Coll. Antropol. **36** (2012) 3: 899–909
Original scientific paper

Strains and Stresses of Workers Caused by Exposure to Noise

Andrej Polajnar[1], Nataša Vujica Herzog[1], Borut Buchmeister[1] and Simona Jevšnik[2]

[1] University of Maribor, Faculty of Mechanical Engineering, Laboratory for Production and Operations Management, Maribor, Slovenia

[2] Academy of Design in Ljubljana, Associated Member of University of Primorska, Ljubljana, Slovenia

A B S T R A C T

This paper examines basic aspects of determining strain due to noise on workers in an industrial environment. Technological development enables better working conditions which then demands changes in methods for measuring strain and stress loadings. A modified method is now presented since the existing method for determining strains caused by exposure to noise is proving insufficient. The objective of the modified method is to eliminate the shortcomings of the existing method by taking into account the complex effects of noise in specific working environments. The effects of exposure to noise will be assessed by using a new strain-assessment procedure which incorporates the effects of nature of noise, characteristics of noise, current standards on protection from noise, and the influence of noise on different jobs. This new noise-assessment approach uses new measurement techniques based on tonality and impulsive noise corrections. The modified method has been tested at various workplaces in the metal-working industry. A comparison of the results obtained by using both methods confirms the suitability of the modified method, thus providing a more complete approach to evaluating strain due to noise.

***Key words**: strains and stresses, ergonomic coefficient, noise, impulsive noise correction, tone correction*

Introduction

Modern manufacturing requires suitable working conditions. While working, the worker is exposed to various strains and stressors that contribute to stress. Noise in the working environment is one of the major and most frequent stressors at work[1–10]. Strains and stresses belong to an important group of factors that reduce human efficiency at work due to disturbed hemostasis, resulting in fatigue. To reduce the effects of this phenomenon, working hours should be interrupted by several rest periods and breaks. The Polajnar-Verhovnik ergonomic coefficient C_{er}[11] can be used for additional protection against the effects of noise on workers since it includes extra time necessary for recovering from certain effects (strains) caused when performing work[12]. It is commonly known that with technical precautions the noise level can be reduced under the allowed line but with an ergonomic coefficient, such as the Polajnar-Verhovnik ergonomic coefficient $C_{er,}$ we can protect the worker working within allowed line. Namely, different studies evidenced that also within the allowed noise area the worker should be protected against negative influence on health and effectiveness.

Where t_1 – standard time; t_m – machining time; t_a – auxiliary time; manual work, non-machinery time; C_a – allowance coefficient; allowance for personal and delay times; C_{er} – Polajnar-Verhovnik ergonomic coefficient

The methodology, used to define strains and stresses, consists of three steps (Figure 1):

1st step: activity sampling, job analysis and evaluation

2nd step: workplace measurement and analysis

3rd step: grading and evaluating strains and stresses obtained in the 2nd step, calculating the Polajnar-Verhovnik ergonomic coefficient[11] C_{er}, and incorporating it into the calculation of standard time.

The Polajnar-Verhovnik ergonomic coefficient C_{er} is obtained by using Equation 1:

$$C_{er} = \frac{\text{the number of strain points}}{\text{the maximum number of strain points}} \cdot 0.3423 \quad (1)$$

where: 0.3423 is the constant acquired by experiment.

The existing method for determining strain and stress seems[12] very general because only noise levels and expo-

Received for publication April 26, 2010

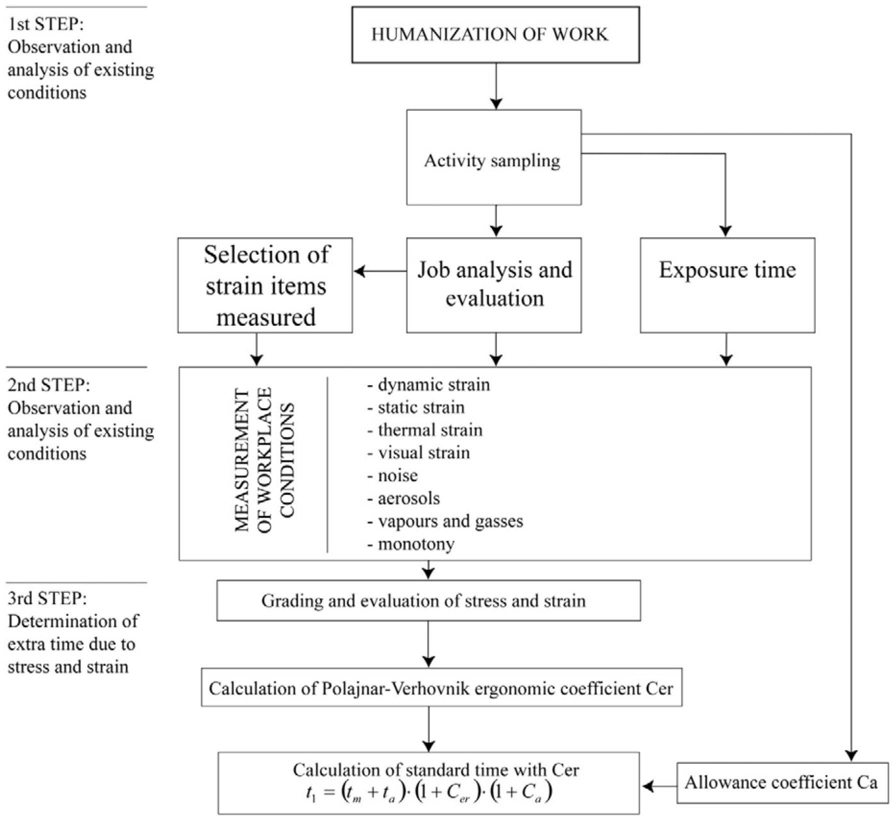

Fig. 1. The methodology for establishing ergonomic strains and stresses at work.

sure times are used for assessing strain at work. According to this method, exposure to noise lower than 90 dB is not considered as harmful. However, it has been discovered and reported that daily exposure to noise from 85 to 90 dB may be very harmful[13–15]. Higher points for strain are assigned to very high noise levels between 91 and 120 dB (noise level over 100 dB, for example, is caused by sledge hammers).

According to the existing method, the influence of noise on the value of C_{er} appears to be evaluated too loosely. The rationale for this observation is as follows;

A. Noise as a noxious factor produces different effects on workers performing different tasks.
B. Correlation between noises attributes such as changes in noise level, interrupted noise, and sudden short-term noise, and human efficiency at work is supported in literature by Croome[16], Harris[17], Loeb[18] and Sanders[13].
C. The characteristics of noise (frequency spectrum, impulsiveness and accentuated tones) have important influence on hearing damage.
D. EU directives regulating noise in a working environment ISO 9612 standard[19], from which the recent Slovenian legislation[14] is derived, introduce more severe criteria: the daily limit value of exposure to noise is 85 dB and the impulsive nature of noise has to be taken into account.

Assessing strain caused by exposure to noise

Several authors have proposed different approaches for assessing strain caused by exposure to noise within the workplace. Slovenian authors Polajnar and Verhovnik determined stress and strains caused by noise using a 5-level scale[12] (Table 1).

The approach by Schmidtke[20] is very similar; however, it has more detailed division which contains a 9-level strain scale (Table 2).

According to REFA (Reichsausschuss für Arbeitszeitermittlung)[22] noise range activities are classified into four levels:

- 40–65 dB; noise can be disturbing for a person but stress depends on the physical and psychical state of the person and his position in view of noise source and activity.
- 65–90; noise has a psychical influence on the person and, in addition, veins on arms and palms are contracted. Reactions are presented apart from the personal relationships and familiarity with noise.
- 90–120 dB; longer exposure to such noise can cause permanent impairment of the hearing organs.
- over 120 dB; even short exposure to this level of noise causes hearing loss.

In regard to the Council directive[21] EEC 86/188 on the protection of workers from the risks related to exposure

TABLE 1
LEVELS OF STRAIN CAUSED BY EXPOSURE TO NOISE

Strain level	Definition
0	Noise up to 50 dB
I	Noise from 51 to 70 dB – undisturbed communication
II	Noise from 71 to 90 dB – disturbed communication, but not gravely
III	Noise from 91 to 120 dB – loud noise, great discomfort, gravely disturbed communication
IV	Noise above 120 dB

to noise at work (the council of the European communities), the main value for assessing annoyance is daily exposure to noise (considering equivalent noise exposure levels and also effective time of exposure). Two different steps can be taken for daily exposure: firstly, action-levels for daily exposures between 85 and 90 dB and, secondly, action-levels for noise louder than 90 dB. The peak action level is also limited to 140 dB, assessed using filter C for sources with a high level of impulse noise. Machinery Safety Directive[23] EEC 98/37 is very important for producers of noisy equipment. According to this directive, all noisy working devices must be equipped with a sonic pressure level, or sonic power (if the sonic pressure level is too high).

Similarly the American standard[24], Occupational Safety and Health Administration – OSHA regulates boundary values using noise dosage. Each noise exposure above 80 dB contributes to a partial noise dosage, which is summed up as a daily dosage. Daily noise dosage is then converted to a time-weighted average – TWA (8-hours time-weighted average). 50% noise dosage (TWA=85dB) requires a special preventive programme and 100% noise-dosage is the boundary of the allowed dose. Impulse-noise is also included but now it is no longer treated as the amount of impulse-noise limitation but included in the noise level dosage.

ISO 9612 standard[19] gives directions for measuring and evaluating noise exposure in working environment including measuring equipment, calibration procedure, and performance measures. A common approach for assessing annoyance is calculating values such as equivalent noise level (L_{AqT}), daily exposure ($L_{EX,8h}$), weekly exposure ($L_{EX,W}$) and peak level (L_{peak}). Impulse and tonality corrections are also mentioned.

Since 2001 in Slovenia, new directions about workers' protection against noise exposure hazard are regulatory, following European directives. Similarly to the ISO 9612 standard, daily and weekly exposure $L_{EX,8h}$, $L_{EX,W}$ should be calculated, peak level in dB(C) (L_{peak}), and equivalent noise level L_{AqT}. 85 dB (A scale) and peak level 140 dB (C scale) is recommended for daily or weekly noise exposures.

Determination of noise level by means of impulsive correction

At the workstation, noise was evaluated throughout the working day. We decided to use the marking system for equivalent level L_{Aeq} instead of the daily noise exposure $L_{EX,8h}$ (new legislation) for the following reasons:

- the same results were obtained when all noise levels over the whole day (even the periods of relative silence) were considered and the equivalent level L_{Aeq} was calculated or when $L_{EX,8h}$ was calculated by considering the period of relative silence,
- $L_{EX,8}$ is usually used to limit daily noise exposures (85 dB) and for this reason it is only reasonable in more noisy working environments.

Noise using impulse correction L_{AIeq} was calculated as (Equation 2):

$$L_{AIeq} = 10 \log \left(\frac{1}{T_e} \sum_{i=1}^{n} T_i 10^{0.1(L_{Aeq,T_i} + K_{Ii})} \right) [\text{dB}] \qquad (2)$$

where: $L_{Aeq,Ti}$ – represents the equivalent A valuated noise level during time interval T_i; K_{Ii} – represents impulsive correction during time interval T_i; T_e – represents the duration to noise exposure.

TABLE 2
LEVELS OF STRAIN CAUSED BY EXPOSURE TO NOISE (BY SCHMIDTKE, 1981[20])

Level	Definiton
1	Under critical level, very little disturbance of communication. $L_{eq}<60$ dB
2	Mostly under critical level, little influence on comfort and little disturbance of communication. $60<L_{eq}<65$ dB
3	Generally still under critical level, moderate disturbance of communication. $65<L_{eq}<70$ dB
4	Partly critical noise, great influence on comfort and noticeable disturbance of communication. $70<L_{eq}<75$ dB
5	Mainly critical noise, very great influence on comfort and great disturbance of communication. $75<L_{eq}<80$ dB
6	Critical noise, very great disturbance of communication, possible reduction of hearing limit. $80<L_{eq}<85$ dB
7	Very critical noise, communication is almost impossible, noticeable possibility for hearing limit reduction. $85<L_{eq}<90$ dB
8	Dangerous noise for health, impossible communication, great possibility for hearing limit reduction. $L_{eq}>90$ dB
9	Not allowed.

Determination of noise level by means of impulsive and tonality correction

Third octave band frequency analysis shows that the levels at certain frequencies exceed the closest neighbouring frequencies (to the left and right) by more than 5 dB. Thus a case of pronounced tones is encountered. In such cases, ISO 9612[19] standard suggests an additional coefficient K_T. The value of $K_T=5$. Noise level using impulsive and tonality correction L_{AITeq} is calculated by using Equation 3.

$$L_{AITeq} = 10 \log \left(\frac{1}{T_e} \sum_{i=1}^{n} T_i 10^{0.1(L_{Aeq,T_i} + K_{Ii} + K_{Ti})} \right) [\text{dB}] \quad (3)$$

where L_{AITeq} is the equivalent noise level during the workday (T_e) with impulse and tonality corrections. K_{Ii} is the impulsive correction during the time interval T_i. K_{Ti} is the tonality correction during the time interval T_i.

The following equation (Equation 4) is used to determine noise level without correction:

$$L_{Aeq} = 10 \log \left(\frac{1}{T} \sum_{i=1}^{n} T_i 10^{L_i/10} \right) [\text{dB}] \quad (4)$$

where T denotes the total workday time, and T_i is the duration (time interval) of exposure to noise level L_i.

When the noise level changes periodically such as in a plumbing workshop the ISO 9612 standard suggests that the following procedure for determining estimated noise level should be used. In n-time number of independent samples Li the estimated level is calculated as follows (Equation 5):

$$L_{Aeq} = \overline{L} + 0.115 s^2 \, [\text{dB}] \quad (5)$$

where:

$$\overline{L} = \frac{1}{n} \sum_{i=1}^{n} L_i \, [\text{dB}][\text{dB}]$$

arithmetic mean of the measured levels in decibels and

$$s = \sqrt{\frac{\sum_{i=1}^{n} (L_i - \overline{L})^2}{n-1}}$$

standard deviation in decibels.

The objective of this research is to include the above-mentioned facts in a modified method when used to determine the effects of exposure to noise in a working environment.

For the purpose of our research, impulse correction was taken into account in accordance with new Slovenian legislation. It defines that the difference between the level measured by the dynamic I (Impulse) and the level measured by the dynamic F (Fast) should be added to the measured equivalent noise level. If the difference is lower than 2 dB, it can be ignored, and if the difference is higher than 6 dB only 6 dB should be added.

Research Methodology

Stress and strain play an important role among those factors that reduce work-performance efficiency. In order to reduce excessive workload by allowing extra-time for an operation, the Polajnar-Verhovnik ergonomic coefficient C_{er} was calculated, which increases production time and so ensures the workload of the operator is not exceeded.

The C_{er} calculation considers eight kinds of strain which are as follows: physical dynamic strain, physical static strain, thermal strain, visual strain, noise, aerosols, vapours and gasses, and monotony. In our research only strain caused by noise was considered in order to certify the modified method more easily and precisely. Other kinds of strain were not included in our research.

For our research, noise data were obtained from three Slovenian metalworking industries. Company A produces special purpose tools. Machines used in this process are milling, turning and cutting, etc. A forging operation was also included for semi-manufactured products, the boiler house, and the compressor unit/station. Company B produces power equipment. Cutting and metal connecting operations are used during the production process. The output of Company C's process is special-purpose upgrading for vehicles. Plumbing and locksmithing processes are the main processes in this operation.

When determining the workers' daily noise exposure at individual workplaces, the working day (7.5 h) was divided-up according to typical work operations. The noise level of an individual operation and operation time duration were measured. Daily exposure was calculated, based on Equations 3, 4 and 5. Equation 2 was also used to estimate noise levels in those workplaces where noise changed periodically.

The coffee break, (30 minutes), was ignored because the relative silence had a negligible effect on the cumulative equivalent level.

Description of measuring procedure

Data were collected in accordance with the ISO 9612 standard. The measurement microphone was set at the workplace regarding ear level, 0.2 m from the ear. The microphone was positioned facing the noise source. Investigators ensured there was no hindrance between the microphone and the noise source.

The measurement time was sufficient to ensure that the equivalent noise level value readings varied by less than 0.5 dB. The measurement times were no shorter than 15 seconds. In cases where pronounced periodical noise occurred, at least one whole period (15 seconds) was to be measured.

Where a worker changed his workstation during the course of the working day, measurements were collected in all locations by considering the times of exposure per workstation.

Where the noise level in the workplace changed periodically, e.g. in the plumbing workshop, measurements were performed randomly at time-intervals sufficient enough to assure independent, relevant results. Five measurements were usually taken to define the estimated noise level (Equation 5).

An additional third octave band frequency noise level analysis was performed in those workplaces where the goal was to evaluate the presence of pronounced tones. Frequency analyses were performed in accordance with the SIST ISO 9612 standard. The frequency spectrum showed on the instrument's monitor.

A Bruel&Kjaer[25] noise measuring instrument was used with serial number 2201657 and measurement range from 50 to 120 dB, and which met the IEC 225, IEC 651 and IEC 804 technical specification regulations.

Validity

Validity of a measure refers to the extent to which it measures what is intended to be measured and thus validation is the process of ensuring that a model or method represents reality at a given confidence level.

Three different types of validity are generally considered: content validity, criterion-related validity, and construct validity. All three types of validity tend to complement each other in practice[26]. Content validity (sometimes also mentioned as face validity) was achieved with the assistance of domain experts. Criterion-related validity regards the predictive nature of the research instrument to obtain the objective outcome. It is sometimes referred as 'empirical' or 'statistical' validity, too. Criterion-related validity involves an objective and quantitative comparison between the actual system and the model. Student t-test was used for verifying criterion-related validity.

Since the same samples were observed under two different circumstances we were faced with the problem of dependent samples. In each of the observed units, paired data were obtained and the difference between the arithmetic means was tested. In order to confirm the measurements' validity the Student t-factor was calculated and compared to the tabulated one. For a sample size of N=40 (number of analyzed different workplaces), t-factor values regarding the different statistically significant level p follow in degrees of freedom m=39 (N – 1) (Table 3).

An overview of the assumptions, simplification and limitations shows that the model adequately represents reality. There were no statistically significant differences between the data sets, so we can conclude the model is considered valid.

Implementation of Modified Method for Determining Strains Caused By Exposure to Noise

1. The existing method for determining strains caused by exposure to noise

The level of strain caused by exposure to noise is obtained directly from Table 1 by selecting the actual equivalent level of noise[12] (Equation 4):

The points for strain evaluation are obtained from the level and the time of exposure to noise given in Table 4.

2. Modified method for determining strains caused by exposure to noise

The objective of the modified method, as presented in this paper, is to eliminate the shortcomings in the existing method by taking into account complexity regarding the effects of noise in specific working environments. This means that the effects of exposure to noise are assessed in terms of risk to health, efficiency at work and the ISO 9612 standard. This modified method consists of a new strain marking assessment procedure which incorporates the effects of the nature of noise, characteristics of noise, current standards on protection from noise[14,19], and the influence of noise on different jobs and new noise assessment calculation which uses new noise measurement techniques (tonality and impulsive noise corrections).

The modified marking approach for assessment regarding the effects of exposure to noise consists of three steps. The objective is to assess the influence of noise levels and the degree of work complexity, together with the nature of noise[26].

The steps are as follows:

In step 1 the work to be performed is classified according to the mental effort it requires – determination of the type of work in step 2 by finding the basic points for strain T_o with respect to the type of work and the equivalent noise level.

In step 3 extra points for weighting factors T_{wf} are obtained with respect to the type (nature) of noise.

The total basic points for strain T_o and the points for weighting factors T_{wf} represent the final number of points for strain T.

TABLE 4
DETERMINATION OF POINTS FOR STRAIN CAUSED BY EXPOSURE TO NOISE

Level	Exposure in hours per shift							
	1	2	3	4	5	6	7	8
0	0	0	0	0	0	0	0	0
I	0.0	0.1	0.1	0.2	0.2	0.3	0.3	0.4
II	0.2	0.3	0.4	0.6	0.7	0.9	1.1	1.2
III	0.4	0.7	1.0	1.3	1.7	2.0	–	–

TABLE 3
VALUES OF STUDENT T – FACTOR

Statistically significant level p	0.1	0.05	0.025	0.01	0.005	0.001	0.0005	0.0001
Student factor t	1.3031	1.6839	2.0211	2.4233	2.7045	3.3069	3.5510	4.0942

TABLE 5
STEP 1 (CLASSIFICATION OF WORK)

Type	Description of work
A1	The most demanding mental work (elaboration of concepts)
A2	Predominantly mental work (demanding office work), speech and telephone communication
A3	Routine work requiring concentration, simple office work, high precision assembly work, complex system control
B1	Supervision of a group of workers performing predominantly physical work, frequent oral instructions to workers, demanding assembly work, simple inspection tasks
B2	Less demanding work requiring concentration and caution, auditory attention and control of the environment, handling of devices, simple systems control
B3	Work demanding no mental effort or auditory attention

Step 1: Classification of work

In noise assessment, work is classified into six groups, from the mentally most-demanding work A1 to the mentally least-demanding work B3. The reason for this is the fact that noise produces different disturbing effects during different types of work (Table 5).

When constructing a classification table of recommendations for allowed noise levels have to be considered for the undisturbed performance of different types of work[13,14,16,18].

Step 2: Determine the baseline points

Table 6 is divided into two parts. The first part contains noise exposure effects during cognitive work, using a 0 to 3 or 4 point scale. The second part contains noise exposure effects for less cognitive work. The evaluation scale extends from 0 to 2.5 points.

Data for A type work illustrate that noise levels disturb the efficiency of cognitive work[16–18]. The points were determined by evaluating the A1 type work (Table 5).

TABLE 6
STEP 2 (THE BASIC EVALUATION POINTS FOR T_O)

T_o Points	Type of work		
	A1	A2	A3
0	<45	<50	<60
1	45–50	50–55	60–65
2	50–55	55–60	65–70
3	55–60	>60	>70
4	>60	–	–
	B1	B2	B3
0	<50	<55	<60
0.3	50–55	55–60	60–65
0.6	55–60	60–65	65–70
0.9	60–65	65–70	70–75
1.2	65–70	70–75	75–80
1.5	70–75	75–80	80–85
2.0	75–80	80–85	85–90
2.5	>80	>85	>90

When determining the level of noise for the B type of work, there was carried out a comparison of various methods provided by the following authors; Harris[17], Croome[16], Sanders[13], and Schmidtke[20]. The points were calculated according to data provided for B3 type of work (Table 6).

Step 3: Adjust points for tonality and impulse

Table 7 shows an attempt to assess the additional effects of the type (nature) of noise on the worker, irrespective of the measured noise values.

The effects of the following different types of noise were studied: continuous noise with disturbances, fluctuating noise, short-term noise, noise spectrum (frequency distribution of noise), night-shift noise on workers in terms of damage to the auditory system (impairment of hearing), and physiological responses of the organism and work efficiency (work output).

The influence of a single type (nature) of noise on workers was determined with points for weighting factor T_{wf}, by considering the characteristics of a single type of noise's influence on the worker[16,17] as well as mutual comparisons of weighting factors T_{wf} and the influence of points T_{wf} on basic points T_o (Table 7). These T_{wf} points were estimated and corrections permitted.

The objective of the presented modified approach to noise evaluation is to incorporate the harmful effects of noise impulses and tonality on workers.

As all noise levels are measured throughout the workday, the workers' daily exposure to noise is denoted by L_{Aeq} instead of $L_{EX,8h}$. L_{Aeq} is used in those cases where not all noise levels are measured (periods of relative silence).

Equation 5, used for calculations, is in accordance with the standard ISO 9612. Impulsive correction is taken into account by adding the difference between the level measured by the dynamics I (Impulse) and the level measured by the dynamics F (Fast), to the measured equivalent noise level. If the difference is smaller than 2 dB, it is ignored. But if it is greater than 6 dB, 6 dB is added[14].

If the third octave frequency band analysis reveals that the level at a certain frequency exceeds the nearest

TABLE 7
STEP 3 (POINTS FOR WEIGHTING FACTORS T_{wf})

Factor	Type of noise	Description	Type of work	T_{wf} points
1	Continuous noise with disturbances	The difference between L_{Aeq} (the daily noise level) and $L_{Aeq,Ti}$ (the level of disturbance during the time interval Ti) is greater than 10 dB – under the condition that the disturbance lasts longer than 5 minutes and that L_{Aeq} >80 dB	B1, B2, B3	+0.1
2	Continuous noise with disturbances	Elevated/lowered noise levels through a longer period of time – under the condition that the change >5 dB	A1 A2 A3 B1, B2 B3	+0.3 +0.2 +0.1 +0.05
3	Interrupted noise	Noise interrupted by periods of effective silence, i.e. noise level below 70 to75 dB, which depends on the frequency	B1, B2, B3	–0.05
4	Fluctuating noise	Noise variations in time, but never dropping below the level of effective silence	B1, B2, B3	–0.03
5	Short-term, sudden noise	Unexpected, instantaneous noise	A1 A2 A3 B1, B2 B3	+0.3 +0.2 +0.1 +0.05
6	Very high frequency noise	Very high noise levels above the frequency of 1 kHz; the corresponding time period is considered (the noise spectrum is assessed by the third octave frequency band analysis)	B1, B2, B3	+0.4
7	High frequency noise	High noise levels above the frequency of 1kHz; the correspon-ding time period is considered	A3 B1, B2, B3	+0.2 +0.2
8	Noise during night shifts	Night shift	A3 B1, B2, B3	–0.1 –0.1

frequencies to the left and right by more than 5 dB, then the issue is tonality. In this case, the standard ISO 9612 suggests that the extra (additional) coefficient K_T be used. The value of K_T is 5dB.

The new noise assessment calculation uses new noise measurement techniques (tonality and impulsive noise corrections). Impulsive noise and the pronounced tones both have negative influences on a person. Pronounced tones are more dangerous than broad spectrum noise, because they influence the defined frequency's range. Even short exposure to pronounce tones can cause a decrease in heart beat for a moment and greater disturbance in the peripheral blood system because the return to a normal condition is very slow. Impulsive noise can cause hearing loss because of its peak and short-time character. The new noise assessment calculation is normally performed as a noise measurement. The noise level with impulsive and tonality correction is calculated using Equation 3, and noise using impulse correction is calculated, using Equation 2.

Results and Discussion

The results of noise levels at the individual workplaces in companies A, B and C are shown in Table 8.

An example of noise level calculation is shown at the workplace Nr. 4, which contains data for the CNC ILR

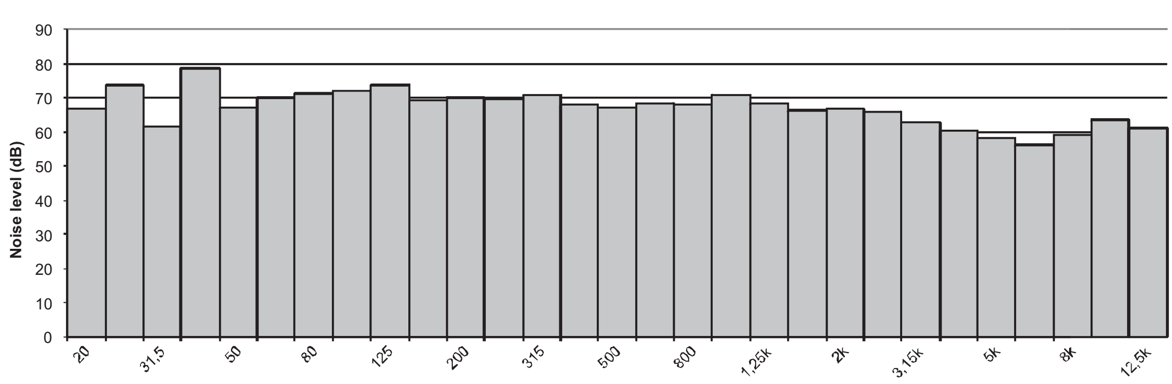

Fig. 2. Frequency analysis result in operation 1 – coarse milling (workplace 4).

TABLE 8
FINAL RESULTS OF NOISE LEVEL

Nr.	Kind of workplace	L_{AITeq} [dB]	L_{AIeq} [dB]	L_{Aeq} [dB]
Company A				
1	Turning	84.3	84.3	84.3
2	Milling	86.0	86.0	84.2
3	CNC Bohle	75.4	75.4	75.4
4	CNC ILR Waldric	87.4	82.4	80.5
5	Oxyacetylene cutting	93.6	92.3	92.3
6	Circular saw Ø 1000	87.6	83.0	83.0
7	Press 400 t	105.6	100.6	94.7
8	Assembly	90.7	87.0	83.0
9	Welding	95.4	92.1	87.8
10	Co-ord. drilling machine	88.7	83.9	83.8
11	Grinding	88.2	85.0	83.9
12	Checking	69.6	69.6	67.1
13	Foreman	71.2	71.2	71.2
14	Construction	48.6	48.6	48.6
15	Sledge-hammer – 20 t	112.6	107.6	101.6
16	Sledge-hammer – 3 t	108.9	103.9	97.9
17	Foreman	97.2	92.3	86.9
18	Compressor-man	88.5	88.5	88.5
19	Boiler house	86.3	83.4	83.4
20	Technician	73.7	68.8	68.8
Company B				
21	Sheet cutting	99.2	94.4	88.8
22	Welder – arc welding	100.0	95.6	92.3
23	Welder – CO_2	101.6	97.1	94.9
24	Fork-lift trucker	89.1	85.2	84.3
25	Lacquerer	84.7	84.7	84.7
26	Plasma sheet cutter – I	90.9	90.9	90.9
27	Plasma sheet cutter – II	86.3	86.3	86.2
28	Punching machine	92.0	87.1	82.3
29	Complicated assembly	73.3	73.3	71.6
30	Production manager	83.4	83.4	79.0
31	Construction	58.1	58.1	52.1
Company C				
32	Assembly-plumbing work with Al	105.4	98.6	95.9
33	Sheet cutting	99.2	94.3	88.8
34	Plumber	105.3	99.6	96.5
35	Locksmith -construction	102.6	98.7	96.8
36	Preparation for lacquering	88.5	83.8	83.8
37	Lacquerer-chamber	82.4	82.4	82.4
38	Machining	83.7	81.1	79.9
39	Works manager	81.6	76.6	71.2
40	Construction	51.9	51.9	51.9

WALDRIC milling machine. The measurement results for single operations and correction factor determination are shown in Table 9.

Final results for equivalent noise levels over the whole working day for the workplace Nr. 4 are (Table 8):

L_{AIeq} =82.4 dB

L_{AITeq} =87.4 dB

L_{Aeq} =80.5 dB

Figure 2 shows the frequency analysis results during operation 1 which contains data from coarse milling (workplace 4). There are two pronounced tones (25 Hz, 40 Hz), K_{Ti}=5 dB. The impulse character: K_{Ii}=4,8 dB (obvious from the measurement results) was present.

Comparison of the measured noise levels

The differences between the measured noise levels $L_{AITeq,}$ L_{AIeq} and L_{Aeq} with corrections due to individual workstations are shown in Figure 3. Comparisons were made for all the 40 analysed workplaces.

When the calculated t-factor value is t=7.93 with a high level of significance (p=0.0001), it can be stated that noise levels obtained by considering impulsive and tonality correction (L_{AITeq}) are statistically significantly higher in comparison to noise levels obtained without correction (L_{Aeq}) consideration.

Furthermore, when the calculated t-factor value is t=6.09 with a high level of significance (p=0.0001), it can be stated that noise levels obtained by considering impulsive correction (L_{Aieq}) are statistically significantly higher in comparison to noise levels obtained without correction (L_{Aeq}) consideration.

Comparing of L_{AITeq} and L_{AIeq} at calculated t-factor value is t=7.48 with a high level of significance (p= 0.0001), it can be stated that noise levels obtained by considering impulsive and tonality correction (L_{AITeq}) are statistically significantly higher in comparison to noise levels obtained by considering impulsive correction (L_{Aieq}). Figure 3 illustrates in which workplaces correction consideration proved to be the most obvious.

From gained results it could be seen that work on those machines causing pronounced impulses: machine scissors, press, sledge-hammer, punching machine, welding, and coarse milling was at workplaces 7, 9, 15, 16, 17, 21, 28, and 33.

Procedures such as: use of hand tools (hammer and alike), shocks, falls and alike (workplaces: 9, 22, 33 and 34), also caused pronounced impulses.

Work on those machines that caused pronounced tones, such as high-speed rotating machines: pumps, turning machine, polishing machine, leveling, drilling, circular were at workplaces 6, 10, 20, 22, 23, and 32.

Those machines that caused impulse character: punch, press, sledge-hammer, and scissor machines were at workplaces 7, 28, 15, 16 and 21.

Other machines that caused impulse character were circular saw, coarse milling, fork-lift truck and suchlike (workplaces: 4, 6 and 24); and procedures bound to using a hammer and suchlike.

The influence of impulsive and/or tonality correction is negligible at workplaces where procedures do not cause impulses or tones produced by operations such as turning, milling, power station, plasma cutting and lacquering, as well as at workplaces with relative silence prevalence (mental work).

The analyses conclude that noise levels that consider corrections are statistically significantly higher than those without corrections. This is especially true when considering tone correction. In this way, noise, when considering tonality and impulsive correction at the same time, often exceeds those levels obtained without correction consideration by more than 10 dB.

Testing the modified method

The modified method was tested at different workplaces in the metal-working industry. Calculations of the strain points (effects of exposure) were carried out according to the procedure described in chapter »Implementation of modified method for determining strains caused by exposure to noise«. The following list of procedures assists in determining the points;

(a) classification of work with respect to the mental abilities required, Table 5,

(b) determining weighting factors with respect to the nature of noise, Table 7,

(c) determining the total number of points for all weighting factors T_{wf}, Table 7,

(d) measuring-evaluating noise level L_{AITeq},

(e) determining points for T_o with respect to noise level, Table 6,

(f) summation of points for T_o and T_{wf},

(g) calculating Polajnar-Verhovnik ergonomic coefficient C_{er} using Equation 1.

In the existing method, strain points are determined according to the description given in chapter »The existing method for determining strains caused by exposure to noise«.

These results were used to determine the Polajnar-Verhovnik ergonomic coefficient C_{er} using the proposed modified method. Comparisons were also made in regard to the existing method.

Table 10 shows the calculated C_{er} coefficients for four workplaces as follows: CNC machine tool, sheet-metal working, and boiler-house operations. Exposure to more

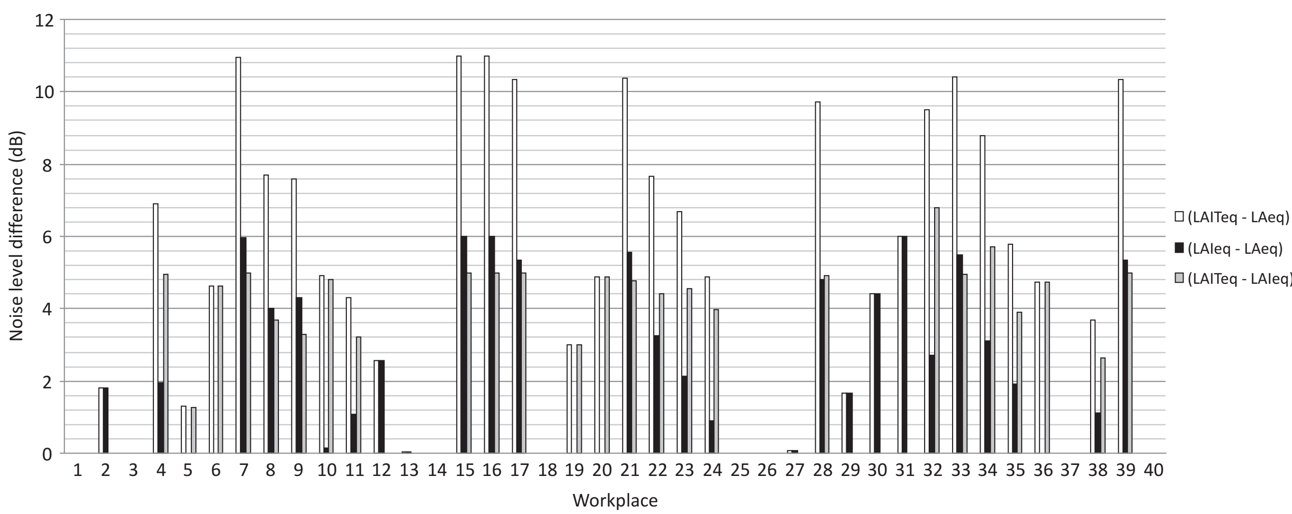

Fig. 3. Difference L_{AITeq} -L_{Aeq}, L_{AIeq} -L_{Aeq} and L_{AITeq} -L_{AIeq} for analyse workplaces.

TABLE 9
MEASUREMENT RESULTS IN WORKPLACE NR. 4 (MILLING)

Measuring parameters	Measurement results		
	Coarse milling	Fine milling	Preparation, other
$L_{AIeq,Ti}$ (dB)	84.5	82.4	74.3
$L_{Aeq, Ti}$ (dB)	79.7	81.6	73.1
T_i (min)	150	240	60
K_{Ii} (dB)	4.8	0	0
K_{Ti} (dB)	5	5	0
$L_{Aeq,Ti}$+K_{Ii}+K_{Ti} (dB)	89.5	86.6	73.1
$L_{Aeq,Ti}$ +K_{Ii} (dB)	84.5	81.6	73.1

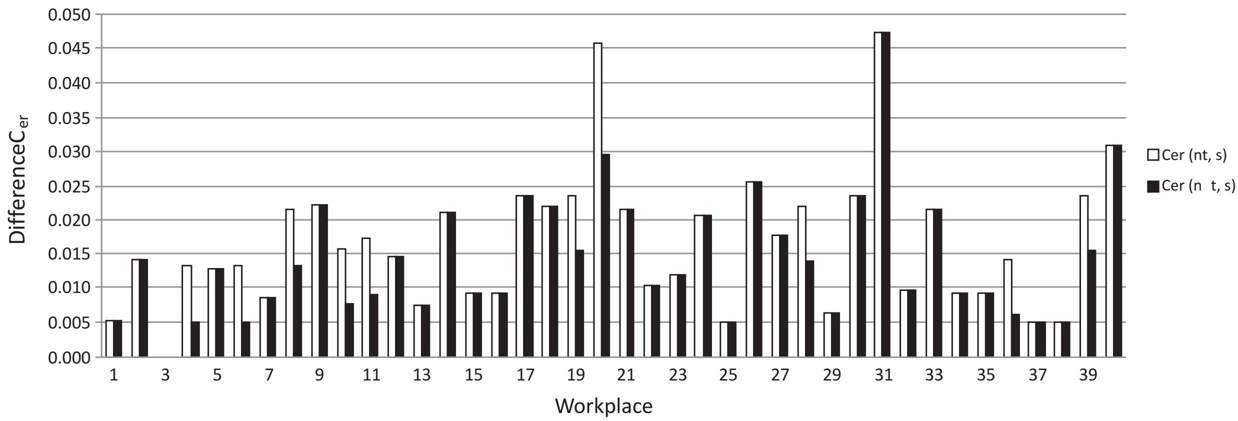

Fig. 4. Comparison of the differences of the Polajnar-Verhovnik coefficient C_{er}, obtained with the modified and the existent method. $C_{er\ (nt,\ s)}$ -the difference between the C_{er} value, obtained from the modified method (noise with both impulsive and tonality correction -L_{AITeq}) and the existent method (noise without corrections L_{Aeq}). $C_{er\ (nbt,\ s)}$ -the difference between the C_{er} value, obtained from the modified method (noise only with impulsive correction -L_{AIeq}) and the existent method (noise without correction -L_{Aeq}).

TABLE 10
THE CALCULATION OF THE POLAJNAR-VERHOVNIK ERGONOMIC COEFFICIENT C_{er}

	Modified method							Existing method		
Workplace	Work code	Weighting factors	Points T_{wf}	L_{AITeq} (dB)	Points T_o	Sum of points	C_{er}	L_{Aeq} (dB)	Points T	C_{er}
CNC machine tool	B3	4	–0.03	75.4	1.2	1.17	0.019	75.4	1.2	0.020
Foreman	B1	2, 3, 5	0.15	71.2	1.5	1.65	0.027	71.2	1.2	0.020
Plumber's work	B3	2, 4, 5, 6	0.10	100.4	2.5	2.60	0.042	95.9	2.0	0.033
Boiler house	B2	1, 2, 3	0.15	86.3	2.5	2.65	0.043	83.4	1.2	0.020

or less constant noise with a weighting factor of 4 is a characteristic of the first workplace. At the second, the worker performs cognitively more-demanding work (weighting factors 2, 3, 5). The influence of considered impulsive and tonality corrections are evident in the case of sheet metal work (plumber's work).

A comparison of the Polajnar-Verhovnik ergonomic coefficient C_{er} calculations was made in the same manner at 40 different workplaces in the metal-working industry.

Comparisons of coefficient C_{er} differences using both modified and existing methods for all the 40 analyzed workplaces are illustrated in Figure 4.

The calculated value of the t – factors is t=10.426 (considering both impulsive and tonality noise corrections). With a 0.01 % risk, it can be maintained that the C_{er} values obtained using the modified method by considering both impulsive and tonality noise corrections (L_{AITeq}) are statistically significantly higher than the C_{er} values obtained using the existing method.

The calculated factor value, by considering only the impulsive noise correction is t=9.723. With a 0.01 % risk, it can be inferred that the C_{er} values obtained using the modified method by considering impulsive noise correction (L_{AIeq}) are statistically significantly higher than the C_{er} values obtained using the existing method.

Conclusion

This paper presents a modified method for determining the effects of exposure to noise. Only strain caused by noise was considered to certify the modified method more easily and precisely. Other kinds of strain which are usually considered in the Polajnar-Verhovnik ergonomic coefficient C_{er} calculation are as follows: dynamic and static strain, thermal strain, visual strain, noise, aerosols, vapours and gasses, and monotony, but these strains were not included in the present research. The wider purpose of the presented research will be to study all the other kinds of strain in the future, too.

The main value of the presented modified method lays in the fact that impulse and tonality corrections are included, thus enabling a more precise method of evaluating noise.

Comparisons of the Polajnar-Verhovnik ergonomic coefficient C_{er} for the existing and modified method, performed at 40 analyzed workplaces, indicated that C_{er} values obtained using the modified method by considering both impulsive and tonality noise corrections are statistically significantly higher than C_{er} values obtained using the existing method. In addition, the goal of our research was not to follow the minor (more beneficial) C_{er} value but the main value of research was to obtain more realistic strains.

The modified method improves the existing one by considering the complexity of influences that workers may experience in a noisy environment. This means that strains, caused by noise, are assessed by considering the risk of health damage, decrease in human efficiency at work, and compliance with new regulatory standards ISO 9612.

REFERENCES

1. LANDSTROM U, KJELLBERG A, TESARZ M, AKERLUND E, Environment International, 21 (1995). — 2. SALVENDY G, Handbook of human factors and ergonomics, (Yohn Wiley and Sons, 1997). — 3. SAILER U. HASSENZAHL M, Ergonomics, 43 (2000) 11. DOI: 10.1080/00140130050174545. — 4. AOYUENYONG S, NANTHAVANIJ S, Computers & Industrial Engineering, 51 (2006). — 5. LOGE FE, AKANDE TM, OLAJIDE TG, European Archives of Oto – Rhino – Laryngology, 263 (2006) 7. — 6. AREZES PM, MIGUEL AS, Safety science, 46 (2008) 6. DOI: 10.1016/j.ssci.2007.11.008. — 7. AGRAWAL Y, PLATZ EA, NIPARKO JP, Archives of internal medicine, 168 (2008) 14. DOI: 10.1001/archinte. 168.14.1522. — 8. UJEVIĆ D, NIKOLIĆ G. DOLEŽAL K, SZIROVICZA L, Coll Antropol, 31 (2007) 4. — 9. SEIF M, DEGIULI N, MUFTIĆ O, Coll Antropol, 27 (2003) 1. — 10. MIJOVIĆ B, UJEVIĆ D, BAKSA S, Coll Antropol, 25 (2001) 1. — 11. VERHOVNIK V, POLAJNAR A, International Journal of Clothing Science and Technology, 1 (1992). — 12. POLAJNAR A, VERHOVNIK V, Work and workplaces design for practical work, (second edition Faculty of Mechanical Engineering, Maribor, 2007). — 13. SANDERS MS, MCCORMICK EJ, Human Factors in engineering and design, (McGraw – Hill International Edition, New York, 1990). — 14. Regulations about workers' protection from risks, caused by noise exposure at work, Slovenian official gazette, 7 (2001). — 15. DRUSANY V, Handbook about security and technological questions (VZA graphical design, Logatec, 1999). — 16. CROOME DJ, Noise, Buildings and people (Pergamon press, Oxford, 1977). — 17. HARRIS CM, Handbook of Noise Control (McGraw–Hill Book Company, New York, 1979) — 18. LOEB M, Noise and Human Efficiency, (John Wiley & Sons, Chichester, 1986). — 19. ISO 9612, Acoustic – Guidelines for the measurement and assessment of exposure to noise in a working environment, 1997. — 20. SCHMIDTKE H, Lehrbuch der Ergonomie Bewertung von Arbeitssystemen (Carl Hanser Verlag, München 1981). — 21. Directives of the Council about workers' protection from risks caused by noise exposure at work, 86/188/EEC (1986). — 22. REFA, Methodenlehre des Arbeitsstudiums, (Arbeitsgestaltung C. Hauser Verlag, München, 1978). — 23. Machinery directive EEC 98/37 (1998). — 24. OSHA, Occupational Safety and Health Administration (USA, 1983). — 25. BRUEL&KJAER, Measuring Sound, (Denmark,1997). — 26. FRAS V, Noise in working environment and its influence on human strain: MS Thesis. In Slovene (University of Maribor, Maribor, 2001).). — 27. JURISIĆ – ERZEN D, BENKO K, LJUBIĆ S, JERKOVIĆ R, Collegium Antropologicum, 35 (2011) 4. — 28. CAREVIĆ V, KUZMANIĆ M, RUMBOLDT M, RUMBOLDT Z, Coll Antropol, 34 (2010) 4.

A. Polajnar

University of Maribor, Faculty of Mechanical Engineering, Laboratory for Production and Operations Management, Smetanova 17, Maribor, Slovenia
e-mail: andrej.polajnar@uni-mb.si

NAPREZANJA I STRES KOD RADNIKA ZBOG IZLOŽENOSTI BUCI

SAŽETAK

Rad istražuje osnovne aspekte utvrđivanja opterećenja radnika bukom u industrijskoj okolini. Tehnološki razvoj omogućuje bolje uvjete za rad, zbog kojih su potrebne promjene u metodi mjerenja naprezanja i stresova zbog izloženosti buci. Uvedena je nova metoda, jer je dosadašnja metoda, koja se temelji na utvrđivanju opterećenja pomoću izloženosti buci, nedovoljna. Cilj modificirane metode je eliminacija nedostataka postojeće metode uzimajući u obzir složenu prirodu buke u specifičnim radnim sredinama. Učinci izloženosti buci ocjenjivat će se pomoću novog postupka koji uključuje učinke prirode buke, karakteristiku buke, trenutne standarde za zaštitu od buke, kao i utjecaj buke na različitim radnim mjestima. Ovaj novi pristup ocjenjivanja buke upotrebljava nove mjerne tehnike temeljene na tonalitetu i korekciji impulsnog zvuka. Modificirana metoda testirana je na različitim radnim mjestima u industriji obrade metala. Usporedba rezultata dobivenih pomoću obje metode potvrđuje primjerenost modificirane metode, čime se upotpunjuje ocjena izloženosti buci.