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Current Importance of the Assessment of the Occupational Noise Exposure in a Quality Approach

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According to the National Statistical data, the work- related hearing impairment shows a decaying trend, remaining the second health impairment cause.
The preliminary results of data collection on a number of industrial activities in different NACE sectors brought into evidence that a large number of Safety Documents provides only general information on the compliance of the exposure levels with the limit values, without any technical detail on the measurement campaign set up and the measures statistical representativeness.
On the Author experience, operating within the research project “The General Safety Issues and Goals in Turin Universities” –TGSIGTU, an effective assessment of the workers’ exposure conditions results a demanding task, whichever the pollutant, especially in universities where advanced research activities and routine operations (often interfering) are performed in the same workplace. This scenario can be compared to the small and medium enterprises working conditions, where a current work reorganization, for an improved adaptability to the production requirements, increases the complexity of the systems.
Starting from a discussion on the critical aspects characterizing the definition of workers’ exposure condition, the paper deals with an Occupational Noise Risk Assessment in a Quality approach consistent with the general requirement of OS&H regulations and specific UNI EN ISO 9612:2011 standard providing technical suggestions for the determination of the occupational noise exposure. This approach has been well - tested both in different NACE sectors and in universities supported by approx. 150 noise data collected in different scenarios.

1. Introduction

The problem related to hearing loss due to work-related noise exposure emerges from the analysis of data on occupational diseases: according to the available information from 2012 to 2016 of National Insurance Institute - INAIL, the hearing loss is still one of the most prominent health impairment (Table 1).

Table 1: Number of cases positive recognized from 2012 to 2016 in Italy

Year Health impairment	2012	2013	2014	2015	2016
asbestos related (ex. asbestosis)	1421	1514	1515	1402	1207
biomechanical overload of upper limb	5562	5292	5841	5521	5033
noise induced hearing loss	1780	1686	1533	1376	1230
lumbar disk herniation	2308	2344	2370	2375	1796

Despite of the trend (in reported cases) of work - related hearing loss and associated compensations seems to decrease in the long run, this scenario highlights undeniable difficulties in the implementing of preventive measures in a constantly changing production systems also affected by a socio economic (employment rate included) modifications. Several are the causes of this situation, among them the poor understanding of a close link between OS&H principles and the system design, essential for the Assessment and Management of

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the System (and its safety) in a Quality Approach. This assumption is supported by what emerges from the analysis of some Safety Documents (in Italy DVRs – Documenti di Valutazione dei Rischi) of industrial contexts: the definition of workers' exposure to Hazard Factors is often lacking in rigorousness, completeness and formalization of the analysis. That means a not repeatable approach affecting for example the revision phase in case of operative and production changing, at the expense of a Quality Management of the system.
With special reference to the noise, some aspects affect the definition of workers' exposure model: a) intrinsic characteristics of noise, b) different sources typologies and synergic effects, c) operative and not operative features of working environment conditioning the noise propagation. In addition the variability of workstations, job duration and workers' time-operation relation, often unknown with sufficient detail, increase the difficulties in the assessment of occupational noise, especially where specific tasks are of critical identification.

2. Overview on Safety Documents

The analysed documents show some criticalities on general aspects of the adopted approach starting from the strategy of information gathering, up to the representativeness of the results deriving from sampling campaigns.

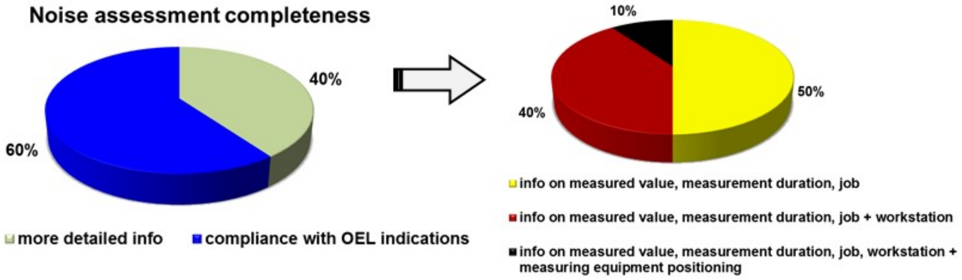

Figure 1: Available information on the analysed Safety Documents

The first problem identified concerns the typology of noise measurements to assess the workers' exposure: in almost all the Safety Documents, the noise exposure assessment is based on stationary samplings. The adoption of a personal sampling approach should be preferred since the use of personal devices (noise exposure personal measuring devices as specified in UNI EN ISO 9612:2011) makes possible to collect noise data more representative of the actual exposure of workers than the data collected by area samplings especially in the case of variability of tasks in different environments.
As summarized by pie charts in Figure 1, some criticalities appear in the noise exposure assessment of analyzed Safety Documents:

1. information on the compliance with the Occupational Exposure Limits*:*

- ✓ the 60% of the examined documents provides indications exclusively on the compliance or not compliance with the noise Lower Action Limit – LAL, Upper Action Limit – UAL, and Occupational Exposure Limit – OEL (2003/10/EC Directive), without specifying the measured values;
- ✓ the complementary 40% of documents clarifies the measured value (A weighted Sound Equivalent Level – $L_{eq(A)}$, C weighted Sound Equivalent Level – $L_{eq(C)}$, and C weighted Sound Peak Level – $L_{peak(C)}$), directly compared with the reference limits; however data cover single noise values for each specific task; no document contains repeated measures for the same task. Moreover, the aspect related to the expanded uncertainty that should be associated to each value is neglected: where the uncertainty is considered, it refers only to the accuracy class of the measuring equipment, disregarding other important factors (e.g. equipment set up and calibration, microphone positioning, boundary conditions, unexpected sources, etc.).

2. measuring process details

- ✓ considering the percentage of documents providing the measured noise values (the 40% in pie chart on the left), the pie chart on the right shows that:
  - the 50% of these documents contains general information on the measuring process, in particular regarding the measuring durations and the working operation involved;
  - the 40% contains some more detailed information, e.g. characteristics of the workstation;
  - remaining 10% provides, in addition, complete information about the measuring strategy, e.g. the phono integrator positioning, the height of microphone from the floor and its orientation towards the workstation, etc.

The lacks observed in the analysed documents disagree with the extensive literature providing in depth information regarding noise measuring approaches (stationary or personal), quantification of the weekly or daily workers' exposure, calculation of uncertainty affecting each measure. The UNI 9432:2011 standard, Appendix E, suggests an evaluation of the measured values compared to reference values, adopting the upper limit of the one sided confidence interval on the daily exposure level (assuming a 95% of confidence level). Only the UNI EN ISO 9612:2011 standard suggests assessing the 8h-shift noise workers exposure through the analysis of variability (±3dB) of almost 3 repeated noise measures, collected in the same situation where operations, tasks and their durations are well known. This condition represents a utopic scenario very different from the actual industrial working contexts, characterized by high variability and unexpected production changes (Spagnolo, 2015). However, in scientific literature very little exists about the comparison, in rigorously statistical approach, between the measured values and the reference LAL/UAL or/and OEL, the only way to identify of the minimum number of noise measures (the minimum sample size), essential to evaluate the sample representativeness.

3. Material and method

In compliance with the Italian law D.Lgs. 81/08, article 190, point 3, "measuring methods and equipment used should be adequate to the characteristics of noise to be measured, to the exposure duration and to the boundary conditions, according to the technical standard recommendations. The adopted methods can include the sampling, provided that it is representative of the worker exposure", the authors propose an approach to improve the definition of the noise workers' model exposure, based on:

- a careful and well-planned design of measuring campaigns to achieve data (measuring process results) that accurately represent the actual working scenario (1^{st} level of representativeness);
- a statistical analysis, to ensure the usability of data, starting from the detection of potential systematic effects and outliers, to the verification of belonging statistical distribution and statistical representativeness of samples (2^{nd} level of representativeness). The latter is essential to compare the exposure data with the Safety regulations, standards and good practices.

3.1 First level of representativeness achievement: measuring campaign design

In general, the evaluation of workers' exposure conditions to occupational noise is a demanding task due to the intrinsic characteristics of the Hazard Factor, the very different typologies of sources and the high influence of the boundary conditions on the noise propagation.

Therefore, the planning of a series of noise exposure measurements requires a thorough analysis and understanding of the working context and activities performed, processes, involved materials, workers' tasks, etc. The preliminary information, fundamental to carry out a careful design of a noise measurement campaign should include:

1. the definition of measurement target: workers' exposure (usually in $L_{eq(A)}$, $L_{eq(C)}$ and $L_{peak(C)}$) and/or sources characterization in terms of emission characteristics (directivity, Sound Power and Intensity measurements, frequency analysis). Additional information (e.g. maximum or minimum values, time history, etc.) can be sometimes useful;
2. the thorough examination of the activity: processed materials and substances, operations equipment, adopted techniques and technologies in order to characterize the working environment, also in terms of simultaneous processes to evaluate potential synergic effects due to the compresence of more sources;
3. special care of workstation locations and operating conditions: is essential to describe as accurately as possible the activities performed (e.g. fixed position or variable operating conditions) to identify the permanence time of workers in the different areas;
4. the efficiency of existing control measures: information on maintenance conditions of equipment, efficacy of dispersion control solutions, working environment countermeasures, etc.;
5. the work organization: information on shifts (tasks associated with each job), number of workers per shift, shift duration and rest periods, and, where possible, identification of homogeneous groups of workers.

An in-depth analysis of working situation makes it possible to design a measuring campaign tailored for each context by selecting the measurements characteristics, instrument layout and setup most suitable to the production characteristics and fluctuations, operative conditions. In addition, the design should provide information on parameters, potentially affecting the measures, and related recording techniques. Moreover, all the measuring equipment should comply with the metrological requirements (Bisio et al., 2016).

3.2 Second level of representativeness: data interpretation

The evaluation of measures' quality (also involving the presence or not of associated uncertainty, and its value), their trend vs the expected values, and the decision about potential anomalous values, can be possible through the interpretation of the achieved measures. Starting from a preliminary general analysis of the overall data on the base of observations collected during the in situ measurements, the measures evaluated coherent become input data for the following representativeness tests.
The interpretation of data should follow the logic order as summarized in Table 2.

Table 2: Logical phases of the suggested approach

Steps	Description and target
1. Possible systematic effects detection	The descriptive statistic (e.g. blox-plot) allows identifying systematic effects that, in the case of noise measures, can be due to measurement systematic errors and/or insufficient stationarity interval - S.I. effect. Where this problem arises a tendency appears, and the stationarity interval should be modified.
2. Outliers identification and discussion	Special tests (e.g. Chauvenet exclusion principle) can be used to identify "potential outliers". In the case of OS&H measures, anomalous data can be due also to particular activities (sources expected or not), which contribute (increase) to the workers exposure, and therefore they should be considered, on the light of significant information collected during the measuring operations, to identify the possible causes (operational) of odd data.
3.Check for belonging statistical distribution	The verification of belonging statistical distribution of the sample, through the Normal Probability Plot, Chi-squared test, etc., is essential to select the suitable representativeness test for the following step. Some tests, e.g. One sided Tolerance Limit – OTL and derived Tuggle (Tuggle, 1982), Leidel & Busch (Leidel et al., 1977), require the normal distribution of data as necessary condition. In the case of occupational noise in not too complex scenarios, data can follow the normal distribution (Malchaire and Piette, 1997).
4.Representativeness of data set	The representativeness tests make possible the definition of the minimum sample size to compare in a statistical approach the noise values with the exposure reference values, taking into account the confidence interval selected and the power of the test.
5. Frequency analysis of data set	The final step, special for noise assessment, involves the frequency analysis of the noisy phenomenon, in order to detect possible critical frequencies (e.g. the case of high-energy contributions centred in specific frequencies, etc.) that can be worsen the exposure of workers.

The method, well tested for define the workers' exposure models to airborne pollutants in working environment (Bisio et al., 2017), had been implemented to be adapted to the assessment of occupational noise.

4. A practical example of noise data processing

This section proposes the preliminary results of the above-discussed method, applied to 20 measures of $L_{eq(A)}$ as specified in Eq.(1), recorded in an University laboratory. This sample was drawn from a database containing data gathered both in industrial and academic working contexts; the authors decided to test the method using, for this first application, data characterized by low variability (controlled standard deviation).

$$L_{Aeq,T} = 10 \log \frac{1}{n} \cdot \left(\sum_{i=1}^{n} 10^{\frac{L_{Aeq,t}}{10}} \right) \tag{1}$$

where:
T = total measuring time (typical work shift);
t = measuring time of each measure (15 - 20 min);
n = number of measures (approx. 20);
$L_{Aeq,t}$ = Sound Equivalent Level of each measure;
$L_{Aeq,T}$ = overall Sound Equivalent Level.

After the verification of systematic effects and/or outliers presence in the data set, and the check of normal distribution of measures, Tuggle approach was selected to identify the minimum number of measures to achieve a representative sample of the considered scenario.
The original method, suitable also for reduced samples size, derives from the OTL test usually adopted to analyse factors lognormally distributed, e.g. airborne particulate matter. This justifies the log transformation of quantities involved in the calculation of Test Statistic. The authors launched an experimental application of the Tuggle method, originally implemented to process noise data belonging to normal distribution, proved by the third step of the proposed method (Table 2).
Table 3 summarizes the test, highlighting the main changes:

- ✓ no log transformation of the ratio between measures and Reference Level – RL (to choose exclusively among the LAL, UAL, or OEL);
- ✓ the selected limit, on the numerator of Test Statistic, is not log transformed, since it belongs to the same (normal) distribution of measured values;
- ✓ a scale factor (C) was introduced to compensate for the different ratio - measured values/reference level - existing in the cases of airborne particulate and noise.

Table 3: Tuggle test modified

Step	Formulas	Notes
1	$PR_i = {x_i}/{RL} = y_i$	x_i = measured value; no log-transformation of PR;
2	$\bar{y} = {1}/{n} \sum_{i=1}^{n} y_i$	n = sample size; $\bar{y}$ = average value
3	$s_y = \sqrt{\frac{\sum_{i=1}^{n} (y_i - \bar{y})^2}{n-1}}$	S_y= standard deviation
4	$Test\ statistic = C \cdot \left(\frac{RL - \bar{y}}{s_y}\right)$	no log-transformation of RL, introduction of C scale factor.

Figure 2 shows the outcomes of the application carried out in three consecutive tests, using as RL the lower and upper action limits and the exposure limit value, step by step. Test 1 involved 3-measures sample size (minimum condition for the applicability of the method); Test 2 a sample size of 10 data; Test 3 the complete set of measures (20).

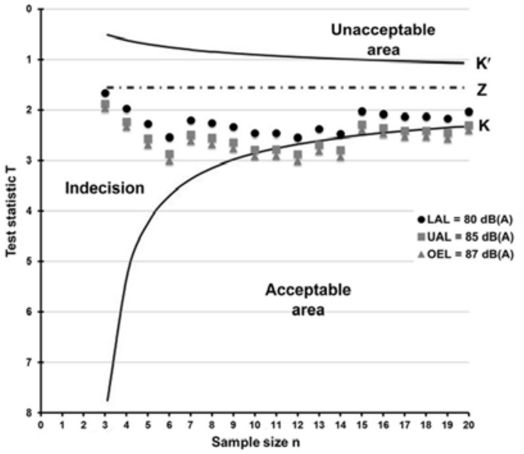

Figure 2: Tuggle results on the selected data: test 1 n=3, test 2 n=10, test 3 n=20

As results from Figure 2, Test 1 does not permit to make decision on the compliance with the three reference parameters of the OTL test (K', Z and K): identified points fall in the uncertainty area. Test 2 results borderline with acceptable area, in the case of RL equal to OEL and to UAL; an additional increase of sample size is required to fall into the acceptable area, especially if we consider the lower action limit. Finally, the complete sample does not allow reaching the representativeness in the case of action limits also using the OEL as reference value, the Test Statistic trend remains in a borderline condition with acceptable area.

In conclusion, the number of measures collected, in the specific working environment, is insufficient to assess correctly the workers' exposure condition, therefore additional measurements are necessary.

5. Discussion

The proposed method puts in evidence some aspects: the most evident is that, despite the data deriving from a "steady" scenario, and hence characterised by a limited dispersion, the sample size (20 data!) is insufficient to characterise exhaustively the exposure of workers and to select the suitable preventive countermeasures.
This result unfortunately shows how an increasing of complexity of noisy phenomena could require more and more noise measurements to reach an actual representative sample. Furthermore, from a preliminary test of the method, it was possible to note that, in the case of small sample size (e.g. 5 measures) the variability of data becomes a limiting factor: the trend of data towards the decision areas (acceptable/unacceptable) "lingers" in the indecision zone longer than in a low data variability condition. The above acceptable/unacceptable condition, for own nature statistically determined, should consider also the individual's susceptibility of the workers (Van Kamp and Davies, 2013).

6. Conclusion

The present work would be the starting point of a deeper investigation, with the aims to define and validate an approach dedicated to defining noise workers' exposure models. The proposed approach makes possible the achievement of data actually representative of the working context (1st level of representativeness), and optimize the measuring campaigns to collect actually usable data (2nd level of representativeness), making effective the workers exposure model definition, and therefore the resulting Risk Management in a Quality approach. The future development of this research work could involve the implementation of the approach to measures collected by personal devices (dosimeters), not neglecting the additional, potential, criticalities and source of error introduced. These equipment could improve the quality of noise data, being on board of the operators, and following them during their working tasks, often very difficult to schematize and accurately define. As collateral result, the research work confirms the benefit (e.g. graphical representation of data, user-friendliness) of the Tuggle method for the evaluation of occupational noise exposure.

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