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Noise, Vibration and Perception of Risks of Workers of the Construction Sector

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Summary

Noise and vibration are two of the physical contaminants most commonly found in the construction sector. They can cause several negative effects on the workers and may have a very important influence on people's health and well-being. Furthermore, the perception of the noise can influence on the awareness of the risks the workers are expose to. Therefore, it is necessary to assess the noise and vibration exposure and to develop mechanisms for studying and proposing preventive solutions.

A number of representative measurements have been carried out using a sound level meter, a dosimeter, a vibration meter and a HATS to collect data from non-specialized workers of the construction sector, which are the most exposed to noise and vibration due to the different tasks involving machines they are in charge of. Analysis of the most important levels and indexes have been done with those data, and afterwards, they have been compared to the limits imposed by the different current regulations.

This work has studied the noise and vibration levels which the workers of the construction sector are exposed to, as well as the perception of the measured noises by workers and another population. The noise and vibration levels the measured workers are exposed to are extremely high and potentially dangerous for their health. The levels surpass the legal limits by far.

The construction workers may be in danger due to high levels of noise and vibrations, depending on the machines they use. The workers are not aware of such danger but they perceive the levels are high and show their discomfort through the subjective tests of perception. Preventive measures should be compulsorily implemented.

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1. Introduction

Noise and vibration are the most persistent physical contaminants in human environment. Noise can be defined as the undesired sound. That concept is joined to a subjective perception, and therefore, a sound can be pleasant for some people but, at the same time, can also be annoying for some other people, or even the cause of physical or psychic illnesses. Vibration is understood as an oscillatory movement of a structure, like the floor, a seat or a handle, measured in m/s^2. Unlike other contaminant agents, the effects of noise and vibration may be unnoticed instantaneously and their accumulation can lead to an obvious physical, psychic and social worsening. The problem is that the exposed people are scarcely aware of the cause-effect relation given that it is produced slowly but progressively [1].

The most obvious parameter to characterize the noise can be its level, measured in decibels, but there are some other important factors to take into account, like duration of exposure, impulsivity, spectrum and psychoacoustic parameters (loudness, sharpness, etc.), which would permit the assessment of the subjective perception of the workers about the noise they are exposed to, what would lead to an improvement of the noisy machines so that they could be less annoying. Noise exposure can cause several risks for the safety and health of workers. It is well known that the noise can mask both, the speech and the alarm sounds. Therefore, it is stated that noise is one factor that can increase the risk of accidents in the workplace [2, 3]. Besides, the effects of the hearing loss induced by noise, together with the requirement of using hearing protection devices, contribute to increase indirectly the rate of accidents due to interferences with sound signals and other non-hearing effects caused by the noise on the health, like stress, loss of attention, increase of blood pressure, etc. [4].

Regarding the vibrations, whose perception is less subjective than the noise, there are two types, the one transmitted to the whole-body system and the one transmitted to the hand-arm system. Generally, the first type is produced by transportation vehicles and big working machinery; the second type is commonly produced by power-tools. Con-

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sequently, the effects the vibration can cause on the human body are divided into two sets [5]: effects caused by whole-body vibration exposure, and caused by hand-arm vibration exposure. Transmitted vibrations to the whole-body system can be perceived by the workers as discomfort or annoyance. Depending on the exposure time, the frequency and the intensity of the oscillations, those symptoms can be unbearable and they can even generate unfitable disorders for work; some examples can be: interference with breathing (1 to 4 Hz), pain in the back (8 to 12 Hz), muscular tension and difficulties in speaking (10 to 20 Hz), etc. Vibration transm itted to the hand-arm system is quite common in the labour environments where power machines are used, like jackhammers, compactors, grinders, impact drills, etc.; some of the effects that can be caused are: peripheral vascular changes in the hand (initially noticed in the fingertips), peripheral neural changes in the hand (noted as intermittent pins and needles and numb in the fingers), etc.

The safer and healthier a workplace is, the fewer probabilities of absenteeism, accidents and low performance, and consequently, cost savings will be achieved. A traditional approach for reducing risks due to noise and vibration in the workplace consists of a three-step process: assessment of risks; adoption of mechanisms for preventing or controlling risks; and, eventually, keeping a periodical monitoring and a revision of the effectiveness of the adopted mechanisms [6]. This work focuses on the construction working sector, which suffers from an excess of noise and vibration. Within this sector, the workers more exposed are those non-specialized that do multiple tasks with power-machines and help the other well-qualified workers. Noise and vibration exposure, together with the perception of the noise, will be studied for this population. Then, this study is centered in the non-specialized workers of the construction sector of Spain, where this is the most important and numerous working sector.

2. Methods

2.1. Regulations

The current regulation in the European Union regarding protection of workers is based, for noise exposure, on the Directive 2003/10/CE [7], that in Spain corresponds to the Royal Decree 286/2006 [8], and for the vibration exposure, on the Directive 2002/44/CE [9], that in Spain corresponds to the Royal Decree 1311/2005 [10]; and in addition, in Spain it has to be considered the law 31/1995 about prevention of risks at work [11]. These documents state a set of minimum disposals with the aim of protecting the workers from the risks for their safety and health, caused or that may be caused by the noise and mechanical vibration exposure.

Regarding the noise, the indexes used for assessing its level in each workplace are the daily equivalent level $L_{Aeq,d}$ and the peak level (L_{peak}). Generally, in the directive 2003/10/CE, and also in the corresponding Royal Decree, the noise exposure is strictly limited, as it is stated that, in no case, the real exposure of a worker may overpass the limit values of $L_{Aeq,d} = 87\,\mathrm{dB(A)}$ and $L_{peak} = 140\,\mathrm{dB(C)}$. So, those limits are the maximum, even considering the attenuation given by the personal hearing devices used by each worker. Summarizing, the limits given by the regulations are:

- The initial preventive alarm levels are $L_{Aeq,d} = 80\,\mathrm{dB(A)}$ and $L_{peak} = 135\,\mathrm{dB(C)}$.
- The action alarm levels are $L_{Aeq,d} = 85\,\mathrm{dB(A)}$ and $L_{peak} = 137\,\mathrm{dB(C)}$.
- The critical top limits are $L_{Aeq,d} = 87\,\mathrm{dB(A)}$ and/or $L_{peak} = 140\,\mathrm{dB(C)}$

Regarding the vibration, the parameter used is the daily exposure normalized for a period of 8 hours, $A(8)$. The 2002/44/CE Directive and its corresponding Royal Decree state the exposure limits and the values of exposure that involves an action.

- The top limit value is set to $A(8) = 5\,\mathrm{m/s^2}$ for hand-arm and $A(8) = 1.15\,\mathrm{m/s^2}$ for whole-body.
- The limit value that implies an action is set to $A(8) = 2.5\,\mathrm{m/s^2}$ for hand-arm and $A(8) = 0.5\,\mathrm{m/s^2}$ for whole-body.

There is no regulation regarding the perception measurements; there are only some recommendations about how to make the noise perception surveys for the assessment of the psychoacoustic parameters. Those recommendations can be found in [12]. Apart from that, there is only one standard, the ISO-532 [13], that explains how to measure the loudness.

2.2. Scope of the study

There are several noise and vibration sources in the construction sector and usually the non-specialized workers are who use those machines. For this study, a population of 30 workers will be analyzed; this population is representative enough for the people taking part in a small-medium work site, which is around 5 non-specialized workers. They work for different companies in seven different construction sites (three housing blocks, three of single family dwellings and one warehouse) and specifically, they used the following machines during the measurements: jackhammers, grinders and machines for making grooves in the walls.

2.3. Measurements

Measurements for this study were performed according to the recommendations for measuring noise and vibration given in [14, 15, 16, 17, 18] and the Spanish and European rules about vibration and noise at work [7, 8, 9, 10].

2.3.1. Noise measurements

For measuring noise, an integrative and averaging sound level meter has been used, in order to have data related to the frequency components of the noise measured. A dosimeter has also been used to get the measurement of the noise exposure along the working day without interfering with the worker. The effective measurements were made using the dosimeter (worn by the worker) and the sound

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level meter (very closed to the worker) simultaneously, measuring common indexes like $L_{Aeq,T}$ and L_{peak}, so as to validate the measurements, for which a tolerance of 2 dB was allowed between the measure of the sound level meter and the measure of the dosimeter. Furthermore, to avoid the effect of a possible aware influence of the worker in the measurement, he was warned that only 2 hours would be selected at random of the whole time he was wearing the dosimeter and that he would be observed periodically during the measurement. Moreover, the first measurements taken in a construction site were ruled out to avoid any deliberate influence and to help the workers of the site to get used to the measurement procedure. Through these techniques, uncertainty can be reduced [19].

2.3.2. Vibration measurements

A vibration meter has been used that complies with [20]. Values of rms acceleration have been taken in each one of the XYZ axis to calculate the daily exposure normalized for a working day of 8 hours; it has been taken into account the most suitable weighting for each case: hand-arm, if a machine has to be grabbed by hands, or whole-body, if the machine can be used seated. Adaptors for hand-arm and whole-body, given by the manufacturer of the meter, have been used in the measurements so that the accelerometers were in an optimum position. Measurements must be averaged over a representative period of the normal use of the machine or the process. Whenever possible, that measurement period should begin as soon as the worker's hands touch the vibrating surface and end when the contact is finished. Measurements of less than 15 seconds are very imprecise if low frequency components have to be considered. Consequently and taking into account the tasks and working cycles observed, the minimum acquisition times for the vibration measurements of this study are 25 seconds for hand machines where the hand-arm weighting applies, and 7 minutes when the whole-body weighting applies.

2.3.3. Perception measurements

Recordings of 120 seconds taken with a HATS have been used for assessing psychoacoustics and noise perception. The most representative psychoacoustic parameters (loudness, sharpness, roughness and fluctuation strength), defined in [21], have been derived by software through those recordings.

A differential semantics survey has been made to relate the psychoacoustic parameters with the noise perception. Several aspects must be considered for choosing the questions of the survey, given that they must be easily understandable to ease the process to the polled people and to correlate with the objective magnitudes derived through the recordings. The questionnaire is as follows:

1. How do you consider the noise in this specific job? Very weak / Weak / Strong / Very strong
2. Absence of bass / Little presence of bass / Bass / Bass enhanced
3. Absence of treble / Little presence of treble / Treble / Treble enhanced
4. Non annoying / A bit annoying / Annoying / Very annoying
5. Very constant / Constant / Variable / Very variable
6. Non impulsive / A bit impulsive / Impulsive / Very impulsive
7. Very dry / Dry / Reverberant / Very reverberant
8. Very surrounding / Surrounding/ Detailed / Very detailed
9. Is the noise compatible with a normal speech? Tot. Incompatible / Incompatible / Compatible / Tot. Compatible
10. How many maximum daily hours should you suffer this noise? 0-1 / 1-2 / 2-3 / 3-4 / 4-5 / 5-6 / 6-7 / 7-8

This set of questions has not been chosen at random, on the contrary, it seeks a relationship, as direct as possible, with the results obtained in the measurements:

- The first question is directly related to loudness, which is also involved in questions four and nine.
- Roughness and fluctuation strength have a direct relation with questions two and five.
- Sharpness is related to question three.
- Question six is related to the noise peak level.
- Question nine is involved with the A and C weighted equivalent noise levels.
- Question ten is related to noise exposure and noise dose.

A numerical value is given to each question from 1 to 9: the adjective on the left is given a value of 1 and that on the right a value of 4. The value for question 10 is directly that of the duration given by the answer. Therefore, statistical values that allow the interpretation of the survey's results can be derived.

The survey has been answered by a population chosen between two groups. The first one is made up of expertise people that work or have worked in the construction sector and are familiar with such noises; the second one includes non-expertise people in that kind of noise. A psychoacoustic survey must be answered, at least, by 16 people in order to achieve a good accuracy, as previous research reveals [22]; then, this has been the minimum number of people polled for each one of the recorded noises.

3. Results

Summarized results of the measurements are included in Table I, where the main parameters, for the 30 workers assessed, are given: the daily equivalent A-weighted level ($L_{Aeq,d}$ in dB(A)), the peak C-weighted level (L_{peak} in dB(C)), the noise dose for an 8-hour-working-day (D_{8h} in %), the maximum time that a worker could be hearing such noise during the working-day for a noise dose of 100% ($T_{D=100\%}$ in hours), the vibration dose for an 8-hour-working-day ($A(8)$ in m/s^2), the psychoacoustic parameters -loudness (L in son), sharpness (S in acum), roughness (R in asper) and fluctuation strength (FS in vacil)-.

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Table I. Measured and calculated parameters.

N	$L_{Aeq,d}$ $(dB(A))$	L_{peak} $(dB(C))$	D_{8h} (%)	$T_{100\%}$ (h)	$A(8)$ (m/s^2)	L (son)	S $(acum)$	R $(asper)$	FS $(vacil)$
1	104.5	134.5	9051	0.09	11.48	163.50	3.63	0.50	1.26
2	104.1	134.6	8309	0.10	10.31	139.50	3.49	0.59	2.03
3	102.6	134.1	5876	0.14	8.51	133.50	4.21	0.58	1.70
4	102.0	139.0	5115	0.16	5.24	142.50	4.32	0.57	1.99
5	100.4	133.4	3542	0.23	5.09	176.00	3.57	0.52	1.41
6	100.2	125.2	3321	0.24	7.01	146.50	3.55	0.58	1.59
7	99.6	133.1	2938	0.27	6.63	144.50	4.11	0.52	1.10
8	99.3	125.8	2703	0.30	5.08	170.00	3.83	0.45	1.27
9	98.7	135.1	2375	0.34	4.91	131.00	3.58	0.76	1.69
10	94.8	123.3	965	0.83	4.27	139.50	3.52	0.54	1.99
11	94.1	123.5	826	0.97	4.82	109.50	3.22	0.57	1.59
12	90.7	126.1	370	2.16	4.71	132.50	3.48	0.58	1.30
13	90.5	122.3	353	2.27	4.00	93.80	3.17	0.46	2.05
14	86.2	118.3	133	6.03	4.25	95.20	2.97	0.58	1.09
15	101.7	137.1	4662	0.17	31.98	138.50	3.42	2.07	1.93
16	95.0	130.9	996	0.80	18.87	103.20	2.63	1.00	1.77
17	93.7	135.2	738	1.08	25.75	81.20	2.65	1.01	2.13
18	92.3	133.7	539	1.48	17.49	85.90	3.00	1.39	2.00
19	91.0	129.8	402	1.99	18.72	86.10	2.73	1.85	1.89
20	92.2	131.9	533	1.50	19.01	77.80	2.72	0.98	2.12
21	91.9	129.8	497	1.61	15.24	86.80	3.04	0.65	0.96
22	91.6	122.8	455	1.76	18.36	97.10	2.57	0.47	1.79
23	90.0	126.4	318	2.51	21.85	80.40	3.05	0.55	3.62
24	89.5	124.5	282	2.84	16.94	102.00	2.87	0.62	1.80
25	95.8	112.1	1221	0.66	3.00	115.50	3.16	0.49	1.25
26	87.7	108.2	188	4.25	3.03	94.80	3.06	0.46	1.20
27	87.0	116.0	144	5.54	2.42	60.80	3.38	0.54	1.33
28	100.9	131.2	3912	0.20	34.52	166.50	2.00	0.51	1.87
29	98.1	131.5	2073	0.39	10.32	142.50	1.93	0.49	1.52
30	92.0	132.0	505	1.58	11.89	127.50	2.15	0.63	2.02
Mean	95.3	128.0	2111	1.42	11.86	118.80	3.17	0.72	1.71
Std.Dev.	5.4	7.4	2428	1.56	8.80	31.38	0.60	0.40	0.50
Maximum	104.5	139.0	9051	6.03	34.52	176.00	4.32	2.07	3.62
Minimum	86.2	108.2	133	0.09	2.42	60.80	1.93	0.45	0.96

Table II. Statistics of the answers to the survey.

	$Q1$	$Q2$	$Q3$	$Q4$	$Q5$	$Q6$	$Q7$	$Q8$	$Q9$	$Q10$
Mean	3.18	2.26	2.61	3.30	2.34	2.26	2.58	2.17	1.85	2.90
Std.Dev.	0.30	0.60	0.63	0.31	0.31	0.22	0.35	0.26	0.24	0.40
Maximum	3.88	3.50	3.75	3.88	3.00	2.75	3.13	2.75	2.50	3.88
Minimum	2.50	1.13	1.38	2.50	1.63	1.88	1.88	1.50	1.50	2.25

Next, the statistics of the answers for the 10 questions of the survey is given in Table II.

The daily equivalent A-weighted level is shown in the chart of the Figure 1. It clearly shows that all the workers but 2 are exposed to noise levels that exceed 87 dB(A), which is the upper limit that implies an action according to the current regulation; and the other 2 workers are between 85 an 87 dB(A). Those levels are correlated with their perception through questions one and nine of the survey, which gives a sensation of a noise between strong and very strong and considers the noise as incompatible with a normal speech. This situation is very worrying, given that all the workers are exposed to high levels of risk for their health as a consequence of a noise dose higher than 100%. Therefore, the maximum time that a worker should be exposed to such noises without surpassing the maximum dose is very little, 1.42 hours on average; this is related to question ten of the survey, where the people considers that the maximum time should be no more than 2.90 hours of a working day. Then, in spite of considering the noise as annoying, according to question 4, the margin of tolerance of the people regarding the noise is still very large, given that,

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Figure 1. Daily equivalent level for each worker measured.

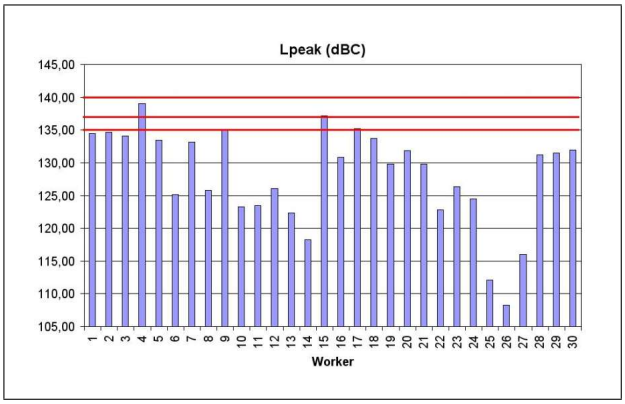


Figure 2. Peak level for each worker measured.

according to their own statements, they are already accostumed to it. But the worst is that, despite the high exposure levels and being the personal protectors available, none of the workers used any kind of protectors in practice.

The chart of Figure 2 compares the peak C-weighted levels. There are only 3 out of 30 workers, 10%, that suffer noise peaks over 135 dB(C), but none of them surpasses the limit of 140 dB(C). This situation is positive, as there is no noise peak level risk in spite of using machines like grinders or jackhammers. This is corroborated by question 6 of the survey, that qualifies the perceived noise only as a bit impulsive.

The chart of Figure 3 shows the vibration exposure received by each worker. There are extremely high values, as the graph and the table reveal. All the workers but one overpass the exposure value that implies a correcting action. Moreover, there are many cases where the limit value is exceeded by a wide margin. Specifically, the workers 15 to 24 and 28 are in a high risk due to vibration, and that fits with the type of machine they use: the jackhammer. It has to be remarked that no worker used any kind of vibration protector and that, according to their testimonies, they were not aware or informed of the possible effects that vibration may cause. Given those results, an extrapolation is studied to obtain the vibration exposure for a reference time of four hours instead of the 8 of the working day; even so, more than half the workers surpass the allowed limit by the current regulations of $5 m/s^2$, what reveals again the high levels of vibration exposure these workers are suffering [23].

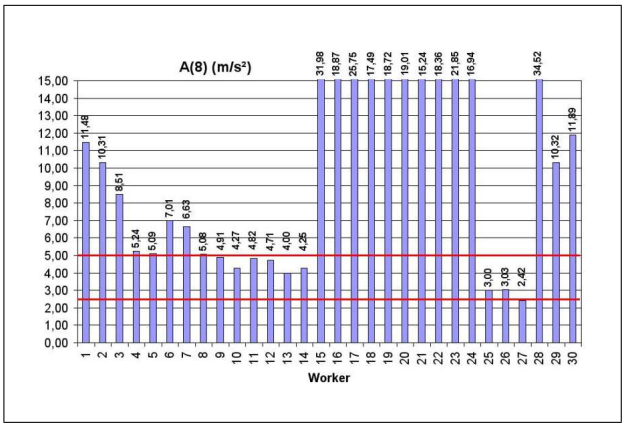


Figure 3. Daily vibration exposure for each worker measured.

4. Discussion

From the data of the Table I, it can be stated that the sound environment which the construction workers studied are within is quite noisy and surely harmful to health, since the lower limit of 80 dB(A) is exceeded in all the cases, and even more, almost in all the cases go beyond the top limit of 87 dB(A). Similar results have been obtained in studies carried out in Germany by the *BIA - BG Institute for Occupational Safety and Health* [24].

The vibration exposure that has been obtained is very dangerous for these workers [23, 25], as it surpasses widely the legal limits stated. Mainly, this is due to the kind of machines these non-specialized workers use.

Regarding the perception survey, the following can be remarked:

- The values achieved show a good homogeneity as the low values of the standard deviation reaffirm. The perceived noise is qualified between strong and very strong (question 1) and incompatible with a normal speech (question 9), which corroborates the high levels of equivalent noise acquired and the high values of loudness measured.
- A joint analysis of questions 7, 8 and 9 leads to the conclusion that the perceived noise can have a very negative influence on the capacity of the workers for hearing any type of advise or emergency message while they are carrying on their duties.
- The noise is perceived more treble than bass (questions 2 and 3), what gives an idea of predominance of medium and high frequency components in the noise spectra; this is reassured by the measured spectra and the high values of sharpness obtained.
- Comparing roughness, fluctuation strength and question 5 leads to the conclusion that the noise is perceived as a bit variable, specially with variations of very low frequency, given that the fluctuation strength values are much higher that those of roughness.

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- Question 6 indicates that the noise is perceived as a bit impulsive, what is related directly to the fact that no worker surpasses the noise peak level.
- Question 10 points out that, on average, one is only willing to use any of the machines measured for no more than 3 hours, but what is more outstanding is that the maximum value achieved in this question is just 3.88 h, that is, less than half the working day. This reaffirms the whole study, given that the levels measured are quite high and so is the perception of the workers and the polled people in general.
- It can be stated, as a sum up of the perception and according to question 4, that the noise is perceived as very annoying for the workers; furthermore, all the polled people have qualified the noise as annoying or very annoying.

In addition, the use of personal hearing and vibration devices in the population studied is very low although their use is compulsory in many occasions in accordance with the Directives 2003/10/EC and 2002/44/EC. This fact reveals two fundamental aspects to deal with the problem of noise and vibration at work: first, the workers are not aware of the problems related to the exposure to noise and vibration and they are the first that overlook their own health state by rejecting the use of the personal protection devices; and second, many companies are not persistent with the observance of the directives against noise and vibration. Therefore, it should be advisable to develop a noise and vibration management procedure as a general preventing guide to avoid such problems [26, 27, 28].

Three types of actions are usually considered in the working procedures of the industrial hygiene to try to control the noise:

- On the source: noise at the source could be reduced by using machines less noisy, for what the labelling systems of emitted sound power can be very useful [29, 30].
- On the environment: reduction by applying the ISO 11690-1:1996.
- On the worker: reduction by using personal hearing devices; for the correct election of a protector, it is necessary to calculate the attenuation considering the manufacturer's data and check if the one chosen fulfils the specific requirements of attenuation for a given worker.

Regarding the vibrations, there are few protection systems to reduce them over the human body, given that it is difficult to act on the vibrations made by a machine and then, a set of preventive measures has to be adopted so that the risk caused by vibrations could be minimized and possible illnesses could be avoided. Some of the preventive criteria recommended are: to decrease the exposure time, to establish rotations at work, to reduce the vibration among the pieces of the machines and the elements to be transformed, to reduce the vibration due to the machine under work, to use personal protection devices -antivibration gloves, belts, boots, etc.- when necessary, etc. At the same time, workers must be informed about the vibration levels they are exposed to and about the personal protection devices available, as well as putting into practice educational programmes to optimize the muscular strain and position to carry out a task so that the suffered vibration could be minimized.

5. Conclusions

This study carries out an analysis of the noise and vibration levels that the non-specialized construction workers are exposed to that is complemented with a noise perception survey. The number of measurements (30) is representative of the real number of those workers (around 5) belonging to a small and medium-sized company involved in an average construction work in the country where the study has been done.

The main conclusion that can be obtained is that this subset of workers of the construction sector suffers very high levels of noise for the tasks they are in charge of. The risk due to vibration depends more on the type of machine they use for a certain task, but it is also very high and can easily surpass the top limit allowed.

Perception of the noise is quite negative, what is directly related to the high noise levels the workers are exposed to. On the whole, the noise is assessed as strong, annoying, a bit impulsive and incompatible with a normal speech. Furthermore, the mean time that one is willing of hearing the noise is less than 3 hours.

Consequently, it seems necessary to find a reasonable combination of worker's behaviour and preventive strategies in the construction site. Unfortunately, it was checked experimentally along the study that such combination is absent for the little and medium-sized construction companies. An improvement should be made to encourage workers, construction companies and authorities to become aware of the problem with noise and vibration at work.

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