STUDY OF NON-AUDITORY EFFECTS OF NOISE

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It is generally known that long-term and repeated exposure to noise has a negative impact on the sense of hearing. However, less is known about the fact that not only auditory organs are affected by noise. Research has shown that noise has effects on the entire organism, especially central and autonomic nervous system. Peterson et al. (1981) conducted a study using monkeys to explore the effects of long-term exposure to noise on blood pressure and auditory function. The animals' blood pressure remained elevated even after noise exposure was terminated, while their auditory sensitivity was not decreased. The paper proposes a methodology of noise assessment, taking into consideration legislative requirements as well as non-auditory effects of noise. The methodology is applicable even in the first phase of product development.

KEYWORDS

noise, risk, auditory noise effects, non-auditory noise effects

1 INTRODUCTION

Reduction of noise in general belongs amongst the most important tasks in developed societies today. It has been estimated that one third of European employees (over 60m people) are exposed to high levels of noise for over a quarter of their working time. Activities in this field focus on primary reduction of oscillation and noise, i.e. direct removal of the causes of significant vibro-acoustic energy of machinery, such as changes in the construction, appropriate choice of materials, or technological changes, e.g. substituting slide bearing (whose noise level is negligible) for roller bearing, centring – balancing the rotating parts of motor, and flexible connection of individual parts of machines. Secondary or additional reduction of vibro-acoustic energy, which works by absorbing a part of it, is less effective and more expensive [Pokorny 2014]. Secondary noise reduction measures, such as use of personal protective equipment, are generally applied by the users themselves. However, best results are achieved when primary reduction of vibro-acoustic energy is applied. The method of vibro-acoustic reduction directly at its source can be applied in the design, development or construction stage of new machinery, technology and vehicles. It utilizes the newest findings of current scientific knowledge. Nevertheless, people still have the highest influence on the resulting level of vibro-acoustic energy, because people influence the accuracy in the production of individual parts, their balance, finish, assembly, selection of construction materials and damping layers, appropriate shape of non-stationary flow pipework, and the choice of appropriate technique [Babish 2015].

2 EFFECTS OF NOISE ON HUMANS

Sound is:

- a sensation stimulated in organs of hearing by acoustic waves,
- an acoustic wave able to cause acoustic sensation,
- periodic changes in pressure, mechanical stress, particle speed, etc. in the environment with internal forces [Ziaran 2001].

Sound is a mechanical oscillation that propagates through particles of compressible media.

Noise is an unpleasant, unfavourable, annoying or harmful sound to human health, caused by everyday human activities [Ziaran 2001]. It is every unwanted, disturbing, unpleasant or harmful sound [Baron 2013].

Acoustic vibration is a part of the physical fields surrounding people. It influences human organism, its health, behaviour, activity, efficiency and wellbeing. [Bicejova 2009].

The effects of noise on humans (Fig.1) can be classified as [Balazikova 2012a]:

- specific, where the resulting effect depends directly on changes and damages to their auditory organs,
- systemic, where function changes affect other parts of the central nervous system, e.g. communication disturbance, masking acoustic warning signals, increased accident occurrence.

Positive effects of auditory perceptions should be seen especially in their information and aesthetic value, activation of the central nervous system, in the influence of rhythmic sounds on some physical activities, in the influence of sounds on the production of endorphins (morphine-like effects produced by the brain tissue), in the analgesic effects of sounds and the possibility of utilization of an indifferent sound as an acoustic shield in order to direct hearers' attention [Babish 2014].

The first group of extra-auditory effects includes the influence of noise on the cardio-vascular system. In 1977, Knipschild and Oudshoorn indirectly proved the effect by noting an increase in antihypertensive medication consumption in a village near an airport, which correlated with an increase in aircraft traffic. A control village that was not near the airport did not demonstrate an increase in cardiovascular medication consumption during the same period. Cardiovascular effects of noise have been examined most thoroughly of all non-auditory effects.

Autonomic effects have also been partially included in research into the effects of noise. For example, Levi (1966) found that urinary adrenaline and noradrenaline levels were higher in subjects who were exposed to short durations of noise and that in some cases the changes bordered on the pathological. However, when exposed to similar noise levels over long periods of time, very little changes occurred in adrenaline and noradrenaline levels. Thus, it appears that habituation may be involved in the autonomic effects of noise.

Exposure to noise can also lead to gastric changes. For example, Bugliarello et al. (1976) described a study in which exposure to 80 dB noise levels resulted in a reduction in stomach contraction strength. Additionally, Burns (1979) conducted a study in which subjects who were unable to control their noise environment experienced increased gastrointestinal motility compared to subjects who could shut the noise off by pushing a switch. As gastric changes are related to ulcers, Bugliarello et al. (1976) and Bragdon (1972) both suggested that noise may be related to ulcer development [Bragdon 1972a,Bugliarello 1976,].

Undesired effects of noise and its threats to human organism can be expressed as C = f ($C_{aud.}$,$C_{non-aud.}$), where [Balazikova 2009]:

- **$C_{aud.}$** are specific (auditory) consequences, which affect the function of the acoustic analyzer,
- **$C_{non-aud.}$** include systemic (non-auditory) consequences, where the dominant functional changes appear in parts of the central nervous system other than the auditory organ system.

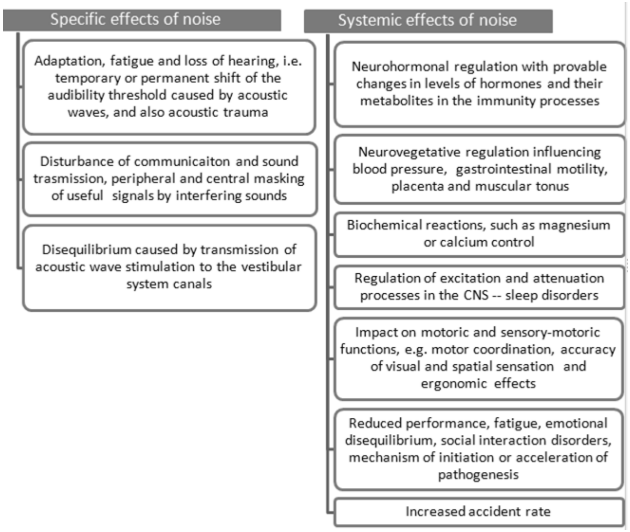


Figure 1. Parameter characteristics of the respondents involved in the experiment

3 CAUSAL DEPENDENCY OF ACOUSTIC RISK

Acoustic causality or acoustic causal dependency (Fig.2) is a direct, concrete and essential incurrence of objective consequences of noise; whereas one process (cause) activates another process (effect). Causality is a relationship that exists between objects, events, processes or systems of objective reality, where under certain conditions the acoustic phenomenon, i.e. cause, either necessarily or inherently initiates another phenomenon, i.e. auditory or non-auditory effect.

The most important phenomenon of causality law is the time spread between the impulse of the action (cause) and the reaction (effect).

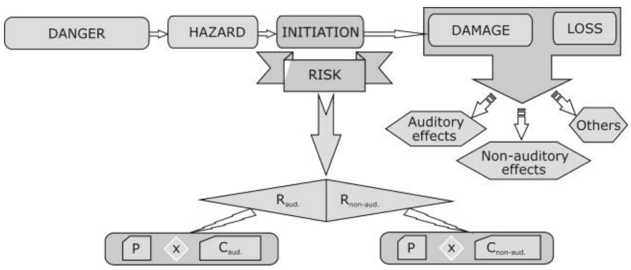


Figure 2. Causal dependency of acoustic risk

The measurement was conducted during woodworking, see Fig. 3. A milling cutter of 1400W input power was used. The experimental group consisted of fifteen students from 21 to 30 years of age, 60 % of whom were male. Basic numeric data of the respondents are listed in Tab. 1.

Table 1. Parameter characteristics of the respondents involved in the experiment

Values	Age (years)	Height (cm)	Weight (kg)
Average	23.40	174.07	72
S.D (standard deviation)	3.09	8.48	16.04
Max	30	192	96
Min	21	160	50

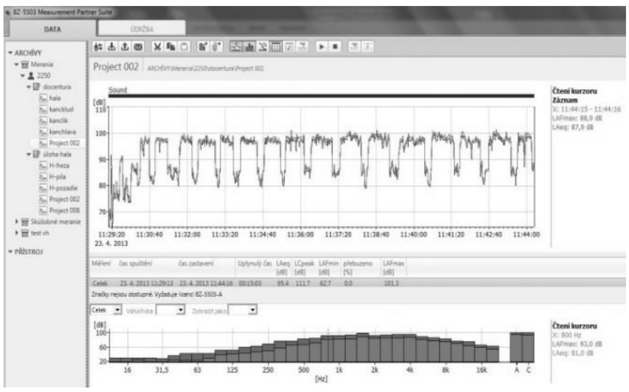
According to the questionnaire responses, it can be stated that no one in the observed sample of people suffers from significant health problems, their BMI index ranges from 18.5 to 24.9, which is considered normal, and health risks related to overweight or underweight are minimal. Majority of respondents were not under medical treatment and only one person smokes. The questionnaire showed no factors that could affect the test results.

The influence on noise on the heart activity was measured as follows:

- ECG record before the presence of individuals in the noisy environment,
- ECG record during the operation of noisy machinery,
- ECG record after the operation of noisy machinery was completed.

Figure 3. Activity – woodworking

The level of noise was measured using a hand-held noise analyser 2250. Measured data were recorded using the BZ 5503 software (Fig. 4a).



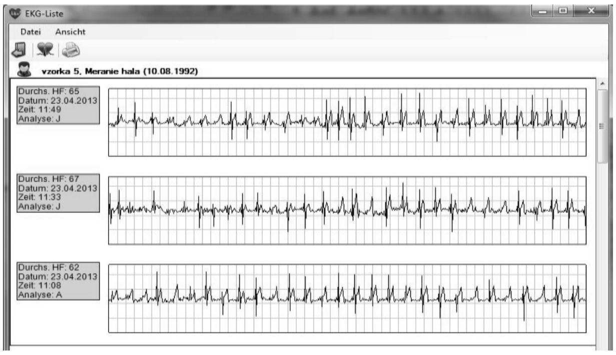


Figure 4. a) Noise level recording software b)ECG recording software

4. VALUES RECORDED DURING EXPERIMENTAL MEASUREMENT

Measuring the influence of noise on heart activity before the presence in the noisy environment

Fig. 5 shows the record of sound levels before the presence of the experimental group in the noisy environment. The following values were recorded $L_{A,min}$ = 29.8 dB, $L_{A,max}$ = 60.1 dB a L_{Aeq} = 44.8 dB.

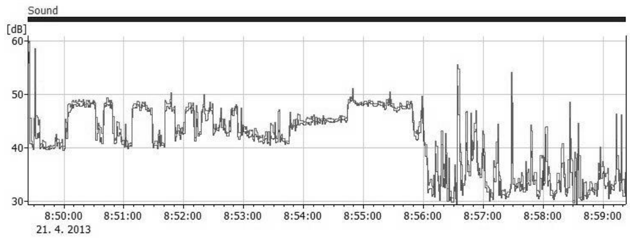


Figure 5. Record of sound levels before the presence in the noisy environment

Selected electrocardiograms recorded before the presence of individuals in the noisy environment are shown in Fig. 6.

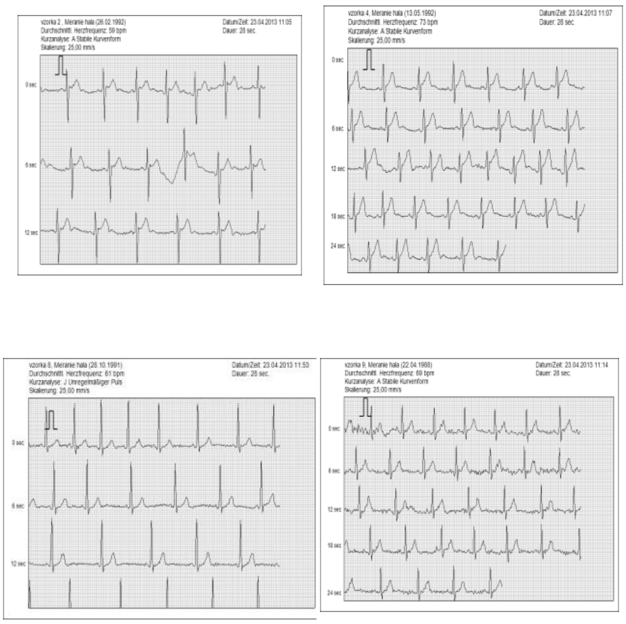


Figure 6. Selected cardiograms recorded before the presence of persons in the noisy environment

The heart rate record of the observed individuals is especially interesting, as there occurred changes in frequency. Individual heart rate values are shown in Tab. 2.

Table 2. Heart rates before the presence of persons in the noisy environment

Respondent number	Measured heart rate [beats per minute]
1	107
2	60
3	58
4	57
5	62
6	72
7	107
8	61
9	69
10	75
11	107
12	60
13	80
14	94
15	83

Measuring the noise influence on heart activity during the operation of noisy machinery.

Fig. 7 shows the record of sound levels before the presence of individuals in the noisy environment. The following values were recorded $L_{A,min}$ = 62.7 dB, $L_{A,max}$ = 101.3 dB, $L_{A,eq}$ = 95.4 dB.

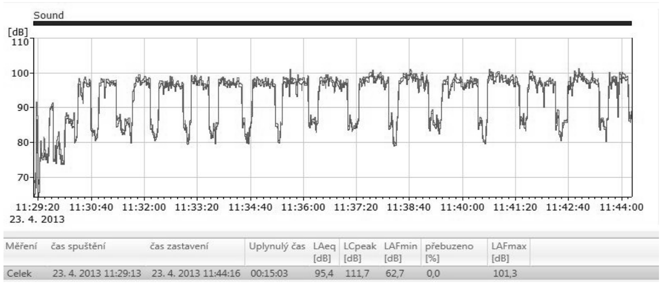


Figure 7. Record of sound levels during the operation of noisy machinery

Selected electrocardiograms recorded during the presence of individuals in the noisy environment are shown in Fig. 8.

Figure 8. Selected cardiograms recorded in the noisy environment

The heart rate record of the experiment participants is especially interesting, as there occurred frequency changes. Individual values recorded during their presence in the noisy environment are presented in Tab. 3.

Table 3. Heart rate values measured in the noisy environment

Respondent number	Measured heart rate [beats per minute]
1	107
2	61
3	65
4	68
5	67
6	87
7	100
8	78
9	75
10	81
11	102
12	76
13	93
14	94
15	87

Measuring the impact of noise on ECG record after the presence of individuals in the noisy environment

Final ECG test was performed in the same environment as the first, which means that the noise exposure level A was equivalent to the first case.
Selected cardiograms from tests performed after the noisy operation was terminated are shown in Fig. 9.

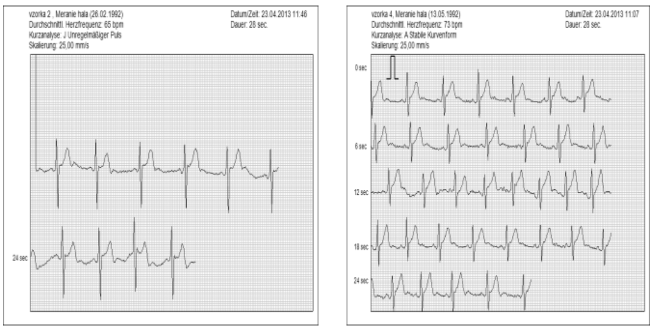


Figure 9. Selected cardiograms recorded after the presence in the noisy environment

Individual heart rates of respondents recorded after their presence in the noisy environment are presented in Tab. 4.

Table 4. Heart rate values measured after the presence in the noisy environment

Respondent number	Measured heart rate [beats per minute]
1	107
2	65
3	64
4	73
5	65
6	74
7	88
8	74
9	75
10	84
11	96
12	85
13	80
14	97
15	87

Based on the data analysis, it can be stated that the average heart rate reaches highest values during the operation of noisy machinery, and also that the heart rate after the exposure to noise is higher than the initial value (Tab.5, Fig.10, Fig.11).

Table 5. Heart rate values of individuals who participated in the experiment (n = 15)

Value	Heart rate (beats per minute)		
	Before exposure	During exposure	After exposure
Average	76.8	82.53	80.93
S.D	18.80	14.37	12.72
Max	107	107	107
Min	57	61	64

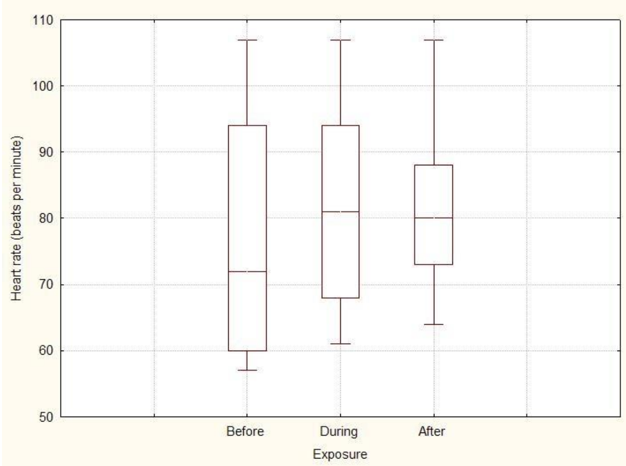


Figure 10. Boxplot

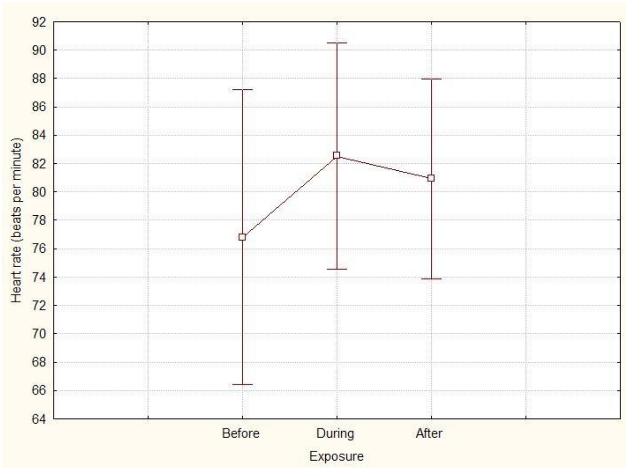


Figure 11. Average values and 95% confidence interval graph

In 46% of ECG records, there occurred a curve deviation during the operation of noisy machinery. In particular, it concerns the irregular pulse curve: J-type – irregular pulse and K-type – irregular pulse and curve deviation. 20% of respondents had the L-type curve – with deviation also after the noisy operation was terminated. It leads to conclusion that noise has an impact on the cardiovascular system.

We used the Friedman test to verify whether the heart rate of the experiment participants changed at random or due to noise present in the environment. It results from the tests that the null hypothesis about random influences on the heart rate can be rejected (the value of test statistics 9.5,
p-value is 0.009). It implies that the heart rate depends on the environment of the experiment participants.

Multiple comparisons of post-hoc tests prove that there is evincible difference between the heart rate of the respondents before and during their presence in the noisy environment. The heart rate values rose, which means the heart activity increased during the operation of noisy machinery.

In case of one respondent, some health issues were revealed – heart murmur and a family history of tachycardia; therefore, the data of this respondent were not considered in the final analysis.

The results excluding respondent No 11

Table 6. Parametric data of the respondents participating in the experiment (n = 14)

Data	Age (years)	Height (cm)	Weight (kg)	Heart rate (beats per minute)		
				Before exposure	During exposure	After exposure
Average	23.1	174.00	71.29	74.6	81.14	79.86
S.D	3.03	8.80	16.39	17.47	13.83	12.48
Max	30	192	96	107	107	107
Min	21	160	50	57	61	64

The Friedman test rejected the null hypothesis about accidental influences on the heart activity (value of test statistics is 12.5 p-value is 0.002). It results from the analysis that the respondents' heart rate values are affected by their environment.

Multiple comparisons prove that there is evincible difference between the heart rate of the respondents before and during their presence in the noisy environment. Similarly, their heart rate values before and after exposure to noise differed. Statistical analysis showed the values rose, i.e. the heart rate values were increased not only during the operation of noisy machinery, but the values measures after the noisy operation was terminated were higher than the initial values (Tab.6).

5. CONCLUSION

There is hardly any doubt that noise and vibration are negative phenomena brought about by civilization. Many people, however, believe that noise produced by an individual who also makes decisions about its origination and transmission is not serious enough to be reduced or eliminated. This could be caused by the fact that consequences are not immediately obvious. Nevertheless, such view is subjective and dangerous to humans. Legislation framework is still the only measure that helps to change this attitude by establishing the acceptable levels of noise, in order to prevent damage to hearing organs. However, the presented experiments indicated that negative effects may occur even in case of shorter exposure to noise.

Workplace noise prediction is a helpful tool in decision making processes related to the workplace noise reduction. Practical realization of prediction procedures in interiors includes appropriate modelling of machines and appliances [8] as sources of noise, workshop layout and elements influencing the transmission of sound.

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