Assessment of the physical load of the waterjet operator using the G. Lehmann method

doi:10.2478/mape-2019-0010
Date of submission to the Editor: 04/2018
Date of acceptance by the Editor: 07/2018

MAPE 2019, volume 2, issue 1, pp. 101-107

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INTRODUCTION

Every work done is a man's creative process that involves the biological burden of his body. The general workload consists: physical load and mental strain. The physiology of work examines the impact of this burden on the employee's body. According to G. Lehmann's view, the purpose of the research is to properly adapt the work to man, ensuring the economic use of his work force, avoiding unnecessary effort and fatigue (Blaszczok, 2018; Lehmann 1966). In practice, this means the possibility of developing selection principles for individual occupations, vocational training, determining the rhythm of work and rest, methods to prevent fatigue, or improving workstations and the work environment as a whole (Gorska, Lewandowski, 2016).

The performance of any professional work requires simultaneous involvement of both muscles, the nervous system as well as other human systems and organs. However, depending on the degree of participation (predominance) of the musculoskeletal system and the nervous system, there is a distinction between physical work and mental work. In the first case, the participation of executive bodies, the so-called effectors (muscles). In contrast, mental work is more involved in the nervous system. Nevertheless, it should be emphasized that each physical work will contain elements of mental work (more or less), while mental work elements of physical work (Blaszczok, 2018; Olszewski, 1997; Rosner, 1985).

The burden on the human body during physical work depends primarily on the type of physical effort put into the implementation of particular activities. Therefore, the static, dynamic and monotype loads are distinguished. The analysis of the physical load consists in the verification of the dynamic and static load. Dynamic work consists in the movement of the body or its selected elements and is characterized by the occurrence of isotonic muscle contractions, associated with the change in its length. Alternate lengthening and contraction of the muscles causes movement.

When assessing the dynamic load, you should consider such risk factors as:

– the mass of the object being conveyed;
– work rhythm (e.g. transfer rate);
– position when working;
– the ability to turn the torso;
– the difference in levels between taking and folding the item;

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– transfer distance.

In turn, during static work there are isometric contractions, causing at least a few seconds muscle tension, while maintaining their length. Work under static load takes place in a forced body position, during which it is not possible to change the body position for more than 50% of the working day time. As an example, you can indicate work with a bent and/or twisted torso, bent and/or twisted neck, on your knees, in a squat, with your arms raised above your head. Determining the type of effort determines the choice of the method of assessing the body's load during physical work.

During work, the human body bears a certain cost associated with this work. There are two types of costs: (Kordecka, 2000)

– ***energy costs*** – the amount of energy spent on performing specific tasks (activities); it is easy to measure or estimate;
– ***physiological cost*** – causing a change (disorder) in the functioning of individual human systems and organs during work.

In the further part of this paper, due to its purpose and scope, energy cost (expense) will be presented as a parameter characterizing the severity of physical effort.

When performing physical work, the energy produced by the human body is converted into mechanical energy and heat. The amount of energy produced at that time is an energy expenditure. It reflects the metabolic rate and makes it possible to assess the severity of physical work performed. The overall (effective) energy expenditure consists of the energy expenditure of resting metabolism and the energy expenditure of effective work. In the resting state the human body shows a constant energy consumption, which is about 1700 kcal for an adult male (7000 kJ), and for an adult woman – about 1400 kcal (5900 kJ) per day. It is the necessary energy used to satisfy basic life processes. It should be emphasized that the level of resting energy depends on many factors, such as: sex, age, body weight, height, as well as the season, body temperature and ambient temperature. With the start of work, depending on its intensity, the energy needs posed by the muscles increase. In this case, the assessment of the energy expenditure depends on: (Zawieski 2004)

– intensity of performed work,
– the type of individual duties,
– the position in which particular activities are performed (kneeling, sitting, standing, etc.),
– involvement of individual parts of the body in the work (arms, hands, legs, the whole body).

Energy expenditure is determined in calorimetric units, i.e. in calories (in cal) or in kilocalories (kcal) and in units of work, i.e. in Joules (J) or kilojoules (kJ). On the basis of the value of energy expenditure, a specific work (activities) is classified as: very light, light, moderate, heavy and very heavy. In addition, according to the regulations in force in Polish legislation (Journal of Laws of 1996 No. 60 item 279), the employer is obliged to provide preventive meals or drinks or refuse to provide them on the basis of energy expenditure measurements and the test report.

METHODOLOGY OF RESERCH

The method of assessing the energy expenditure of G. Lehmann consists in determining two grades when performing work:

– body position (part A) – the energy expenditure resulting from maintaining proper body position is estimated using the criteria described in Table 1;
– involvement of body fragments (muscle groups) and the degree of its severity (part B) – in this case, the energy expenditure is estimated taking into account the scope of activities and the individual muscle groups involved in their performance (Table 2).

Table 1
Energy expenditure depending on the position of the body

Position of the body	Energy expenditure	
	[kcal/min]	[kJ/min]
Seated	0.3	1.3
Kneeling	0.5	2.1
Stagnant	0.6	2.5
Standing inclined	0.8	3.3
Going	2.6	10.89

Source: Lehmann 1996.

The following criteria should be considered during the initial qualification by gravity:

– ***light work*** – work done at a free pace, the weight of the tools used and the objects being transported is negligible,
– ***medium-heavy work*** – work requiring fast pace and handling (or transport) with items of mass (M) 5 < M <10 kg or work at a moderate pace, but when moving items with a mass of 10 < M < 15 kg,
– ***heavy work*** – work requiring fast pace and operations using objects of 10 < m < 15 kg or moderate work with objects of mass > M > 15 kg.

The energy cost of work is defined as the sum of the results obtained in both discussed stages multiplied by the time of work (Bugajska; Lahmann 1966).

Table 2
Energy expenditure depending on the type of work

Type of work		Medium range [kcal/min]		Medium range [kJ/min]	
Work of fingers, hands and forearm	*light*	0.4	0.2–1.2	1.7	0.8–5.0
	average	0.7		2.9	
	heavy	0.9		3.8	
Work of one arm	*light*	1.0	0.7–2.5	4.2	0.8–10.5
	average	1.4		5.9	
	heavy	1.8		7.6	
Work of both arms	*light*	1.5	1.0–3.5	6.3	4.2–14.7
	average	2.0		8.4	
	heavy	2.5		10.5	
Work of the whole body	*light*	3.5	2.5–15.0	14.7	10.5–63.0
	average	5.0		21.0	
	heavy	7.0		29.4	
	very heavy	9.0		37.8	

Source: Lehmann 1966.

On the basis of the amount of energy expenditure, the degree of work's severity is determined (Table 3). The correct assessment depends on a reliable list of all work activities performed by the employee, the proper classification of these activities to the type of work and their effort by selecting light, medium or heavy work.

Table 3
Classification of work severity based on effective energy expenditure in the course of a work shift

The degree of heaviness of work	Energy expenditure during the working day			
	Men		Women	
	[kcal]	[kJ]	[kcal]	[kJ]
Very light	< 300	< 1256	< 200	< 837
Light	300–800	1256–3350	200–700	837–2930
Moderate	800–1500	3350–6280	700–1000	2930–4187
Heavy	1500–2000	6280–8374	1000–1200	4187–5024
Very heavy	> 2000	> 8374	> 1200	> 5024

Source: Lehmann 1966.

It should be emphasized that the values given in the tables refer to work performed in conditions of moderate thermal environment. In the case of a hot environment, the energy expenditure is higher by approx. 12%, and the cold environment – 10%.
The main advantage of the presented method of testing energy expenditure by G. Lehmann is easy to use, which is related to the fact that it can be used in almost all conditions. In addition, the assessment process has no impact on the course of activities performed by the employee. The error obtained when using this method falls within the limits accepted in practical research.
In turn, the disadvantage of this method may be that it does not take into account external conditions that prevail when the employee performs specific activities (e.g. excessive temperature in the workplace, static load), and does not take into account the individual characteristics of the employee (e.g. age, state of health).

RESULTS

The assessment of the energy expenditure was carried out for the station of the waterjet operator using the timing and tabulation method according to G. Lehmann. The work of a waterjet operator consists in performing activities related to cutting a wide range of materials such as: metals, all types of steel, wood, ceramics, foam, rubber, plastics or glass. The work takes place in a shift cycle, 8 hours per working shift.
The employee performs activities in accordance with the established process, usually in a standing or Going position. The implementation of some tasks requires the operator to use force. The machine is controlled by a computer, and the cutting of materials is carried out with water under pressure (with or without abrasive). Materials for the stand are transported by hand (up to 1 kg) either by a forklift or a crane, after which it is inserted into the plotter table by means of a lifting device and manually adjusted by the operator under the plotter's working head (which requires standing from the worker, inclined). The operator's tasks also include transporting the cut materials to the place of storage, cleaning the workstation and performing minor repairs and maintenance (in accordance with his skills).
The operator's station is located in the hall with the following dimensions: length: 30 m; width: 12 m; height: 9 m. The object is heated by a central heating installation and meets the requirements for minimum temperatures at physical workplaces. The place of work is illuminated by daylight through the trained surfaces of the walls and in the ceiling. Additional lighting is provided by fluorescent lamps. The floor is even, uncluttered, dust-free and without any frets between the rooms. Employees have access to full sanitary and hygienic facilities. Evacuation routes have been designated

on the company's premises and are marked with appropriate pictograms.
Assessment of the energy expenditure of the author's own research requirements, which consists of several legitimate stages. The first of these was to observe the activities performed by the employee at a particular workplace and to prepare a photograph of the working day (timekeeping). The employee was observed within 8 working hours (100% of working time). Then, activities based on a similar energy expenditure were grouped on the basis of the photograph of the working day. The next stage of the study consisted in reading from the tables the energy expenditure associated with the assumed body position and the energy expenditure characteristic of the light load on the muscles involved in the work. Effective energy expenditure was estimated by summing up the above-mentioned partial values. The results are shown in Table 4.

Table 4
Assessment of energy expenditure for the waterjet operator

Lp.	Professional activities	Time [min]	Body position	A group of muscles involved in the work	Energy expenditure
1.	Disguise in work clothes, taking a job	10 min	Going	Work of both arms	(10.89 + 6.3) x 10 = 171.9
2.	Preparation of the workplace plotter table	10 min	Standing inclined	Work of both arms	(3.35 + 6.3) x 10 = 96.5
3.	Manual transport of materials to the	18 min	Going	Work of the whole body	(10.89 + 14.7) x 18 = 460.6
4.	Mechanical transport of materials to the plotter table (gantry crane)	8 min	Going	Work of both arms	(10.89 + 6.3) x 8 = 137.5
5.	Embedding material on the template	21 min	Standing inclined	Work of both arms	(3.35 + 6.3) x 21 = 202.65
6.	Input of data to the control computer	8 min	Stagnant	Work of one arm	(2.51 + 4.2) x 8 = 53.7
7.	Supervision of the process (in a hazard-free zone, working in front of a computer	295	seated	Work of fingers, hands and forearm	(1.26 + 1.7) x 295 = 873.2
8.	Transporting the finished product and waste to the place of storage	14 min	Going	Work of the whole body	(10.89 + 14.7) x 14 = 358.3
9.	Cleaning works (sweeping, wiping water)	17 min	Going	Work of both arms	(10.89 + 6.3) x 17 = 292.2
10.	Physiological needs	14 min	Going	Work of both arms	(10.89 + 6.3) x 14 = 240.7
11.	Organizational breaks	25 min	Going	Work of both arms	(10.89 + 6.3) x 25 = 429.8
12.	Regulatory breaks	30 min	seated	Work of both arms	(1.26 x 6.3) x 30 = 226.8
13.	Shower, clothes of your own clothing	10 min	Going	Work of both arms	(10.89 + 6.3) x 10 = 171.9
SUM		480 min			3 715.75

The effective energy expenditure at the work station of the waterjet operator per shift (480 minutes) is 3 715.75 kJ, and the work is performed by a man, which results in the classification of the work performed in terms of its severity as moderate work.

CONCLUSION

Based on the reading of this publication, conclusions and final statements can be formulated:

1. Work is a creative process undertaken by man, involving the nervous, muscular and other human systems and organs to varying degrees. Depending on the degree of their load, the work performed distinguishes between physical and mental work, which is extremely important from the point of view of physiology and ergonomics of work. However, this is a division that is fairly conventional, as there are no such categories of work in Polish law.
2. Excessive physical strain on a person may lead to fatigue, injuries and musculoskeletal disorders, as well as lower quality and efficiency of work and affect the safety of the employee and his colleagues.
3. The basic parameter determining the severity of physical work is the energy expenditure, which means the amount of energy spent by a person during work. Its value depends on such factors as body position, physical activity, weight of objects being moved or held, speed of work, as well as microclimate (cold, hot, changeable).
4. The Lehmann energy expenditure study method presented in the work belongs to the group of estimation methods in which the value of energy expenditure is read out from the developed tables for typical professional and non-professional activities. It is characterized by the ease of measurement, does not require the use of specialized equipment and is not burdensome for the subjects and does not interfere with the course of work. The disadvantage of the presented method may be that it does not take into account external conditions that prevail when the employee performs specific activities (eg excessive temperature, static load) and individual characteristics of the employee (eg age, health).
5. The results of the energy expenditure assessment can be the basis for changes in environmental conditions, tools and working methods used to improve the employee's effort or they can also be a warning against the effects of excessive workload. In addition, such an assessment is indispensable in the implementation of Polish legal regulations, in particular the regulations on prophylactic meals and beverages, as well as on the work of troublesome, dangerous or harmful to pregnant women and breast-feeding women.
6. The analysis of the scope of activities performed by the waterjet operator allows to state that it accepts different body positions during the work shift (walking, sitting, standing inclined), and the work engages different muscle groups.
7. The waterjet operator's work is carried out at a free pace, and the weight of the tools and materials being transported is negligible, which allowed it to be classified as moderate.
8. The assessment of the energy expenditure at the workplace of the waterjet operator using the G. Lehmann method allows to qualify the work as moderate. Therefore, it appears that the employer is not obliged to provide employees with prophylactic meals and drinks.

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Abstract. Basic parameter characterizing the body's workload (in particular physical work) is the energy expenditure, which determines the amount of energy used to perform a specific job (in kcal or kJ). The purpose of this work was to determine the energy expenditure at the station of a water-cutting machine using the tabular-timing method according to G. Lehmann. As part of the author's own research, the position of the waterjet operator was described, taking into account the basic hazards present in the work environment and the requirements regarding occupational health and safety. The paper also presents the results of the energy expenditure assessment and their analysis, which allowed to propose corrective and preventive actions.

Keywords: Lehmann's method, energy expenditure, physical load, ergonomic diagnosis, water-cutting operator