



Estimated reverberation time values compared to the measured ones; measure RT (blue), estimated RT by Odeon (yellow)

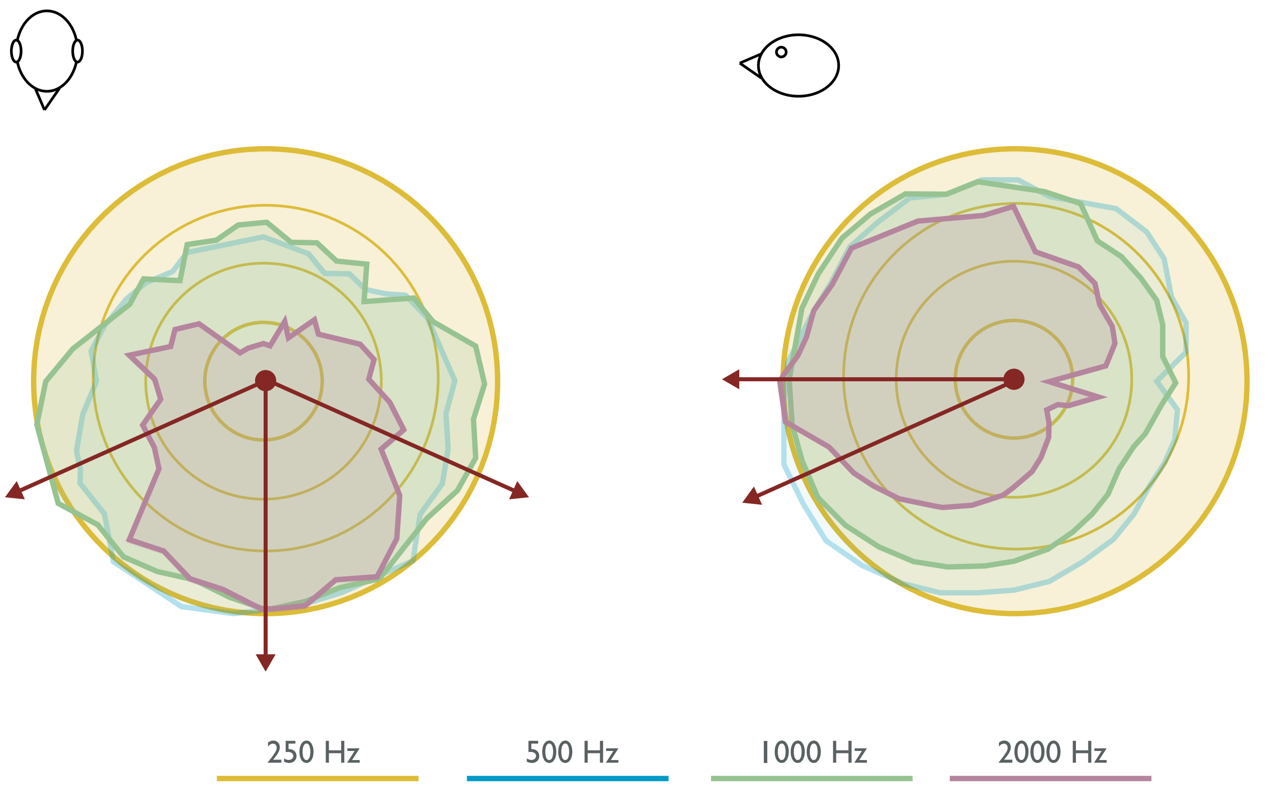
The results of the simulation show that direct sound has a considerable influence on the receiver as the estimated values are satisfying the standard, but they are not so far from the limit value. It is though quite impossible to limit teacher's noise exposure, but it can be managed always taking into account reflections of sound and students' positions in the room.

The next steps of the simulations are to try to keep the teacher's noise exposure under control, increasing the reverberation time of the room to obtain a better acoustical quality for its didactic purpose.

INCREASING THE REVERBERATION TIME OF THE ROOM

Increasing the reverberation time of the room implies a change of the materials and their absorption coefficients to let the sound waves reflect more and be less absorbed by the surfaces.

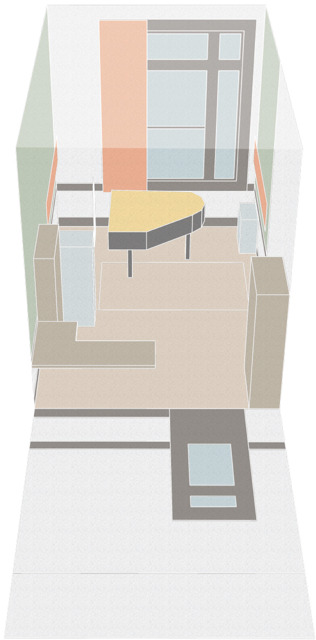
To manage and monitor teacher's exposure, absorbing surfaces have to be guaranteed where the directivity of the student (source) is addressed.



Soprano directivity at the frequencies of 250 Hz, 500 Hz, 1000 Hz, 2000 Hz.

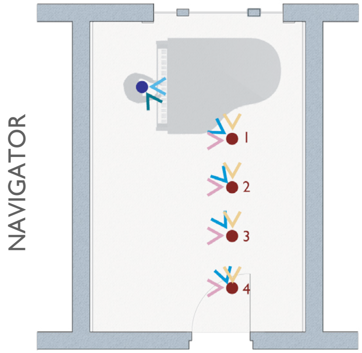
SIMULATION 4

Lateral panels

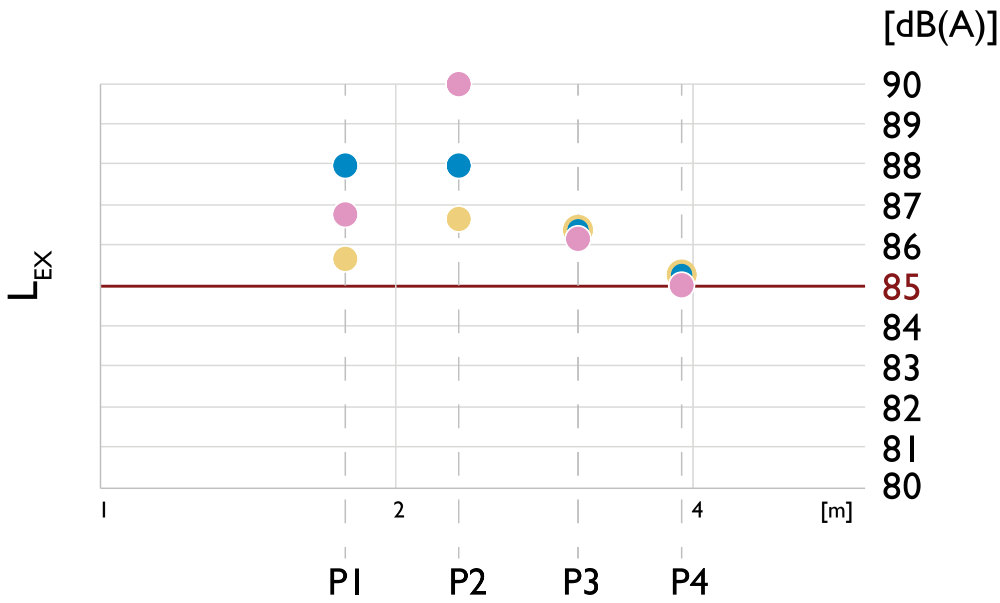


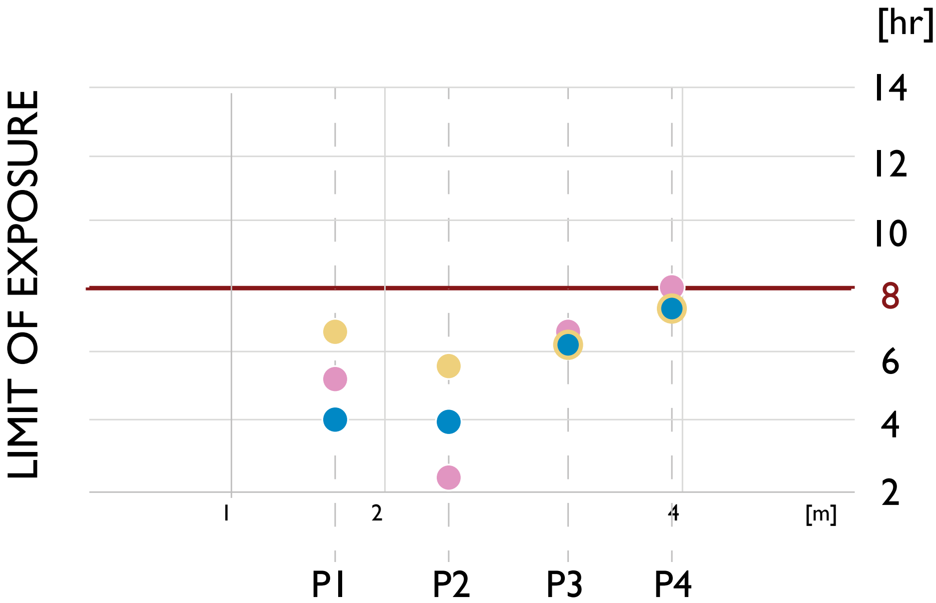
Materials	Frequency range [Hz]							
	63	125	250	500	1000	2000	4000	Surfaces [m^2]
Wood	0.10	0.19	0.23	0.25	0.25	0.37	0.42	11.10
Glass	0.15	0.15	0.05	0.30	0.03	0.02	0.02	4.00
Linoleum	0.02	0.02	0.02	0.03	0.04	0.04	0.05	18.80
Plaster	0.04	0.04	0.05	0.06	0.08	0.04	0.06	24.60
Piano	0.20	0.14	0.10	0.08	0.08	0.08	0.08	4.25
Book cabinets	0.20	0.16	0.11	0.08	0.11	0.05	0.05	4.35
Metal cabinets	0.01	0.01	0.01	0.01	0.01	0.02	0.02	9.78
Absorbing panels	0.10	0.10	0.15	0.30	0.60	0.90	0.85	5.10
Felt	0.35	0.35	0.65	0.90	0.90	0.95	0.90	1.95
Membrane absorbers	0.30	0.40	0.30	0.20	0.13	0.10	0.10	25.90

Room materials with their absorption coefficients and surfaces.



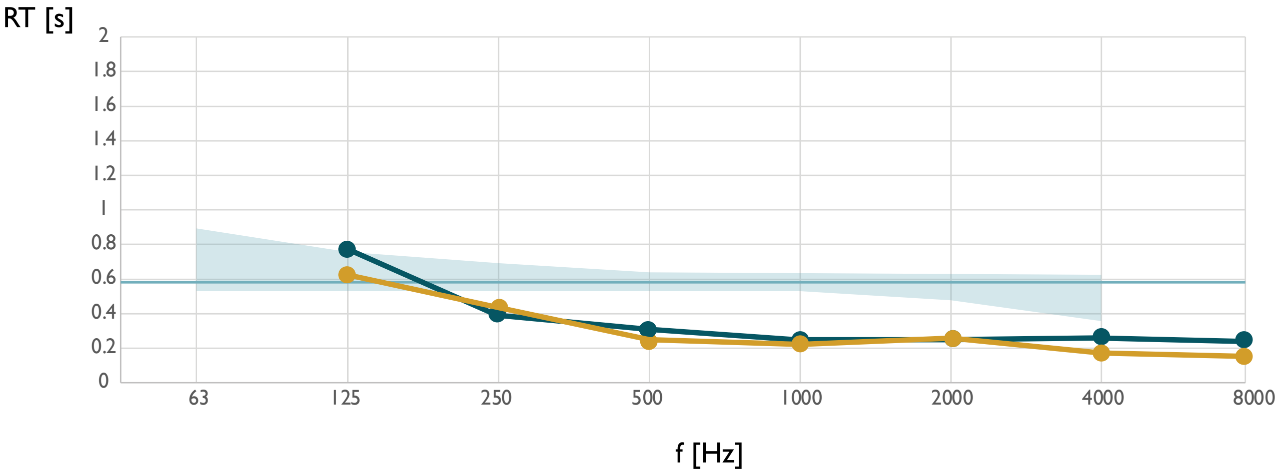
Monoaural exposure results at receiver's point												
Sources	1			2			3			4		
Orientations	a	b	c	a	b	c	a	b	c	a	b	c
SPL(A) soprano voice	92.5	88.1	90.4	92.5	90.1	95.5	88.9	88.9	88.7	86.7	86.5	85.9
SPL(A) piano	90.0	90.0	90.0	90.0	90.0	90.0	90.0	90.0	90.0	90.0	90.0	90.0
SPL(A) voice&piano (32%)	94.4	92.2	93.2	94.4	93.1	96.6	92.5	92.5	92.4	91.7	91.6	91.4
SPL(A) speech (45%)	52.3	52.3	52.3	52.3	52.3	52.3	52.3	52.3	52.3	52.3	52.3	52.3
SPL(A) background noise (23%)	37.8	37.8	37.8	37.8	37.8	37.8	37.8	37.8	37.8	37.8	37.8	37.8
Lex (A)	88.0	85.7	86.8	88.0	86.6	90.2	86.1	86.1	86.0	85.2	85.2	85.0
max duration of exposure [hr]	4.0	6.7	5.3	4.0	5.5	2.4	6.2	6.2	6.4	7.6	7.7	8.0





Tables and graph showing the estimated values accordingly to the 4 different possible student's positions and its 3 possible orientations.

	Frequency range [Hz]						
	125	250	500	1k	2k	4k	8k
RT $_{measured}$ **[s]**	0.78	0.39	0.30	0.24	0.24	0.25	0.23
NS_T$_m$ [s]	0.58	0.58	0.58	0.58	0.58	0.58	0.58
RT $_{estimated, Odeon}$ **[s]**	0.64	0.41	0.24	0.21	0.26	0.18	0.17



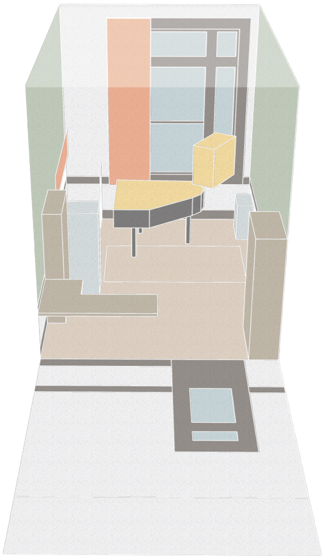
Estimated reverberation time values compared to the measured ones; measure RT (blue), estimated RT by Odeon (yellow).

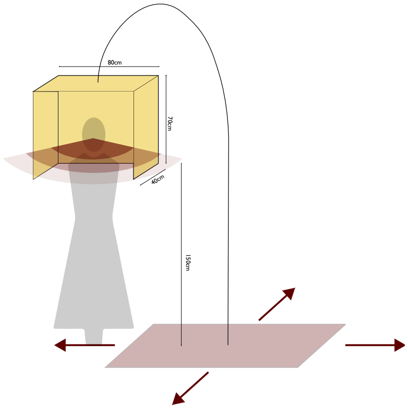
This solution is similar to the helmet solution as it has in common the leaf panel and the felt on the piano and it reaches acceptable values in terms of reverbreration time.

The teacher's exposure is slightly above the limit in most of the student positions. This fact does not mean that the teacher is at risk while teaching, but that his/her exposure has to be reduced in terms of time of classes per day: it would be considered unsafe to teach for 8 hours in a day. However, it can be considered to be a safe situation if she/he teaches for less hours.

SIMULATION 5

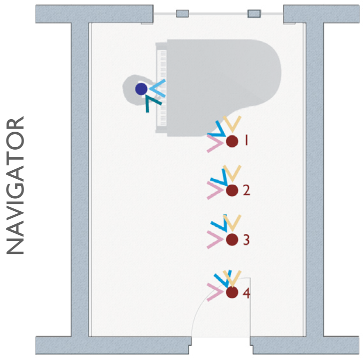
Absorbing helmet



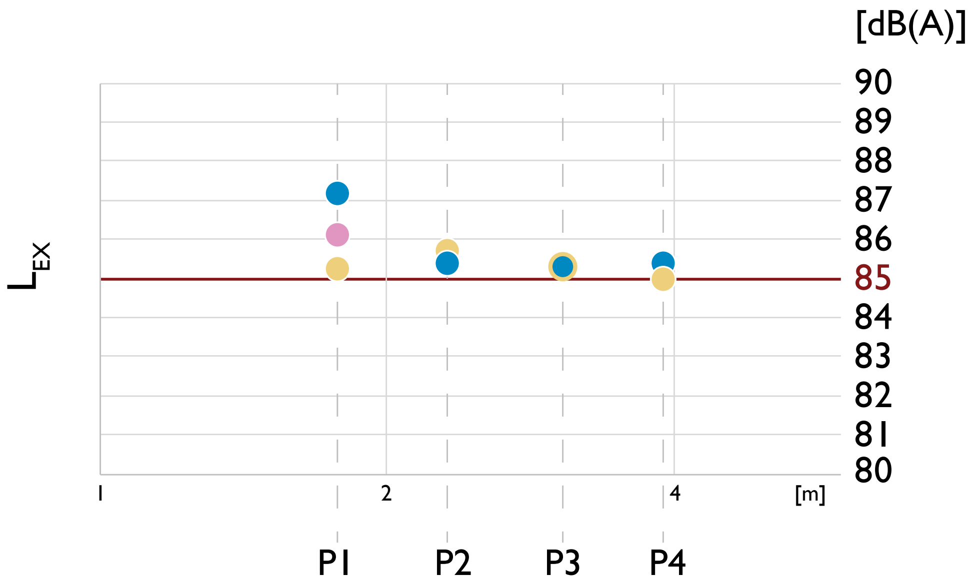


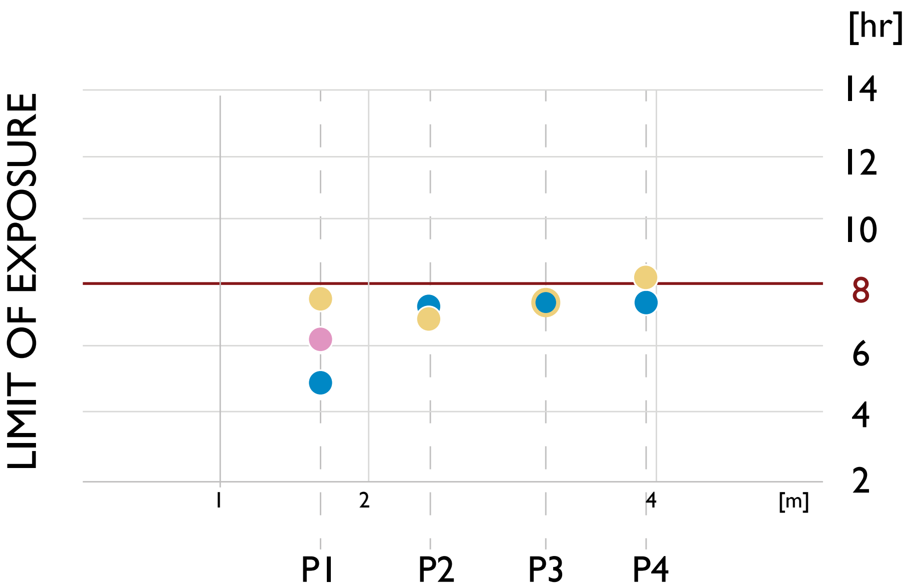
Materials	Frequency range [Hz]							
	63	125	250	500	1000	2000	4000	Surfaces [m^2]
Wood	0.10	0.19	0.23	0.25	0.25	0.37	0.42	11.10
Glass	0.15	0.15	0.05	0.30	0.03	0.02	0.02	4.00
Linoleum	0.02	0.02	0.02	0.03	0.04	0.04	0.05	18.80
Plaster	0.04	0.04	0.05	0.06	0.08	0.04	0.06	18.30
Piano	0.20	0.14	0.10	0.08	0.08	0.08	0.08	4.25
Book cabinets	0.20	0.16	0.11	0.08	0.11	0.05	0.05	4.35
Metal cabinets	0.01	0.01	0.01	0.01	0.01	0.02	0.02	9.78
Absorbing panels	0.10	0.10	0.15	0.30	0.60	0.90	0.85	3.85
Felt	0.35	0.35	0.65	0.90	0.90	0.95	0.90	3.40
Membrane absorbers	0.30	0.40	0.30	0.20	0.13	0.10	0.10	34.20

Room materials with their absorption coefficients and surfaces.



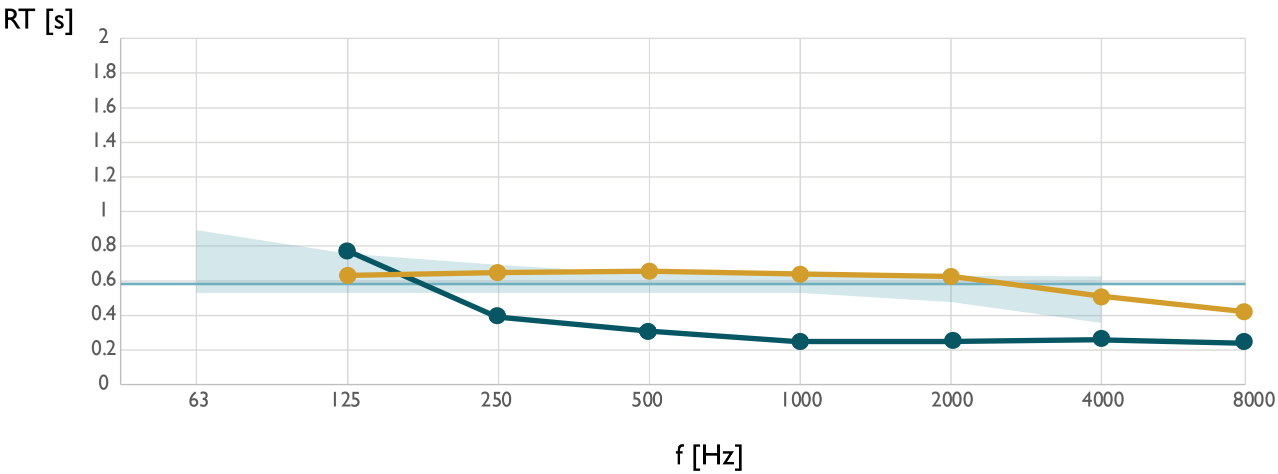
Monoaural exposure results at receiver's point												
Sources	1			2			3			4		
Orientations	a	b	c	a	b	c	a	b	c	a	b	c
SPL(A) soprano voice	91.2	86.7	88.9	87.3	87.9		86.8	86.7		86.9	85.7	
SPL(A) piano	90.0	90.0	90.0	90.0	90.0		90.0	90.0		90.0	90.0	
SPL(A) voice&piano (32%)	93.7	91.7	92.5	91.9	92.1		91.7	91.7		91.7	91.4	
SPL(A) speech (45%)	52.3	52.3	52.3	52.3	52.3		52.3	52.3		52.3	52.3	
SPL(A) background noise (23%)	37.8	37.8	37.8	37.8	37.8		37.8	37.8		37.8	37.8	
Lex (A)	87.2	85.2	86.1	85.4	85.7		85.3	85.2		85.3	85.0	
max duration of exposure [hr]	4.8	7.6	6.2	7.2	6.9		7.5	7.6		7.4	8.1	





Tables and graph showing the estimated values accordingly to the 4 different possible student's positions and its 3 possible orientations.

	Frequency range [Hz]						
	125	250	500	1k	2k	4k	8k
RT $_{measured}$ [s]	0.78	0.39	0.30	0.24	0.24	0.25	0.23
NS_T$_m$ [s]	0.58	0.58	0.58	0.58	0.58	0.58	0.58
RT $_{estimated,\ Odeon}$ [s]	0.63	0.66	0.68	0.65	0.63	0.55	0.44



Estimated reverberation time values compared to the measured ones; measure RT (blue), estimated RT by Odeon (yellow).

This simulation takes into account only students' positions that can be practical in terms of the classes. The absorbing helmet can be a useful and comfortable element thank to its characteristics of being light and movable, but it can phisically limit the view between teacher and student during classes, which is fundamental for an educational purpose.

CONCLUSIONS

The present study research has been an opportunity to link fields apparently different from eachother.
It focuses on the teachers and their occupational safety as far as voice and hearing are concerned, the two being strictly related to the space where the activities are conducted.
The results show teachers' vocal improvement after classes. Therefore it can be affirmed that they know how to use their voice in a way that they reported an improvement of their vocal qualities after classes, which does not affect their lifestyle in the working environment.
According to the standards, both International and Italian, the measured sound levels to which teachers are exposed are high and over the recommended limits.
Noise exposure and architecture can be linked between eachother and have an influence becoming a fundamental aspect to guarantee safety.
The research aims at finding a solution that guarantees safety in terms of teachers' noise exposure and acoustic quality operating on the reverberation time of the space.
As far as room acoustics can have a direct influence on the noise exposure, the research lead to the conclusion that, in this case, the space does not play a fundamental role as the most important cause of the high sound levels is the source and the direct sound it emits; the simulation conducted in the room, taken as example, set up a configuration of a total absorbing space and it shows that the environment doesn not considerably influence the receiver by making the source the only responsible of the teacher's noise exposure.
However, some solutions can be adopted to reduce sound reflections so as to guarantee a decrease in the intensity of the reflections of sound and a more balanced exposure of both receiver's ears.
Once the reflections have been analysed and monitored with the help of absorbing elements, the acoustic quality has been dealt acting on the reverberation times. The room has a music educational purpose and it needs reverberation times values to be balanced: they do not have to be too low nor too high to always guarantee the best perception for both teacher and singer. The measured reverberation times in the actual

room are considered too low and they can have a negative influence on voice education.
For this reason, it has been considered to replace materials in the room adding more reflective surfaces to increase the reverberation times while paying attention to the directivity of the source: absorbing surfaces are guaranteed in the directions in line with the source's voice directivity allowing to have controled noise exposure levels and, at the same time, increasing the acoustic quality of the room.

To conclude it is possible to affirm that voice teachers, in this kind of room configuration with its characteristics, will never reach an acceptable value of noise exposure for what the standards recommend unless the student will position himself at a considerable distance, didactically uncomfortable as it would affect a good view between teacher and student.
However, it is possible to reduce sound reflections and decrease the sound intensity the teacher is exposed to allowing the teacher to lead classes in better and safe conditions.
Overstepping the recommended limit value of noise exposure does not mean that the teachers can not run their acitivity; merely they would have to be aware of the risk they are exposed to and, by consequence, ensure to teach less than 8 hours per day.

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