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Assessment of noise environment quality of industrial workplaces

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Abstract. This work represents first results of an attempt to practically describe soundscape and noise environment at the factory, using easy to measure and calculate descriptors. The sound quality of the four factories investigated did not differ significantly from each other. Some low-frequency peaks were found, but the STI, the shape of the spectrum, and the impulsivity did not differ significantly from the reference values of the general quality quantities. For infrasound, the hearing threshold was not exceeded. Most findings connected to sound annoyance were low frequency noise like tonality and low frequency ratio. Sharpness values were relatively low. The equivalent sound pressure level (L_{pAeq}) remains an important parameter.

1. Introduction

Research on the well-being at work of industrial workers is limited, and in terms of soundscape and noise, the examinations are usually limited to loud noise, which is considered dangerous to hearing. The ongoing multidisciplinary research funded by the Finnish Work Environment Fund "Työn äänet" aims to expand the understanding of industrial sounds and soundscapes and their significance for employees' well-being at work, on-the-job learning and the fluency of work.

Disturbing sound is a stress factor [1] that has a wide range of immediate and long-term effects on human functioning and well-being. Disturbance predicts health effects even better than noise levels [2], but noise abatement in industrial workplaces focuses on noise potentially dangerous to hearing. The stressfulness of sounds is affected by individual factors, context and interpretation, such as the perceived usefulness of the sounds [3]. In office and expert work, research results on noise annoyance have already had an impact on noise abatement practices [4–5]. This project proposes that these practices be applied also for industrial noise abatement.

The research project examines the interpretations and meanings given to sounds, in addition to their physical properties. The framework has been applied to research on outdoor spaces, urban environments and shopping centres [6–8], but only to a few working life surveys [9–11]. There is a lack of research data on the significance of context and action for the experience and evaluation of sounds measured at a certain level, when a voice is thought to be negative or positive, and what kinds of differences there are in the experience. [5]

In recent years, building regulations for work environments with lower noise exposure, such as office, teaching and care facilities, have also been revised [12] on the basis that the premises achieve a "sufficiently good sound environment corresponding to the operation" and prevent

disturbing and annoying sound environment. In industrial workplaces, this aspect of sound has rarely been brought up. We could argue that the management of the sound environment in industrial environments appears to lag in many ways and that the diverse research data and methods on the effects of sound have not been applied to nearly the same extent as in other work environments and leisure time noise contexts.

2.Motivation and Purpose of the Study

The annoyance of sound is defined by measurable sound properties, such as sound pressure level, impulsiveness, narrowband [13], but also by the predictability, controllability and usefulness of the sound [1]. Measuring acoustic quantities does not reach the psychological side of annoyance [14], so interdisciplinary and multi-method approach are necessary. The time, activity, place and attendance affect the assessment of sound as positive or negative [5]. The meanings and messages of sounds can be shared, but also different: important to some, but noise to others [15, 16]. Control over the soundscape increases positive experiences [17]. Well-being at work is a summary concept that describes the quality of working life, including occupational safety and health aspects. It is a significant determinant of productivity at the level of the individual, the company and society. [16]

The quality of industrial noise environment is here assessed by standardized, practical, easy to acquire quantities like tonality, impulsiveness, low frequency content and combined with more traditional quantities e.g. reverberation time or spreading loss. Consideration is given to effective improvement means, some results of implemented improvements are presented.

3.Measurement Methods and Quantities

The research focuses on the soundscapes of industrial companies in four different industries and their significance for the well-being of employees at work. Factory 1 is an assembly factory, and it has metal workshop, assembly, testing and painting environments. Factory 2 manufactures sheet metal components by pressing, painting, forming, welding and assembly. Work place 3 is a nuclear power plant. This is a large facility, and working environment varies across turbine island, offices, control rooms and maintenance areas. Factory 4 is a tyre manufacturing plant, where rubber and steel wire materials are industrially formed to all kinds of tyres, including quality inspection. Thus the general category in these factories is process and metal industry.

The workplace related sociological data was collected through observations, interviews and interactive workshops.

Acoustic data was obtained by quantitative measurements and qualitative observational, interview and workshop data obtained through soundscape walking [18, 19]. The following physical quantities were recorded (reverberation time, sound propagation attenuation, speech transmission and intelligibility index (STI, SII, especially for control room work). The noise dose from workers was also measured to determine the exposure to impulse noise and the need for hearing protection. These were used as technical noise control design basis.

General signal analyser Svantek 958A and precision sound level meter Nor-150 was utilised for measurement of sound parameters and waveform recording. 9 mm pistol blank impulse was used to measure reverberation time. The quality descriptors were later calculated as laboratory work. Rion NB-14 was used for dose measurement.

Table I shows the elaborated parameters for the sound evaluation in addition to directly measured values like equivalent noise level (A- and C-Weighted) and peak level L_{Cpeak}.

Table 1. Qualitative description of analysed noise quality parameters

Parameter	Analysis method
Tonality	Analysis of the prominence of distinct tones versus broadband noise
LF ratio	Energy at 25…160 Hz to 200…1000 Hz
HF ratio	Energy at 200…1000 Hz to 1250…8000 Hz
Flatness	Geometrical average pressure versus arithmetic average pressure.
Spectral slope	Linearization of sound pressure level
Spectral shape	How much energy exists at different frequencies
Sound flatness	How uniformly sound energy is distributed across different frequencies
Crest factor	Maximum sound pressure level versus rms sound pressure level
Sharpness	Analyse the loudness distribution, in particular higher frequencies

Table 2. Analysis of averaged noise quality parameters over four industrial premises

	Tonality	STI	LAFmax	LAeq	Spectral slope	LFRatio	HFRatio	Flatness	Crest	Sharpness	LCpeak	|LAeq-Lceq|	LZeq	LCeq
factory 1	11.7	0.56	70	62	17.7	0.3	1.0	0.0	3.6	0.7	90	0.8	63	62
factory 2	7.5	0.45	88	81	21.0	0.0	1.6	0.0	3.4	0.7	101	0.4	82	82
power plant 3	18	0.2	80	74	-4.4	348.0	0.3	0.1	5.5	0.2	98	11.0	87	85
factory 4	13	0.4	88	78	-1.1	5.5	1.1	0.4	4.7	0.3	104	4.6	85	82
reference value	<10	0,2-0,6	< 90 dB	< 80	0	< 10	< 10	< 1	< 5	< 1	< 125	abs > 5	< 100	< 100
remark		fair/good							peak / rms			LF indicator		

4. Results

Table 2 show results of the measured and analysed sound quality parameters. The sound quality of the factories did not differ significantly from each other. Some low-frequency tones were present, but the STI, the shape of the spectrum, and the impulsivity did not differ significantly from the reference values of the general quality quantities. As to infrasound, the hearing threshold was not exceeded. The variables also logically explain each other, e.g. L_{pAeq}-L_{pCeq} and LFRatio, or Crest factor and L_{pCpeak} and L_{pAeq}.

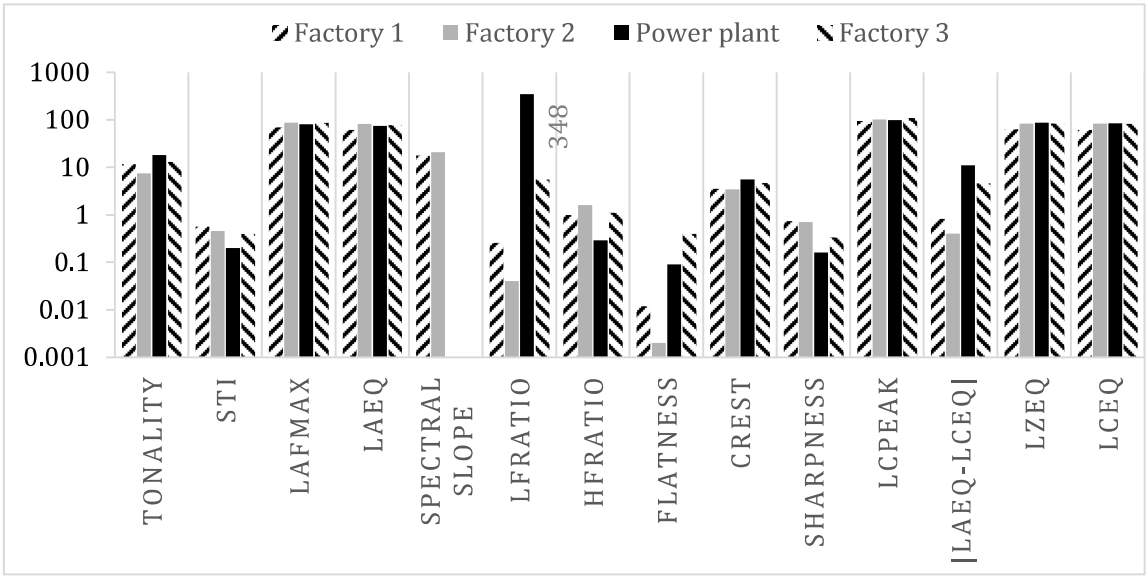


Figure 1. Sound quality parameters in logarithmic and graphical form. Negative values cannot be shown in logarithmic presentation, thus L_{pAeq}-L_{pCeq} shown as absolute value.

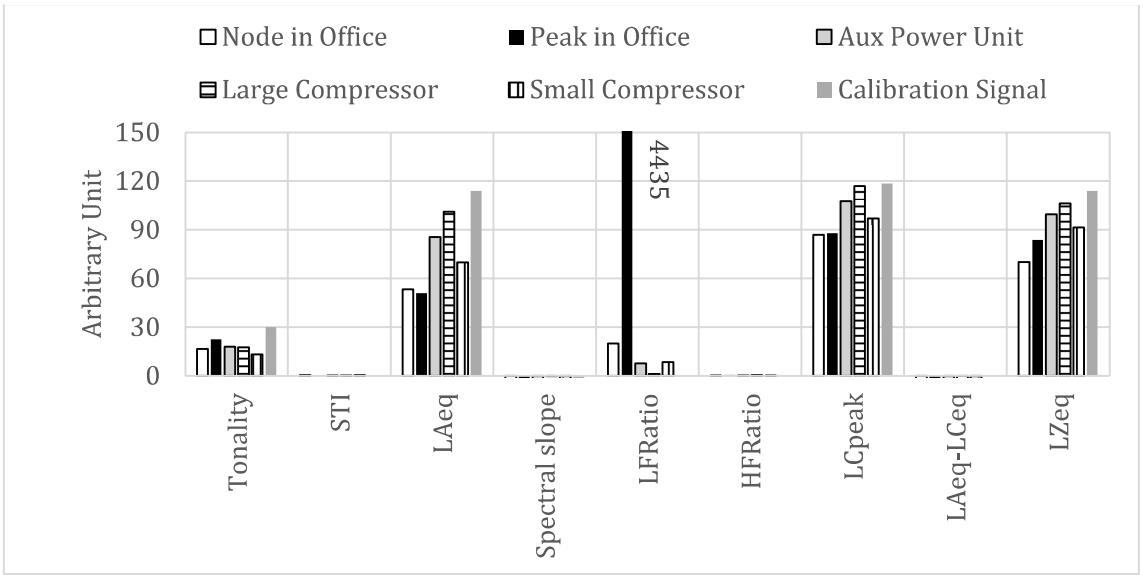


Figure 2. A comparison of power plant noise descriptor values' variance depending on location inside a single factory but at different workstations.

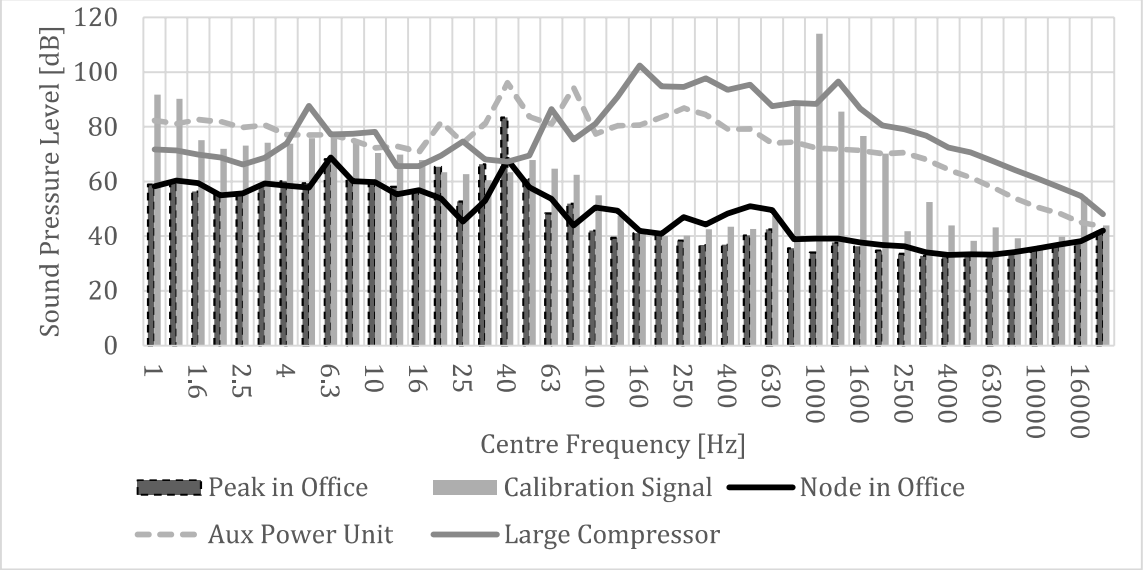


Figure 3. Four samples of noise spectra and calibration signal, standing for tonality, low frequency noise and spatial variation of low frequency noise inside the office space. Sample from workplace 3, nuclear power plant.

5.Discussion

Most findings connected to sound annoyance were low frequency noise (tonality and low frequency ratio). Sharpness values were relatively low; this appears to reduce annoyance perception [20]. The equivalent sound pressure level (L_{Aeq}) is also an important parameter.

The study represents a paradigm shift in occupational safety and health from the prevention of loud noise to the cooperative proactive design of soundscapes [21]. The study examined the soundscapes of industrial work more extensively than just in terms of sound that is harmful to hearing. This need emerged in our previous study [16]. The results present a first understanding of the possibilities for developing well-being at work in terms of the sound environment in situations where the noise level does not necessarily require the use of personal protective equipment. The importance of sound for worker recovery and rest is characterized.

The standard assessment criteria [22] usually consider only noise exposure (L_{Aeq}) and peak levels (L_{Cpeak}). Typical to an industrial application the spectrum quality, impulsivity, frequency weighting, narrow band or sound propagation are not considered. Nor are there any speech transmission criteria important for speech communication. Measuring and analysing these enriches the usual acoustic engineering data and enables the identification of new acoustic quantities to capture the meanings of soundscapes. From the point of view of noise abatement, modelling and information on the reverberation of the space are also needed. The study is part of the groundwork to map out which major perspectives on the assessment of the disturbing nature of the industrial sound environment and well-being at work are useful.

The results are indicative, as they represent examples and average values from different factories. Then there is a significant uncertainty. However, our purpose has been to get first impressions on those used sound quality parameters, and later use them in evaluating the parameters, when subjective complaints on the sound exist.

6. Conclusion

The application of standard, relatively easy to calculate acoustical quality descriptors to practical samples was successful and straightforward.

Next work will be to connect these acoustical parameters to perceived sound environment in psychological and sociological perspective during the spring of 2026. We expect this will provide clear insights into assessment of sound quality of industrial sounds and noise at workplaces.

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