Hearing damage in pop/rock musicians: assessment of their rehearsal environment

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Abstract

Musicians are one of the population sectors that are in high risk of suffering hearing diseases. As music is sound that generally don’t disturb even at a high volume, the awareness of potential issues derived from being exposed to those high levels is very low.

The present thesis is developed considering a pop/rock style. It is aimed to rise the awareness of the problem among musicians of one of the most important music styles as former studies state that 74% of rock musicians suffer hearing loss.

Throughout the following sections it will be presented different approaches and solutions that were taken in former studies.
As part of this thesis goals and as a starting point in prevention, it will be presented a methodology in order to asses the sound levels to which one is exposed to.
In addition measures of a real rehearsing situation were taken.

Hearing damage in musicians does not only represents a decrease in their quality of life but also a potential loss of the essential component that they need to do what they probably love.

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Generally actions when exposed to high levels like for instance in working environments are seriously taken under consideration. Nevertheless those preventions are not considered within the music industry even though the same noise levels are found.
That may have a reason in the fact that even when played at high volumes music is not considered annoying. But the reality is that our hearing is strongly damaged after a prolonged exposure to high levels, regardless the sound source [2].

Hearing disorders in musicians is a major problem that always has been there. Lately professional players are more conscious about the issue however there is still a way in prevention [8].
Education in hearing protection can definitely make a difference but unfortunately in most of the orchestras or music schools that subject is still pending.

Some orchestras are taking actions by giving information to musicians or offering regular hearing checks [8].
In the last years there are several researches addressing this important topic by assessing the exposition of the musicians and also by testing potential acoustic solutions.
Nevertheless they are mainly focused into classical music.

It was found a gap in assessing and creating an awareness among musicians of other styles where the problem could be affecting more.
Some researches have found that the issue is even higher in the case of pop/rock musicians[3].

Professional musicians playing that music style are more likely to have access to asses their environments and potentially take actions in prevention. But it exists an important amount of amateur musicians that in one hand probably are not aware of the potential risk and on the other hand don’t have access to a first approach in assessing their environments in terms of sound levels.

STATE-OF-THE-ART

2.1 Hearing diseases

Noise can be described as a sound at such intensity that can interfere with verbal communication and may cause discomfort of the ears or reduction of hearing sensitivity.

In order to get a better understanding of how this hearing damage happens, it is important to comprehend how we hear. [1]

In a first step, sound waves enter the outer ear and travel through the ear canal that ends in the eardrum. The eardrum is a membrane that vibrates from the incoming sound waves and transmits these movements to three tiny bones called malleus, incus and stapes. This part of the auditory system is named middle ear.

At this point, air vibrations from the eardrum are coupled to fluid vibrations into the cochlea, part of the inner ear and shaped as a snail. The cochlea, filled with liquid, hosts the basilar membrane, which is an elastic partition placed from the base to the apex of the former.

On top of the basilar membrane are located the hair cells. The vibrations transmitted to the liquid into the cochlea cause the fluid to ripple and hence the hair cells to move, transforming this mechanical movement into electrical signals that are carried to the brain by the auditory nerve.

Most hearing loss is caused by the damage and eventual death of these hair cells. Unfortunately unlike other animals, human hair cells don’t regenerate so that hearing loss can be permanent.

So far researches have concluded that different diseases may occur depending on the level of bending of the hair cells, coming from mild to severe disorder as explained below.

2.1.1 Auditory fatigue

To be exposed to a certain noise may induce to a decrease of the ear’s sensivity as a measure of protection. Hence only sounds over a determined level could be heard.

The shift could be temporary but also become into permanent, depending on both the time exposure and the level of the noise. Unlike musical noise, it has been proved that non-musical noise has a more harmful effect on shifting the sensitivity threshold.

Temporary Threshold Shift or TTS affection is normally reversed in a time space between 2 minutes and 24h. However in some cases could take up to seven days to be recovered. [3]

On the other hand, Permanent Threshold Shift or PTS happens after a prolonged and repeated exposure resulting in a important hearing damage.

People working in or exposed to noisy environments would experience TTS that could turn into chronic if it is repeated regularly and there is not sufficient time between exposures. Therefore, this population are in high risk of developing PTS. [4]

2.1.2 Acoustic trauma

Hearing can be permanently lost even if the exposure is very short.

High level exposures (over 140dB) would gravely damage the fibers within the inner ear. Under this circumstances, hair cells bend excessively, beyond their elastic limits so that eventually they tear them apart. The Organ of Corti then becomes detached from the basilar membrane and it is followed by a scar tissue which covers the damaged area so that it will not regenerate. [2][3]

This situation is caused by impulsive sounds that produce a mechanically damage within the ear. Therefore the sound pressure level is more important than the time exposure.

Such sounds can be mainly found in explosive events as pistol shots, that produces 160-170dB or firecrackers detonation close to the head, up to 170dB. [2]

2.1.3 Noise-Induced Hearing Loss (NIHL)

Rather than a mechanically damage, exposures between 90-140dB cause a metabolically harm in the cochlea. Unlike the acoustic trauma, Noise-Induced Hearing Loss is developed over years after being regularly exposed to an average over 90dB so that it is relative to the time of exposure but also to its level. There are 3 different stages a person would experience.

In a first stage, sensory cells within the cochlea are strongly hurt and eventually are replaced by a scar tissue. After weeks or years of exposition, it is in the second stage when high frequencies start to be missed and the hearing loss can be detected audiometrically. However, speech frequencies necessary for understanding are not lost until the third stage. Up to this point the patient becomes more aware of the problem by himself although most of the damage is already done. [2][3]

2.2 Hearing Loss in Musicians

Regarding to the previous paragraphs, it can be inferred how important is to regulate noise exposure, especially at work. There are several institutions that are in charge of researching and determine limits, connecting time and sound pressure level.

One of the most important organizations is the National Institution for Occupational Safety and Health (NIOSH), established in the United States in 1970 to help ensure safe conditions at work.
In Great Britain it exists the Health and Safety at Work, an institution that developed the Control of Noise at Work Regulation in 1989.

NIOSH developed a standard by setting a certain time of exposure according to the SPL of the noise. [12]

Exposure level, L (dBA)	Duration, T			Exposure level, L (dBA)	Duration, T		
	Hours	Minutes	Seconds		Hours	Minutes	Seconds
80	25	24	—	106	—	3	45
81	20	10	—	107	—	2	59
82	16	—	—	108	—	2	22
83	12	42	—	109	—	1	53
84	10	5	—	110	—	1	29
85	8	—	—	111	—	1	11
86	6	21	—	112	—	—	56
87	5	2	—	113	—	—	45
88	4	—	—	114	—	—	35
89	3	10	—	115	—	—	28
90	2	31	—	116	—	—	22
91	2	—	—	117	—	—	18
92	1	35	—	118	—	—	14
93	1	16	—	119	—	—	11
94	1	—	—	120	—	—	9
95	—	47	37	121	—	—	7
96	—	37	48	122	—	—	6
97	—	30	—	123	—	—	4
98	—	23	49	124	—	—	3
99	—	18	59	125	—	—	3
100	—	15	—	126	—	—	2
101	—	11	54	127	—	—	1
102	—	9	27	128	—	—	1
103	—	7	30	129	—	—	1
104	—	5	57	130–140	—	—	<1
105	—	4	43	—	—	—	—

Table 1: Combination of noise exposure levels and maximum duration recommended according to NIOSH standard. *NIOSH, 1998. Occupational Noise Exposure. Criteria for a Recommended Standard.*

The above information has been and is still applied to regulate working hours depending on the level of noise in the working environment. Further researches about guidelines or good practices to follow in order to reduce or eliminate noise exposure are also addressed by NIOSH.

Relating the values from the table to musicians, it was estimated that the exposure of a professional musician performing classical music in orchestras would be equivalent to 8 hours at 85.5dB per day. It is slightly above of the established limit although it has to be taken into account that most of these musicians does not wear protection so that the damage is worse. [3]
Actually, it was determined that musicians placed in front of trumpets exceed the limit after 10 hours per week.

Rock and jazz musicians are also in high risk as 74% of them suffer hearing loss, permanent in 20% of the cases. [4]
High noise levels does not only occur at rehearsals but also at live performances. Average level at venues was estimated in 103.4dB at rock live performances while at orchestra concerts levels fluctuate between 80 and 110dB. [5]

Professional musicians are exposed to high levels for long periods of time, and that situation is regular. Hence it makes sense that NIHL is the most spread disease among them, but not the only one, as subsequent affections like auditory fatigue, tinnitus and hyperacusis also strongly affect the performers.

Even though they are not subject of this research, it is important to mention that people working at venues and live events are also in high risk of suffering NIHL, as they are usually exposed between 94.9 and 106,7dB. According to the values on table 1 it can be inferred that the limit can be easily exceeded. [4]

Based on the studies developed by organizations like NIOSH, government institutions in charge of safety and health at work try to assure safe conditions.
However, it is controverted that in general these regulations are not applied to professional musicians. They normally are not officially recognized as workers in most of the countries having these regulatory organizations, so that orchestras and production companies are not forced to fulfill any requirement.

In 2005, the Health and Safety at Work institute in Great Britain updated the Control of Noise at Work Regulation. According to this version, from 2008 onwards employers from music and entertainment industry are forced to evaluate noise. The regulation states that the assessment has to be addressed if levels exceed 80dB. They also must provide protection if levels are above 85dB. [10]

In addition, among musicians it doesn't exists an awareness of the magnitude of the problem since only a 8% find hearing loss a big issue.
Beyond the purpose of this study, to educate in auditory health and prevention could avoid future diseases as, according to Zhao et al., out of 9000 respondents, only 14% declared to be using earplugs, however 66% will be keen to use them. [3]

2.3 Previous Studies

Noise assessment within orchestras pits has been addressed by many researches. These studies are aimed to present not only the extent of the problem but also to provide subjective data in order to propose solutions.

In 2006, Brueck carried out one of the aforementioned evaluations. In the context of an orchestra environment he placed microphones at certain spots that captured the sound level. Besides, in order to analyse the noise perceived by the musician, he used dosimeters in several instruments player such as trumpets, cello and clarinet.

After gathering all the captured information, it was found that musicians at brass section and adjacent peers are usually exposed to 90dB(A) or more, even if their instrument produces lower levels.

As a possible measure, it was discovered that allowing more space between players could lead up to 6dB of reduction of the noise, which perceptually means that the perceived noise would be the half. [6]

The latter is already performed by some orchestras, as evidenced a study that evaluated the methods applied by 8 different orchestras regarding to noise treatment.
Further control practices were found such as rostering according to predicted noise exposure, as well as playing at lower level, both performed by 1 out of 8 orchestras. [8]

Furthermore, it was proved that an equitable noise distribution simply by rotating seats could help to give some rest to those musicians located at noisy spots within the orchestra pit. However, it would be ideal to have some rest between expositions, even more after noisy passages.

Acoustic treatment also has a presence in noise assessment. Screens are the most common used object and they are usually made of Perspex, but wood can also be seen.
O'Brien et al. concluded that a diffusive pattern onto the screens would be more appropriate than absorptive, given that the latter would be likely to have side effects of causing overplaying and associated strain injuries.

Likewise, they also found that some orchestras use “horn reflectors” in order to enable the sound to be projected more easily to the front of the orchestra so that volume required from the instrument would be lower. [8]

Assessment and evaluation of the noise caused by all the instruments playing at the same time yields to valuable information in order to apply possible solutions. However it is interesting to analyse the sound produced by each instrument itself so that it can be deduce the direct sound that reaches the performer ear and evaluate the influence of adjacent instruments while playing within the orchestra.

Cáceres Armendáriz and García González performed individual measures for different instruments, taking samples in two different positions: the closest to the ear (shoulder), noted as F, and directly in front of the instrument, noted as G. Results are shown below. [9]

INSTRUMENT	Lpk max. in dB	Leq in dB(A)	
		F	G
Violin	108	86.2	79.4
Oboe	102	85.8	84.6
Trumpet in Do	115.7	95.5	92.5
French horn	116	92.8	89.1
Trombone	115.3	93.2	93.7
Piccolo	110	92.8	92.6
Xylophone	119.8	96.8	94.8
Snare	131.1	99.6	98.4

Table 2: Individual measurements in rehearsal room. *Cáceres Armendáriz, P. & García Gónzalez, J., 2001. El ruido y los músicos de la orquesta sinfónica. In XII Congreso Nacional de Seguridad y Salud en el Trabajo. pp. 1–8*.

In some of the instruments it exists a considerable difference between both positions, in some cases reaching 6dB. Two different aspects could lead to this. The first one is the room conditions, as it is not completely anechoic although very similar. The second one could be the structure of the instruments as well as the produced sound, as high frequencies have more directivity than low ones.

Nonetheless, this highlights that one of the biggest sources of noise within the stage comes from the musician’s instrument itself.

However to add musicians has also a strong influence in the perceived levels, as it can be inferred from the figure below.
According to Cáceres y García, the noise level increases in 2dB every 10 musicians added. [9]

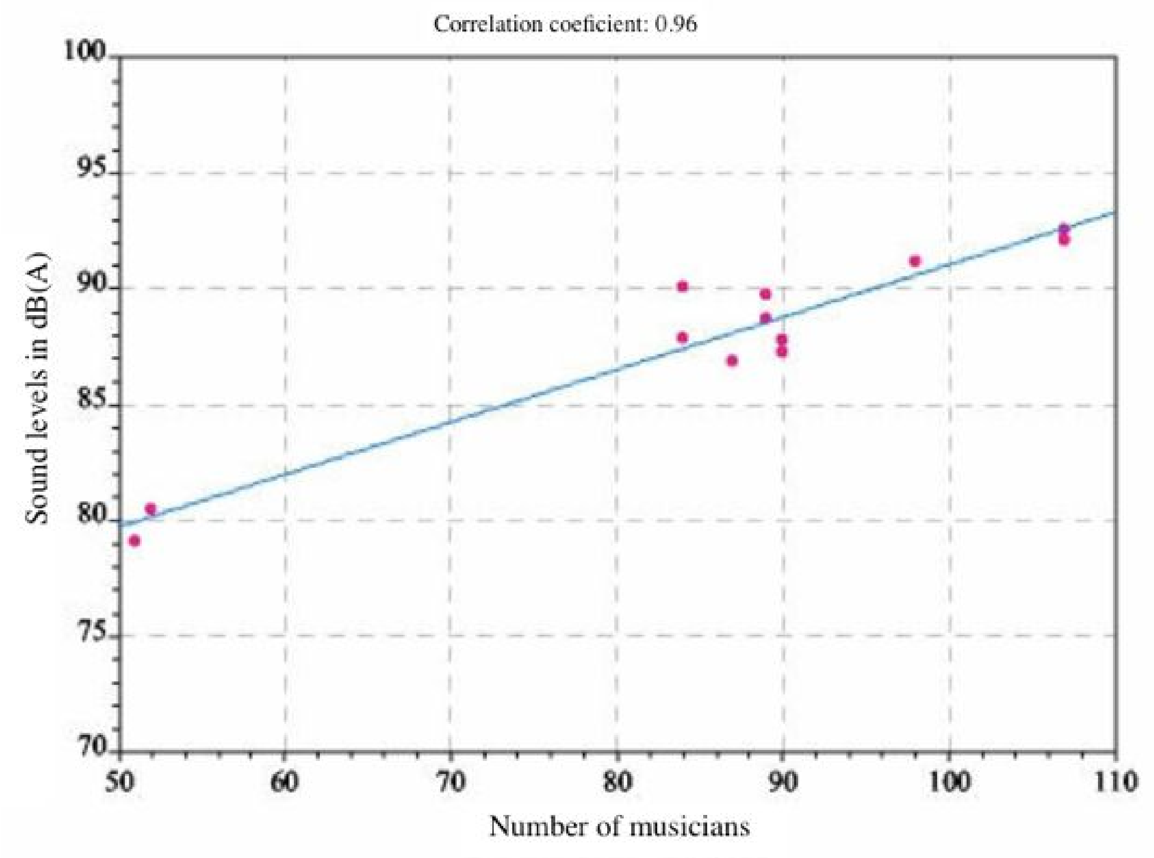

Figure 1: Combination of noise levels with number of musicians. *Cáceres Armendáriz, P. & García Gónzalez, J., 2001. El ruido y los músicos de la orquesta sinfónica. In XII Congreso Nacional de Seguridad y Salud en el Trabajo. pp. 1–8*.

In addition to the previous solutions, probably the most effective one is the use of hearing protectors. There are several models that Patel analysed as long as its usage among musicians. [10]

According to her findings, there are three factors to take under consideration when considering the use of hearing protectors:

· **Excessive attenuation.** Currently protectors tend to reduce the noise between 9 and 25dB. However up to 10dB would be enough for a musician.

· **Coloured sound and tonal alteration.** By entering a protector into the ear canal, its natural resonant peak is cancelled, usally located at 2.7KHz at 15dB. This cancellation is noticeable given that most of the instruments generate frequencies around that value. Besides, high frequencies are missed so that many harmonics would not be heard.

- **Occlusion effect.** This effect occurs when an object fills a portion of the ear canal so that sound vibrations reverberate off that object. Sound reflects back toward the eardrum causing an increase of loudness perception of the own voice. It also boosts low frequencies.

As it can be inferred, the usage of hearing protectors could hinder the communication among musicians as well as their own perception of what they are playing and listening from other instruments. Some protectors are also uncomfortable and, what it is very remarkable, some musicians refuse to wear them because they don't want to look like having a "weak" hearing.

On the other hand, it is important to understand what hearing is for a musician. Beyond the fact that they would experience a misunderstanding in speech, suffering from hearing loss could stop a musician's career.

Currently there is a wide range of hearing protectors whose features and characteristics varies according to the usage.

- **Earmuffs.** Very effective protectors, delivering a large attenuation. Since they cover the pinna, occlusion effect does not exists. However they are not that effective when using jewellery or with long hair as they need to fit and be perfectly sealed.

- **User-Formable earplugs.** This type of earplugs are cheap and easily malleable by the user. The small size and the effectiveness against high level noise make them a good choice if large attenuation is required. Nevertheless, they colour the sound and cause occlusion effect and hence they are not recommended to vocalists and musicians playing wind and metal instruments.

- **Pre-Moulded earplugs.** Considered a better option than the former given that they are made of silicone and that their shape (Christmas tree or domed toadstool) so that it is easier to enter and more comfortable. Even so, since they are not customized, occlusion effect happens as well as that the sound is coloured.

- **Custom-Moulded earplugs.** This customizable protector is designed according to the shape of the ear. Its design also includes filters to shape the heard sound. It is a good option for musicians, but very expensive, and the finish has to be very precise and accurate.

Apart from these protectors, there are also some options including the possibility of receiving signal, This is the case of in-ear monitors, with which the musician is not only isolated from the outside noise but he also receives the sound he wants at a decent volume.
This system is more a more being used by professional artists but there are no researches assessing them from the point of view of hearing loss.

In order to give a more precise point of view, Santoni and Fiorini assessed the use of hearing protectors among pop-rock musicians.
Pre-Moulded and custom-moulded earplugs were the chosen given that they are the most suitable for musicians, although their attenuation are 9-25dB and 20dB respectively. [11]

Most of the musicians refused to use them during a live performance due to the fact that quality sound decreases and also because communication among players becomes difficult. According to the survey, the most negative point of using protectors refers to the pressure inside the ear canal and the perception of dampened voice.

However, 20% of 196 musicians that participated in the study ended up using hearing protectors. To note that these 20% already suffered of NIHL.
Besides NIHL, tinnitus (56.5% after a show) and hyperacusis (34.8%), there were a number of them that experienced insomnia and occasional memory loss (26.1%). [11]

2.4 Conclusion

In the previous pages it has been presented the current problem of Hearing Loss in musicians. According to their exposure, professional musicians are in higher risk than amateur musicians. However it would not be fair to underrate the latter, as the exposition levels could be the same or even higher considering the low concern they might have about the issue plus the conditions of rehearsal rooms and instruments set-up.
In addition, people attending to music schools and conservatories, both students and teachers are also exposed to high levels for long periods of time, either in rehearsals or concerts. Furthermore, most of the studies related to hearing loss in musicians are from an orchestra scope, however there are just a few that address the issue with pop and rock musicians. Somehow, the solutions described in the previous pages can be applied to the latters but in general most of them could not be valid.

A rock band layout is completely different from an orchestra layout. It is not only the disposition of the musicians, but also the instruments themselves as most of them in a rock band are amplified.
Besides, rehearsal rooms usually do not bring together the same acoustic conditions as orchestra pits.

The present document brings to light two main issues that have not been addressed yet: the lack of research of the topic with pop/rock musicians and the necessity of making accessible both assessment and possible solutions to amateur musicians.

To disseminate and to cover the aforementioned points could prevent important future hearing diseases. However, to educate in good practices from the beginning always has been and will be the best solution.

RESEARCH GOALS

According to what has been exposed in the previous literature review, two main goals were set:

- To disclose and rise the awareness of the problem of hearing loss among pop/rock musicians.
- To make accessible a first approach in sound levels assessment.

In the following sections will be presented the work developed in order to achieves the aforementioned goals.
As it was not found any type of data regarding to the sound levels within a pop/rock band, a set of measures were taken. It will be presented the procedure and the values that were recorded so that musicians can have an estimation of the levels to which they are exposed to. It will also be explained a methodology by using sound recorders aimed to provide an estimation of the exposition.

MEASUREMENTS

4.1 Introduction

This part will present the procedure that was followed to measure the sound levels within the pop/rock band layout.

As the purpose is to provide realistic data, it was recreated a regular situation for any pop/rock band therefore any acoustically prepared or anechoic room was avoided.
The room selected was the one where the band usually rehearses.
The acoustic specifications of the room are low as only perforated panels were covering the walls.
The size of the room was large considering most of rehearsal rooms: 8.5m width by 10m length by 3.5m height. A large room was needed in order to have enough space to take measurements in different spots at a certain distance.
As a measure to reduce reverberation time there were several elements scattered like desks, bookshelves, chairs and cupboards that helped in achieving more than a decent sound.

In regards to the distribution, it was difficult to decide which disposition was the most accurate as there is not an established common layout as it happens in classical music. Besides sometimes more instruments can be added to the basic pop/rock band layout.

In order to include at least all the basic instruments of this type of music and to determine a basic layout it was selected the disposition shown in figure 2. Distances between musicians are described in table 2.
The main instruments that set a pop/rock band are a lead voice, an electric guitar, a bass guitar, a keyboard and a drum-set.
All the instruments were connected to their corresponding amplifier. Both electric guitar and bass guitar amplifiers were located right next to the corresponding musician and had a power of 100W.
In the case of the voice, a PA speaker of 150W was placed just in front of the position of the singer and the keyboard was also connected to a PA speaker of 150W of power right next to the instrument.
The equipment used to evaluate the levels was the sound level meter PAA3 designed by Phonic. It is a digital sound level meter that offers a 31-band spectrum.

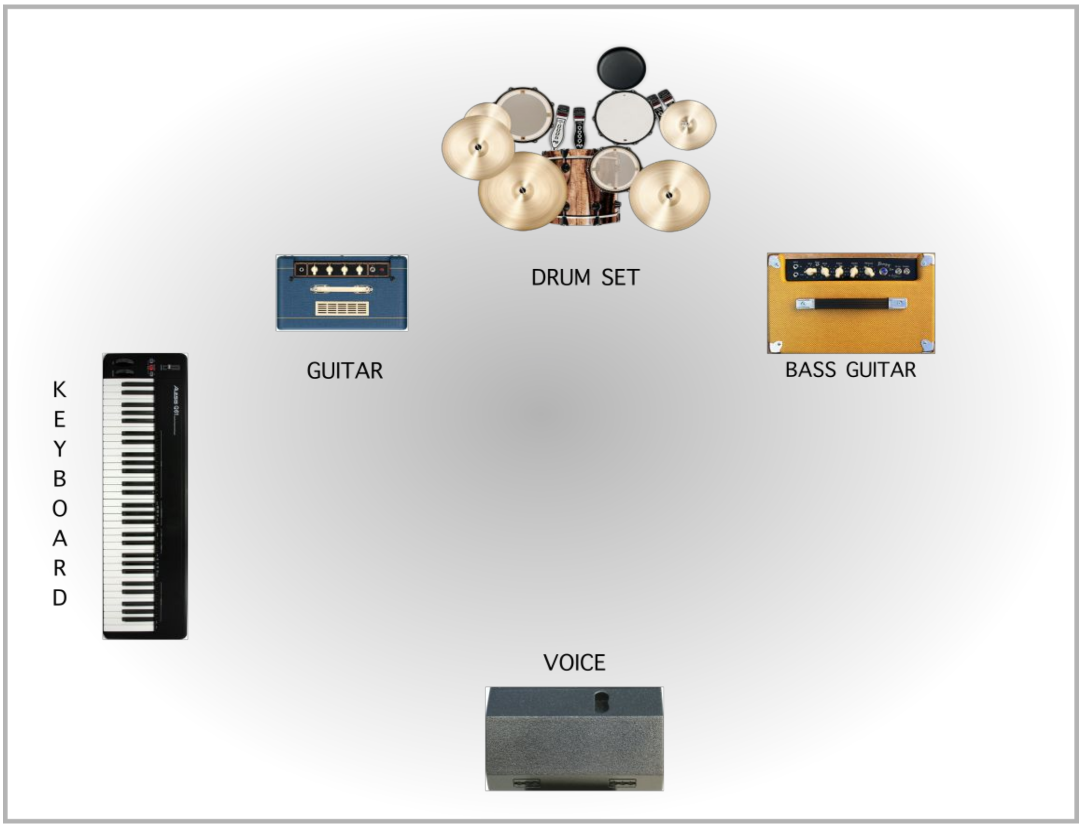

Figure 2: Basic pop/rock band layout. This configuration was used during the session when measurements were taken

DISTANCES (cm)					
	Guitar	Bass guitar	Keyboard	Drum set	Voice
Guitar	-	190	180	200	214
Bass guitar	190	-	350	220	222
Keyboard	180	350	-	370	245
Drum set	200	220	370	-	380
Voice	214	222	260	380	-

Table 3: Distances (cm) between musicians position according to the layout shown in figure 4.

4.2 PROCEDURE

Before starting to take any measure musicians were requested to play freely for a few minutes. It was essential to do so as a warm up method.

During this warm up period musicians set volumes up by themselves. It was decided to do it in that way as a regular rehearsing situation was being pursued. Minor arrangements regarding to the equalization were done once they finished.
It was very important to get the musicians relaxed and confident so that they would play as normal.

After warming up musicians were requested to stay playing all together.
This first part consisted in taking measures while the entire band is playing. Sound levels were collected at the musician's position, right next to them.

In order to be more precise, measures were taken while playing two songs, one a bit higher in tempo and volume and a second one slightly lower in both parameters. The final value shown on table 4 is an average between 10 measures per musician and position, equally divided between the 2 songs. Peak levels were also registered.

ENTIRE BAND										
	Guitar		Bass guitar		Keyboard		Drum set		Voice	
dbSPL	Leq	Lpeak	Leq	Lpeak	Leq	Lpeak	Leq	Lpeak	Leq	Lpeak
Musician position	98	103.4	99.2	105	93.8	101.4	94.7	104	97.7	103

INDIVIDUAL										
	Guitar		Bass guitar		Keyboard		Drum set		Voice	
dbSPL	Leq	Lpeak	Leq	Lpeak	Leq	Lpeak	Leq	Lpeak	Leq	Lpeak
Musician Position	92.1	104	89.8	97	90.6	98.5	90.4	98.8	84	88.3
2 meters	87.6	97.8	82.7	90.4	81.5	87	82.2	88.4	80.4	84

IN GROUPS OF 2					
Position	Guitar	Bass guitar	Keyboard	Drum set	Voice
dBSPL	Leq	Leq	Leq	Leq	Leq
Guitar	-	97.8	92.6	95.6	92.6
Bass guitar	93.2	-	88	105.9	91.2
Keyboard	96.6	97.7	-	89.8	90
Drum set	97.7	100	94.6	-	91.8
Voice	98.9	99.3	89.2	93.6	-

Table 4: Sound levels registered within a pop/rock band according to the layout in figure 4.

Individual measures were taken in two different spots: at the musician's position and 2 meters away in a straight line.
In this part as in the following one it was very important to keep the pace and volume like if the musician was playing along with the band. To do so the procedure was that the band started playing all together and at some point everybody but the musician in evaluation stopped.
As well as in the previous round of measures two songs were played. Again, the average of the sound level was calculated by taking 5 measures in each song, per musician and position.

In the last set of measures, in groups of 2, the procedure was the same as in the individual ones but leaving 2 instruments playing in stead of one.

CALIBRATION

5.1 Introduction

One of the main purposes of the present thesis is to make accessible the assessment of sound levels within a rehearsal room environment. In this section will be explained a methodology aimed to provide a first-approach evaluation.

Generally when talking about measuring sound levels it comes to mind a sound level meter. It is actually the best option to evaluate the sound pressure to which one is exposed to. Nevertheless the usage of these devices is not as spread among musicians as among technicians or professionals working in the field of sound.

In order to offer a more suitable approach to everybody, it was decided to use sound recorders as these elements are easier to find in musician's equipment and also the cost is generally lower than the former devices.

It could not be found in the literature any statistic or research regarding to the most used sound recorder. Hence for the purpose of this thesis *Zoom H4n* and *Zoom H1* models were selected as both recorders lay within a medium professional equipment that can be affordable to every amateur or experienced musician.

In the case of the sound level meter, it was used the model *PAA3* made by *Phonic*
Further details of the technical specifications of both recorders and the sound level meter can be found in the appendix.

5.2 Procedure

As it can be seen in previous chapters, all the sound values are referred as dBSPL. There are different units to measure the levels as dBFs and dBU among others. They represent the same level but in a different scale.
The Zoom recorders measure the sound levels in a dBFs scale whereas the sound level meter provides that information in a dBSPL scale.
Therefore in order to compare the *Zoom* recorder values with the NIOSH standard previously shown in table 1, it is necessary to perform a calibration between the two scales.
The equivalent values for each scale are shown in table 5 and table 6.

Freq (Hz)		63		125		250		500	
Sound level (dBSPL)	RecLevel	H1 (dBFs)	H4 (dBFs)	H1 (dBFs)	H4 (dBFs)	H1 (dBFs)	H4 (dBFs)	H1 (dBFs)	H4 (dBFs)
100	100	0	0	0	0	0	0	0	0
	80	0	0	0	0	0	0	0	0
	60	0	0	-3	-6	0	0	-3	-4
	40	-6	-14	-12	-14	-3	-6	-9	-12
	20	-12	-18	-21	-22	-9	-14	-20	-21
90	100	0	0	0	0	0	0	0	0
	80	-3	-7	-6	-8	0	0	-3	-6
	60	-12	-12	-12	-16	-3	-7	-12	-14
	40	-21	-20	-23	-24	-12	-15	-21	-22
	20	-27	-29	-32	-32	-21	-23	-27	-30
80	100	-6	-10	-7	-10	0	-2	-6	-8
	80	-15	-18	-15	-18	-6	-10	-12	-16
	60	-24	-25	-24	-25	-15	-18	-21	-24
	40	-30	-32	-31	-33	-21	-26	-27	-31
	20	-34	-40	-40	-41	-30	-34	-34	-40
70	100	-21	-24	-15	-19	-6	-11	-12	-18
	80	-27	-32	-21	-28	-15	-18	-21	-25
	60	-34	-40	-30	-35	-21	-26	-28	-33
	40	-40	-47	-37	-42	-30	-35	-38	-41
	20	-40	-48	-40	-48	-34	-42	-40	-48
60	100	-22	-26	-21	-26	-12	-18	-21	-26
	80	-27	-34	-26	-35	-21	-27	-27	-35
	60	-40	-42	-37	-42	-27	-35	-34	-42
	40	-40	-48	-40	-48	-34	-42	-40	-48
	20	-40	-48	-40	-48	-40	-48	-40	-48

Table 5: Equivalences between dBSPL and dBFs for each rec level value on the Zoom H1 and H4n sound recorders considering tones of frequencies 63Hz, 125Hz, 250Hz and 500Hz.

Freq (Hz)		1000		2000		4000		8000	
Sound level (dBSPL)	RecLevel	H1 (dBFs)	H4 (dBFs)	H1 (dBFs)	H4 (dBFs)	H1 (dBFs)	H4 (dBFs)	H1 (dBFs)	H4 (dBFs)
100	100	0	0	0	0	0	0	0	0
	80	0	0	0	0	0	0	0	-2
	60	0	-4	0	-2	0	-3	0	-6
	40	-6	-11	-10	-11	-3	-12	-6	-6
	20	-15	-21	-21	-19	-9	-25	-12	-12
90	100	0	0	0	0	0	-3	0	0
	80	0	-6	0	-4	0	-6	-6	-3
	60	-9	-15	-9	-12	-6	-18	-13	-9
	40	-15	-23	-18	-21	-15	-24	-27	-18
	20	-24	-31	-24	-31	-24	-38	-30	-27
80	100	0	-6	-5	-12	0	-6	-9	-1
	80	-9	-12	-12	-18	-3	-17	-12	-7
	60	-17	-22	-21	-25	-12	-24	-24	-18
	40	-24	-30	-30	-34	-24	-30	-29	-26
	20	-30	-39	-34	-43	-34	-35	-34	-33
70	100	-12	-15	-8	-17	-15	-15	-9	-9
	80	-21	-25	-19	-26	-24	-24	-20	-17
	60	-27	-33	-27	-34	-29	-30	-30	-24
	40	-31	-41	-31	-40	-40	-40	-38	-33
	20	-40	-48	-40	-48	-40	-48	-40	-42
60	100	-15	-24	-18	-24	-24	-24	-19	-19
	80	-24	-32	-25	-33	-30	-31	-27	-27
	60	-27	-41	-33	-42	-37	-39	-32	-34
	40	-40	-48	-40	-48	-40	-48	-40	-43
	20	-40	-48	-40	-48	-40	-48	-40	-48

Table 6: Equivalences between dBSPL and dBFs for each rec level value on the Zoom H1 and H4n sound recorders considering tones of frequencies 1000Hz, 2000Hz, 4000Hz and 8000Hz.

Considering the frequency range of pop/rock instruments, this calibration between the devices were developed taking into account frequency octaves from 63Hz to 8000Hz

One tone of each frequency octave was played, by setting the level firstly using the sound level meter and then measuring the captured sound for each rec level set in the recorder.

The levels on the sound level meter start at 100dBSPL reducing 10dBSPL until 60dBSPL as being exposed to lower values does not represents a harmful situation.
Regarding to the sound recorders, the rec level represents the sensitivity of the microphones. In the case of both Zoom models this rec level goes from 0 to 100. Steps of 20 units were taken.

The speaker that was used was *Adam A8X.* All the measures were taken at 0.5m of distance from the centre of the main driver.

5.3 Exposure assessment using the calibration curves

According to the information collected and using Matlab it was drawn 5 curves for each recorder – One for each rec level value. All the curves for both Zoom H1 and Zoom H4n recorders can be found in sections 5.3.1 and 5.3.2.

The Y-axis represents the values in dBFs where 0 corresponds to the highest level and -48 to the lowest. In the case of the Zoom H1 the minimum value that can capture is -40dBFs.
The X-axis represents the frequency range. Each curve is drawn according to the dBSPL value.

In order to estimate the exposure, the recorder should be placed at 0.5m of the sound source and the rec level has to be such that the recorder does not clip. Finally, considering that rec level, the registered value on the recorder and the frequency range of the sound being measured on can estimate the exposure in dBSPL by using the curves.

5.3.1 Zoom H1 calibration curves

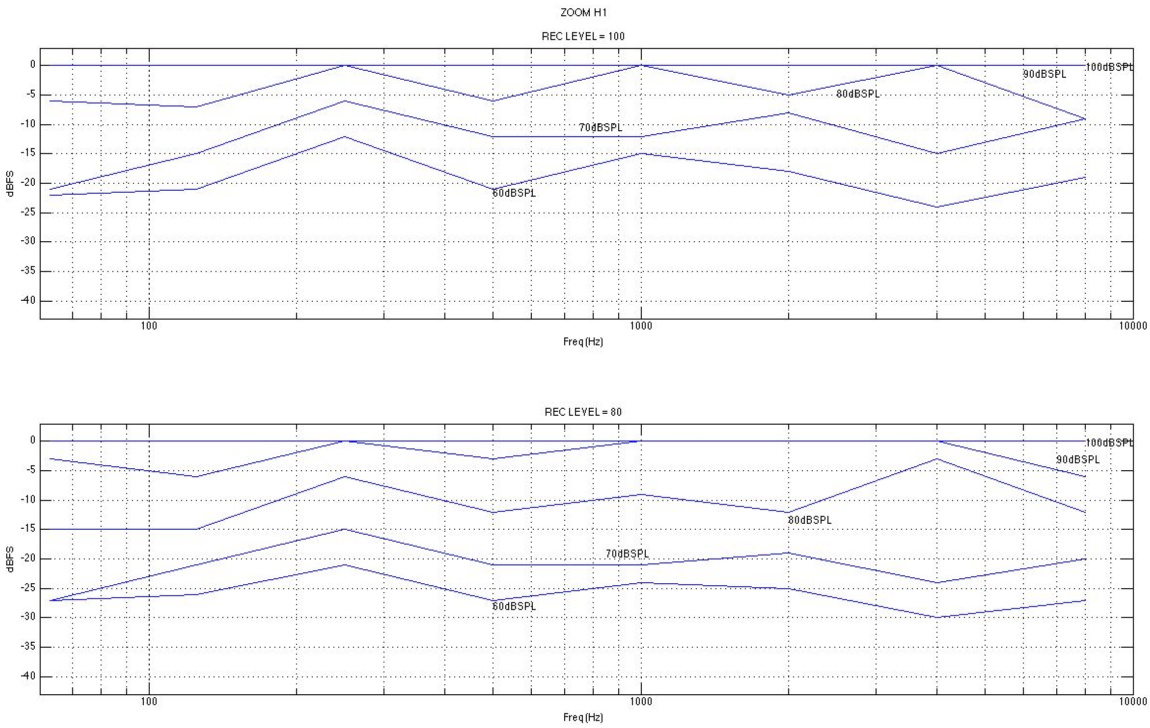

Figure 3: Zoom H1 calibration curves for rec levels set at 100 and 80.

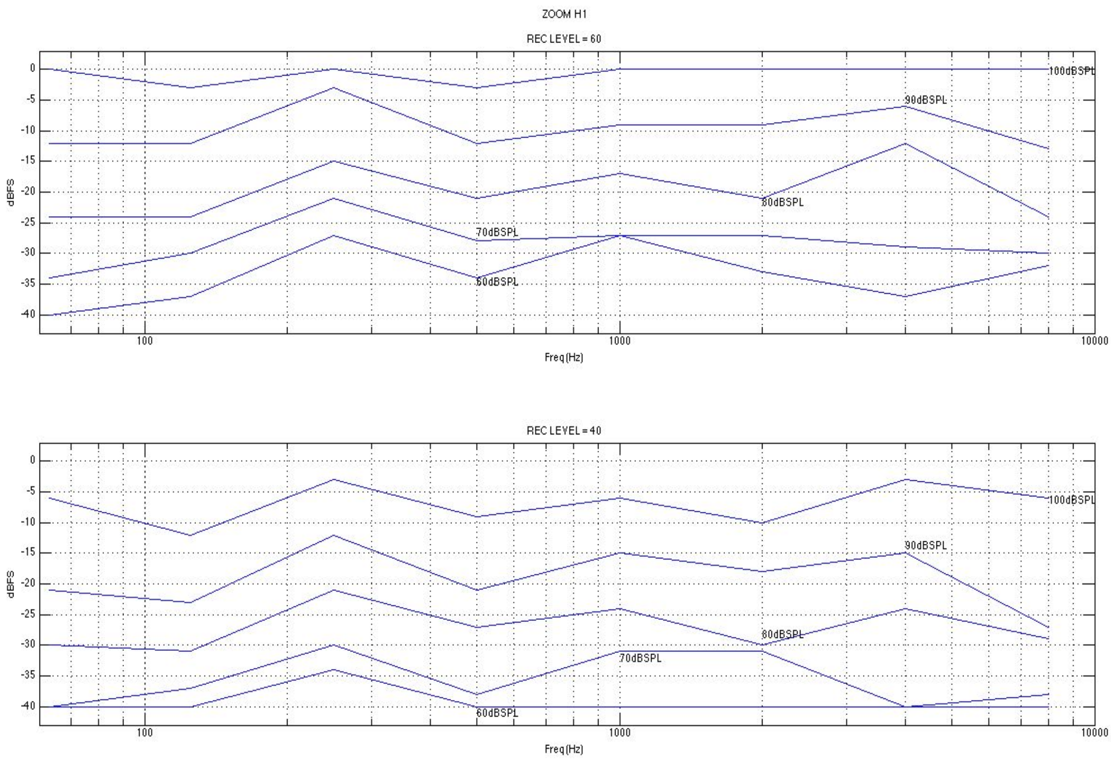

Figure 4: Zoom H1 calibration curves for rec levels set at 60 and 40.

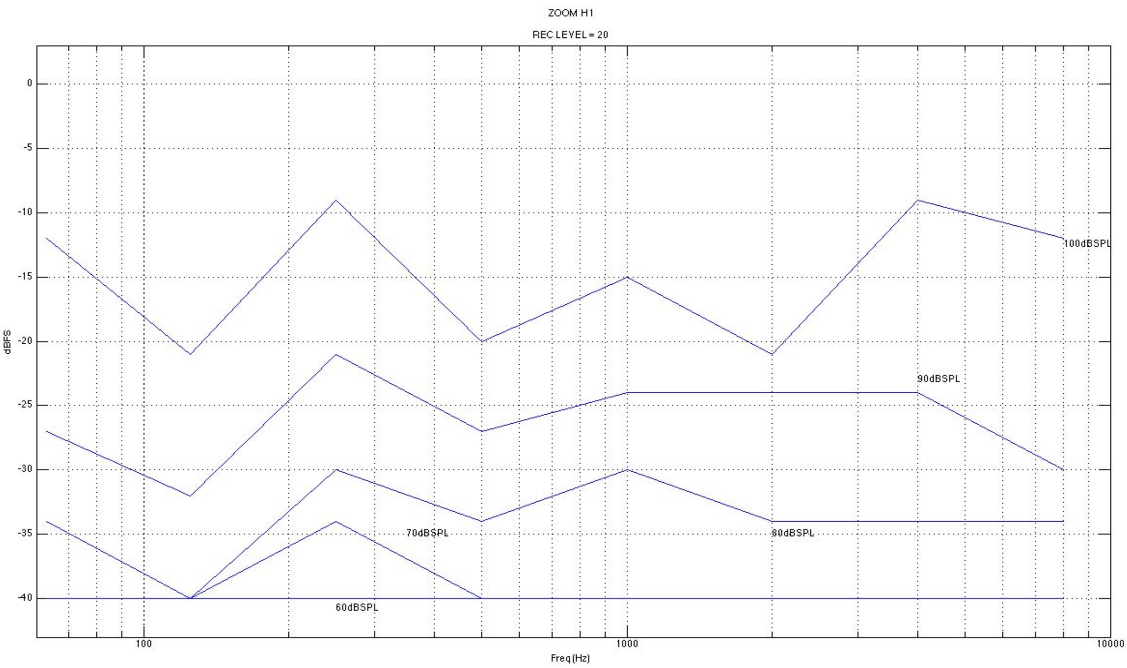

Figure 5: Zoom H1 calibration curves for rec level set at 20.

5.3.2 Zoom H4n calibration curves

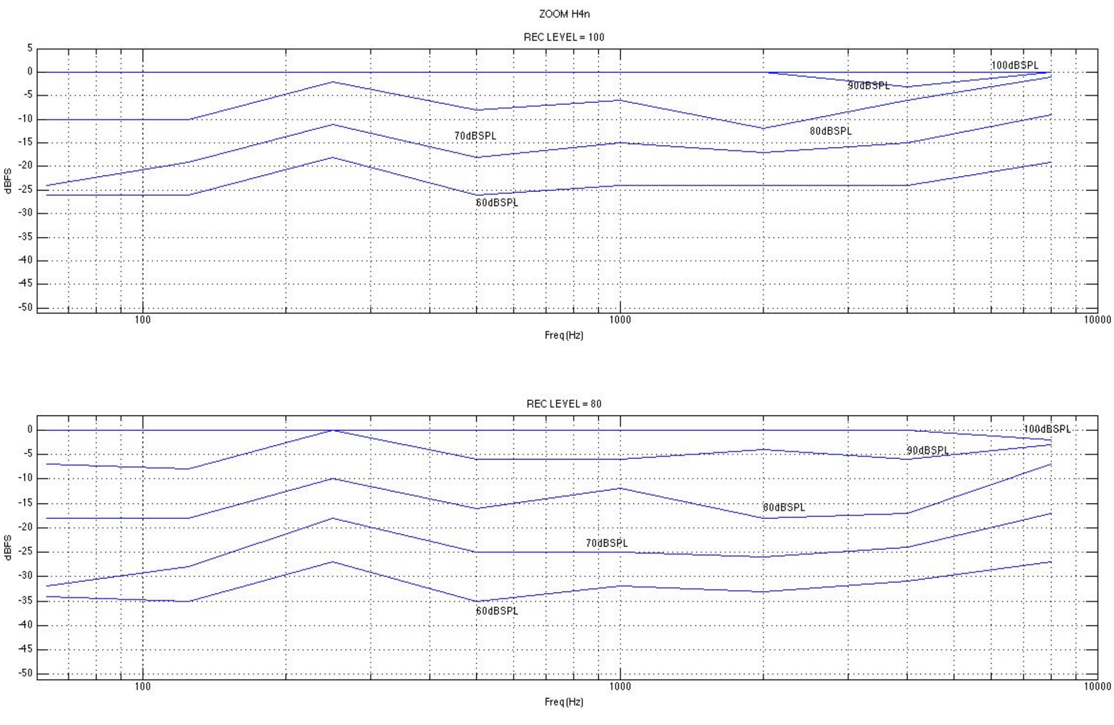

Figure 6: Zoom H4n calibration curves for rec levels set at 100 and 80.

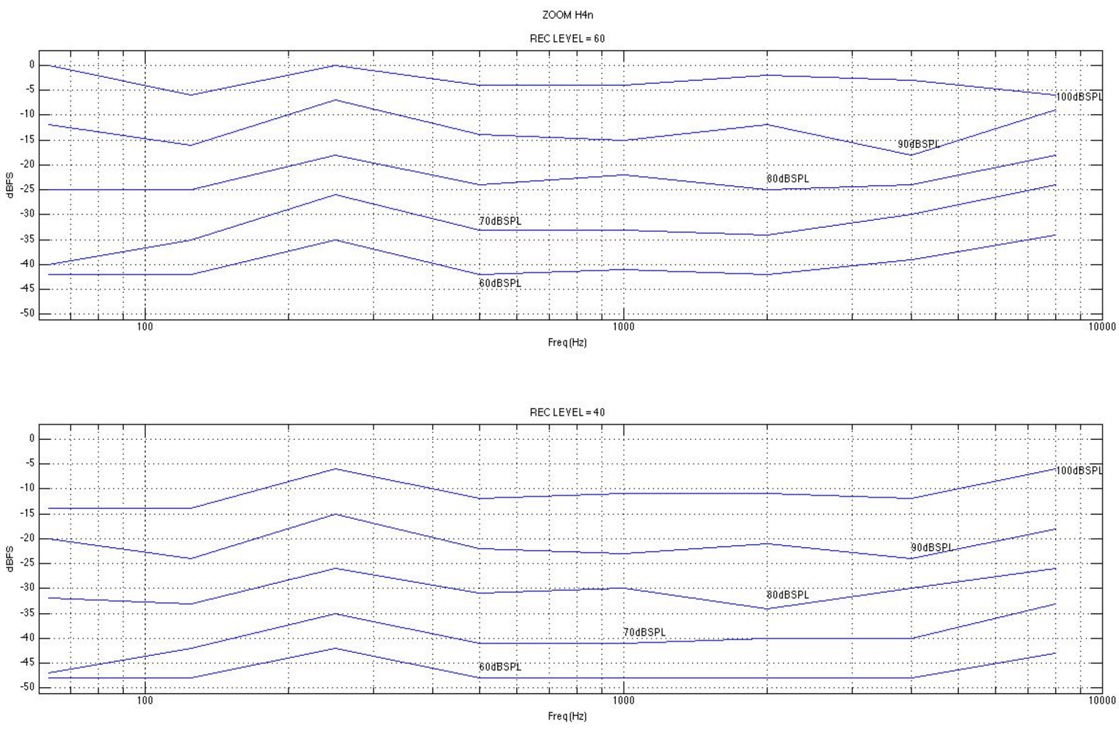

Figure 7: Zoom H4n calibration curves for rec levels set at 60 and 40.

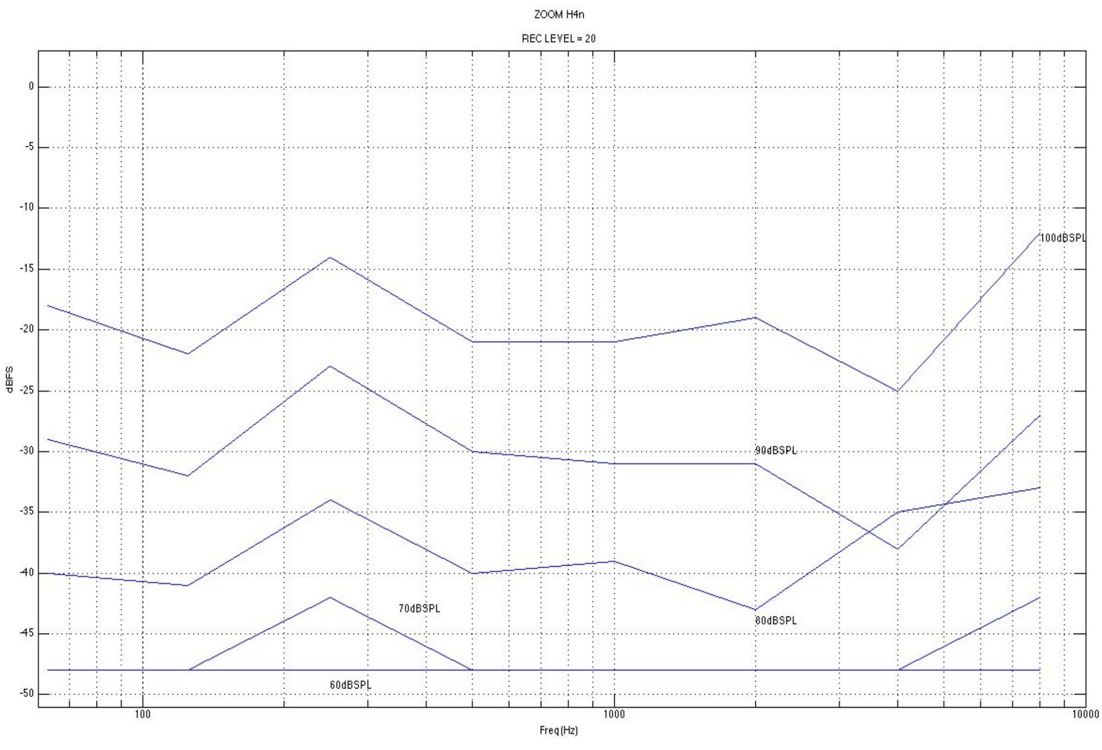

Figure 8: Zoom H4n calibration curves for rec level set at 20.

5.4 Considerations

This method allows to estimate the level of sound to which one is exposed. It should be considered a first approach in noise evaluation as in order to collect very accurate data a sound level meter should be used.

As mentioned before, the current example was carried out with the models Zoom H4n and H1, nevertheless the same method could be applied using any other sound recorder that use a dBFs scale.

Besides, the current method accuracy could be improved by reducing the steps taken in the sound level meter and in the recorders.

DISCUSSION

6.1 Introduction

In the following paragraphs the set of measures that were taken will be analysed.

Musicians are exposed to high sound levels both when rehearsing by themselves and when playing along with the rest of the performers of the band so both situations were evaluated.

According to the registered values shown in table 4, when the entire band is playing the lowest level is 93.8 dBSPL whereas the highest is up to 99.2dBSPL. These numbers corresponds to the musicians playing the keyboard and the bass guitar respectively.
By recalling NIOSH standard shown in table 1, the former can be playing a maximum time of 1 hour per day before starting to suffer any hearing disease, while the latter could only be 18 minutes.

The previous values are consistently reduced when the musician is rehearsing alone.
In the case of the bass guitar, the performer is exposed to 89.8dBSPL. The sound level is dropped in almost 10dBSPL which extends the maximum exposition time to almost 2 hours and 31 minutes. Although it is an important decrease, the number of hours that the musician can play is still low.
In the case of the singer the sound level is reduced to 84dbSPL so that the exposition time is slightly over 10 hours.
In regards to the guitar and the keyboard, noise levels are reduced from 98dBSPL to 92.1dBSPL and from 93.8dBSPL to 90.6dBSPL respectively.

A really interesting fact was found when individual measures were taken at a certain distance. The exposition strongly decreases when the musician is located at 2 meters away of the sound source. The minimum decrease occurs with the voice as 3.6dBSPL are reduced. In the case of the keyboard this number is higher reaching a level of 81.5dBSPL against the 90.6dBSPL if the musician is located right next to the sound source.
Putting some distance makes the difference especially having in mind that, according to NIOSH standard, for every 3dBSPL of increase the exposition time is halved.

As it can be inferred from the previous data, the sound levels are importantly risen when more instruments are involved, especially in the case of the bass guitar and the singer.
In order to evaluate how other instruments can affect to each other, measures in groups of two were taken.
In regards to the voice, levels are increased between 6dBSPL and 8.6dBSPL. There is not such a big difference between the influence of each instrument which could have an

explanation in the location as the singer is placed in a position where the distance to other instruments does not vary importantly.

The biggest influence occurs in the case of the drum set and the bass guitar.
At the drum set position, when the bass guitar is playing the sound level that it is reached is 105.9dBSPL whereas in the position of the bass guitar the level is 100dBSPL. Both numbers are importantly high and they definitely define these two instruments as the ones that influence the most.

6.2 Limitations

During the session when the measures were taken there were some limitations that could lead to possible faulty readings. In the following lines these difficulties will be explained.

As in general when involving people in collecting data, it was tough to find bands that accepted to be part of the study. The main reason of this is because it was not just like a normal rehearsal but they would had to follow instructions and hence that time wouldn't be so productive to them.
After a few weeks in contact with bands, one of them finally accepted the request. Nevertheless two of the components could not be present due to personal circumstances so that an external guitar player and a bass guitar player joined to the rest of the band.

The main idea behind was to have had one band that normally play together. The reason being is because it is essential to them to be confident and relaxed while playing so that they will play the instruments at the normal levels.
Prior to the session, musicians met each other to get to know the repertoire and gain confidence. The components who were not part of the band expressed that this helped them to feel more comfortable during the session however there were some moments where it was difficult to register the right values as they were not playing totally confidently.

In addition it was difficult to get a room that comply the requirements as a large room was needed in order to take measures from distance. Most of the rehearsals rooms with the required size were acoustically well prepared what it was not realistic.
Besides it was asked permission to get access to some rooms in music schools but it was not possible as this session would take place at the busiest period of the course.
Thank you to the band members it was possible to have access to the room where they usually rehearse. It fitted into the required specifications but there was a limit of time of use so that it was not possible to do several attempts.

All of that is reflected in some of the measures that were not correctly registered, especially when only two of the musicians were playing at the same time. In that specific part of the session a lower level was registered at the keyboard position when the bass guitar was playing along. The same issue happened at the drum set position playing along with the keyboard. Finally, a wrong setup of the sound level meter led to a misreading from the guitar position when it was playing along with the voice.

Therefore it is important to note that the measures provide a general overview of the sound levels that can be found within a band rehearse room and also to determine which instruments influence the most. However if a more precise future work is aimed, it would be necessary to repeat them. A suggestion would be that if that is the case, most of the limitations could be avoided by having a complete band playing in their regular rehearse room, if possible.

6.3 Future work

As it has been presented along this thesis, hearing damage in musicians is a major problem and there is still a way to be done in prevention.
Classical music is the style that has been mainly assessed. During the literature review it was found a lack of research in other styles that require a different approach. Evaluating each different type of music and assessing the levels that can be found would be a good starting point that can lead to the next step.

This next step is providing solutions either involving acoustic treatment or electronic tools. In this thesis has been proved that putting distance between musicians and the sound source can lead to an important decrease of the level. Hence it would be interesting to evaluate different layouts within the band.

Currently there are also important improvements in audio technology to increase the quality of in-ear headphones that could be applied to this field and hence help not only in reducing the exposition but also in the quality of the sound that musicians listen to when rehearsing

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