Exposure of Passengers to Noise at Lisbon Metropolitan

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Abstract— Occupational noise is legislated, but there is a gap in relation to standards for other human activities, namely, on journeys between home and work (noise transportation), which may involve high exposure to noise. To assess exposure to noise on the Metropolitano de Lisboa, a continuous noise measurement campaign was carried out on all lines of this transport network. The study shows that the approximately 170 million passengers transported per year by Metropolitano de Lisboa are exposed to high levels of noise during travel. This issue should be viewed from the perspective of public health issues and strategies to mitigate noise should be sought. The measurement campaign was carried out with an App for smartphones, duly calibrated in an anechoic chamber. External microphones have been attached to improve accuracy. This solution allows obtaining results with maximum errors of 2 dB. Sound levels were between 84 and 87 dB(A) and with peak values that usually exceeded 100 dB(C). The dose for two daily trips on the same line (round trip) reaches, in some cases, 25% of the maximum dose recommended for workers. This dose of additional noise exposure is not accounted for in occupational noise, but it is an effective exposure to noise that contributes to the poor quality of trips and to the accentuation of the degradation of hearing and quality of life for travelers. Recommendations are made to mitigate user's exposure to public transport noise with interventions at the level of metro lines and carriages. Also, the design and construction of new lines should take into account the minimization of the noise they produce for users.

Keywords— Occupational Noise Exposure, Lisbon underground, public transport, ISO 1999:1990. Acoustics.

I. Introduction

The present work aims to verify the exposure to noise of passengers on the Metropolitano de Lisboa, where commuting is common (one outward trip plus one return trip) focusing on exposure levels, noise intensity and time of exposure to noise. Using for such verification, equipment that is easy to acquire and accessible to the general population (such as smartphones), thus not limiting it to devices with excessive costs and that require specialized knowledge for their use.

Subsequently, the results were analyzed from the accounting of these measures against the legislation. And through the results, exposure to noise on daily trips (non-occupational exposures) was verified, which presented relevant values to be taken into account when accounting for the total daily exposure to noise of workers.

Exposure to noise in means of transport has been studied by the scientific community since the 1950s. As an example, Northwood (1954), who in the context of a growing population in large urban centers in Canada and the high demand for mass transport, specifically in Toronto, expressed scientific concern about the noise emitted by carriages according to the type of brake used, compared to British brake shoes. After 63 years of this study, Yao et al., (2017) expressed scientific concern about the potential hearing loss induced by exposure to noise from these same transports. The study developed measurements at stations and platforms obtaining average sound levels, which were situated at 79.8 dB(A) +/- 4 dB(A).

Mostafa & Aly (2004) followed the same line of investigation as Northwood (1954), developing measurements in the metro in Cairo, Egypt. The study resulted from complaints from users of the Cairo metro who referred to the high levels of noise emitted by the public transport unit circulating in the tunnels, especially when cornering and when braking. The study consisted of collecting noise exposure data (measurements) inside carriages. The authors concluded that noise is significant within train units and that it could be attenuated by up to 25 dB(A) if noise-proof windows were installed and used correctly. However, on the platforms of the stations, the study attributes the high degree of discomfort for users to the reflections of sound waves on the walls, this noise originates from the action of the brakes when the carriages stop (deceleration), in addition to the shape of the tunnels and the tiled flooring smooth ceramic, highly reflective of sound waves.

In the metropolitan area of Madrid, Spain, there were also noise measurements carried out by Tabacchi et al., (2011), who addressed the methodology for assessing commuting noise and its contribution to the total exposure to daily noise. This publication aimed to quantify “values that play an important role in terms of the assessment related to the dose of noise and the response to workers' health, that is, the importance of assessment in the non-occupational exposure of

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individuals" in Metro de Madrid. The authors concluded that "exposure to non-occupational commuting noise can considerably affect a worker's exposure dose".

Garbala & Agustina (2015) evaluated the potential noise-induced hearing loss caused by commuting on the London/England subway, through measurements in carriages and stations. This analysis showed that the rolling noise did not produce significant changes in the hearing threshold, and that these trips did not exceed the levels established by the legislation in force in England, at the time of publication of this study. However, they found that exposure to commuting noise contributed significantly to exposure to occupational noise, concluding that ignoring commuting noise accumulated on work trips, for example, can lead to underestimation of employees' exposure to noise, thus influencing work safety and health calculations.

In Naples (Italy) Berardi et al. (2015), investigated four stations of the local subway, in which there was a type of art gallery, where visitors and passengers could enjoy seasonal exhibitions. After the study, it was identified that the acoustic reverberation is particularly high, and that sometimes the warning signs are not perceptible and not audible because they are muffled by the noise on the railway line, reporting in the conclusion the concern with the state of the workers at the stations and passengers, as the results were alarming in terms of the safety and health of those exposed.

Han et al. (2016) evaluated the thermal, luminous and acoustic comfort, through a questionnaire and investigation by measurement in six stations of the Seoul subway, in South Korea. The questionnaires revealed that the passengers were bothered by the noise they were exposed to, but that after some time they stopped noticing the degree of discomfort they were experiencing.

Sun & Zhang (2016) published an analysis of the annoyance induced by structural vibration and ambient noise in train carriages, through a normal distribution function they evaluated the structural vibration caused by noise and the degree of annoyance at pre-established levels. The article published in China found that the proposed mathematical models performed very well and concluded that most of the measurement points were within a "reasonable range" and a small portion of the measurement points could generate adverse experiences. authors pointed out that these points capable of causing significant discomfort should undergo interventions for immediate correction.

In addition to the publications mentioned throughout this chapter, which apply to sampling methods and scientific research in various parts of the world, research was also carried out in the area of equipment in order to evaluate materials and instruments to be applied in monitoring ambient noise.

II. Methodology and Procedures

A. *Planning and Frequency of measurements*

The acoustic measurements and data collection campaigns were carried out considering the characterization of the flow and circulation in the Metropolitano de Lisboa.

The first campaign took place between July and August 2020, the school vacation months. The second campaign intended to measure the exposures equivalent to the time that people remain on the docks of the stations waiting for the carriages. Then, measurements were taken at the connection stations between lines and terminal stations, which serve as the beginning and end of the trip. Totaling 19 stations. In the third data collection campaign, the same methodology as in the first stage was applied, but carried out between October and November 2020. These are the normal months of activities, with the highest number of ML users. According to the pandemic moment, at this point we predicted that perhaps routine activities would be returning after the lockdown. In addition, educational activities tend to resume. In this sense, we thought it would be a good time to repeat the measurements and compare them.

For the effective collection of data, timetables and periods were established based on the information disclosed by INE. Then, five types of measurements were determined (Table 1).

TABLE I
TYPES OF MEASUREMENTS CARRIED OUT

Measurement (type)	Time	Description
Fundo (**type** 1)	6h45 to 8h00	Start of operation of ML.
Ponta (**type** 2)	8h15 to 9h30	Greater flow of people.
Tarde (**type** 3)	12h00 to 14h00	Afternoon period.
Fim de Semana (**type** 4)	10h00 to 11h00 17h00 to 19h00	Saturday and Sunday (morning and afternoon period).
Estações (tipo 5)	14h00 to 18h00	Select stations, weekdays.

Although there were 3 noise measurement campaigns, this article only presents results from the first campaign.

B. *Analysis parameter*

The parameter to be analyzed in this study is the noise to which LM users are being exposed. However, the existing rules regarding noise in public transport (NP 4475:2020 and NP 4475:2008 -Portuguese Standard for the Public Passenger Transport Service - Metro Network) do not explicitly refer to the maximum permissible noise. Thus, we defined that the noise monitoring parameters suggested by laws and regulations will be used, more specifically, the RGR and NP ISO 1996:2019 and Decree-Law No. 182/2006, which presents the minimum safety and health guidelines respectively to a worker's daily personal exposure. This is called 'LEX,8h'.

$$L_{EX,8h} = 10 \cdot \log \left[\frac{\sum_{k=1}^{k=n} T_k \, 10^{(L_{Aeq,\,TK})/10}}{\mathbf{8}} \right] \quad (1)$$

where:
Tk – exposure time;
LAeq,TK – sound pressure level equivalent to Tk;

This parameter is equivalent to the logarithmic average (in dB) of noise exposure of a worker whose daily workload is equivalent to eight hours.

The measure of daily exposure to noise depends on factors such as sound pressure level and duration of exposure to noise, intended to be used to measure a worker's daily exposure dose, for example. It depends in this way, mainly on the duration of the work shift. Therefore, it is understood that the worker exposed to noise has a percentage of tolerable or admissible exposure equivalent to 100%. The D (dose) is the 'consumed' quantification of these 100% in exposure with duration ti, that is, what plausible percentage is consumed from the maximum daily exposure of 100% (Castle Group Ltd, 2020), given by:

$$D = \frac{100}{T_C} t_i 10\left(\frac{L_i - L_C}{q}\right) \quad (2)$$

where:

Tc – Length of daily work period (usually 8 hours);

ti – Duration of the exposure in question;

q – Dosage doubling factor;

Li – Sound pressure level concerned;

Lc – Limit considered in accordance with European and Portuguese legislation;

C. Equipments

Murphy et al. (2015) developed tests and research on seven smartphone applications with the aim of measuring ambient noise. They compared the data generated from these applications with data obtained by a calibrated and approved sound level meter (SLM). In summary, this publication defined, in terms of average differential, that ambient noise measurement applications that use the iOS platform (Apple brand) performed better compared to smartphones that used the Android platform (given that there are many models with different types of microphones), in addition, the results point to a specific application, SPLnFFT (iOS), as the best performing application. In addition to performance results classified as good and with an operating interface that they judged to be easy and intuitive.

A second study tested apps and smartphones in a similar way. Kardous and Shaw (2014) tested sixty-two applications for Android and four for iOS on nine brands of smartphones. In conclusion, the authors found that “Apple smartphone sound measurement applications can be considered accurate and reliable to be used to assess noise exposures”. The publication also explained that there is an improvement in the results with the use of an external microphone, as the internal microphones are subject to wear and tear, the results are affected by the diffraction effects of the cell phone body and are difficult to calibrate.

Although the NP ISO 1996:2019 standard indicates the need to use a sound level meter approved by the IPQ for any monitoring and measurement of ambient noise, the purpose of the study is to carry out a type of monitoring/measurement within the daily life of a public transport user in your own routine, such as commuting to work, school, college or leisure, using only a smartphone with an application and possibly an external microphone given its ease of use and cost.

This study fits into the scenario of empowerment of the general public regarding the measurement of their own sound exposure. In other words, not only easily accessible devices and microphones are determined, but also reliable applications.

To achieve this purpose, data resulting from investigations by Murphy et al. (2015) and Kardous & Shaw (2016), thus defining the SPLnFFT application as a tool for measurements, as it proved to be efficient after being tested on the iOS operating system, together with the Dayton Audio iMM-6 microphone. In the present study, the equipment used in conjunction with the application was previously tested and calibrated to ensure the reliability of the measurements.

The Dayton Audio iMM-6 measurement microphone is considered by the manufacturer to be a professional precision equipment in critical measurements, for use in Apple devices (however compatible with Android and Windows Phone). It states that it is an electret microphone, has an omnidirectional directivity pattern with a frequency response of 18 to 20000 Hz, Max SPL = 127 dBSPL and SNR = 70 dBA.

The SPLnFFT application developed by Fabien Lefebvre is a sound pressure level meter (SPL) that allows measurements in dB with A or C weighting, capable of capturing up to 130 dB. The data generated by the measurement can be monitored in real time through the mobile phone screen. The values are generated in 1/8 of a second, that is, eight measurements per second in either FAST or SLOW mode. These values are dependent on the measurement filter applied during the measurement: A or C.

According to the application's user manual, Figure 1, at the beginning of use, attention should be paid to certain procedures for generating and exporting data. At first, the frequency weighting, A or C or none, should be selected, followed by connecting the external microphone (when used) after being properly calibrated together with the application, as described in the same usage document. Data is exported to a Dropbox account previously configured in the application.

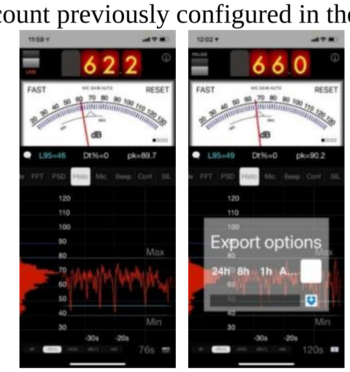

Fig. 1 SPLnFFT application user interface

For better use of cell phones (sound recording and noise measurement) together with the microphone, a backpack strap was adapted. Thinking about how to keep the microphone stationary and close to the ear, for this purpose, we applied two support elastics directly to the internal structure of the handle, inside a zipper that facilitates access to the structure in question, as shown in Figure 2. A backpack always remained in the same position in all measurements.

In this way, the possibility of variation due to its positioning was excluded, that is, the microphone remained immobile. In addition, the person responsible for data collection should keep their hair tied back and always be aware of any interference by direct contact with the microphone. It is important to point out that the adaptation in the backpack was modified in order to keep the microphone, as much as possible, in the line and direction of the ear at shoulder height.

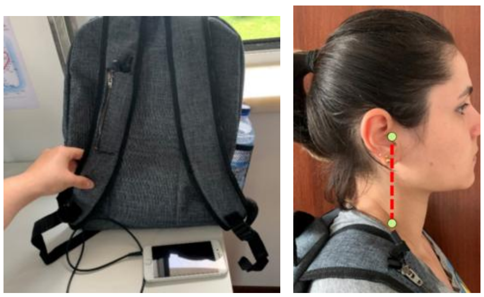

Fig. 2 Adaptations in the backpack used for data collection and positioning of the microphone in the direction of the hearing aid

A smartphone (Apple Iphone models 5 and 6) always in airplane mode, SPLnFFT application, Dayton Audio iMM-6 microphone and cable extension between the smartphone connection and the microphone were used.

The 'noise measurements form' (Annex 5) was designed, which aims to standardize all the measurements to be carried out, in this way the objective is to control the data collection and systematization of the same, making the measurements standardized and methodical. Some of the information collected were: the direction of the carriage in the measurement, the total number of carriages on the train, the start time of the measurement, the model of the carriage, the number of people sitting and standing, the opening hours of the doors, the of the alert notice for the closing of the doors, the closing time of the doors, the time of the announcement of the stations, the exact position inside the carriage at the moment of the measurement and other relevant information.

It is important to point out that the application used for measurement (SPLnFFT) generates a file in a specific format that can only be converted on a computer with a MacOS application system. This file is sent to the 'cloud' as soon as we finish collecting data and subsequently converted into an XLS file. The application records a data file for each day, that is, at 00:01 a new file starts and the previous one is automatically deleted. Therefore, special attention must be paid to collecting the files generated on the same day as the measurement.

The table extracted from the application generates a row of data for every eighth of a second (Figure 3). The hour, minute, second, octave of a second, dB FAST value and dB SLOW value are displayed on each line. Therefore, eight lines of data refer to one complete second of measurement (referred to in item 7 of this study).

	A	B	C	D	E	F
1	Hours	Minutes	Seconds	8ths	FAST	SLOW
266178	9	14	32	0	83,553413	84,713821
266179	9	14	32	1	84,242332	84,516571
266180	9	14	32	2	84,439354	84,471642
266181	9	14	32	3	84,87851	84,352234
266182	9	14	32	4	84,745308	84,352058
266183	9	14	32	5	83,972641	84,2939
266184	9	14	32	6	83,380257	84,23629
266185	9	14	32	7	84,575874	84,161896
266186	9	14	33	0	83,611465	84,25309
266187	9	14	33	1	83,85836	84,259308

Fig. 3 Rows of data extracted from SPLnFFT

In addition to the sound pressure measurement iphone, a secondary smartphone was used for sound recording. This recording begins with the identification of the measurement (start time, ML line and identification of the station of origin and final destination) and aims at the sound characterization of the measurement.

These files are generated in m4a format, extracted from the cloud, which are later processed and analyzed in the 'Adobe Audition' application, which allows characterizing the waveform and sound spectrum from these signals.

D.Calibration of measuring equipment

The reliability of the information collected in the measurements was guaranteed based on the laboratory calibration of the equipment used in the measurements, namely the Dayton Audio iMM-6 microphone together with the SPLnFFT application on the Apple 5s mobile phone.

Calibrations were performed in the anechoic chamber of Instituto Superior Técnico (IST). This camera has a cut-off frequency of around 60 Hz and has a background noise level of 18.8 dB(A).

As a reference equipment, a Brüel & Kjaer sound level meter, model 2260 Investigator (2012) and an acoustic calibrator (SLC) of the same brand, model type 4230, which produces a sound pressure level equal to 94 dB @ 1000 Hz. Calibration of the sound level meter took place before any initial measurement.

After proper calibration of the sound level meter, which aims to generate data for comparison, it was installed on a tripod to the equipment with the sound level meter and the Dayton iMM6 microphone connected to the cell phone with the SPLnFFT application open and running. The microphone and the sound level meter were installed in such a way as to be aligned horizontally with the sound column, which, in turn, emits a controlled sound, of the white noise type. The Dayton iMM-6 microphone was positioned with a support structure under the sound level meter, also aligned with the sound column.

Subsequently, we installed the mobile device with the SPLnFFT application, fixed on the sound level meter support tripod and connected directly to the Dayton microphone as well as to the charger (Figure 4).

Fig. 4 Mobile phone and SPLnFFT application in calibration tests

The tests were carried out with pink noise for the incidence angles 0º, 45º and 90º, to evaluate the directivity diagram presented by the microphone manufacturer.

A total of five measurements were performed, one experimental and the other two following the same experimental measurement systematics. Two measurements take place at medium level with emissions controlled at 63.6 dB(A), and two at high level with emissions at 72.5 dB(A). The results are shown in Table 2.

TABLE II
RESULTS OF MEASUREMENTS 1 AND 2 OF CALIBRATION FOR 2 VALUES OF SOUND PRESSURE LEVELS (63.6 DBA AND 72.5 DBA)

Medição	Ângulo	Brüel & Kjaer 2260 Investigator dB(A)	Dayton iMM6 + SPLnFFT dB(A)	Δ dB(A)	% erro
1ª	0 º	63,6	62,5	- 1,1	1,7
	45º	61,9	61,7	- 0,2	0,3
	90º	59,5	60,0	0,5	0,8
2ª	0 º	63,6	62,5	- 1,1	1,7
	45º	61,9	61,7	- 0,2	0,3
	90º	59,5	60,1	0,6	1,0
1ª	0 º	72,5	71,5	- 1,0	1,3
	45º	70,5	70,5	0,0	0,0
	90º	68,3	69,0	0,7	1,0
2ª	0 º	72,5	71,5	- 1,0	1,3
	45º	70,5	70,4	- 0,1	0,1
	90º	72,5	71,5	- 1,0	1,3

The results show that the equipment is adequate and calibrated for data collection, taking into account a maximum variation of 1.1 dB and a maximum error percentage equal to 1.7%.

III. Results

The first measurement campaign generated 47,152 seconds of measurement time (13 hours 5 minutes and 52 seconds) totaling 377,216 lines of data. 36 unit measurements were carried out, equivalent to 18 commuting trips, from 07/21 to 07/28/2020. The duration of each measurement followed the variation in LM functioning.

Measurements were performed independently, that is, one by one. Every two independent trips thus forms a commuting trip. Figure 5 shows a single trip for the various Metro lines.

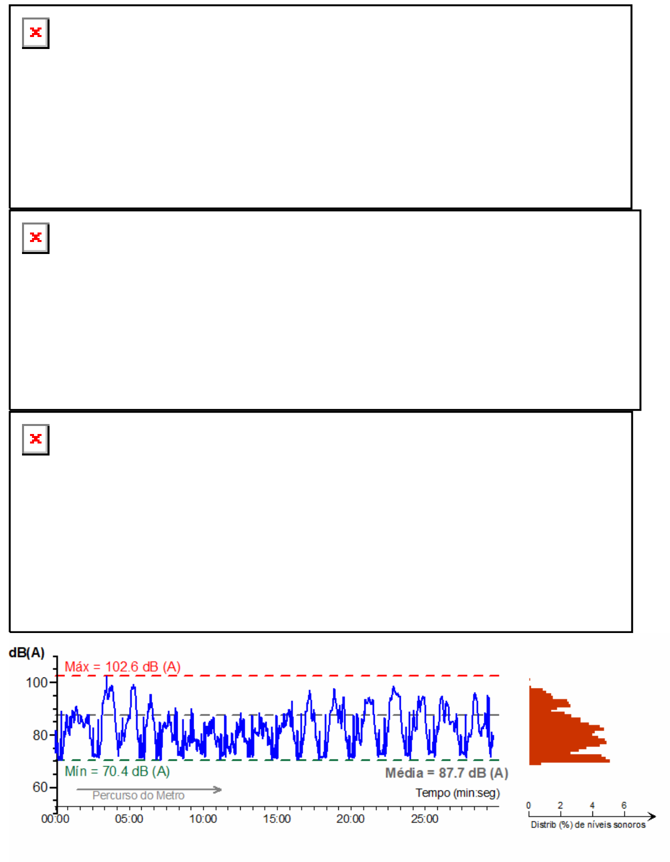

Fig. 5 Measurement 07/21/2020, Yellow, Green, Red and Blue Line (from top to bottom)

Histograms of noise levels are also shown.

The results obtained in the measurement campaign were filtered, in order to represent in this work, only the commuting trips that exceed the ELV = 87 dB (A), in ascending order of LEX,8h (Table 3).

TABLE III
RESULTS OF THE FIRST STAGE WITH LEX,8H ≥ 87 DB (A)

Date (07/2020)	Measurement type	Line	$L_{EX,8h}$ dB (A)	Dose pendular %	Dose $_{8h}$ %
22	Ponta	VR	87	7,36	160,40
23	Ponta	AM	87	8,90	185,48
28	Tarde	AZ	87	5,27	99,14
25	Final Semana	VD	88	5,37	138,61
22	Fundo	VR	88	9,36	253,43
28	Tarde	VR	88	10,46	197,33
25	Final Semana	AZ	88	15,50	245,96
25	Final Semana	VR	89	12,04	255,79
23	Fundo	AM	89	9,94	199,22
23	Tarde	AM	89	8,85	176,73
21	Ponta	AZ	89	12,77	186,03
25	Final Semana	AM	89	10,94	255,93
21	Fundo	AZ	89	15,34	239,80
23	Tarde	AM	89	12,04	239,66

Figure 6 presents the same data related to Table 25, but provides a better visual location of the lower action value, upper action value and exposure limit value among the averages (LEX,8h) obtained in each commuting trip.

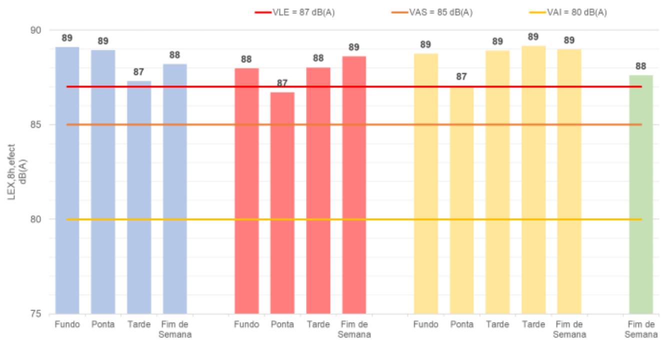

Fig. 6 Results of the first stage with LEX,8h ≥ 87 dB (A)

Each column represents the respective metro line equivalent to its color: Blue Line = blue color, Red Line = red color, Yellow Line = Yellow color and Green Line = green color. The LEX,8h was rounded to whole numbers, and any measurement-related uncertainty was not accounted for.

IV. Previous Studies And Their Resulting Comparatives

In the publications referenced in the Introduction chapter, we identified some similarities to such as the methodology we use, the legislation that guided us regarding the calculation of averages and exposure, and thus, we decided to compare the results obtained with the results of these references. Considering only the most recent publications (last six years).

Tabacchi et al. (2011), found that in a trip with 26 observations/transfers between Madrid metro trains and lines, the highest average exposure mentioned in the publication is equal to 82.3 dB (A) (logarithmic average) and the duration of this exposure was 160.3 minutes, equivalent to approximately 1.95 dB(A)/min. Compared to the results of our study, the highest average exposure is equal to 89 dB (A) with a duration of 42.17 minutes, which is equivalent to 2.11 dB (A)/min (referring to the commuter trip on the 23/ 07/2020, Line AM, type Afternoon, developed in the first measurement campaign). It is important to emphasize that the methodology applied in this publication is very similar to that applied in our study.

Yao et al. (2017), released the results in a publication that summarized that “the average noise on platforms in the subway of Toronto (80.9 +/- 3.9 dBA) were higher than the average noise exposure inside carriages (76 .8 +/- 2.6 dBA)”, but remained within the exposure thresholds according to the legislation in force until the publication that indicated LEX,8h = 90 dB (A). Taking into account that the methodology applied to the study developed in Toronto is similar to the methodology applied to our work, it is considered plausible to compare the results between them. Therefore, the maximum average noise exposure on the Toronto subway in 2016 is equivalent to 79 dB (A), and the maximum average noise exposure on a commuter trip on the Lisbon subway in 2020 is equivalent to 89 dB (A), a difference of -10 dB(A) from the maximum logarithmic mean. Comparing the minimum value (84 dBA) obtained in our study with the maximum value in the study by Yao et al. (2017) the ML presents a superior difference equivalent to + 5 dB (A).

Garbala & Agustina (2015), says that “the levels of exposure to noise in the use of the London underground do not exceed the exposure limits established by regulations in force in the year of publication” and in a table the author presented the average exposure to noise (LEX,8h) on the London Underground in 2015 equal to 73 dB(A) in duration equivalent to 74 minutes. Comparing with the lowest average exposure to noise in our study, equivalent to 84 dB (A), the ML presents about + 11 dB (A) when compared to the London metro. It is noteworthy that Garbala & Agustina (2015) also present a measurement and calculation methodology similar to that of our study, and for this reason the respective results were compared with the results of this development.

V. Conclusions

The study made it possible to analyze the contribution of noise to daily exposure on commuting trips (round trip) on the Metropolitano de Lisboa. According to the calculation procedures in the appropriate laws and regulations, it is concluded that most of the results obtained from the average exposure on commuting trips remained above the Exposure Limit Value (VLE). Being, 67.85% of LEX,8h ≥ ELV, 28.57% LEX,8h ≥ VAS and finally, 3.57% of LEX,8h ≥ VAI.

As for the Exposure Dose, the Pendular Dose, Pendular Dose%/km and Pendular Dose%/min, the AZ Line expressed the highest values. As well as it also presented the longest exposure times because it is the largest line.

When considering the exposure of a prolonged commuting trip to eight hours of work (Dose8h) about 91.07% of the Commuting Doses resulted in 122.75%, that is, 22.75% above the 100% allowed daily. In addition, it exposed longer durations for the same commuting trips on different dates. For example, the commuting trip on 07/25/2020 (AZ, Weekend) which resulted in Commuting dose=32.87%/min of the daily dose, the measurement on 07/21/2020 (AZ, Fund) which resulted in Dosependular= 32.05%/min of the daily limit dose and finally, the measurement on 07/21/2020 (AZ, Ponta) which resulted in Dosependular=31.87%/min.

It is worth mentioning in the conclusion of this study that the noise of opening and closing doors that occur in the rolling stock corresponding to the serial number ML90, with entry into service estimated in 1993/1996, present about 12 dB(A) more in the mechanical action when compared to ML99 series carriages, which entered service in 2000.

The materials used to carry out the planned measurements proved to be credible and easy to use, thus fulfilling the objective of the work.

The development of the study proved sensitive to the lack of specific legislation regarding noise in rail transport, and non-occupational exposure to noise in quantitative terms, thus lacking a standardized method to compare the results obtained. There was also a lack of clarity on the part of the service provider in its reports published in public media (for example, the sustainability report, this being the only one in which there is any evidence about noise), as well as evidence about acoustic insulation, degrees of discomfort and measures possibly related to noise mitigation inside the rolling stock.

The results show that Metropolitano de Lisboa passengers are exposed to high doses of noise during their trips in this means of transport. The main source of noise comes from the wheelsets and the opening/closing of doors. The ML should consider decreasing this source of noise. Effectively, those who make several trips on the ML per day accumulate a reasonable amount of exposure to noise that may even exceed legal limits.

It is suggested that a new monitoring be carried out in terms of normal use of the Metropolitano de Lisboa, also involving the backlight hours, peak hours, afternoon hours, on weekdays and weekends, for the various lines of the Metropolitano de Lisboa . As well as carrying out a new monitoring campaign for stations, especially those with connections between lines.

It is also suggested that the exposure of workers who use more than one means of public transport be monitored on routes that start around greater Lisbon and that aim to travel to the center of Lisbon, in daily routines of commuting to work. Doing this way, the sum of exposures between train, bus and metro routes. It will also be interesting to evaluate the exhibitions of the suburban train lines, such as the Azambuja Line, the Sintra Line, the Cascais Line and the Setúbal Line, at previously established timetables based on the timetables with the greatest circulation of users.

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References

[1] M. Tabacchi , I. Pavón , M. Ausejo , C. Asensio, M. Recuero, Assessment of Noise Exposure During Commuting in the Madrid Subway, Journal of Occupational and Environmental Hygiene, Volume 8, 2011 - Issue 9. https://doi.org/10.1080/15459624.2011.600237

[2] M. Garbala, L Gomez-Agustina, Passenger noise exposure in London underground, Proceedings of the Institute of Acoustics, Vol. 37. Pt. 2, 2015.

[3] Chucri A. Kardous, Peter B. Shaw, Evaluation of smartphone sound measurement applications, The Journal of the Acoustical Society of America 135, EL186 (2014), http://dx.doi.org/10.1121/1.4865269]

[4] Chucri A. Kardous, Peter B. Shaw, Evaluation of smartphone sound measurement applications - A follow-up study, The Journal of the Acoustical Society of America 140, EL327 (2016); http://dx.doi.org/10.1121/1.4964639

[5] Enda Murphy, Eoin A King, Testing the accuracy of smartphones and sound level meter applications for measuring environmental noise, Applied Acoustics 106 (2016) 16–22, http://dx.doi.org/10.1016/j.apacoust.2015.12.012

[6] Enda Murphy, Eoin A. King, Smartphone-based noise mapping: Integrating sound level meter app data into the strategic noise mapping process, Science of the Total Environment 562 (2016) 852–859, http://dx.doi.org/10.1016/j.scitotenv.2016.04.076

[7] George Drosatos, Pavlos S. Efraimidis, Ioannis N. Athanasiadis, Matthias Stevens, Ellie D'Hondt, Privacy-preserving computation of participatory noise maps in the cloud. Journal of Systems and Software, February 2014. DOI: 10.1016/j.jss.2014.01.035 https://doi.org/10.1016/j.jss.2014.01.035

[8] Informação Institucional do Metropolitano de Lisboa, https://www.metrolisboa.pt/institucional/, consultado em 11 de Setembro de 2020.

[9] Relatório de Gestão 2017, Metropolitano de Lisboa, Lisboa, Portugal, 2018.

[10] Fabien Lefebvre, SPLnFFT for iOS, https://apps.apple.com/us/app/splnfft-noise-meter/id355396114

[11] Benjamin Roberts, Chucri Kardous, Richard Neitzel, Improving the accuracy of smart devices to measure noise exposure, Journal of Occupational and Environmental Hygiene, 13:11, 840-846, DOI: 10.1080/15459624.2016.1183014 https://doi.org/10.1080/15459624.2016.1183014

[12] Informação Institucional do Metropolitano de Lisboa, https://www.metrolisboa.pt/institucional/, consultado em 11 de Setembro de 2020.

[13] Relatório de Gestão 2017, Metropolitano de Lisboa, Lisboa, Portugal, 2018.

[14] Guia prático para medições de ruído ambiente - no contexto do Regulamento Geral do Ruído tendo em conta a NP ISO 1996, APA-Agência Portuguesa do Ambiente, 2020

[15] Decreto-Lei n.º 182/2006 de 6 de Setembro, Diário da República, Portugal.

[16] Directiva n.o 2003/10/CE, do Parlamento Europeu e do Conselho, de 6 de Fevereiro, Jornal Oficial da União Europeia.

[17] Norma Portuguesa NP ISO 1996-1:1990, IPQ.

[18] INE-Instituto Nacional de Estatística, Mobilidade e funcionalidade do território nas Áreas Metropolitanas do Porto e de Lisboa : 2017, INE, Lisboa, 2018.