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The Effect of Body Mass on Physiological Indicators in the Performance of Forestry Workers

Ivan Martinić[1], Ksenija Šegotić[2], Stjepan Risović[2] and Vlado Goglia[2]

[1] Department of Forest Engineering, Faculty of Forestry, University of Zagreb, Zagreb, Croatia
[2] Department of Mathematics and Technical Basics, Faculty of Forestry, University of Zagreb, Zagreb, Croatia

A B S T R A C T

The paper presents the results of research into the effects of body mass (BM) on basic physiological indicators of work capability among forestry workers. The indicators included the maximum theoretical heart rate, the maximum heart rate in exertion tests, and the basal energy expenditure. The effects of the deviation of the actual from the ideal BM values were analysed on a sample of 8 workers. The variables included age, body height and mass. These were used to determine the maximum theoretical heart rate. The maximum heart rate was determined in an ergonomic laboratory in a programmed exertion test on a treadmill. Using standard formulae in work physiology, values of work capability indicators were calculated for the actual and ideal BM of each worker. The results, embracing individual and summary values and their absolute and relative ratios, showed that workers exceeded their ideal BM by an average of 9.9 kg. In all workers, the maximum theoretical heart rate was higher than that achieved in the exertion test. It was also found that even significant deviations of the ideal from the actual BM (the actual BM was more than 20% higher than the ideal BM) did not have any considerable effects on the maximum theoretical heart rate. The analysis of oxygen consumption showed that in relation to physical capability of the ideal BM and the maximal theoretical heart rate, physical capability of each worker was lower by an average of 11.5%. The highest reduction of physical capability was found in those workers with the least favourable ratio between the theoretical and the maximal tested heart rate. It was concluded that on average, the basal energy expenditure in each worker was higher by 7.45% due to the deviation of the actual from the ideal BM. At constant values of other factors, this means an equivalently lower capacity for daily physical performance.

Key words: *forestry, forest workers, body mass, heart rate, physical capability*

Introduction

Investigating physical exertion of forestry workers

Ergonomic research at the Faculty of Forestry, University of Zagreb, has been conducted systematically for over three decades. Researchers' interest focuses on the ergonomic features of forestry mechanisation and physical exertion of workers during forestry activities.

A research model of physical exertion in forestry activities, developed by the researchers in the Department of Organisation and Economics of the Faculty of Forestry in Zagreb, includes measuring and testing workers in the laboratory and measuring the workers' heart rate during work in a forest[1] (Figure 1).

Laboratory exertion tests include monitoring the heart rate (hereinafter: HR) at constant progressive exertion on a treadmill; the performance is supervised by a doctor, while a medical technician assists in performing the test and participates in measuring certain parameters. For easier and more reliable evaluation of functional capability, clinical check-up is done in the laboratory and the body height and mass are taken (hereinafter: BM).

An individual functional status is evaluated and work capability of each worker determined on the basis of exertion tests.

HR is measured in forest sites and a time study is performed in the following way: the worker's HR is read every minute during actual work and the type of the activity is recorded.

So far, about ten most important forest activities have been evaluated with this research model with the goal of determining daily exertion levels. In accordance with international categorisation, the level of work exertion/dif-

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ficulty was determined in relation to the average HR and the respective energy consumption[2–5].

Based on these results, Vondra[6] developed a model for calculating daily normal work time and the respective normal effects in given forestry activities. Goglia[7] and Risović[8] place the cutter's strain caused by the noise and vibrations of a chain saw in the context of daily physical exertion levels.

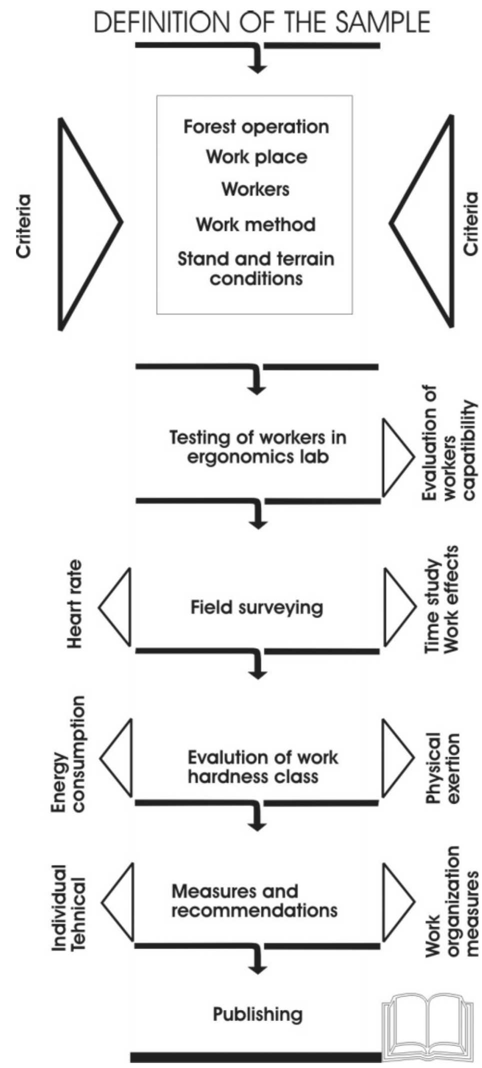

Fig. 1. Research model of forest workers' physical exertion (according to[1]).

Work capability

The capability of a worker to perform certain types of work rises with age. Years of working experience develop professional awareness and increase responsibility, patience, alertness, caution, discipline and a studious attitude towards work.

The effect of work increases until the middle age (40 – 45 years of age), then stagnates and mildly declines. Muscle power reaches its maximum at about 30 in men and at about 25 in women.

Ageing decreases the reactivity of the cardiovascular system in an individual (lower HR at given exertion levels), so that in programmed exertion tests, peak oxygen consumption values decrease when multiplied with the correction age factors[9] (Table 1).

TABLE 1
CORRECTION FACTOR FOR AGE AT PEAK OXYGEN CONSUMPTION (FOR BOTH GENDERS)

Age (years)	Correction factor
25	1.00
35	0.87
40	0.83
45	0.78
50	0.75
55	0.71
60	0.68
65	0.65

Oxygen consumption during work is a measure of hardness (heaviness) of work, in the first place because the performed physical work – the consumed oxygen ratio is firmly dependent and linearly proportional. This ratio, which is different for each individual, defines a man's physical capability. Similarly, during pure physical work the heart rate – oxygen consumption ratio is also firmly linear.

Physical capability is also dependent on body weight, dietary habits and physical activities. With ageing, physical capability rapidly diminishes when even a short-lasting excessive increase in body weight occurs.

Tomlinson and Manenica[10] point to the effects of age, body mass and height on the maximal heart rate value (HRmax) and oxygen consumption (VO_2). The same authors found functional calibration relations between HRmax and VO_2 for 10 respondents – forestry workers (In Table 2 labeled A–J) in different jobs – different ages, body height and mass. The results are presented in the form of linear equations in Table 2. The results served as a basis for graphic presentations of subject relations (Figures 2 and 3).

Since the effects of BM were not specifically analysed in our past research of work capability and assessment of energy consumption of forestry workers, this paper, as the first step in the analysis, investigates physiological effects of deviations of individual BM values from average or ideal BM values. Awareness of the real importance of such deviations might encourage better perception of BM in the physiology of productive forestry work.

Subjects and Methods

The objective of this research was to study the values of three standard indicators in the physiology of forest

TABLE 2
CORRELATION OF HEART RATE AND OXYGEN CONSUMPTION IN FORESTRY ACTIVITIES (Tomlison and Manenica[8])

Worker	Age (years)	Height (cm)	Weight (kg)	Maximal heart rate $HR = F(VO_2)$	Oxygen consumption $VO_2 = F(FS)$
A	27	178	89	$HR = 28.2\ VO_2 + 66.9$	$VO_2 = 0.028\ FS – 1.49$
B	36	180	78	$HR = 22.3\ VO_2 + 63.7$	$VO_2 = 0.042\ FS – 2.57$
C	43	179	76	$HR = 30.9\ VO_2 + 66.5$	$VO_2 = 0.030\ FS – 1.87$
D	48	165	71	$HR = 34.6\ VO_2 + 60.4$	$VO_2 = 0.026\ FS – 1.46$
E	50	173	77	$HR = 28.0\ VO_2 + 65.7$	$VO_2 = 0.028\ FS – 1.59$
F	50	173	70	$HR = 27.4\ VO_2 + 59.7$	$VO_2 = 0.032\ FS – 1.71$
G	56	178	90	$HR = 17.4\ VO_2 + 70.2$	$VO_2 = 0.057\ FS – 3.98$
H	57	180	82.5	$HR = 25.8\ VO_2 + 72.7$	$VO_2 = 0.036\ FS – 2.50$
I	60	178	87	$HR = 31.7\ VO_2 + 70.4$	$VO_2 = 0.019\ FS – 0.83$
J	62	168	68	$HR = 30.6\ VO_2 + 64.6$	$VO_2 = 0.030\ FS – 1.80$

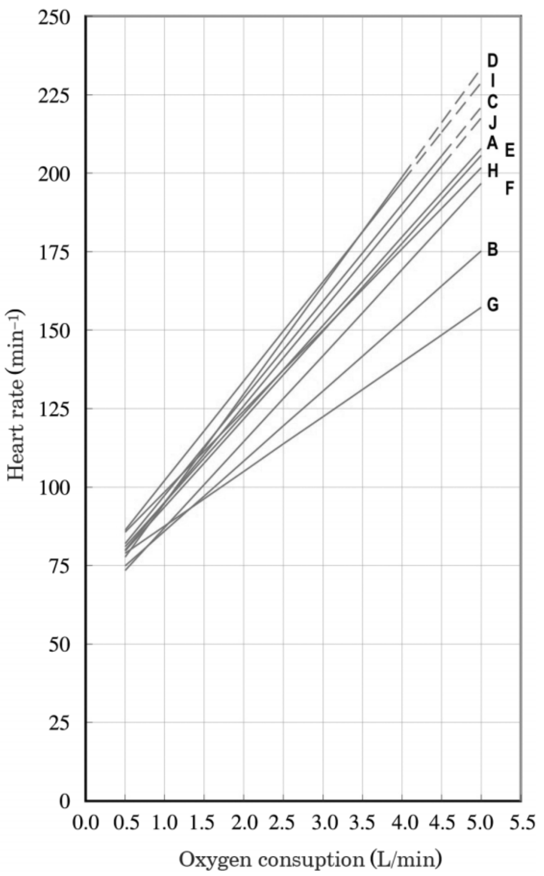

Fig. 2. Dependence of heart rate on oxygen consumption.

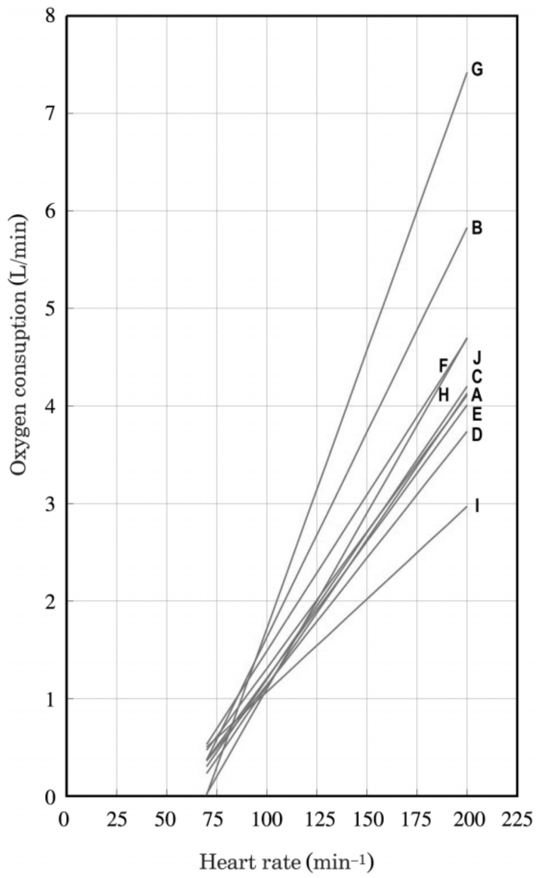

Fig. 3. Dependence of oxygen consumption on heart rate.

work on a sample of eight workers (labelled with numbers from 1 to 8), taking into consideration their actual BM (ABM) and ideal BM (IBM). The following indicators were studied:

- the maximal theoretical heart rate (HRmax),
- the maximal HR attained in a progressive exertion test
- basal energy expenditure.

During laboratory testing, the body height and mass were taken for each worker.

The choice of workers for the study was made on the basis of representative age, vitality and the achieved work effects (Table 3, columns 2, 3, 4).

Results

Actual and ideal body mass ratio

The ideal body mass (BM) of each worker was calculated using the formula[11] that expresses functional dependence of BM on gender, height and age.

$$IBM = (H–100) – (H–150)/ X + (A–20)/4 \quad [1]$$

Where:
IBM – ideal body mass in kg
H – body height in cm
X = 4 for male gender; X = 2.5 for female gender
A – age in years

The obtained values of the IBM were compared with the ABM by calculating an individual deviation and an average deviation. The results are given in Table 3 (Col. 6) and Figure 4.

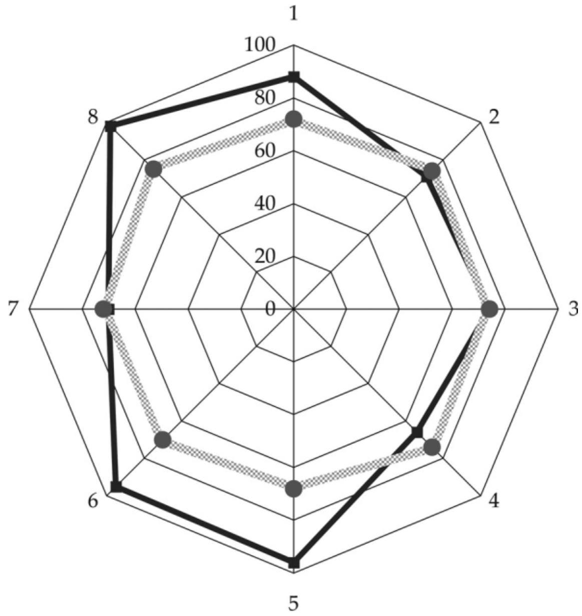

Fig. 4. The ratio of actual body mass, ABM), (full line) and ideal body mass, IBM, (dotted line) in kg. Workers are labelled with numbers 1–8.

Data analysis revealed the following:

- in relation to the IBM, the sum of deviations in BM in all eight workers was 79 kg,
- the highest individual deviation was 28 kg,
- on average, workers exceeded their IBM by 9.9 kg,
- in as many as 3 out of 8 workers the deviation of the actual from the IBM exceeded 1/5 of their ABM (workers W5, W6, W8).

Maximal heart rate

In work physiology, the maximal HR (hereinafter HRmax) is a standard indicator of the highest acceptable individual exertion.

In an individual, the HRmax rises with the level of routine and decreases with age. Changes in the HR during physical work are directly proportionate to the intensity and duration of work. This means that the level of HR is proportionally dependent on the intensity and duration of work (the more intensive and longer the work, the higher the heart rate).

According to Lipoglavšek[9], the maximal upper pulse values start declining from the age of 25 and decline evenly throughout the lifetime. In order for a worker to complete his full working life, during heavy dynamic work the difference between the pulse at rest and the maximal pulse should reach an average of 50% at the most, or 40 beats per minute (1/min) above the pulse at rest (taken in a lying position).

The theoretically maximal HR for each worker was calculated using the formula[9], which takes into account age (A) and BM

$$HRmax\ (min^{-1}) = 210 – \text{half the age} – 10\%\ \text{body mass} + 4 \quad [2]$$

TABLE 3
BASIC DATA ON WORKERS

Worker	Age (years)	Height (cm)	ABM (kg)	IBM (kg)	Deviation (kg)
W1	42	175	88	72	+16
W2	63	171	71	74	– 3
W3	50	175	74	74	0
W4	50	175	66	74	– 8
W5	43	169	96	68	+28
W6	42	172	95	70	+25
W7	41	176	70	72	– 2
W8	40	180	98	75	+23
Sum (kg)			658	579	79
Average (kg)			82.3	72.4	9.9

IBM – ideal body mass in kg, ABM – actual body mass, W – workers 1–8

TABLE 4
THEORETICAL AND ATTAINED MAXIMAL HEART RATE (HRmax) VALUES

	Theoretical HRmax (min^{-1})			HRmax in the exertion test (min^{-1})	Ratio (5/3) %
	f (A, ABM)	f (A, IBM)	f (A)		
1	2	3	4	5	6
W1	189	191	189	176	92.15
W2	180	180	176	168	93.33
W3	187	187	184	173	92.51
W4	187	187	184	169	90.37
W5	188	191	189	175	91.62
W6	189	191	189	168	87.96
W7	191	191	190	167	87.43
W8	189	192	191	179	93.23

IBM – ideal body mass in kg, ABM – actual body mass, A – age, W – workers 1–8

The theoretical HRmax was calculated on the basis of the ABM (Table 4, Column 2) and the IBM (Table 4, column 3).

The theoretical HRmax was separately calculated using the formula [3] that does not take into account the body mass but only the age (A) of the respondents (Table 4, Column 4).

$$HRmax\ (min^{-1}) = 210 - 0.65\ Age \qquad [3]$$

In order to determine the HRmax in an exertion test, the workers were tested in the ergonomic laboratory of *Srčana stanica za prevenciju i liječenje kardiovaskularnih bolesti*, Draškovićeva 13, Zagreb. The HRmax results obtained in programmed exertion tests (the Bruce protocol was used), are given in Table 4, Column 5.

Data in Table 5 were analysed with the following results:

- The calculated theoretical HRmax in all workers was higher than the HRmax attained in the exertion test. The greatest difference was 12.57%.
- At an individual level there were almost no differences between the values of the theoretical HRmax for the ABM, or the IBM.
- Not even severe deviations of the ideal from the ABM (for workers E and F) had any profound effects on the individual theoretical HRmax; this is explained as insensitivity of the applied formula, which in the calculation of HRmax takes into account the ABM only in the amount of 10% – which is evidently insufficient for a stronger influence of BM on HRmax.
- The application of the formula that takes into account only age also yields approximately equal values in the calculation of the theoretical HRmax.

TABLE 5
PEAK OXYGEN CONSUMPTION

Worker	Peak oxygen consumption VO_2 (l/min)		Ratio (3/2), %
	HRmax – theoretical for IBM	HRmax – test for ABM	
1	2	3	4
W1	3.68	3.32	90.22
W2	3.44	3.10	90.12
W3	3.60	3.24	90.00
W4	3.63	3.13	86.23
W5	3.64	3.29	90.38
W6	3.66	3.10	84.70
W7	3.74	3.07	82.09
W8	3.68	3.40	92.39
Average	3.63	3.21	88.43

HRmax – maximal heart rate, IBM – ideal body mass in kg, ABM – actual body mass, A – age, W – workers 1–8

Oxygen consumption in the evaluation of physical capability

To determine overall physical capability, physiological parameters of change or the peak pulse or oxygen consumption values (hereinafter: VO_2) are the most suitable.

Oxygen consumption shows the ability of adapting respiration and blood circulation to growing requirements for oxygen (ability of reception and transfer). Physical activity during a working task is possible up to determined peak oxygen consumption.

In work physiology, the optimal working capacity is that amounting to 40% of the maximal oxygen consumption.

Based on data by Lipoglavšek[11] on the HR and VO_2 ratio, Martinić[12] designed a formula for the calculation of oxygen consumption:

$$VO_2 = -1.4533 + 0.027106\ HR \qquad [4]$$

where:
VO_2 – oxygen consumption in L/min
HR – heart rate, min^{-1}

TABLE 6
OXYGEN CONSUMPTION AT WORK AND LEVELS OF DIFFICULTY (ACCORDING TO Hollman[13])

Oxygen consumption (L/min) males	Levels of difficulty in physical work			
	Light work	Medium hard work	Hard work	Peak exertion
	> 0.81	> 1.26	> 2.15	3.20

Using the formula [4], individual oxygen consumption (VO_2) was calculated for each worker, whereby in one case the basis was the theoretical HRmax calculated for the IBM (Table 6, Col. 2), and in another case the HRmax was attained in a laboratory exertion test (Table 5, Col. 3). The correlation of the results at an individual level is given in Column 3, Table 5.

Data in Table 5 were analysed with the following results:

- At IBM the calculated VO_2 is higher than that calculated for the ABM from exertion tests for all workers.
- An average 9.9 kg excessive BM per worker results in an average decline of physical capability by 11.5 % for every worker – in relation to that for the IBM and theoretical HRmax.
- The highest reduction of physical capability was found in those workers who achieved the most unfavourable ratio of theoretical and attained HRmax in the exertion test (W6 and W7).

Oxygen consumption, as well as the pulse, is a suitable indicator of heavy work when dynamic physical exertions prevail in work. Based on oxygen consumption, physical work is classified into levels of difficulty[13] (Table 6).

In order to classify work by difficulty levels according to the categories in Table 6, the highest VO_2 value (Table 6, col. 3) was decreased for each worker by multiplying it with the correctional factor for age (Table 7).

As seen from Table 8, in all the cases the physical load that the workers were subjected to in the test had all the characteristics of heavy work.

TABLE 7
CORRECTED PEAK OXYGEN CONSUMPTION AND THE RELEVANT DIFFICULTY LEVELS

Worker	Correction factor	Corrected VO_2	Difficulty level
W1	0.87	2.89	Heavy work
W2	0.71	2.20	Heavy work
W3	0.83	2.69	Heavy work
W4	0.83	2.60	Heavy work
W5	0.87	2.86	Heavy work
W6	0.87	2.70	Heavy work
W7	0.87	2.67	Heavy work
W8	0.87	2.96	Heavy work

Basal energy expenditure

Energy expenditure indicates a worker's strain at work, his capability of task performance in the course of the working day, the necessary amount of food and other needs and the abilities of a human organism.

Basal energy expenditure (BEE) in a healthy person increases linearly with body mass and height and declines with age.

The average daily basal energy expenditure in young adults is 7,116.2 kJ for men and 6,027.84 kJ for women[14].

During work an organism uses additional energy for increased activity of the respiratory and cardiac systems, as well as for muscle activity, or task performance.

Correlative dependencies of basal energy expenditure on body weight, body height and age were calculated by Harris and Benedict[15] using the following equations:

$$\text{For men: } BEE = 66.437 + 13.7516\,BM + 5.0033\,H - 6.755\,A \quad [5]$$

$$\text{For women: } BEE = 655.0955 + 9.5634\,BM + 18.496\,H - 4.6756\,A \quad [6]$$

where:
BEE = basal energy expenditure in calories/24 hours
B – body mass in kg
H – body height in cm
A – age in years

TABLE 8
BASAL ENERGY EXPENDITURE

Worker	Basal energy expenditure (kJ/day)	
	For ABM, H, A	For IBM, H, A
W1	8,841.14	7,517.16
W2	7,117.29	7,232.42
W3	8,444.34	7,005.24
W4	8,104.23	7,183.20
W5	8,410.80	6,799.00
W6	7,072.12	7,072.12
W7	6,611.60	7,072.12
W8	6,448.06	6,620.75
Sum	61,049.58	56,502.01
Difference 2–3	+4,547.57	
Av. summary	7,631.20	
Average	568.45	
% of the average	7.45	

IBM – ideal body mass in kg, ABM – actual body mass, A – age, H – height, W – workers 1–8

Using the equation [5], the basal energy expenditure was calculated for each worker, where the ABM was taken into account in one case and the IBM in another. Summary and average results are given in Table 8.

The results indicate that due to the deviation from the IBM, the basal energy expenditure of each worker is higher by 7.45% on average. At constant values of other important factors, the increased basal energy needs might mean an equivalent reduction in the capability for performing daily physical work.

Discussion

Since the research was not aimed at proving the statistical significance of the attained results, in order to arrive at a more concrete evaluation of the effects of deviations of the actual from the IBM in the forestry workers' work physiology, target research should include a significantly larger sample of workers and more measurements.

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I. Martinić

Department of Forest Engineering, Faculty of Forestry, University of Zagreb, 10000 Zagreb, Croatia
e-mail: martinic@sumfak.hr

UTJECAJ TJELESNE MASE NA FIZIOLOŠKE POKAZATELJE PRI RADU ŠUMARSKIH RADNIKA

SAŽETAK

U ovom članku prikazani su rezultati istraživanja utjecaja tjelesne mase (TM) radnika u šumarstvu na osnovne fiziološke pokazatelje njihove radne sposobnosti. Ti su pokazatelji obuhvatili najveću teorijsku frekvenciju srca, najveću frekvenciju srca na testu opterećenja i osnovnu energetsku potrošnju. Na uzorku od 8 radnika posebno su analizirali učinci odstupanja stvarnih od idealnih vrijednosti TM. Za svakog je radnika utvrđena životna dob, izmjerena tjelesna visina i masa, te je na osnovu njih određena teorijski najveća frekvencija srca. U ergonomskom laboratoriju određena je najveća frekvencija srca na testu programiranog opterećenja na pokretnoj traci. Primjenom standardnih formula u fiziologiji rada izračunate su vrijednosti pokazatelja radne sposobnosti za stvarnu i idealnu TM svakog radnika. Rezultati koji su obuhvatili individualne i zbirne vrijednosti i njihove apsolutne i relativne odnose pokazali su da je prosječno svaki radnik težio 9,9 kg više od svoje idealne TM. Kod svih je radnika teorijski najveća frekvencija srca bila veća od one postignute na testu opterećenja. Pokazano je da čak ni velika odstupanja idealne od stvarne TM (preko 20 % veća stvarna od idealne TM) ne utječe značajno na teorijski najveću frekvenciju srca. Analiza utroška kisika pokazala je prosječno 11,5 % smanjenju fizičku sposobnost svakog radnika u odnosu na onu za idealnu TM i teorijski najveću frekvenciju srca, a najveća je redukcija fizičke sposobnosti utvrđena kod onih radnika koji su imali najnepovoljniji odnos teorijske i, na testu ostvarene, najveće frekvencije srca. Utvrđeno je da radi odstupanja stvarne od idealne TM svaki radnik prosječno ima 7,45 % višu osnovnu energetsku potrošnju, što uz stalne vrijednosti ostalih činitelja znači i ekvivalentno manju sposobnost za dnevno obavljanje fizičkog rada.