UDC 331.44
DOI: 10.15587/1729-4061.2024.302886

DEVELOPMENT OF A NEW ERGONOMIC RISKS MANAGEMENT ALGORITHM ON THE EXAMPLE OF DRIVERS

Vitaliy Tsopa
Doctor of Technical Sciences, Associate Professor
Department of Management
International Institute of Management
Shulyavska str., 10/12 V, Kyiv, Ukraine, 04116

Serhii Cheberiachko
Doctor of Technical Sciences, Professor*

Yurii Cheberiachko
Doctor of Technical Sciences, Professor*

Oleg Deryugin
PhD, Associate Professor
Department of Transportation Management**

Olga Chencheva
Corresponding author
PhD, Associate Professor***
E-mail: chenchevaolga@gmail.com

Dmytro Rieznik
PhD, Associate Professor***

Eduard Klimov
PhD, Associate Professor
Department of Automobiles****

Yevhenii Lashko
PhD, Associate Professor***

Dmytro Pashko
Main Department of the State Emergency Service of Ukraine in the Poltava Region
M. Biryuzova str., 26/1, Poltava, Ukraine, 36007

Viktoriia Biliaieva
Doctor of Technical Sciences, Professor
Department of Energy Systems and Energy Management
Ukrainian State University of Science and Technologies
Lazaryana str., 2, Dnipro, Ukraine, 49010

*Department of Labor Safety and Civil Security**
**Dnipro University of Technology
Dmytra Yavornytskoho ave., 19, Dnipro, Ukraine, 49005
Department of Civil Safety, Labor Protection, Geodesy and Land Management*
****Kremenchuk Mykhailo Ostrohradskyi National University
Pershotravneva str., 20, Kremenchuk, Ukraine, 39600

The object of the study: the process of determining and managing ergonomic risks at workplaces when performing professional activities on the example of truck drivers.

The problem lies in uncertainty when making decisions in occupational safety and health management systems. The hypothesis of the study was the possibility of assessing ergonomic risks in the occupational safety management systems of organizations based on the identification of regularities between the load index, typical working postures when performing operations and the intensity of joint movements.

An ergonomic risk assessment algorithm was developed, taking into account the load index, which includes a sequence of eleven steps, which can be conditionally divided into three groups. The first is determination of the intensity of joint movement. The second is the determination of the impact of activity and the duration of the production task. The third is determining the impact of environmental factors. An assessment of the ergonomic risk of drivers was carried out for three types of production work: driving a vehicle, replacing a damaged wheel, and repairing a car. At the same time, the ergonomic risk assessment algorithm takes into account the worker's individual state of health and environmental factors, as well as experience and work experience. It has been established that there is a high level of ergonomic risk during car maintenance due to the highest total load index, which is 30 % higher compared to other types of work of vehicle drivers.

The practical application consists in the development of a universal check list of drivers based on an algorithm to determine the ergonomic risk of workers at workplaces, which consists of 11 steps

Keywords: check sheet, diseases of the musculoskeletal system, ergonomic risk, load index, working posture

Received date 08.02.2024
Accepted date 16.04.2024
Published date 30.04.2024

How to Cite: *Tsopa, V., Cheberiachko, S., Cheberiachko, Y., Deryugin, O., Chencheva, O., Rieznik, D., Klimov, E., Lashko, E., Pashko, D., Biliaeva, V. (2024). Development of a new ergonomic risks management algorithm on the example of drivers. Eastern-European Journal of Enterprise Technologies, 2 (3 (128)), 38–49. https://doi.org/10.15587/1729-4061.2024.302886*

1. Introduction

Work-related musculoskeletal disorders (WMSDs) of workers rank first in the world among other diseases that are fixed at work [1]. First of all, it is related to uncomfortable working postures, long-term static operations, monotony of work and other dangerous factors of the production environment. Also, the level of individual physical health of a person [2], which determines the possibility of transferring physical overload, also affects. A significant number of occupational diseases leads to an increase in financial losses for the employer [3]. This is due not only to compensation for injured workers, but also due to a decrease in labor productivity, training of other workers to replace them, and possible fines [4]. The described situation requires employers to implement effective solutions in the occupational safety and health management systems for creating comfortable conditions for the performance of production tasks. Any management decision must have an appropriate justification to guarantee the achievement of the set results [5]. This basis is the process of risk assessment, which allows considering all possible scenarios of the development of events and choosing the safest one [6]. In the context of the development of occupational diseases, there is a need to determine ergonomic risks (ER). This makes it possible to identify the most complex, physically exhausting, as well as traumatic production operations and to justify preventive measures to reduce the ER level.

The ER assessment depends on the first and very important step – the identification of all dangerous factors that affect the physical and mental state of the worker. Such factors include the intensity of movements, the type of working posture, and the duration of the production task [7]. It is important not only to identify all dangerous factors and assess the ER level, but also to compare it with the individual level of health of the worker. This will allow, at least, determining the regime of work and rest, as well as to adjust the level of physical exertion [8]. In the future, the question will arise of replacing the production technology or using automated production processes to avoid damage to the human motor apparatus. The development of effective methodical principles of ER management in occupational safety and health management systems is urgent. They will allow, on the basis of regularities between the intensity of joint movements and physical overload, taking into account the level of health of the worker, to offer the best solution for reducing the ER level. Conducting scientific research on the identification of the mentioned regularities for the development of an effective process of managing ER is an urgent task that will improve control over working conditions. Its solution will preserve both the health of workers and the financial resources of business owners.

2. Literature review and problem statement

A significant number of different methods of determining the impact of a static working posture on the occurrence of occupational diseases or injuries in a worker have been investigated in scientific works [9, 10]. These approaches generate ER values based on typical work postures, against which comparisons allow the evaluator to establish appropriate scores. However, the total sum of these points does not allow determining the risk of an occupational disease or injury, as it evaluates only one of the ER components: the load index, which can be compared with the probability of a dangerous event. At the same time, the methods of «Rapid Entire Body Assessment» (REBA) or «Rapid Upper Limb Assessment» (RULA) lack the second necessary component for risk assessment – the severity of consequences, which is the main drawback of these approaches. In addition, they also do not take into account the individual level of health of the worker. The approach in the study [11] indicates the need to assess such an impact. The authors insist on the need to take into account the compliance of production conditions with the characteristics of workers (physiological, psychological and anthropometric) with an assessment of their health status when studying ER [12, 13], but a comprehensive approach that would take into account all these indicators and peculiarities of technological processes, in the work not suggested. The need to take individual health into account when assessing ER is indicated by a study [14], which clearly argues that the initial state of health significantly affects the risk of traumatic events during the performance of work duties.

As a rule, the risk of injury from an awkward posture is determined separately from the worker's level of health, which is determined by physical exertion. Then the obtained point scores are combined based on the empirical dependencies presented in [15]. Complex mathematical models are also often used, which describe the impact of dangerous ergonomic factors on human health through biomechanical analysis [16, 17]. Each of the reviewed studies pays attention to a separate group of factors that characterize the ergonomic risk of a worker, but today there is no general checklist for a full assessment of all indicators on a point scale that can influence the overall risk assessment. Thus, it is necessary to combine and generalize all the specified parameters to determine the complex ergonomic risk, determine the point equivalents of the impact of each of the factors on the overall ergonomic risk, and develop preventive measures to minimize the occurrence of traumatic events.

The development of the ER research methodology consists of three stages: determination of ergonomic factors (working conditions, equipment, task requirements, human physical condition, pace and rhythm of work), calculation of ER in points and assessment of the effectiveness of primary actions [18]. To determine the total number of points, a comparison of indicators characterizing the conditions of performance of the production task with normative indicators taken from regulatory requirements is proposed. The main disadvantage of all mentioned approaches is the lack of experienced observers, as well as the fact that the obtained results can be subjective [19]. To avoid this, various sensor technologies are implemented, including a system of sensor controllers, which clearly allow determining individual risk [20]. However, the specified approach does not allow to extend the obtained dependencies to work performed in other conditions, as it requires an appropriate check for adequacy [21]. Most studies evaluated their methods on the basis of laboratory experiments, which differed significantly from real production conditions. Therefore, future research requires the development of appropriate software products that will allow obtaining high performance. In addition, known approaches do not take into account the presence of occlusion in captured videos or images, which may lead to inaccurate analysis of workers' ER.

The analysis of the conducted studies [9–21] showed that in general there are two main approaches to the ER assessment. The first is based on the defined physical activity of the worker, thanks to the use of different time scales. The second is based on the predicted metabolic energy expenditure of a person (used in scientific research, requiring significant resources). The first are the most popular for ER quick assessment in production [22]. They do not require laboratory equipment, complex models, or specially trained specialists. However, they have some drawbacks, which are related to the failure to take into account the worker's health level, activity and duration of the production task. The reason for their occurrence is the need to take into account the change in the worker's physical condition due to the accumulation of fatigue. This requires appropriate refinement of the specified methods in order to reduce uncertainty in decision-making in occupational safety and health management systems.

3. The aim and objectives of the study

The aim of the study is to develop an algorithm for assessing the ER level based on the worker's load index, using drivers as an example. This will make it possible to reduce the number of professional drivers' WMSDs.

To achieve the aim, the following objectives were solved:

– to evaluate the driver's load and determine the index when performing typical operations;

– to determine the sequence of assessment of ergonomic risks of drivers taking into account individual health indicators;

– to calculate the car drivers' ER for three types of production work: driving a vehicle, replacing a damaged wheel, repairing a car;

– to analyze the calculation indicators of drivers' ER and its results.

4. Materials and methods of the study

The object of the study is the process of determining and managing ergonomic risks at workplaces when performing professional activities on the example of truck drivers.

The hypothesis of the study was the possibility of assessing ergonomic risks in the occupational safety management systems of organizations based on the identification of regularities between the load index, typical working postures when performing operations and the intensity of joint movements.

The ER assessment was carried out on the example of drivers who performed various production operations: driving a vehicle, replacing a damaged wheel, repairing a car that is on a lift. 6 participants aged 25 to 45 (men) who gave written consent to participate in the study took part in the study. The participants were introduced to the testing program and the parameters that will be determined during the experiment. All participants were informed about the conducted experiment, about the data that will be used to check the effectiveness of the developed method of assessing ER. A «Nikon Z711 Body» camera with a resolution of 1024×768 pixels was used to photograph the working poses of the drivers. The shooting was carried out at a distance of one meter. To determine the ER, photographs were taken of the main working movements of the drivers while performing the relevant technological operations. At the same time, only the largest load indicator was left for further analysis.

To determine the level of health of drivers, it is proposed to assess the biological age. The following devices are used for this: tonometer «Nissei DS-1902» (Japan); non-contact infrared thermometer «Maniquick MQ-160» (Switzerland), medical scales «VM-150» (Ukraine), stopwatch «HS-43» Citizen (Japan). Subjective health assessment (SHA) was performed using a questionnaire including 27 questions [23, 24]. Determination of individual indicators took place during a pre-race medical examination in a special medical office.

The drivers' working conditions were determined by noise load, vibration level and microclimate parameters. A digital contact vibrometer «AR63A (GM63A)» (China) was used to measure the vibration load at the driver's workplace. Parameters of the temperature environment of the workplace were measured with a TENZOR-41 ball thermometer (Ukraine), an anemometer «Testo 405-V1» (Germany). The noise load at the workplace was measured with the device «Shum-1M» (Ukraine) when the car was moving at a speed of 45–60 km/h.

The data were systematized and calculated using Microsoft Office programs – Excel 2010 (developer «Microsoft Corporation», USA). The obtained data had a normal law of probability distribution, and Parametric Student's criteria were used for their analysis. The number of observations was sufficient to obtain objective scores of the first two moments: arithmetic mean (M) and standard deviation (δ). A significance level of $p<0.05$ with a confidence level of 95 % was considered reliable.

5. The results of the assessment of the ergonomic risk of workers, taking into account the load index

5. 1. Audit of the worker's workload when performing production activities

The well-known «Task, Individual, Load, and Environment» (TILE) approach was used to develop the ER assessment algorithm, which provides for the identification of ergonomic factors that are formed by the worker's working posture, depend on its individual state of health, the amount of work and the influence of the environment. At the same time, ER is presented as a set of indicators of the load of all muscles of a worker when performing a production task for a regulated time and experience:

$$P = LI \times EW, \quad (1)$$

where LI – load index, which is calculated as the sum of all loads on muscle groups, points; EW – experience of working with the appropriate level of muscle load, points. The probability of occurrence of a dangerous event can be calculated using the load index, which is defined in points. The latter is formed taking into account the working posture, the number of repetitive movements, the rhythm and pace of work and other indicators that affect the probability of the WMSDs development.

To determine the risk levels of the development of workers' professional WMSDs workers, the requirements of the Hygienic classification of working conditions were taken into account according to indicators of harmfulness and danger of factors of the industrial environment, difficulty and tension of the labor process [17].

Exceeding the above indicators by up to 15 % corresponds to the level of acceptable risk with mandatory control of indicators (yellow zone). It is characterized by a violation of blood circulation and metabolism, which can lead to stretching, squeezing, pinching of nerve trunks in bone canals or muscle ligaments. This is especially evident during work performed with constantly bent limbs.

Exceeding the indicators by more than 15 % is an unacceptable risk (red zone). Work in this area will lead to the development of occupational pathology. Such conclusions were made on the basis of the analysis of a number of scientific studies on the establishment of the dependence between the load and the WMSDs development. In particular, studies [23, 25] established a correlation between the development of osteoarthritis of the knee joint and the number of hours spent kneeling or squatting (more than 5,000 hours), as well as the number of squats per work shift up to 10,000 times.

In work [24] it was established that the development of diseases of the shoulder and forearm joints is manifested when working with a load of 20 kg for more than one hour or with ten repetitions. In addition, the frequency of movements more than 15 times per minute, frequent lifting of loads more than 5 kg (2 times per minute) can lead to these problems. The relationship between the combined biomechanical impact on the neck muscles and the frequency of lateral epicondylitis was determined by the authors in [26], where it was established that the number of head movements should be no more than 15–20 per minute.

Exposure to ER (uncomfortable posture, vibration, force loads, repetition and/or kneeling), which occurs for more than 25 % of the working time, leads to the occurrence of workers' WMSDs [27]. Also, the duration of work in an uncomfortable static position for more than two hours of an eight-hour work shift leads to the disease [28].

5. 2. Determination of the sequence of assessment of ergonomic risks

An eleven-step procedure is proposed to determine the ER level based on the established level of the load index:

Step 1. Identification of the movements of the muscles of the neck, trunk and legs, where, in comparison with the specified movements, schematically shown in the control sheet (Fig. 1), it is provided for the determination of points based on the photo of the worker performing the task.

Step 2. Determination of the load index of the muscles of the neck, trunk and legs based on their ratio, which is presented in the Table 1.

Table 1

Determination of the load level of neck, trunk and leg muscles (A) in points

A_1. Neck muscle load level		1				2				3			
A_2. Leg muscle load level		1	2	3	4	1	2	3	4	1	2	3	4
A_3. Body posture muscles load level	1	1	2	3	4	1	2	3	4	3	3	5	6
	2	2	3	4	5	3	4	5	6	4	5	6	7
	3	2	4	5	6	4	5	6	7	5	6	7	8
	4	3	5	6	7	5	6	7	8	6	7	8	9
	5	4	6	7	8	6	7	8	9	7	8	9	9

Table 2

Determination of the load level of the muscles of the neck, trunk and legs (A) taking into account the weight of the equipment involved in the technological process (C): $A+C$, in points

No.	Load level		Shock or rapid increase in load		Designation	The level of the combined load of the muscles of the neck, trunk and legs, taking into account the load – C
	Criterion	Points				
1	<5 kg	+0	absent	+0	C_1	+0
			available	+1	C_2	+1
2	from 5 to 10 kg	+1	absent	+0	C_3	+1
			available	+1	C_4	+2
3	>10 kg	+2	absent	+0	C_5	+2
			available	+1	C_6	+3

Step 3. Determining the load level on the muscles of the neck, trunk and legs, taking into account the weight of the equipment based on the assessment of the weight of the equipment up to 5 kg, from 5 kg to 10 kg, more than 10 kg and the speed of the task (Table 2).

Step 4. Identification of the movements of the muscles of the shoulder, lower leg, and wrist, where a comparison is provided with the specified movements schematically shown in the control sheet in Fig. 2, to determine points based on a photograph of a worker's working posture.

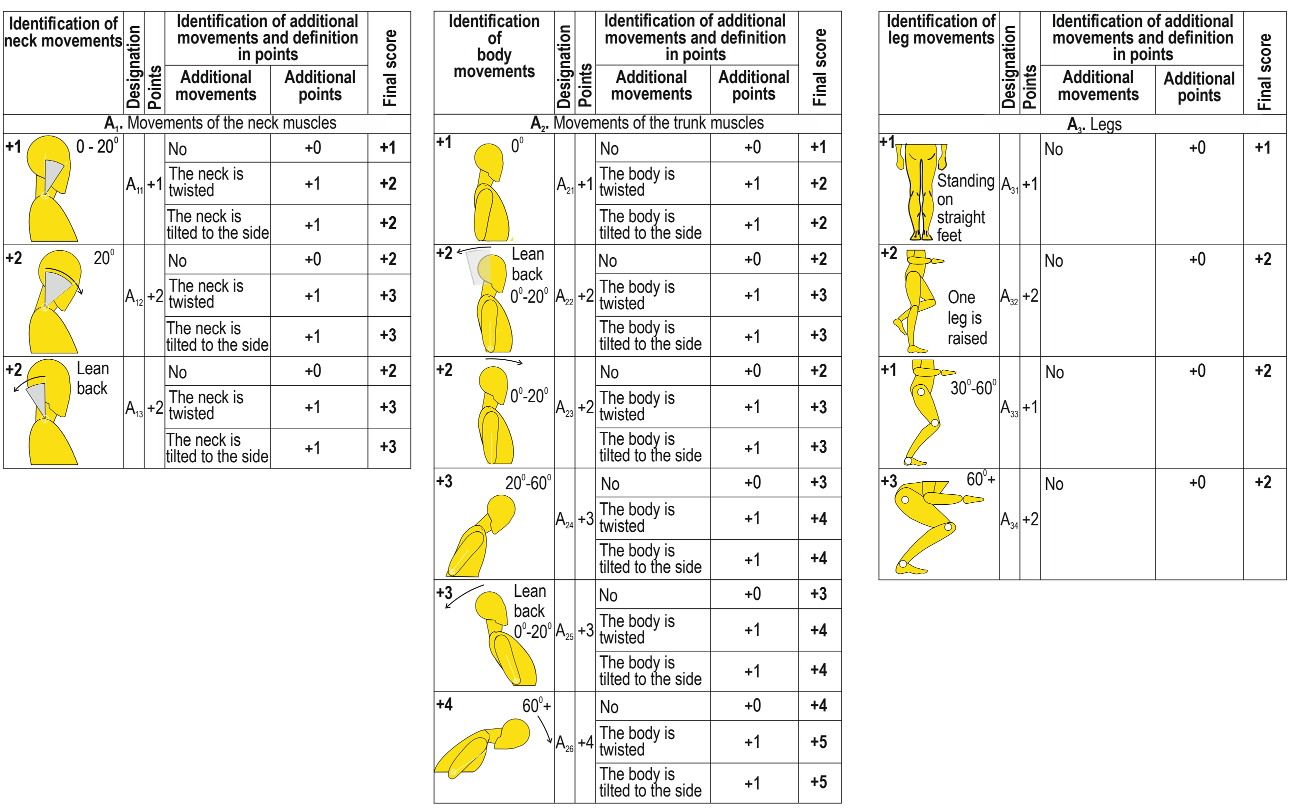


Fig. 1. Step 1 – identification of the movements of the muscles of the neck, trunk and legs

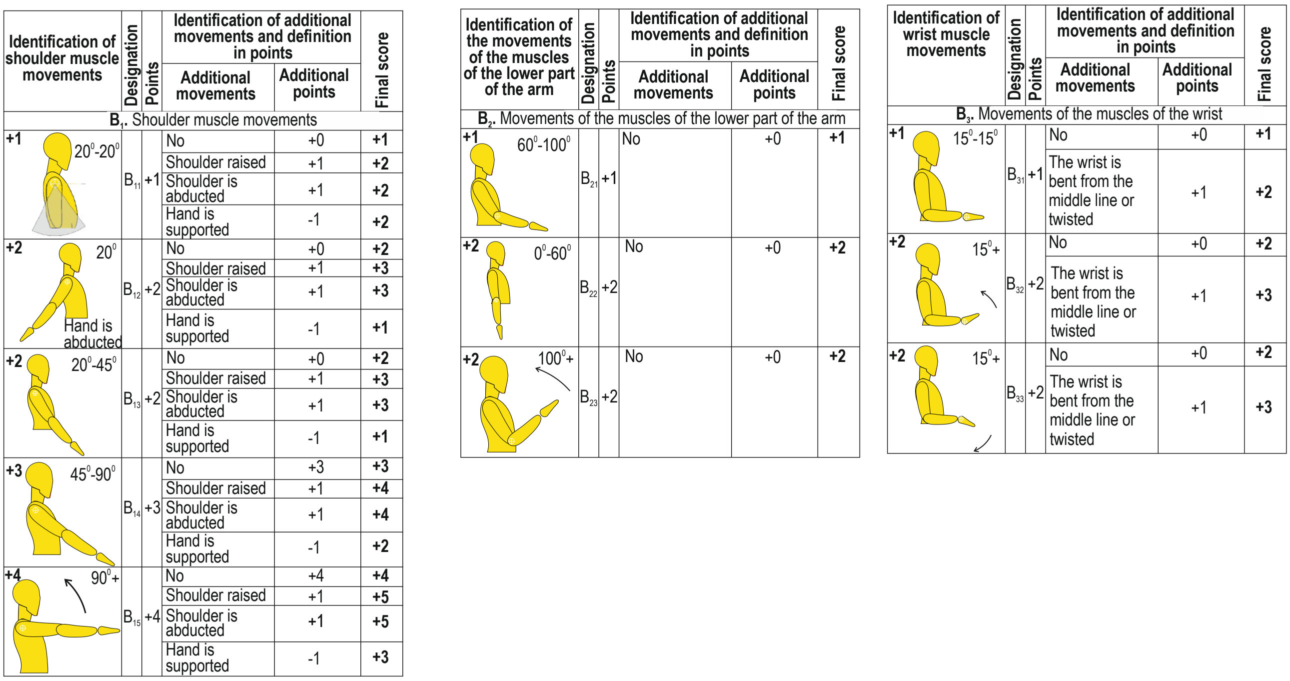


Fig. 2. Step 4 – identifying the movements of the muscles of the shoulder, lower leg, and wrist

Step 5. Determination of the load level of the muscles of the shoulder, the lower part and the wrist of the hand according to the matrix given in the Table 3.

Table 3

The matrix for determining the level of the combined load of the muscles of the shoulder, the lower part and the wrist of the hand – *B*

B_2. The lower part of the arm		1			2		
B_3. Wrist		1	2	3	1	2	3
B_1. Shoulder	1	1	2	2	1	2	3
	2	1	2	3	2	3	4
	3	3	4	5	4	5	5
	4	4	5	5	5	6	7
	5	6	7	8	7	8	8
	6	7	8	8	8	9	9

Step 6. Determination of the load level on the muscles of the shoulder, forearm, and wrist, taking into account the grip of the hand on the surface of the tool (equipment), based on the recommendations given in the Table 4.

Table 4

Determination of the level of combined load on the muscles of the shoulder, forearm, wrist (*B*) taking into account the grip of the hand on the surface of the tool (*D*) – *D*+*B*

No.	Identification of the clutch with the tool	Designation	Scores
1	Good handle and grip with medium power (good)	D_1	+0
2	Acceptable but not ideal hand hold or acceptable grip	D_2	+1
3	Hand holding is not acceptable, but possible (bad)	D_3	+2
4	No handles (not allowed)	D_4	+3

Step 7. Determination of the load index level H_1 according to the data of the matrix given in the Table 5, on which the load index values of the muscles of the shoulder, forearm and wrist are shown horizontally. They are given taking into account the grip of the hand of the equipment and the load index of the muscles of the neck, trunk and legs, taking into account the weight of the equipment involved in the technological process.

Table 5

Matrix for determining the load level index H_1

H_1		Load level – *B*+*D*											
		1	2	3	4	5	6	7	8	9	10	11	12
Load level *A*+*C*	11	1	1	1	2	3	3	4	5	6	7	7	7
	2	1	2	2	3	4	4	5	6	6	7	7	8
	3	2	3	3	3	4	5	6	7	7	8	8	8
	4	3	4	4	4	5	6	7	8	8	9	9	9
	5	4	4	4	5	6	7	8	8	9	9	9	9
	6	6	6	6	7	8	8	9	9	10	10	10	10
	7	7	7	7	8	9	9	9	10	10	11	11	11
	8	8	8	8	9	10	10	10	10	10	11	11	11
	9	9	9	9	10	10	10	11	11	11	12	12	12
	10	10	10	10	11	11	11	11	12	12	12	12	12
	11	11	11	11	11	12	12	12	12	12	12	12	12
	12	12	12	12	12	12	12	12	12	12	12	12	12

Step 8. Determination of the level of activity and duration of the load index H_2 based on the identification of the speed of execution of the production task. It allows determining the number of body parts involved in the production process, as well as the number of repetitions of movements and the duration of the production task (Table 6). The H_2 load index is determined by the matrix (Table 7), where the horizontal is the level of activity, and the vertical is the level

of duration. In the presence of one critical factor (activity/duration), when the other is insignificant, let's determine the points according to the data in the Table 6.

Table 6

Determination of the level of the load index H_2 taking into account the activity *AC* and the duration *DU*

No.	Description of activity and duration of load	Designation	Scores
Identification of the level of muscle load activity			
1	One or more body parts are held for longer than 1 minute (static)	AC_1	+1
2	Repeated actions over a short distance (more than 4 times per minute)	AC_2	+2
3	The action causes rapid large changes in posture or an unstable foundation	AC_3	+3
Identification of the level of duration of muscle load			
1	The duration of the workload of the work task 0–20 %	DU_1	+1
2	The duration of the workload of performing the work task is 20 % to 40 %	DU_2	+2
3	The duration of the work load 40–60 %	DU_3	+3
4	The duration of the work load 60–80 %	DU_4	+4
5	The duration of the work task load 80–100 %	DU_5	+5

Step 9. Identification of the state of health of the worker, its gender and the influence of environmental factors, which is carried out in accordance with the recommendations of the Table 8 in the presence of one critical factor, when others are insignificant, for example, when working conditions are acceptable.

Table 7

Matrix for determining the load index H_2

H_2		Activity – *AC*		
		AC_1	AC_2	AC_3
Duration	DU_1	+0.2	+0.4	+0.6
	DU_2	+0.4	+0.8	+1.2
	DU_3	+0.6	+1.2	+1.8
	DU_4	+0.8	+1.6	+2.4
	DU_5	+1.0	+2.0	+3.0

It is proposed to assess the state of health of the worker by biological age in comparison with the calendar age. It is considered that the excellent result is when the biological age is less than the calendar age (E_1). Good – the biological age coincides with the calendar age (E_2). Satisfactory – biological age exceeds calendar age up to 5 years (E_3). Unsatisfactory – biological age exceeds the calendar age by more than 5 years (E_4). The proposed equation (2) is used to determine biological age [7, 29]:

$$BA = 26.985 + 0.215 \times SBP - 0.149 \times BHB - \\ -0.151 \times SB + 0.723 \times SAH, \quad (2)$$

where *BA* – biological age, *SBP* – systolic blood pressure, mm·Hg.; *BHB* – duration of breath hold after a deep breath, s; *SB* – static balancing, c; *SAH* – subjective assessment of health (defined in points), a special questionnaire is used.

To calculate the appropriate point from the influence of noise, vibration, lighting, climatic conditions (temperature, humidity, air movement speed), the ratio of actual indicators and normative ones was used. They are determined by the maximum permissible values by establishing environmental impact factors (*EIF*). Normal working conditions are those in which the environmental impact factor is less than or equal to one. Such conditions are considered good (*EIF*=1); if the environmental impact factor is exceeded by 1.3 times, the conditions are satisfactory (*EIF*=2); if the environmental impact factor is greater than 1.3, such working conditions are considered unsatisfactory and the *EIF* will be equal to 3. The excess may be mainly due to one indicator, such as temperature – then the *EIF* will be 1.3 or 2.

Table 8

Identification of the state of health of the worker, its gender and the influence of environmental factors

No.	Description of factors for determination	Designation	Scores
Identification of the worker's health status			
1	$BA/CA>1$	E_1	+0
	$1>BA/CA>1.5$	E_2	+1
2	$BA/CA<1.5$	E_3	+2
4	$BA/CA>1.5$	E_4	+4
Identification of the worker's gender			
1	Man	E_5	+1
2	Woman	E_6	+2
Identification of working conditions			
1	Acceptable working conditions	HW_1	0
2	Harmful working conditions of class 3.1	HW_2	+1
3	Harmful working conditions of class 3.2	HW_3	+2
4	Harmful working conditions of class 3.3	HW_4	+3

Step 10. Determination of the worker's health status indicator, limitations of physical condition and influence of environmental factors H_3. Based on the recommendations given in the Table 9, which takes into account limitations of physical condition (horizontally) according to the level of health, and the influence of the environment (vertically).

Table 9

Matrix for determining the load index H_3

Working conditions	Worker's health status and gender					
	E_1	E_2	E_3	E_4	E_5	E_6
HW_1	0	+2	+4	+2	+4	+6
HW_2	+1	+3	+5	+3	+5	+7
HW_3	+2	+4	+6	+4	+6	+8
HW_4	+3	+5	+7	+5	+7	+9

Step 11. The total load indicator is determined as the total number of points according to the formula:

$$IH = H_1 + H_2 + H_3. \quad (3)$$

Based on the hygienic classification of work, as well as taking into account methodical recommendations for the attestation of workplaces, the boundaries of the ER matrix are established (Fig. 3). At the same time, the distribution of ER levels: green color – acceptable ER (low probability of WMSDs occurrence); orange –acceptable with ER verification (moderate probability of WMSDs); red – unacceptable ER (high probability of WMSDs).

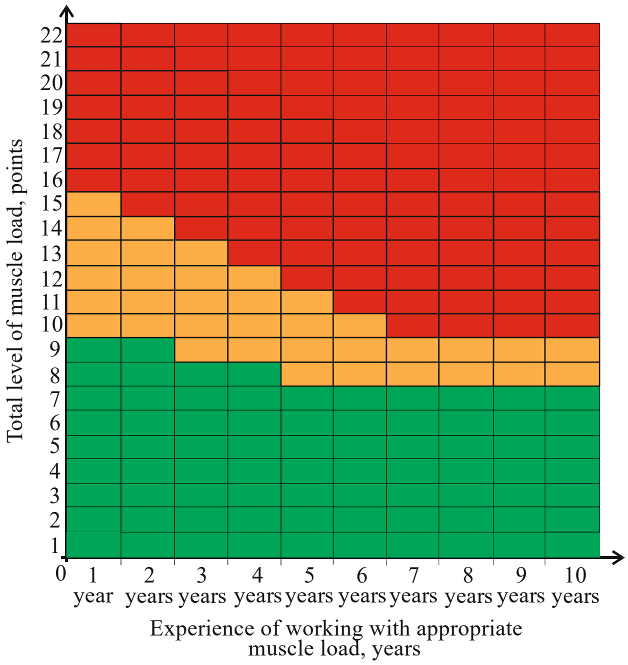


Fig. 3. ER matrix (ergonomic risks)

To display the intermediate results of calculating the load index, taking into account the length of service, a special tabular form (Table 10) is proposed, which shows the sequence of steps, a place for displaying the corresponding points and calculation formulas.

The uniqueness of the specified algorithm is the consideration of additional factors: the state of worker's health, its gender, and factors of the production environment, which significantly affect the overload of the worker. The algorithm also allows taking into account the possible physical limitations of the worker by determining the appropriate points that characterize the activity of work performance.

5. 3. Calculation of the ergonomic risk of car drivers by type of production work

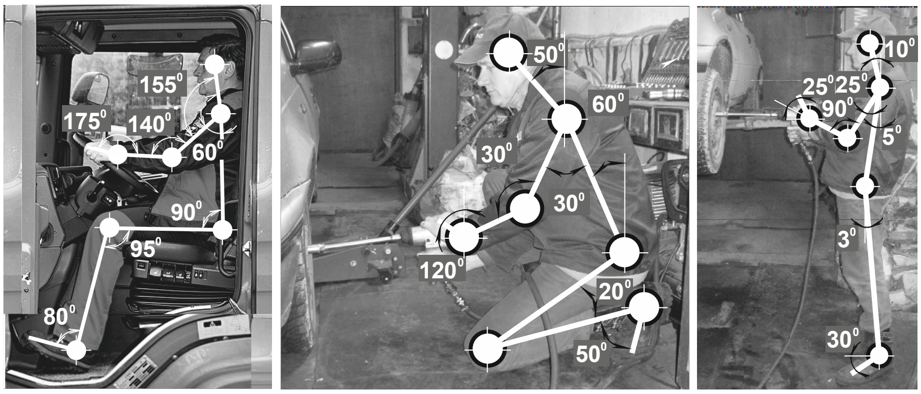
The ER of drivers who make several trips with a return to the place of departure after a certain period of time (after a month) was evaluated. It was assumed that 90 % of the time of the transport work of the driver is occupied with driving the car, 7 % – on the pre-trip inspection and 3 % – on the ongoing minor repairs (for example, changing a wheel on the road).

To carry out the ER assessment, let's use photos of the production poses of the drivers: driving a car, replacing a damaged wheel and conducting a pre-race inspection, which are shown in Fig. 4. There are marks on the photo that allow to place the location of body parts in accordance with the specified positions on the control sheet (Fig. 2) to establish the corresponding point scores.

Table 10

Algorithm and form of assessment of muscle load index

Danger	Dangerous event	Consequences	Harmful factors of muscle strain of the worker		Designation	Step number	Points
Muscle overload	MSD disease	Loss of working capacity	Detection of neck, trunk and leg muscle movements		A		
			Movements	neck	A_1	1	point
				stem	A_2		point
				legs	A_3		point
				load factor	A	2	point
			Determination of the load level on the muscles of the neck, trunk and legs, taking into account the weight of the equipment involved in the technological process		$A+C$	3	point
			Identification of the movements of the muscles of the shoulder, lower leg, and wrist		B		
			Movements	shoulder	B_1	4	point
				lower arm	B_2		point
				wrist	B_3		point
				load factor	B	5	point
			Determination of the load level on the muscles of the shoulder, forearm, and wrist, taking into account the grip of the surface of the equipment by the hand		$B+D$	6	point
			Determination of the load index level		H_1	7	point
			Determination of the load duration and activity indicator		H_2	8	point
			Identification of the worker's state of health, limitations of physical condition and influence of environmental factors		E, HW	9	point
			Determination of the worker's health index, limitations of physical condition and influence of environmental factors		H_3	10	point
Determination of the general load index					$LI=H_1+H_2+H_3$	11	point
ER assessment					$P=LI\times EW$	Full ER assessment according to set points	



a *b* *c*

Fig. 4. Photographs of production poses with applied lines to determine the ergonomic risks of the driver: *a* — when driving a car; *b* — when replacing a damaged wheel; *c* — during maintenance or repair of a vehicle on a lift

To determine indicators of activity and duration of work, the time of a full work shift (we calculate that it is 9 hours) is compared with the time of transport work, that is, we calculate the time of breaks and stops. Through observation, the duration of the driver's stay in one working position, the speed of work execution and the repeatability of operations were recorded (Table 11).

Data on the individual state of health of the drivers was collected. For this purpose, key indicators (blood pressure, self-esteem index, breath holding time and static balancing time) were determined during pre-race medical examinations to determine the value of calendar age (*CA*) according to formula (2). The obtained results were compared with the calendar age (according to passport data), which was the basis for determining the points (Fig. 3). Intermediate calculation results and point scores are given in the Table 12.

The last preparatory stage is the assessment of the impact of environmental factors at the driver's workplace (noise, temperature, vibration), which was carried out according to certification maps of working conditions. The determination of the indicators of only the three mentioned factors was carried out due to the fact that they have the greatest impact on the physical condition of drivers and lead to common occupational diseases – nervous disorders and increase the likelihood of a traffic accident. After establishing the actual data of factors of the external environment (vibration, noise, ambient temperature), they were compared with the maximum permissible values recorded in the relevant regulatory documents. The largest deviation from the norm was detected and taken into account when assessing the impact on the value of the load index when performing the corresponding production task. The results of determining the influence of drivers' environmental factors are shown in Table 13. Having previously collected all the necessary data, the load index was calculated, consistently performing the indicated actions listed in the Table 10, while the results of evaluating the weighting index, as an example, for water are given in the Table 14.

The values of the load index for each driver when driving a vehicle, servicing the car and changing a wheel are given in the Table 15.

Table 11

Determination of indicators of activity and duration of the driver's working positions

Danger factor	Observation during the performance of a production task		Score
Activity	Time of non-productive work, min.	30	1
	Repeatability of production operations, times/min.	10–15	
	Load activity, %	20	
Duration	Time for one operation, min.	80	3

Table 12

The results of the assessment of the biological age of drivers and the determination of load index points taking into account the health state

No.	*CA*, years	*SBP*, mm·Hg	*HR*, beats/min	*SAH*, scores	*SB*, s	*BA*, years	Scores
1	25	121	72	6	116	22	1
2	27	124	82	8	119	27	1
3	29	134	86	7	63	30	1
4	33	136	85	9	48	34	1
5	41	128	86	13	33	41	1
6	43	139	93	15	27	49	2

Table 13

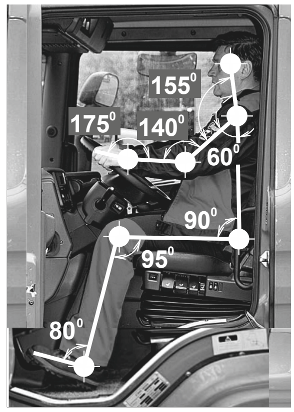
Indicators of the influence of the environment on the load index of drivers

No.	Vibration, dB		Air temperature, °C		Noise, dB		Class of working conditions	Scores
	Actual	MPV*	Actual	MPV*	Actual	MPV*		
1	112	90	29	20–24	77	80	3.1	1
2	102		28		75		3.1	1
3	105		28		74		3.1	1
4	96		26		77		3.1	1
5	103		28		78		3.1	3
6	101		30		74		3.1	4

*Note: *MPV – the maximum permissible value of the factor*

Table 14

An example of driver load index assessment

No.	Risk components			Harmful factors of muscle strain of the worker		Designation	Scores
	Danger	Dangerous event	Consequences				
1	Muscle overload	MSD	Loss of working capacity	Detection of neck, trunk and leg muscle movements			
				Movements	A_1 – trunk muscles movements	A_{23}	2
					A_2 – leg muscle movements	A_{33}	2
					A_3 – neck muscles movements	A_{11}	1
					A – load factor	3	
				Determination of the level of load on the muscles of the neck, trunk and legs, taking into account the weight of the equipment		$A+C$	5
				Identification of the movements of the muscles of the shoulder, lower leg, and wrist			
				Movements	B_1 – shoulder	B_{15}	5
					B_2 – lower shoulder	B_{21}	2
					B_3 – wrist	B_{31}	1
					B – load factor	7	
				Determination of the level of load on the muscles of the shoulder, forearm, and wrist, taking into account the grip of the surface of the equipment by the hand		$B+D$	7
				Determination of the load index level		H_1	+9
				Determining the duration and activity of the load		H_2	+0.6
				Determination of the worker's state of health, limitations of physical condition and influence of environmental factors		E, HW	1, 2, 1
				Determination of the worker's health index, limitations of physical condition and influence of environmental factors		H_3	+2
				Determination of the general load index		LI	≈12

As a result of the study, a load indicator was established that characterizes the work of drivers. At the same time, the ER value, taking into account the length of work, showed that the most dangerous for the development of WMSDs is changing the wheel, which is characterized by an uncomfortable working position and a significant load. Car maintenance does not have a high load index due to the short duration of work.

On the basis of the total load index, ER was calculated taking into account the experience of the drivers according to formula (1), taking into account the data of the matrix shown in Fig. 3.

The results of the risk assessment make it possible to find a correlation between the state of health of the worker, its work experience and the ER size in the future, this is the basis for the development of preventive measures and management of ER.

The difference of this approach to determining the individual ER lies in the calculation of its value for each worker. At the same time, the obtained results allow to assess the presence of ergonomic hazards not only by type of activity, but also by length of service. This will allow an in-depth analysis to determine the most dangerous factor/group of factors, as well as to timely identify workers who have limitations both in terms of physical health and seniority.

Table 15

The results of the ER assessment of drivers

Driver	Load index			Equivalent load index	Experience	Risk level
	Driving a car	Replacement of wheels	Maintenance			
1	12	12	9	11	5	average
2	12	12	9	11	5	
3	13	12	9	11	5	
4	14	13	10	12	10	
5	14	13	11	13	15	
6	13	12	9	11	5	

5. 4. Results of the analysis of indicators for calculating the ergonomic risk of drivers

The results are given in the Table 6, show that the drivers under numbers 4 and 5 have different ER values from other drivers, which is explained by the presence of significant work experience. With age, drivers gain considerable experience, but their activity, which was established taking into account the reaction to a threat, decreases. In addition, any person accumulates various chronic diseases with age, affecting the level of health, which was determined based on the calculation of biological age [29]. From here it is possible to draw a conclusion regarding the reduction of the duration of transportation, since this factor is characterized by the largest number of points (Fig. 5). It is also possible to more carefully analyze the determination of points regarding the intensity of joint movement and find the reason why the highest score was recorded for shoulder movements. Perhaps due to the lack of adjustment of the steering wheel or significant physical exertion when switching the gearbox. Eliminating the cause will reduce the impact of the dangerous factor.

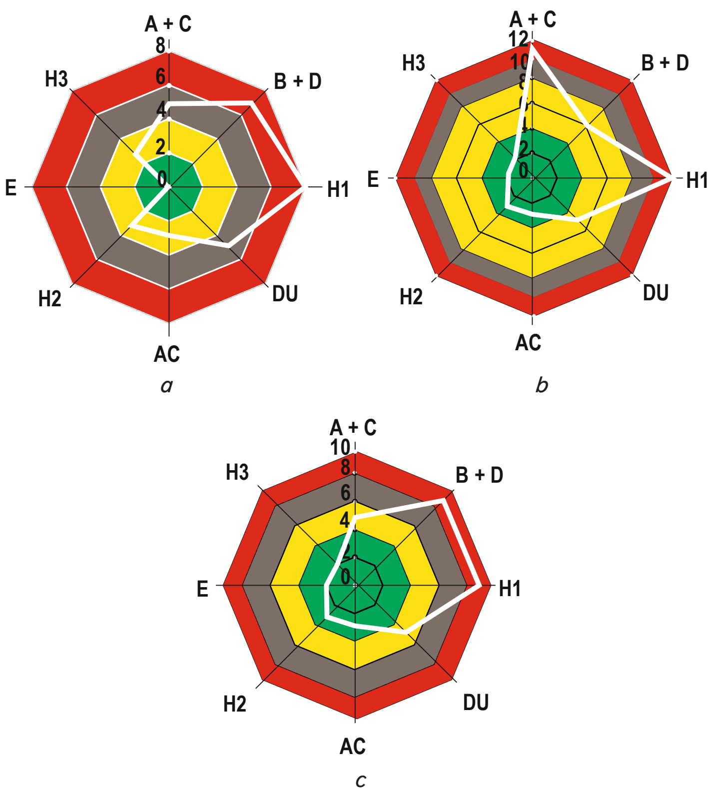


Fig. 5. Radar diagram of ergonomic risk: *a* — driver while driving; *b* — driver when replacing a damaged wheel; *c* — driver during maintenance or repair of a vehicle on a lift

The research also showed that there is a high level of ER during car maintenance due to the highest indicator of the total load, which is 30 % higher compared to other types of work of drivers (Fig. 5). This is where the analysis of the work performance technology begins to find out the reason for obtaining relatively high scores.

6. Discussion of the results of the ergonomic risk assessment

The developed algorithm for assessing ER made it possible to identify dangerous factors of the production process, which have the greatest impact on the physical overload of the driver. This makes it possible to establish the cause and propose appropriate solutions in occupational safety management systems that would change the probability of the development of an occupational eye injury. Based on the given checklist (Fig. 1, 2), as well as the obtained calculations in the Table 5, the level of ER for six drivers was determined as the average. This requires further analysis to determine the impact of each component (dangerous factor) on the obtained total result. The result will be the development of recommendations to reduce the likelihood of developing occupational diseases of drivers.

The main difference between the proposed ER calculation algorithm and the existing RULA, REBA [11] approaches is to establish the relationship between the load index, work experience, intensity of movements and the level of health of the driver. At the same time, the algorithm can be conditionally divided into three groups: determination of the intensity of joint movement; determining the impact of activity and duration of the production task and determining the impact of environmental factors. Dangerous factors, which are determined on the basis of the recommendations given in the checklists, affect the activity of performing production operations, which decreases over time due to the accumulation of fatigue. In addition, the proposed algorithm takes into account the duration of work and the influence of environmental factors, which also reduce workability due to the need for adaptation of the body [30]. The known approaches are limited only to the assessment of the working posture taking into account the load [31]. Sometimes the execution time is taken into account. The proposed algorithm makes it possible to assess the influence of the age and length of service of workers due to the change in biological age.

The advantages of the developed load index assessment checklist include the ability to assess the convenience/uncomfortableness of the working posture with the appropriate level of effort that the driver must exert to perform the task. It is also necessary to detect the influence of dangerous factors of the external environment and to determine how much the load corresponds to the driver's level of health. The checklist of the proposed checklist even provides for the presence of physical limitations of the driver, which are associated with an injury or a previous illness.

The developed algorithm for assessing ER, as can be seen from the conducted analysis, allows substantiating the appropriate decisions in the occupational safety management systems of organizations. The proposed solutions provide, first of all, the elimination of the main causes that increase the likelihood of the development of occupational diseases.

In addition, if it is impossible to achieve the desired level of ER, appropriate steps are developed either to replace the type of truck [32], or to choose another route [33], or to transfer the worker to another job. All the given recommendations are offered on the basis of a thorough study of the identified dangerous cells (Table 5), which allows to clearly identify the weak points of the technological process.

At the same time, the limitations of the study include the lack of a classical approach to the assessment of ER, when to establish the probability of the occurrence of a dangerous event – an occupational disease or injury and the severity of the consequences. Based on the appearance of the working posture, it is difficult to detect risks experimentally.

In addition, the specified algorithm is time-consuming and requires research into the biological age of drivers, working conditions, identification of physical limitations of drivers, and observation of the specifics of task performance. The limitations of this study include the lack of consideration of the influence of psychosocial risk factors on ER values, which are planned to be included in the next development of the checklist.

7. Conclusions

1. The relationship between the load index of the worker of industrial activity and the intensity of movements, taking into account the level of individual health of the worker, was established, which made it possible to calculate the ER value as a set of load indicators of all the driver's muscles when performing an industrial task for a given time and experience. Thus, taking into account work experience and biological age, which collectively have a significant impact on the overall risk assessment, allows assessing changes in the worker's physical condition due to the accumulation of fatigue.

2. The sequence of ergonomic risk assessment was determined and the load index and its impact on the overall result of ergonomic risks were assessed. It was established that the greatest impact is caused by changing the wheel, which is characterized by an inconvenient working position and a significant load. The proposed sequence of ergonomic risk assessment, which cnsists of eleven steps, can be conditionally divided into three groups: determining the intensity of joint movement; determining the impact of activity and duration of the production task and determining the impact of environmental factors.

3. According to the calculations of the comprehensive assessment of ergonomic risks among 6 drivers, it was determined that seniority and work experience can influence the amount of risk due to a decrease in reaction to threats with an increase in knowledge. Also, the accumulation of fatigue and chronic diseases has a significant impact on the duration of transportation. The typical performance of movements, such as gear shifting, can increase the impact on the motor activity of the shoulder joint, which also leads to an increase in the load index and the risk of traumatic events or the accumulation of static fatigue.

4. It was established that there is a high level of ER during car maintenance due to the highest indicator of the total load, which is 30 % higher compared to other types of work of drivers.

Conflict of interest

The authors declare that they have no conflict of interest in relation to this study, including financial, personal, authorship, or any other, that could affect the study and its results presented in this article.

Financing

The study was conducted without financial support.

Data availability

The manuscript has data included as electronic supplementary material.

Use of artificial intelligence

The authors confirm that they did not use artificial intelligence technologies when creating the presented work.

References

1. Ong-Artborirak, P., Kantow, S., Seangpraw, K., Tonchoy, P., Auttama, N., Choowanthanapakorn, M., Boonyathee, S. (2022). Ergonomic Risk Factors for Musculoskeletal Disorders among Ethnic Lychee–Longan Harvesting Workers in Northern Thailand. Healthcare, 10 (12), 2446. https://doi.org/10.3390/healthcare10122446
2. Tsopa, V. A., Cheberiachko, S. I., Yavorska, O. O., Deryugin, O. V., Aleksieiev, A. A. (2022). Improvement of the safe work system. Naukovyi Visnyk Natsionalnoho Hirnychoho Universytetu, 6, 104–111. https://doi.org/10.33271/nvngu/2022-6/104
3. Kim, D. K., Park, S. (2021). An analysis of the effects of occupational accidents on corporate management performance. Safety Science, 138, 105228. https://doi.org/10.1016/j.ssci.2021.105228
4. Yokoyama, K., Iijima, S., Ito, H., Kan, M. (2013). The socio-economic impact of occupational diseases and injuries. Industrial Health, 51 (5), 459–461. https://doi.org/10.2486/indhealth.500
5. Monteiro, A. P., Vale, J., Silva, A. (2021). Factors Determining the Success of Decision Making and Performance of Portuguese Companies. Administrative Sciences, 11 (4), 108. https://doi.org/10.3390/admsci11040108
6. Bazaluk, O., Tsopa, V., Okrasa, M., Pavlychenko, A., Cheberiachko, S., Yavorska, O. et al. (2024). Improvement of the occupational risk management process in the work safety system of the enterprise. Frontiers in Public Health, 11. https://doi.org/10.3389/fpubh.2023.1330430
7. Bazaluk, O., Tsopa, V., Cheberiachko, S., Deryugin, O., Radchuk, D., Borovytskyi, O., Lozynskyi, V. (2023). Ergonomic risk management process for safety and health at work. Frontiers in Public Health, 11. https://doi.org/10.3389/fpubh.2023.1253141
8. Ispăşoiu, A., Milosan, I., Gabor, C., Oancea, G. (2023). A New Methodology for Validation of the Ergonomics Risk Assessment in Industry. Processes, 11 (12), 3261. https://doi.org/10.3390/pr11123261
9. Kee, D., Na, S., Chung, M. K. (2020). Comparison of the Ovako Working Posture Analysis System, Rapid Upper Limb Assessment, and Rapid Entire Body Assessment based on the maximum holding times. International Journal of Industrial Ergonomics, 77, 102943. https://doi.org/10.1016/j.ergon.2020.102943
10. Gómez-Galán, M., Callejón-Ferre, Á.-J., Pérez-Alonso, J., Díaz-Pérez, M., Carrillo-Castrillo, J.-A. (2020). Musculoskeletal Risks: RULA Bibliometric Review. International Journal of Environmental Research and Public Health, 17 (12), 4354. https://doi.org/10.3390/ijerph17124354

11. Thani, S. K. S. O., Cheok, N. S., Hussein, H. (2022). A Preliminary Assessment of Neuro-Salutogenic Landscape Stimuli in Neighbourhood Parks: Theory-Based Model for Stress Mitigation. IFMBE Proceedings, 461–469. https://doi.org/10.1007/978-3-030-90724-2_50
12. Zhao, Y., Rokhani, F. Z., Sazlina, S.-G., Devaraj, N. K., Su, J., Chew, B.-H. (2022). Defining the concepts of a smart nursing home and its potential technology utilities that integrate medical services and are acceptable to stakeholders: a scoping review. BMC Geriatrics, 22 (1). https://doi.org/10.1186/s12877-022-03424-6
13. Wu, Y., Wu, W., Lin, Y., Xiong, J., Zheng, X. (2022). Blood pressure states transitions among bus drivers: the application of multi-state Markov model. International Archives of Occupational and Environmental Health, 95 (10), 1995–2003. https://doi.org/10.1007/s00420-022-01903-2
14. Nygaard, N.-P. B., Thomsen, G. F., Rasmussen, J., Skadhauge, L. R., Gram, B. (2022). Ergonomic and individual risk factors for musculoskeletal pain in the ageing workforce. BMC Public Health, 22 (1). https://doi.org/10.1186/s12889-022-14386-0
15. Remy, V. F. M., Guseva Canu, I. (2023). Healthy Bus Drivers, Sustainable Public Transport: A Three-Time Repeated Cross-Sectional Study in Switzerland. International Journal of Public Health, 68. https://doi.org/10.3389/ijph.2023.1605925
16. Rypicz, Ł., Rozensztrauch, A., Fedorowicz, O., Włodarczyk, A., Zatońska, K., Juárez-Vela, R., Witczak, I. (2023). Polish Adaptation of the Alarm Fatigue Assessment Questionnaire as an Element of Improving Patient Safety. International Journal of Environmental Research and Public Health, 20 (3), 1734. https://doi.org/10.3390/ijerph20031734
17. Yang, Z., Zhou, W., Xu, G., Li, X., Yang, M., Xiao, Q. et al. (2023). The analysis and optimization of thermal sensation of train drivers under occupational thermal exposure. Frontiers in Public Health, 11. https://doi.org/10.3389/fpubh.2023.1164817
18. Zhang, M., Zhang, L., Cao, X., Li, B., Zhou, A. (2023). FRAM-based causal analysis and barrier measures to mitigate dust explosions: A case study. PLOS ONE, 18 (6), e0287328. https://doi.org/10.1371/journal.pone.0287328
19. Vijayakumar, R., Choi, J. (2022). Emerging Trends of Ergonomic Risk Assessment in Construction Safety Management: A Scientometric Visualization Analysis. International Journal of Environmental Research and Public Health, 19 (23), 16120. https://doi.org/10.3390/ijerph192316120
20. Chatzis, T., Konstantinidis, D., Dimitropoulos, K. (2022). Automatic Ergonomic Risk Assessment Using a Variational Deep Network Architecture. Sensors, 22 (16), 6051. https://doi.org/10.3390/s22166051
21. Palikhe, S., Lee, J. Y., Kim, B., Yirong, M., Lee, D.-E. (2022). Ergonomic Risk Assessment of Aluminum Form Workers' Musculoskeletal Disorder at Construction Workstations Using Simulation. Sustainability, 14 (7), 4356. https://doi.org/10.3390/su14074356
22. Freitas, A. A., Lima, T. M., Gaspar, P. D. (2022). Ergonomic Risk Minimization in the Portuguese Wine Industry: A Task Scheduling Optimization Method Based on the Ant Colony Optimization Algorithm. Processes, 10 (7), 1364. https://doi.org/10.3390/pr10071364
23. Verbeek, J., Mischke, C., Robinson, R., Ijaz, S., Kuijer, P., Kievit, A., Ojajärvi, A., Neuvonen, K. (2017). Occupational Exposure to Knee Loading and the Risk of Osteoarthritis of the Knee: A Systematic Review and a Dose-Response Meta-Analysis. Safety and Health at Work, 8 (2), 130–142. https://doi.org/10.1016/j.shaw.2017.02.001
24. van der Molen, H. F., Foresti, C., Daams, J. G., Frings-Dresen, M. H. W., Kuijer, P. P. F. M. (2017). Work-related risk factors for specific shoulder disorders: a systematic review and meta-analysis. Occupational and Environmental Medicine, 74 (10), 745–755. https://doi.org/10.1136/oemed-2017-104339
25. Nakaz Ministerstva okhorony zdorovia Ukrainy. No. 248 vid 08.04.2014 r. «Pro zatverdzhennia Derzhavnykh sanitarnykh norm ta pravyl «Hihienichna klasyfikatsiya pratsi za pokaznykamy shkidlyvosti ta nebezpechnosti faktoriv vyrobnychoho seredovyshcha, vazhkosti ta napruzhenosti trudovoho protsesu». Available at: https://zakon.rada.gov.ua/laws/show/z0472-14#Text
26. van Rijn, R. M., Huisstede, B. M. A., Koes, B. W., Burdorf, A. (2008). Associations between work-related factors and specific disorders at the elbow: a systematic literature review. Rheumatology, 48 (5), 528–536. https://doi.org/10.1093/rheumatology/kep013
27. Andersen, L. L., Fallentin, N., Thorsen, S. V., Holtermann, A. (2016). Physical workload and risk of long-term sickness absence in the general working population and among blue-collar workers: prospective cohort study with register follow-up. Occupational and Environmental Medicine, 73 (4), 246–253. https://doi.org/10.1136/oemed-2015-103314
28. Hulshof, C. T. J., Pega, F., Neupane, S., van der Molen, H. F., Colosio, C., Daams, J. G. et al. (2021). The prevalence of occupational exposure to ergonomic risk factors: A systematic review and meta-analysis from the WHO/ILO Joint Estimates of the Work-related Burden of Disease and Injury. Environment International, 146, 106157. https://doi.org/10.1016/j.envint.2020.106157
29. Deryugin, O. V., Cheberyachko, S. I., Tretyak, O. O., Cheberyachko, I. M. (2018). Determination of bus drivers' biological age. Pedagogics, Psychology, Medical-Biological Problems of Physical Training and Sports, 22 (2), 77. https://doi.org/10.15561/18189172.2018.0203
30. Tasdelen, A., Özpinar, A. M. (2023). A Dynamic Risk Analysis Model Based on Workplace Ergonomics and Demographic-Cognitive Characteristics of Workers. Sustainability, 15 (5), 4553. https://doi.org/10.3390/su15054553
31. Rahman, M. H., Ghasemi, A., Dai, F., Ryu, J. (2023). Review of Emerging Technologies for Reducing Ergonomic Hazards in Construction Workplaces. Buildings, 13 (12), 2967. https://doi.org/10.3390/buildings13122967
32. Deryugin, O., Cheberyachko, S. (2015). Substatiation of truck selection in terms of minimizing psychophysiological stress on a driver. Eastern-European Journal of Enterprise Technologies, 3 (3 (75)), 15–22. https://doi.org/10.15587/1729-4061.2015.42127
33. Theeraviriya, C., Pitakaso, R., Sillapasa, K., Kaewman, S. (2019). Location Decision Making and Transportation Route Planning Considering Fuel Consumption. Journal of Open Innovation: Technology, Market, and Complexity, 5 (2), 27. https://doi.org/10.3390/joitmc5020027