Procjena fizičkog opterećenja statističkom analizom srčane frekvencije u radnice na vrpci u punionici pića

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ESTIMATION OF PHYSICAL WORK LOAD BY STATISTICAL ANALYSIS OF THE HEART RATE IN A CONVEYOR-BELT WORKER

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Physical work load was estimated in a female conveyor-belt worker in a bottling plant. Estimation was based on continuous measurement and on calculation of average heart rate values in three-minute and one-hour periods and during the total measuring period. The thermal component of the heart rate was calculated by means of the corrected effective temperature, for the one-hour periods. The average heart rate at rest was also determined. The work component of the heart rate was calculated by subtraction of the resting heart rate and the heart rate measured at 50 W, using a regression equation. The average estimated gross energy expenditure during the work was 9.6±1.3 kJ/min corresponding to the category of light industrial work. The average estimated oxygen uptake was 0.42±0.06 L/min. The average performed mechanical work was 12.2±4.2 W, i.e. the energy expenditure was 8.3±1.5%.

Key terms:
energy expenditure, heart rate, oxygen uptake

In estimating physical strain during work it is important to determine energy expenditure. Direct measurement can only be done in laboratory conditions. Indirectly, energy expenditure can be determined from oxygen uptake at different work loads and by multiplication with the energy equivalent dependent on the respiration quotient. Its estimated value is roughly 21 kJ/L of oxygen (1–4).

Energy expenditure can be estimated from heart rate owing to a linear relationship that exists between them up to the submaximal oxygen consumption (70–90% of maximal consumption) (1–3, 5). It can be roughly estimated from the energy expenditure tables for different kinds of work obtained on large samples

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(6). The work load can be classified according to the metabolic equivalent of basal metabolism (MET) of 3.5 ml of oxygen/kg/min (2-6).

Detailed analyses of the average heart rate values in different work periods have been reported (2). The following heart rate components are distinguished: the standard component i.e. the heart rate at rest, the thermal, dynamic and isometric work components and the emotional component. Mental stress during work, i.e. the emotional heart rate component is estimated by the combined arrhythmia measure (CAM).

This study aimed at determining the thermal and work heart rate components during work and at estimating physical work load, oxygen uptake, gross energy expenditure and work load from the average heart rate values in case no instrument for direct measurement of oxygen intake during work was available. The purpose was to use this method for assessing work load by statistical analysis of heart rate during work.

SUBJECT AND METHODS

The subject in the study was a female conveyor-belt worker in a bottling plant, age 35 years, height 159 cm, weight 60 kg, having no acute or chronic disease at the time of study, who did not take any medication.

On the first day of examination the average heart rate values were measured during two hours of rest. At the beginning of each hour the ambient air parameters necessary for the calculation of corrected effective temperature (CT_{eff}) were measured in the standard way. The value of heart rate at rest (hr_0) i.e. in conditions of basal metabolism was obtained as the difference between the average measured heart rate (hr) and the thermal heart rate component ($\Delta_1 hr$) during the second hour of rest when dynamic and isometric work as well as mental stress were absent. $\Delta_1 hr$ was determined from the regression equation which uses Ct_{eff} (2):

$$\Delta_1 hr = 1{,}637 \times 10^{-6} \times CT_{eff}^{4{,}897} \qquad /1/$$

Energy expenditure at the level of basal metabolism during 24 hours was determined using the equation according to Benedict and Harris (2). From that value obtained energy expenditure in conditions of basal metabolism in kJ/min was determined, and then, oxygen uptake in conditions of basal metabolism in L/min was calculated by division by the energy equivalent (5).

After the rest, the examinee was submitted to the load test on a bicycle ergometer, according to the Sheffield protocol (6). The test started at the load of 50 W and stopped after the theoretical maximal heart rate in relation to age had been achieved. The theoretical maximal heart rate was calculated using the equation from the protocol. In order to determine the examinee's functional aerobic capacity, the theoretical maximal oxygen uptake (VO_{2Max}) was calculated by means of the equation according to Bruce (3). The oxygen uptake at the different work

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loads on the bicycle ergometer was determined from the nomogram used in ergometry establishing a relationship between work load (in W) and oxygen uptake (in L/min) (6). At the beginning of this phase CT_{eff} was calculated.

Heart rate at rest was measured continuously in the following way: The examinee was connected to an electrocardiograph from which the signal was transferred to the Statistical Pulse-rate Analyser in Real Time (SPART-XT) after Sušnik and Mastnak (2). This unit calculates the average values and standard measures of heart rate variability during three-minute and one-hour periods, as well as during the total measuring period. It also calculates CAM in these periods. CAM is the quotient of the sums of weighted time intervals of R-peaks (MA_1) and the changes of momental heart rate direction changes (MA_2):

$$CAM = MA_1/MA_2 \qquad /2/$$

The increase in heart rate, caused by work or mental stress, results in the increased CAM values whereas the increase in the number of changes of momental heart rate direction changes (increase : decrease) leads to CAM decrease reflecting the presence of mental stress. If no mental stress is observed during work, the variations can be attributed to the physical or thermal load.

Two hours before the examinations, the examinee was not allowed to smoke, consume coffee, drink alcohol, or take medication. She was well rested. During the test she was stripped to the waist.

On the second day of examination, heart rate was continuously measured during work and at rest. Work shift was from 7.30 a.m. to 3.30 p.m., with a break from 10.00 to 10.30 a.m. On the day of examination the examinee worked effectively from 7.37 to 9.37 a.m. and from 10.37 a.m. to 3.00 p.m. The measurements were performed from 7.37 to 9.37 a.m. and from 10.37 a.m. to 2.37 p.m., or during six hours of effective work on the conveyor belt. During these periods ambient measurements were also done, and CT_{eff} and $\Delta_1$hr were calculated as previously described. In three-minute and one-hour periods the average values of heart rate and CAM were automatically calculated and registered. By subtraction of $\Delta_1$hr and hr_0 from hr, the work component values were obtained ($\Delta_2$hr). The mechanical work performed at the actual measured heart rate values was determined by the regression equation:

$$x = \frac{y}{b} - \frac{a}{b} \qquad /3/$$

where
x = performed work in W,
y = heart rate (hr - $\Delta_1$hr);
a, b = regression factors

The total oxygen uptake for the actual heart rate values was determined in the same way. In that case x was the total oxygen uptake in L/min, y was heart rate, a and b the regression factors.

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Regression equations were determined from the following system of equations with two unknowns (7):

$$\Sigma y = N \times a + \Sigma x \times b$$

$$\Sigma xy = Sx \times a + Sx^2 \times b \qquad /4/$$

Since the respiration quotient was not measured the gross energy expenditure in kcal/min was obtained by dividing oxygen uptake in millilitres by 1000, and multiplying by the caloric equivalent (5).

Work category and the range of work activities were recorded.

RESULTS

At the work load of 0 W, i.e. during the second hour of rest, after the subtraction of the thermal heart rate component, the average heart rate of the examinee was 59.6/min. At the work load of 50 W on bicycle-ergometer, the average heart rate obtained in the same way, was 165.0/min. From these values the following regression equation was developed:

$$R(W) = \frac{hr(L/min)}{2.1} - 28.5 \qquad /5/$$

At the load of 0 W i.e. heart rate of 59.6/min at rest, the oxygen uptake calculated as described in Methods was 188 ml/min, corresponding to the energy consumption at the level of basal metabolism of 0.9 kcal/min. Consequently, the examinee's individual MET value of was 3.1 ml/kg/min. At 50 W, i.e. at the heart rate of 165.0/min, the calculated oxygen uptake was 900 ml/min corresponding to the examinee's energy expenditure of 4.8 MET. From all these values the following regression equation was obtained:

$$VO_2(L/min) = \frac{hr(L/min)}{148.0405} - 0.2145 \qquad /6/$$

The work load achieved at the examinee's theoretical maximal heart rate of 187/min was 75 W during one minute equalling the load of 58.3 W during three minutes. So, the maximal achieved oxygen uptake was 996 ml/min or 39.6% of the maximal theoretical oxygen uptake, or the decrease in aerobic capacity of 60.4% meaning a greater decrease of work capacity.

The examinee's job was to mount plastic cork wrappers on the bottles moving on the conveyor belt. After 30 seconds the examinee would stop the conveyor belt for 20 seconds so that the bottles, after passage through the thermal unit

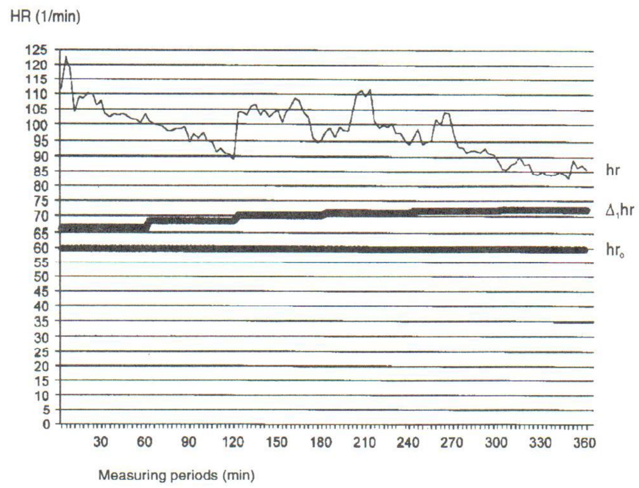

Figure 1 *The average values of actual heart rate (hr), and of thermal ($\Delta_1 hr$) and standard heart rate components (hr_0) in three-minute periods*

where the wrappers were fixed to bottles' necks, could proceed without delay to the part of the conveyor belt where the labels were automatically put on, under supervision of another worker.

The work paused from time to time when bottles fell off from the conveyor belt, or new labels had to be supplied. Several times during the work the phone rang sounding like an alarm system because of continuous machine noise in the work room. Noise level was estimated at 70 dB; loud conversation was hardly understandable at the distance of 1 m. The bottles fell off five times during the observed shift. The examinee had to make several steps and bend forward to lift the bottles and place them back on the conveyor belt. During one of the pauses the examinee smoked a cigarette and during another she drank a glass of coca-cola.

The examinee performed the job with her right arm holding the wrappers in the left hand. At the end of each one-minute cycle she took new wrappers from the box beside her with her left hand. For the first three hours she worked in the still-standing position supporting herself against the machine. For the further three hours she worked sitting in a non-physiological body posture on two vertically placed plastic cases without a support for the back. During the first two hours of work there was lighting in the work room and daylight during the rest of the time. The air temperature ranged from 22.5 °C in the beginning of the shift to 27 °C in the end. The relative humidity ranged from 84 to 85% during the first four hours of measurement, and decreased to 81% over the last two hours. The air pressure was 756 mm Hg during the whole shift and bulb globe temperature ranged from 24.5 °C in the beginning of the shift to 28 °C in the end. CT_{eff} ranged from 22.3 to 25.5 °C. Airflow speed was 0.3 m/s throughout the shift.

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Figure 1 shows the average values of actual heart rate (hr), thermal ($\Delta_1$hr) and standard heart rate component (hr_0) during three-minute periods. In Figure 2 the average values of actual heart rate (hr) during one-hour periods are presented. The average actual heart rate during the whole shift was 98.7±8.9/min. The value of thermal component of heart rate ranged from 6.6/min in the first hour to 12.6/min in the end of the shift, following an increasing trend in daily temperature in the work room.

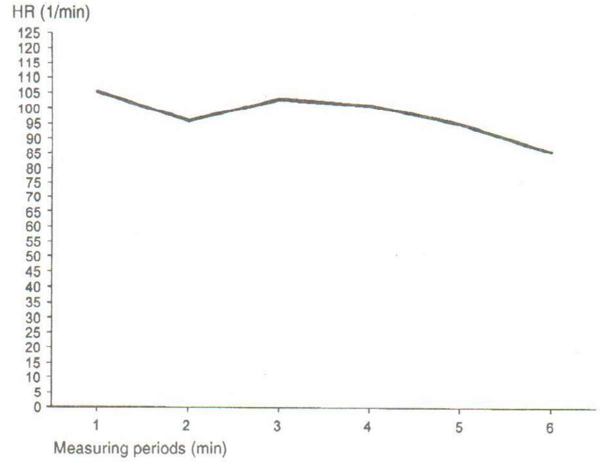

Figure 2 *The average values of actual heart rate (hr) in one-hour periods*

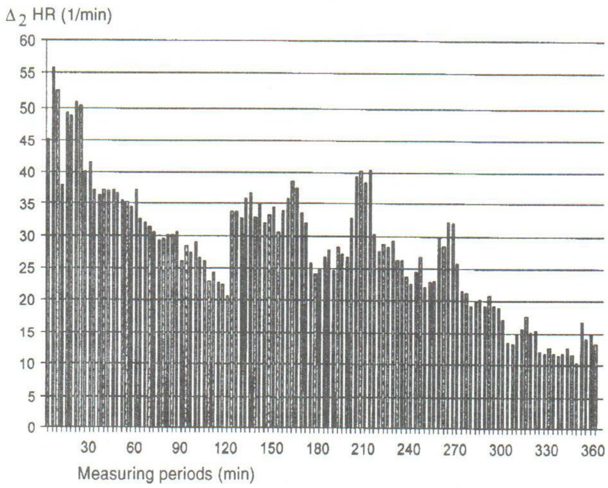

Figure 3 *The average values of the work component of heart rate ($\Delta_2$hr) in three-minute periods*

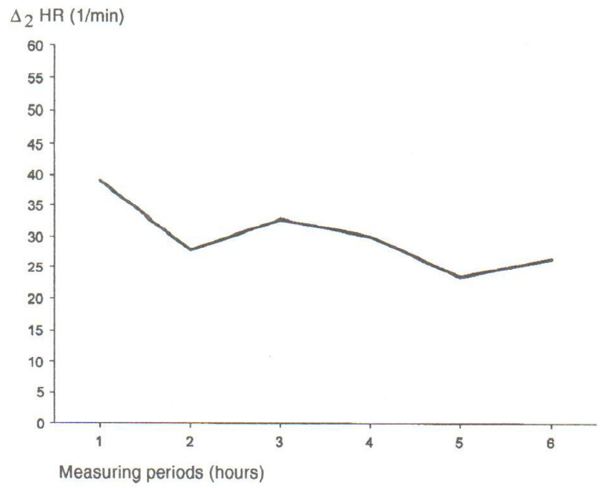

Figure 4 *The average values of the work component of heart frequency ($\Delta_2$hr) in one-hour periods*

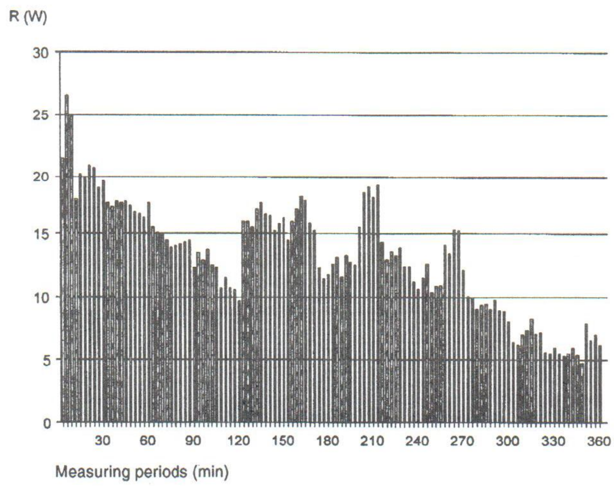

Figure 5 *The average values of performed work (R) in three-minute periods*

The average values of work heart rate component ($\Delta_2$hr) in three-minute periods are given in Figure 3 and in one-hour periods in Figure 4. The average value of work heart rate component during the whole measuring period was 26.5±8.9/min.

Figure 5 shows the average calculated values of the performed mechanical work (R) in three-minute periods. The average value of performed mechanical work during the whole measuring period was 12.5±4.2 W.

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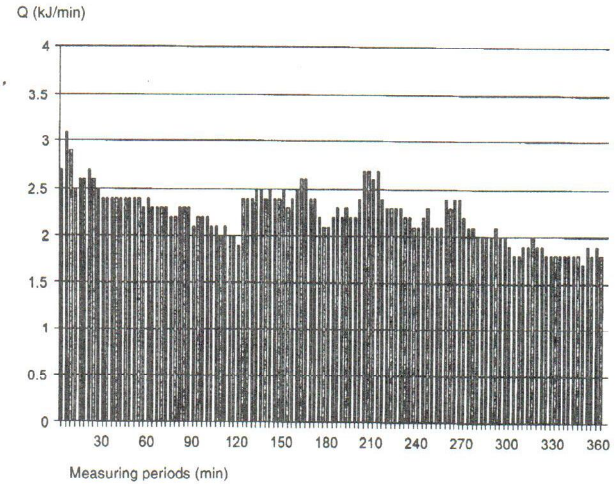

Figure 6 *The average values of gross energy expenditure (Q) in three-minute periods*

The average calculated values of the gross energy expenditure in three-minute periods are presented in Figure 6. The average gross energy expenditure during the whole measuring period was 9.7±1.3 kJ/min.

The average calculated values of oxygen uptake in three-minute periods are given in Figure 7. The average value of oxygen uptake during the whole measuring period was 452.2±60.1 ml/min.

Figure 8 shows the average CAM values in three-minute periods.

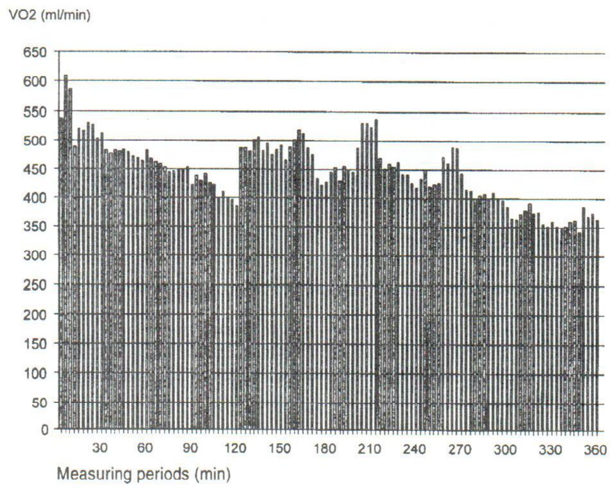

Figure 7 *The average values of oxygen uptake (VO_2) in three-minute periods*

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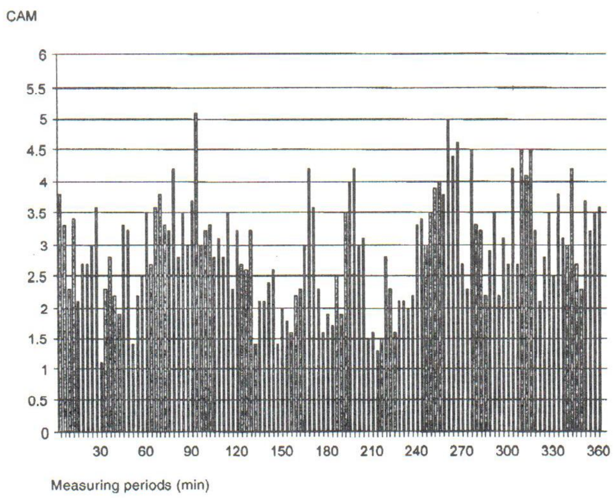

Figure 8 *The average values of combined arrhythmia measure (CAM) in three-minute periods*

DISCUSSION

From the results of the study it is obvious that highest values of all parameters were obtained at the beginning of the shift and after the break. This could be explained by higher physical work load due to lack of training or to faster work rhythm. Higher CAM values suggested the absence of mental stress whereas low CAM values recorded three times during the first two hours could be related to mental stress caused by phone ringing or bottle dropping from the conveyor belt. In any other period when CAM were extremely low a connection with stress situations could not be established. All described conditions point to light industrial work, which is mainly performed in the standing or sitting positions with simple arm movements. Evidently, forced body posture at work in the sitting position contributes to the body strain.

Lower values of the investigated parameters at the end of the shift or before the break can be explained by slowing down the work rhythm. During the first hour the examinee mounted 36–45 plastic cork wrappers on the bottles per minute, during the second hour and the first hour after break from 25 to 36, and during the last three hours from 20 to 25 wrappers per minute. During the first three hours the examinee worked standing and during the next three hours in the sitting position, which could also be an indication of fatigue. This was in accordance with the established low working capacity of the examinee or 39.6%

of the theoretical maximal oxygen uptake that corresponds to the level of moderate work load.

It is known that workers are not able to work more than a half of their working time with the maximal oxygen uptake (5), or full working time with half this capacity. For our examinee this meant the oxygen uptake of 498 ml/min. The average oxygen uptake calculated from the measured heart rate during effective work ranged from 400 to 600 ml/min corresponding to 6–7 ml/kg/min or 1.7–2.0 standard METs, or to 1.9–2.3 METs of the examinee.

The average gross energy expenditure of 9.7±1.3 kJ/min in our examinee, or the net energy expenditure of 5.9±1.3 kJ/min corresponds to the gross energy expenditure of 4637 kJ or to the net energy expenditure of 4186 kJ during the whole shift. According to the table values by Šarić and co-workers (6) this corresponds to the energy expenditure at work in the standing position (1340 kJ/8 h) involving simple arm movements (2512 kJ/8 h) and light physical work during 30 minutes (400 kJ), or to walking at 3 km/h without weight (6). Evidently, the calculated energy expenditure in our examinee corresponds to her activities at the workplace.

According to the WHO classification from 1978, the energy expenditure of 9.7 kJ/min for women aged 30–39 pertains to light work, i.e. corresponds to the category of light industrial work (5).

The examinee's maximal oxygen uptake of of 996 ml/min or 16.6 ml/kg/min, or the energy expenditure of 21 kJ/min imply low aerobic capacity for women of that age (5). Considering the table values by Andersen and theoretical maximal capacity of the examinee of 2512 ml/min i.e. 41.9 ml/kg/min, we can conclude that it is light work (8). Namely, the oxygen uptake during work amounted to 452.2 ml/min or 7.5 ml/kg/min. This was 18% of maximal aerobic capacity and 45% of maximal aerobic capacity which our examinee could achieve. For her it was moderately heavy work.

Comparison with the values reported by some authors also leads to a conclusion that the examinee performed light work. They define light work as the energy expenditure from 6.5 to 14.3 kJ/min for women of 55 kg body weight. Considering the tables of Christensen from 1953 this would be classified as very light work (9). The values of Wells from 1957 (10) suggest that the tasks performed by the examinee would be classified as light work, the gross energy expenditure being below 16.4 kJ/min (10).

According to the values of Illmarinen from 1979 this corresponds to the category of light work or light activity performed in the standing position which comes to 243% of MET or 18% of the theoretical maximal aerobic capacity of our examinee (11).

The actual heart rate of the examinee was between 90/min and 100/min.

As also maintained by other authors continuous measuring of heart rate during work and making inventory of work activities are valuable methods for monitoring work conditions (12–17).

Although some authors prefer the control of physical load based on respiration value obtained by measuring the blood lactates, they consider heart rate an equally valuable indicator when objectively and continuously measured as well as reliably and statistically analysed.

CONCLUSION

The average value of actual heart rate of the conveyor-belt worker in a bottling plant was 98.7±8.9/min during the entire measuring period.

The standard heart rate component was 59.6/min, the average value of the thermal heart rate component 10.4±2.3/min, and of the work heart rate component 26.5±8.9/min. The average value of performed work during the same period was 12.5±4.2 W, the average oxygen uptake 452.2 ml/min, and the average gross energy expenditure 9.7±1.3 kJ/min.

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Sažetak

PROCJENA FIZIČKOG OPTEREĆENJA STATISTIČKOM ANALIZOM SRČANE FREKVENCIJE U RADNICE NA VRPCI U PUNIONICI PIĆA

U radu je prikazan način procjene fizičkog opterećenja u radnice na vrpci u punionici pića, temeljene na kontinuiranom mjerenju i izračunavanju prosječnih vrijednosti srčane frekvencije u trominutnim i jednosatnim razdobljima, te tijekom čitavog razdoblja mjerenja. Regresijskom jednadžbom koja koristi vrijednost korigirane efektivne temperature, izračunane iz parametara mikroklime mjerenih u jednosatnim razdobljima, izračunata je toplinska sastavnica srčane frekvencije. Tijekom mirovanja također je određena prosječna vrijednost srčane frekvencije. Oduzimanjem srčane frekvencije u mirovanju i toplinske sastavnice srčane frekvencije od aktualne srčane frekvencije, dobivena je radna sastavnica srčane frekvencije za sva spomenuta razdoblja. Iz vrijednosti srčane frekvencije u mirovanju i srčane frekvencije postignute pri opterećenju od 50 W na biciklergometru dobivena je regresijska jednadžba korelacije frekvencije i izvršenog rada, na temelju koje je izračunavan izvršeni rad u spomenutim razdobljima. Iz primitka kisika pri opterećenju od 50 W na biciklergometru, primitka kisika na razini bazalnog metabolizma, srčane frekvencije pri opterećenju od 50 W i srčane frekvencije na razini bazalnog metabolizma izračunana je regresijska jednadžba korelacije srčane frekvencije i primitka kisika, i prikazan procijenjeni primitak kisika tijekom rada u svim razdobljima mjerenja. Primitak kisika na razini bazalnog metabolizma izračunan je iz energetske potrošnje dobivene jednadžbom po Harrisu i Benedictu, a primitak kisika pri opterećenju od 50 W iz nomograma koji se koristi pri ergometriji. Iz procijenjenog primitka kisika izračunavana je bruto energetska potrošnja za sva razdoblja mjerenja. Prosječna procijenjena bruto energetska potrošnja tijekom šest sati efektivnog rada ispitanice iznosila je 9.7±1.3 kJ/min, što odgovara kategoriji laganog industrijskog rada. Prosječni procijenjeni primitak kisika u istom razdoblju iznosio je 0,45±0,06 L/min, prosječno izvršeni mehanički rad 12,5±4,2 W, odnosno energetska efikasnost 7,8±1,4%.

Ključne riječi:
potrošnja energije, primitak kisika, srčana frekvencija

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