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The Tests of Miner's Physical Effort Using Statistical Methods during Rescue Exercises on Exercise Devices

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ABSTRACT*: The article presents the results of physical effort research during rescue exercises on a group of miners working as mining rescuers belonging to the mining rescue station. 100% of the population they were miners from one hard coal mine. 150 rescuers were examined, divided into five groups according to the number of exercise devices. The substantial aim of the study was the analysis of the impact of the sequence of the training exercises on the heartbeat frequency of the rescuers. Five test groups were formed for the study. Each group comprised 30 rescuers, corresponding to 6 rescue teams. The members of the test groups were selected randomly, as the aim of the study was the sequence of exercises performed using different training machines. Physical fitness of mine rescuers affects the quality of activities performed during the actual rescue. During the tests it was observed that the endless ladder is the most burdensome, regardless of the order on which the device was previously performed. The current way of doing exercises is properly selected, thus allowing the rescuer to maintain physical fitness at a high level.*

KEY WORDS: *mining rescuer, mine, rescue, training, exercises*

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I. INTRODUCTION

We hear about mine rescue services i.a. during the conducted rescue actions. When asked, people answer that mine rescuers save human lives in extreme conditions what is unquestionable. The service of a mine rescuer may be analyzed from different perspectives, and the most comprehensive approach is of a multidimensional character. The analysis of the profession may be commenced with the most basic definitions, such as the psychology of work, which analyzes the tasks by selection of diagnostic methods of desirable qualities, determines the motivation methods and shapes the work environment [1]. The primarybehavioral standards during the performance of work safely and healthily – also concerning the mining rescue services – may be analyzedgiven the safety culture assessment. One of the proposals regarding the safety culture consists in its division into two dimensions – the so-called visible and hidden manifestations. The study of the safety climate is one of the elements of the analysis of the safety culture [2]. The analysis of the safety culture, i.a. based on checklists, measurements of the work environment, occupational accidents statistics and observation of the behavior of employees is not sufficient for shaping the level of the safety culture in places of employment [3]. Work in the conditions of mining hazards requires proper psychophysical fitness and the reason why a mine rescuer must be well-prepared both physically and mentally. Due to the above, mine rescue team members undergo appropriate physical training, which is one of the necessary conditions to perform that profession. Mine rescuers take part in rescue actions and disasters that may lead i.a.to losses in fixed assets. The subject of pricing of fixed assets lost in result of mining disasters was raised in the study of the market, asset and profit methods [4]. Additionally, the rescuers participate in the design of underground tourist routes to ensure safe conditions for tourist traffic. The rescuers conduct test passages and evacuation of tourists to the surface. The subject of designing underground tourist routes was taken up in the publication regarding the protection of historic underground objects in line with natural processes [5].

Most often, the subject of physical effort of miners and mine rescuers is considered as a part of other detailed studies, such as:

- the analysis of energy expenditure e.g. [6],
- analysis of adaptation to heat load e.g. [7],
- analysis of safe passage time of rescue teams e.g. [8],
- analysis of physiological parameters in view of climatic hazard e.g. [9].

An example of analysis of physiological parameters and professional experience in view of the passage time of rescue teams, conducted using the CSRG S.A. training chamber in Bytom, has been presented in a series of publications regarding:

- Introduction to the subject and basic scientific assumptions [10],
- Dependence between the passage time of rescue teams and the BMI index [11],
- Dependence between the passage time and of rescue teams and the height of rescue team members [12],
- Impact of the age and professional experience of mine rescuers on the passage time of rescue teams [13],
- Impact of the heart rate of mine rescuers on the passage time of rescue teams [14],
- Comparative analysis of study results and summary [15].

II. MATERIAL AND METHODS

The research methods currently applied in mining are based on i.a. numerical simulations - e.g., the impact of climate change on the distribution of gas concentrations around the shaft [16], a long-term analysis of deformations of workings [17].

In case of the analysis of the occupational safety and health, most of all, quantitative methods are pursued, and for it the direct measurements are substantiated in case of the assessment of physiological parameters.

The aim of the study was the analysis of the level of physical effort of a mine rescuer while performing exercises using different cardiac stress devices while considering the criteria of heart rate, weight and height of the population in concern. Selected statistical methods were used to study the physical effort of the mine rescuers. The statistical analysis was usedto determine whether the heart rate of mine rescuers measured during the rescue training is within the safe range for a given population.

The study group was selected based on the number of mine rescuers in one of the coal mines (100%), that is, 150 mine rescue team members. Due to the number of cardiac stress test devices (5), that is, group I – bicycle, group II – treadmill, group III – hammer, group IV – indoor rower and group V – ladder. The research sample was assigned evenly to each of the machines - 30 rescuers in each of the groups.

The tests were conducted in OSRG in Bytom in a training chamber in the years 2016-2017 during rescue training. Each of the rescue team members was to exercise using each of the cardiac stress devices. For make the exercises more efficient, the exercises were conducted in teams of five while not disturbing the conducted rescue training – before a rescue team member entered the room, they were registered using a computer, measured and weighted as well as each rescuer received a heart rate monitor. A rescuer prepared in such a way had to log in into the system before commencing the training. After the exercise was completed, there was a break before switching the training device, e.g., a person starting with a hammer switches to the indoor rower, ladder, bicycle and treadmill. The entire study was supervised by a medical doctor who monitored the condition of the rescuers taking part in the study on a current basis.

All results were archived in measurement tables, separate for each of the study groups. The tables contained the results of heart beats per minute (the initial and final values as well as the difference), separately per each of the cardiac stress testing devices. Example of a fragment of a measurement table has been shown in Table I.

Table II presents the data of the rescuers from group 1 and contains the age, weight and the height of the rescuers. Five test groups were formed for the study due to the number of the cardiac stress testing devices. Five testing devices were used in the study. Thus one team could actively participate in the study simultaneously. Each of the devices (test group) served the testing of 30 rescuers (6 full teams).

Arithmetic mean was calculated for the test groups, being the basic classical measure of the central tendency, constituting the sum of the variable of all the units of the studied population divided by the number of the units [18]:

$$\bar{x} = \frac{1}{n} \cdot \sum_{j=1}^{n} x_j \qquad (1)$$

where:
x_j – the value of the measurable feature
n – the size of the observed set of units.

Table I. Fragment of a measurement table with results for rescuers commencing the exercises with the ladder exercise

	Instrument I bicycle			Instrument II treadmill			Instrument III hammer			Instrument IV indoor rower			Instrument V ladder		
	ValueInitial	Finalvalue	Difference	Initial Value	Finalvalue	Difference	Initial Value	Finalvalue	Difference	Initial Value	Finalvalue	Difference	Initial Value	Finalvalue	Difference
Rescue mining	100	120	20	130	110	-20	100	100	0	100	110	10	80	140	60
	90	130	40	100	100	0	80	120	40	100	120	20	90	100	10
	110	140	30	130	120	-10	120	130	10	120	140	20	100	160	60
	110	120	10	120	110	-10	100	110	10	120	120	0	80	150	70
	90	100	10	100	100	0	80	100	20	90	100	10	80	120	40
	100	140	40	100	120	20	100	130	30	120	120	0	80	120	40
	120	160	40	150	130	-20	120	140	20	130	130	0	90	170	80
	100	120	20	110	100	-10	80	120	40	100	100	0	80	140	60
	100	120	20	120	120	0	80	120	40	120	120	0	80	140	60
	100	140	40	110	110	0	100	120	20	120	120	0	90	110	20
	120	140	20	140	130	-10	120	130	10	120	140	20	100	160	60
	110	140	30	100	120	20	100	120	20	100	130	30	100	120	20
	90	120	30	80	110	30	90	100	10	80	120	40	80	140	60
	90	120	30	100	100	0	80	120	40	100	120	20	90	100	10
	100	140	40	130	120	-10	100	120	20	120	140	20	100	160	60

Table II. Data of the group I rescuers

Number of the rescuer	Age [years]	Weight [kg]	Height [cm]	Number of the rescuer	Age [years]	Weight [kg]	Height [cm]
1.	41	75	175	16.	32	80	197
2.	46	79	174	17.	28	75	175
3.	39	68	168	18.	31	75	172
4.	37	90	180	19.	37	88	183
5.	30	83	177	20.	35	91	182
6.	43	87	176	21.	38	83	187
7.	31	79	176	22.	41	78	174
8.	39	95	182	23.	36	78	175
9.	33	78	182	24.	28	96	186
10.	39	105	190	25.	40	90	173
11.	43	89	180	26.	36	78	175
12.	42	95	170	27.	24	64	174
13.	48	77	177	28.	36	88	187
14.	37	85	176	28.	26	85	184
15.	25	90	185	30.	36	98	178

Table III presents the comparison of the test groups in view of the age, weight and height. The calculations of the arithmetic mean of the age of the participants, a range of 35 to 38 years was obtained, in case of the body mass, the range was from 84 to 87 kg and in case of height the range was 176 cm to 179 cm.

Table III. Comparison of test groups based on the criterion of age, weight and height

	Group I (bicycle)	Group II (treadmill)	Group III (hammer)	Group IV (indoor rower)	Group V (ladder)
Age	36	37	38	36	35
Weight	84	85	84	86	87
Height	179	178	176	179	179

Table III presents the comparison of the test groups in view of the age, weight and height. The calculations of the arithmetic mean of the age of the participants, a range of 35 to 38 years was obtained, in case of the body mass, the range was from 84 to 87 kg and in case of height the range was 176 cm to 179 cm.

The median (M) is a descriptive positional measure. In a set of values ordered from minimum to maximum (or the other way round), it is the value of the feature, above and beneath which, a similar amount of units of the statistical population occurs (50% of units has a lower value and 50% exhibit values higher than the median). For individual data, the median is determined without calculations while in case of [18]:

✓ An uneven number of units:

$$M_x = x_{j=(n:2)+1} \quad (2)$$

✓ -Even number of units:

$$M_x = \frac{x_{j=n:2} + x_{j=(n:2)+1}}{2} \quad (3)$$

Quartiles – the first quartile (Q_1) in the set of values ordered from min to max is the value of the feature under which, 25% of the population units occur while 75% of the units are above the value (25% of units exhibits lower values and 75% exhibits values that are higher than the first quartile).The third quartile (Q3) in the set of values ordered from min to max is the value of the feature under which, 75% of the population units occur while 25% of the units are above the value (75% of units exhibits lower values and 25% exhibits values that are higher than the first quartile).

The quartiles were calculated based on the following formula:

$$Q_x = 1/2\left(x_{m(n:4)} + x_{m(n:4)+1}\right), \text{ when n:4} \quad (4)$$

$$Q_x = \begin{cases} 1/2\left(x_{[m(n+1):4]-0,5} + x_{[m(n+1):4]+0,5}\right) \\ x_{m(n:4)+0,5} \\ x_{m(n+1):4} \end{cases}, \ when \begin{cases} (n+3):4 \\ (n+2):4 \\ (n+1):4 \end{cases} \quad (5)$$

Interquartile range – the difference between the third and the first quartile.50% Of all the observations fit in the interquartile range (after rejecting the 25% of the highest and the lowest).The higher is the range; the more is the feature variable.

III. RESULTS AND DISCUSSIONS

The analysis of the selected results of the tests of physical effort of rescuers during the training was based on statistical methods and compiled below in tables IV-X.

Table IV. Arithmetic mean of the heart rate for individual test groups

Exercise device	Group I (bicycle)	Group II (treadmill)	Group III (hammer)	Group IV (indoor rower)	Group V (ladder)
bicycle	18	-3	-1	-5	-3
treadmill	23	27	12	15	20
hammer	19	25	27	16	16
indoor rower	29	34	32	37	27
ladder	34	44	36	45	54
Final result	59	37	37	49	44

Table IV presents the values of the arithmetic mean for the individual test groups while considering the difference between the initial and the final heart rates.

Test groups' results included in table 4:

✓ Test group I commenced the exercises with the bicycle, reaching 18 BPM,
✓ Test group II commenced the exercises with the treadmill, reaching 27 BPM,
✓ Test group III commenced the exercises with the hammer, reaching 27 BPM,
✓ Test group IV commenced the exercises with the indoor rower, reaching 37 BPM,
✓ Test group V commenced the exercises with the ladder, reaching 54 BPM,

Moreover, Table IV presents the final result which constitutes the final arithmetic mean, that is, after performing all five exercises, the following results were reached:

✓ Group I – 59 BPM,
✓ Group II – 37 BPM,
✓ Group III – 37 BPM,
✓ Group IV – 49 BPM,
✓ Group V – 44 BPM.

Table V. Quartiles for the heart rate values – final values after performing exercises using all the cardiac stress testing devices

Statistical size	Group I (bicycle)	Group II (treadmill)	Group III (hammer)	Group IV (indoor rower)	Group V (ladder)
Q_1	40	20	20	40	40
$Q_{2=Me}$	60	40	40	50	40
Q_3	70	50	40	50	50
Interquartile range	30	30	20	10	10

Table V presents the values of the first quartile Q1 for all the test groups. In groups I, IV and V, values lower than 40 BPM were observed in case of 25% of rescuers and higher than 40 BPM in case of 75%.The third quartile Q3 in group I designates that 75% of the rescuers reached values lower than 70 BPM and 25% of the rescuers reached values higher than the third quartile.A median was calculated for all test groups, where the highest value was exhibited by group.I – 60 BPM, which means that 50% of the rescuers reached values that were higher and 50% reached values that were lower than 60 BPM.The highest interquartile range was observed for the test groups I and II, reaching 30 BPM after rejecting 25% of the lowest and 25% of the highest obtained values.

Table VI. Quartiles for the heart rate values – a difference of values after performing exercises using all the cardiac stress testing devices

Exercise device	Statistical size	Group I	Group II	Group III	Group IV	Group V
	(bicycle)	(bicycle)	(treadmill)	(hammer)	(indoor rower)	(ladder)
bicycle	Q_1	10	-10	-10	-10	-10
	$Q_{2=Me}$	20	0	0	-5	0
	Q_3	20	0	10	0	10
	Interquartile range	10	10	20	10	20
treadmill	Q_1	0	20	0	10	10
	$Q_{2=Me}$	20	25	10	10	20
	Q_3	0	40	20	20	30
	Interquartile range	0	20	20	10	20
hammer	Q_1	10	20	20	10	0
	$Q_{2=Me}$	20	20	30	20	20
	Q_3	30	30	40	20	20
	Interquartile range	20	10	20	10	20
indoor rower	Q_1	20	20	20	30	20
	$Q_{2=Me}$	30	40	30	35	30
	Q_3	40	40	40	40	30
	Interquartile range	20	20	20	10	10
ladder	Q_1	20	30	30	30	40
	$Q_{2=Me}$	40	45	40	50	60
	Q_3	50	60	50	60	70
	Interquartile range	30	30	20	30	30

Table VI presents the results for the first quartile Q1 while considering the test groups and the sequence of exercises. The highest values were reached in group V – 40 BPM - the group that started the exercises with the ladder. In case of the third quartile Q3, the highest value was also noted in group V, where the result of 70 BPM was reached. The highest median value, that is, 60 BPM and the interquartile range of 30 BPM was noted in the group commencing the exercises with the ladder.

Table VII presents the results of the numbers for individual differences of the heart rate values for the two test groups. In case of the first group, the most common value was observed in 17 miners during the exercise on a treadmill (20 BPM).The treadmill was the second device in the exercise sequence, preceded by the bicycle, where an identical result was noted in 15 rescuers in the same heart rate difference value range..In case of the second group, the most common value was noted during the hammer exercises - 16 rescuers. This exercise was conducted as second, while in 13 rescuers no increase or decrease of heart rate was noted during the bicycle exercise which was the last in the sequence.

Table VII. Number of the most common heart rate values – groups 1 and 2

Number	Group 1					Group 2				
	bicycle	treadmill	hammer	indoor rower	ladder	bicycle	treadmill	hammer	indoor rower	ladder
-40	0	0	0	0	0	0	0	0	0	0
-30	0	0	0	0	0	0	0	0	0	1
-20	0	0	0	0	0	0	0	0	0	4
-10	0	0	2	0	0	0	0	0	0	6
0	2	1	5	0	0	0	0	0	1	13
10	8	3	4	6	4	3	3	3	1	4
20	15	17	9	5	8	12	16	5	5	2
30	4	5	4	9	2	7	4	6	4	0
40	1	3	4	7	8	7	6	10	4	0
50	0	1	2	2	4	1	1	4	4	0
60	0	0	0	1	3	0	0	2	7	0
70	0	0	0	0	1	0	0	0	1	0
80	0	0	0	0	0	0	0	0	3	0
90	0	0	0	0	0	0	0	0	0	0

Table VIII. Number of the most common heart rate values – groups 3 and 4

Number	Group 3					Group 4				
	bicycle	treadmill	hammer	indoor rower	ladder	bicycle	treadmill	hammer	indoor rower	ladder
-40	0	0	0	0	0	0	0	0	0	0
-30	0	0	0	1	0	0	0	1	0	0
-20	0	0	0	1	0	0	0	5	0	1
-10	0	0	1	8	1	0	0	9	0	0
0	1	0	2	12	9	0	1	11	6	5
10	2	0	1	6	7	1	1	0	10	8
20	10	9	3	2	11	6	4	4	9	10
30	9	10	4	0	1	8	2	0	2	2
40	8	9	9	0	1	8	6	0	3	4
50	0	0	6	0	0	3	6	0	0	0
60	0	2	4	0	0	3	6	0	0	0
70	0	0	0	0	0	0	2	0	0	0
80	0	0	0	0	0	1	2	0	0	0
90	0	0	0	0	0	0	0	0	0	0

In case of the third group the most common value was observed during the bicycle exercise - 12 rescuers (Table VIII). The bicycle exercise was the fourth in the sequence. In case of the fourth group, which performed the bicycle exercise as the third in the sequence (Table VIII), no increase or decrease of heart rate was noted in 11 rescuers (Table IX).

Table IX. Number of the most common heart rate values – group 5

Number	Group 5				
	bicycle	treadmill	hammer	indoor rower	ladder
-40	0	1	0	0	0
-30	0	0	0	0	0
-20	0	6	0	0	0
-10	0	7	0	0	0
0	0	8	3	8	0
10	1	4	7	6	3
20	4	2	11	9	11
30	0	1	4	5	9
40	4	1	5	2	7
50	1	0	0	0	0
60	11	0	0	0	0
70	4	0	0	0	0
80	4	0	0	0	0
90	1	0	0	0	0

Table IX presents the numbers for individual differences in the heart rate values for the last test group. The most common value was observed during the performance of the ladder exercise, the treadmill and the indoor rower exercises in 11 rescuers, however, in case of the ladder the value was (60) and (20) in case of the treadmill and indoor rower.

Table X. Numbers of the most common heart rate values – final values after performing exercises using all the cardiac stress testing devices

Number	Group 1	Group 2	Group 3	Group 4	Group 5
0	0	1	0	0	0
10	0	0	1	0	0
20	1	8	7	0	1
30	4	5	3	4	1
40	4	8	12	9	18
50	3	3	3	10	5
60	5	4	4	3	4
70	7	0	0	1	1
80	2	1	0	3	0
90	3	0	0	0	0
100	1	0	0	0	0

Table X presents the numbers for the final values, after the performance of exercises using all the cardiac stress testing devices. In group I the most common value was 70 BPM (7 rescuers).In group II the most common values were 20 and 40 BPM (8 rescuers in each case).In group II the most common value was 40 BPM (12 rescuers).In group IV the most common value was 50 BPM (10 rescuers) and in group V, it was 40 BPM (18 rescuers).

The analysis of the registered heart rate during the exercise using the cardiac stress testing devices indicates that the measurement result is within the safe range for the training rescuers - irrespective of the sequence of the exercises. Costa et al. [19] developed the physical training for mining rescuers. They also studied the heart rate in the Laboratory of Rescue and Rescue Operations INCD INSEMEX Petroşani, Romania. The authors noticed a trained rescuer has better achievements during rescue operations [19]. While analyzing the rescuers who conducted the bicycle exercise as the first one, it is notable that Q_1, $Q_{3,}$and$Q_{2=Me}$ reached the highest value after the first exercise. An interquartile range of 20 BPM was observed only in groups III and IV. In 2008, Ian B Stewart et al. researched 91 mining rescuers. Rescuers participated in the Queensland Mines Rescue Challenge competition in Australia. During the competition, they performed fitness exercises related to health and rescue. The bike is one of the devices during fitness exercises [20].

The rescuers who conducted the treadmill, hammer and ladder exercise as the first have reached the highest values of It may be noted, that the calculated Q_1, $Q_{3,}$and$Q_{2=Me}$ values have peaked during the first exercise irrespective of what the first exercise in the sequence was. The obtained highest values can be compared with the strength of a mine rescuer. Similar studies have been carried out by Palmer et al. [21], where the rescuer's heart rate, abdominal strength, flexibility, lower back strength, leg strength, bending strength, arm strength, lower back strength and leg strength have been measured.

Only the group I, which commenced the exercises with the bicycle exercise have reached Q_1, Q_3, $Q_{2=Me}$ and the interquartile range values from 10 to 20 BPM. The remaining groups reached lower Q_1, Q_3, $Q_{2=Me}$ values of than group I. It may be stated that the heart rate was decreased irrespective of the device used for the exercise.The reduction in the heart rate was also noticed in research of Costa et al. [19]. After the set of exercises proposed for mining rescuers in 2012, the research was repeated. The results were very comforting because rescuers got a 7% drop in heart rate.

IV. CONCLUSIONS AND RECOMMENDATIONS

- Regardless of the type of device from which the rescuers start the exercise, the value of the heart rate is the highest.
- Value differences were only analyzed during the quarter interval analysis. Only exercise performed on a bicycle resulted in an increase in heart rate, and during exercise on subsequent devices, no higher values were found than those obtained during cycling.
- An increase in the heart rate was observed during exercise, which is within the safe range for the rescuer. Moreover, after completing the exercises on the device rescuers have time to regen the body before proceeding to the next exercise.
- The highest observed interquartile range was observed during the so-called endless-ladder exercise, irrespective of the exercise preceding this exercise.

- The analysis and the study of the physical effort of the rescuers during exercises performed with the cardiac stress testing devices could in future be complemented by medical examination subject to safety requirements and health protection of the rescuers.

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