SECTION – SPORT SCIENCE

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# THE EFFECTS OF AN 18-WEEK TRAINING PROGRAMME ON MOVEMENT ECONOMY OF A LONG-DISTANCE RUNNER – A CASE STUDY

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**Authors' contribution:**

A. Study design/planning
B. Data collection/entry
C. Data analysis/statistics
D. Data interpretation
E. Preparation of manuscript
F. Literature analysis/search
G. Funds collection

**Keywords:** running economy, training load, long-distance runs

## Abstract:

**Study aim:** The aim of the work was to determine the effects of an 18-week training programme on the economics of running at a speed corresponding to the lactate threshold of an athlete from the track-and-field section of AZS AWF (University of Physical Education) Kraków. In addition, the objective was to determine the average heart rate and speed during a 10-km during in relation to threshold values for these parameters.

**Materials and methods:** In the study, heart rate and speed at lactate threshold were determined using the pitch test. The indirect calorimetry method was applied to assess energy expenditure of the run. The training work carried out by the study participant was subject to registration and quantitative as well as qualitative analysis.

**Results:** Observations indicated that the implemented training programme resulted in a reduction of energy expenditure by 6.32% when running at threshold speed. During the 10-km competitive run, the studied athlete obtained an average heart rate and running speed at a level corresponding to 109% and 108% (respectively) of the threshold values for the specified parameters.

**Conclusions:** The proposed training programme had a positive effect on running economics at threshold speed. It was shown that the average heart rate and speed obtained during the competition over a distance of 10 km exceeded the threshold values of the mentioned parameters by 9 and 8%, respectively.

## Introduction

One of the factors determining the level of starting opportunities in endurance competitions - next to maximal oxygen intake and lactate threshold - is the economics of movement [1]. On the basis of long-distance running, the criterion of economy is the amount of energy expenditure incurred to cover the cost of physiological movement at a certain speed. The less energy the athlete's body uses while running at a given pace, the more effective his/her work can be [2]. Observations indicate that inter-individual variation in running economics may reach up to 40% [3].

Among factors affecting economics of running, morphological and structural features characterising the locomotor apparatus, biomechanical parameters of the running step (kinetic and kinematic), physiological indices, properties of the external environment, training experience, are listed [4]. The relationship between running economics and starting abilities has been quite well-documented in literature on the subject. Thus, Pollock's research [5] from the second half of the 70s comparing good American runners with the elite, showed that competitors presenting a higher level of sport are more economical. Di Prampero, Capelli and Pagliaro [6] estimated that improving the economy of running by 5% induces the progression of results in long-distance running by about 3.8%. Conley and Krahenbuhl [7], in research conducted among 12 well-trained runners (VO2max ~ 72 mL/kg/min; record for 10 km ~ 32 min), demonstrated a significant correlation between the energy cost of the run with submaximal speeds (14, 16, 18 km/h), and the result of the competition over a distance of 10 km. In addition, many authors confirm that assessment of the energy cost of running at submaximal speed is a more precise way to predict starting capabilities than measuring maximal oxygen intake - especially among homogeneous groups in terms of VO2max [8-11].

However, there is a clear deficit of studies on the impact of specific training loads (volume, intensity, methods, forms and measures used, the nature of the interval for restitution) on the economy of running - that is, "ways of its training". These types of observations have the greatest applicative value from the perspective of sport in its competitive context.

## Study aim

The objective of the work was to determine the effects of exercise loads implemented as part of an 18-week training program on the economics of running at a speed corresponding to the lactate threshold of a competitor for the track-and-field section of KS AZS AWF (University of Physical Education) Kraków.

In addition, the objective was to determine the average heart rate and speed during a 10-km during in relation to threshold values for these parameters.

## Research questions

- How will the proposed training programme affect the economics of running at threshold speed?
- What average heart rate and running speed will the subject achieve during the 10-km race in relation to the threshold values of the specified parameters?

## Research methods and materials

### Characteristics of the studied athlete

The subject of the study was a 25-year-old track-and-field athlete of the KS AZS AWF Kraków section, specialising in long-distance runs. Between the age of 13 and 21, the participant practiced road cycling at a master class level. From the age of 22, the subject has been undergoing regular running endurance training. The observed athletes combines sports activity with studies and professional work.

### Organisation of the research project

The research project was divided into 3 blocks. Block 1 contained 2 running tests: (1) the pitch test - on the basis of which physiological and kinematic parameters were determined at the level of lactate threshold

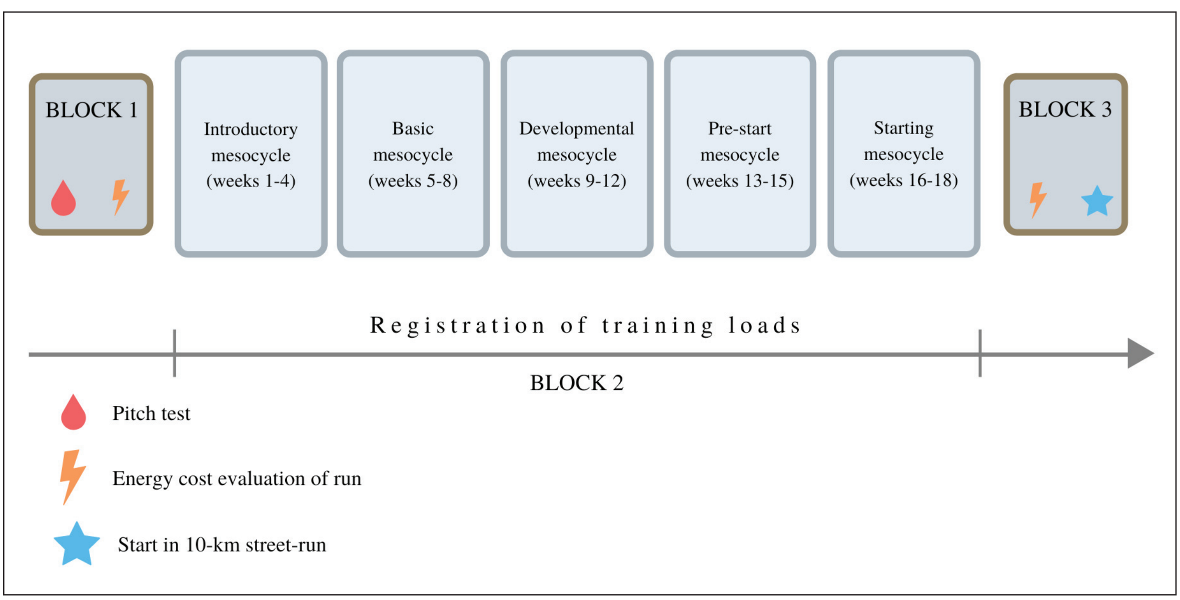


**Fig. 1.** Organisational scheme of research project

and intensity zone, (2) assessment of energy expenditure of running at threshold speed - obtained in the pitch test. Block 2 assumed the implementation of an 18-week training programme and registration of the work performed. In Block 3, the energy expenditure of the race at threshold speed was reassessed and the project was completed by participating in a street race covering a distance of 10 kilometres. An organisational scheme of the study is shown in Figure 1.

## Pitch test

The pitch test was used to determine heart rate and running speed corresponding to the intensity at lactate threshold level [12]. The trial consisted of 4, 6-minute efforts of progressively increasing intensity, separated by a 2-minute interval. The first effort ($HR_1$) was performed with heart rate calculated on the basis of the following formula: $HR_1 = 220 - (50 + age\ in\ years)$, and with each subsequent running interval, the intensity was increased by 10 bpm. Each time, following completion of the exercise, a blood drop (0.5 $\mu$l) was collected from the fingertip to measure lactate concentration, tested via the enzymatic-amperometric method using the Lactate Scout device from SensLab GmbH (Germany). The threshold heart rate (hrLT) and running speed (vLT) were calculated by averaging the values recorded by the Garmin Fenix 3 sport-tester in the final 3 minutes of exercise preceding the running interval, during which an increase in blood lactate concentration of at least 0.5 mmol/L was noted.

### Evaluation of energy expenditure

Energy expenditure evaluation of the run was performed via the indirect calorimetry method during exercise on a treadmill inclined at a 1-degree angle using the MES Start2000M ergospirometer. The same footwear was used for both trials, which consisted of a preparatory and proper part. During the preparatory phase, a 10-minute warm-up was carried out at a speed of 10 km/h, followed by a 5-minute period for placing the measuring apparatus. The proper part began with a 3-minute measurement of resting value in a seated position. Then, an 8-minute effort was performed at threshold speed, and following, a 10-minute measurement during the restitution period (in a sitting position) was performed. In the proper part, the following cardiopulmonary indices were recorded:

- Energy expenditure - EE [kJ/min]
- Heart rate - HR [beats/min]
- Oxygen consumption - $VO_2$ [L/min] [ml/kg/min]
- Respiratory exchange rate - RER
- Ventilatory-oxygen index - $VE/VO_2$
- Oxygen-ventilatory index - $VO_2/VE$

The comparative materials comprised the average values of the above-mentioned indices from the final 4 minutes of the effort - after achieving functional balance [13].

### Training programme and its implementation

The 18-week training programme - the assumptions of which are presented in Table 1, was designed based on the general principles of endurance training periodisation [14]. The programme anticipated 5, 3-4 weekly training mesocycles (introductory, basic, developmental, pre-start, start). It was assumed that the last week of each mesocycle was a microcycle for regeneration, while the rest were treated as training microcycles. The majority of microcycles assumed 4 main tasks (training 1-4). Continuous running in the 1st, 2nd and 3rd intensity zones and intermittent running in the 4th intensity zone were used as the basic training measures. Continuous efforts were designed and implemented based on the measurement of heart rate, while intermittent efforts with respect to running speed. In addition, the training programme included jogs, run-ups and general fitness exercises.

### Registration of training loads

The performed work was subject to registration in terms of time (min) including intensity zones, using the Garmin Fenix 3 heart rate monitor. The intensity zones were defined in relation to heart rate (hrLT) and running speed (vLT) corresponding to lactate threshold - determined in the pitch test. The following were adopted in accordance with Mirek [15]:

- Regeneration zone <90% hrLT / vLT
- Sub-threshold zone 90-95% hrLT/vLT
- Threshold zone 96-100% hrLT/vLT
- Supra-threshold zone >100% hrLT/vLT

### Statistical analysis

Statistical analysis of the obtained results was carried out using the MS Office 2016 suite. All quantitative variables were presented in the form of basic descriptive statistics - arithmetic average.

## Results

### Pitch test

In Table 2, the data collected in the pitch test are presented. The lactate threshold was reached in the 3rd effort, with a heart rate (hrLT) of 167 bpm and running speed totalling (vLT) 15.79 km/h. Based on the obtained values of physiological indices and kinematic parameters, the following intensity zones were determined:

- Regeneration zone <150 bpm / <14.21 km/h
- Sub-threshold zone 150-159 bpm / 14.21-15.00 km/h

**Table 1.** Assumptions and implementation of training programme

| Mesocycle | Microcycle | Training 1 | Training 2 | Training 3 | Training 4 |
|---|---|---|---|---|---|
| Introductory | Assumptions | Intermittent run<br>Volume: 8 km<br>I: 106% vLT<br>Work: 400 m<br>Interval: 60-45-30″ | Continuous run<br>I: 90-95% hrLT<br>Volume: ~20 km | Continuous run<br>I: 96-100% hrLT<br>Volume: 9-10 km | Continuous run<br>I: <90% hrLT<br>Volume: ~20 km |
| | Implementation 1 | 20x400 m/p.60′ | 20 km | 9 km | 20 km |
| | 2 | 20x400 m/p.45″ | 20 km | 10 km | 20 km |
| | 3 | 20x400 m/p.30″ | 20 km | 10 km | 20 km |
| | 4 | - | - | 9 km | 16 km |
| Basic | Assumptions | Intermittent run<br>Total work: 11-14 km<br>I: 106% vLT<br>Work: 900 m<br>Interval: 1′ | Continuous run<br>I: 90-95% hrLT<br>Volume: 20-23 km | Continuous run<br>I: 96-100% hrLT<br>Volume: 14-16 km | Continuous run<br>I: <90% hrLT<br>Volume: 21-25 km |
| | Implementation 5 | 13x900m/p.1′ | 20 km | 14 km | 21 km |
| | 6 | 14x900m/p.1′ | 22 km | 15 km | 22 km |
| | 7 | 15x900m/p.1′ | 23 km | 16 km | 25 km |
| | 8 | - | - | 10 km | 15 km |
| Developmental | Assumptions | Intermittent run<br>Total work: 6-8 km<br>I: 109% vLT<br>Work: 400 m<br>Interval: 60-45″ | Continuous run<br>I: 90-95% hrLT<br>Volume: do 20 km | Intermittent run<br>Total work: 10 km<br>I: 109% vLT<br>Work: 1 km<br>Interval: 90″ | Continuous run<br>I: <90% hrLT<br>Volume: 20-30 km |
| | Implementation 9 | 16x400m/p.60″ | 20 km | 10x1 km/p.90″ | 20 km |
| | 10 | 20x400m/p.60″ | 20 km | 10x1 km/p.90″ | 20 km |
| | 11 | 20x400m/p.45″ | 20 km | 10x1 km/p.90″ | 20 km |
| | 12 | - | 15 km | - | 30 km |
| Pre-start | Assumptions | Intermittent run<br>Total work: 8-10 km<br>I: 109% vLT<br>Work: 2 km<br>Interval: 3′ | Intermittent run<br>Total work: 3 km<br>I: 127% vLT<br>Work: 100 m<br>Interval: 30″ | Continuous run-variable<br>I: 105%/100% vLT<br>Proportion: 1-0.5<br>Volume: do 12-15 km | Continuous run<br>I: <90% hrLT<br>Volume: 20-25 km |
| | Implementation 13 | 4x2km/p.3′ | 30x100m/p.30″ | 8x1km/500 m | 20 km |
| | 14 | 5x2km/p.3′ | 30x100m/p.30″ | 10x1km/500 m | 22 km |
| | 15 | - | 30x100m/p.30″ | - | 25 km |
| Start | Assumptions | Intermittent run<br>Total work: 8-9 km<br>I: 114% vLT<br>Work: 1 km<br>Interval: 90″ | Continuous run-variable<br>I: 105%/100% vLT<br>Proportion: 1-0.5<br>Volume: do 12-15 km | Intermittent run<br>Total work: 4 km<br>I: 127% vLT<br>Work: 200 m<br>Interval: 45-40-35″ | Participation in competitive race |
| | Implementation 16 | 8x1km/p.90″ | 8x1 km/500 m | 20x200 m/p.45″ | Start-cross-country 5 km |
| | 17 | 9x1km/p.90″ | 10x1 km/500 m | 20x200 m/p.40″ | Start-cross-country 8 km |
| | 18 | **Stress test** | - | 20x200 m/p.35″ | **Start-street 10 km** |

**Table 2.** Final protocol of pitch test

| Effort | HR [beats/min] | LA [mmol/L] | S [km] | P [min/km] | V [km/h] |
|---|---|---|---|---|---|
| 1 | 144 | 1.2 | 1.38 | 04:20 | 13.85 |
| 2 | 156 | 1.5 | 1.47 | 04:05 | 14.69 |
| **3** | **167** | **1.9** | **1.58** | **03:48** | **15.79** |
| 4 | 178 | 4.6 | 1.70 | 03:32 | 16.98 |

**Table 3.** Speed – before and after implementing training programme

| | Before | After | Δ | [%] |
|---|---|---|---|---|
| **HR [beats/min]** | 178.50 | 175.50 | -3.00 | -1.71% |
| **VE[L/min]** | 109.40 | 98.20 | -11.20 | -11.41% |
| **RER** | 0.90 | 0.91 | +0.01 | +1.64% |
| **$VO_2$ [L/min]** | 4.50 | 4.21 | -0.29 | -6.77% |
| **$VO_2$[ml/kg/min]** | 64.25 | 60.18 | -4.07 | -6.77% |
| **EE [kJ/min]** | 92.61 | 87.11 | -5.50 | -6.32% |
| **$VE/VO_2$** | 24.327 | 23.309 | -1.018 | -4.36% |
| **VO2/VE** | 0.041 | 0.043 | +0.002 | +4.20% |

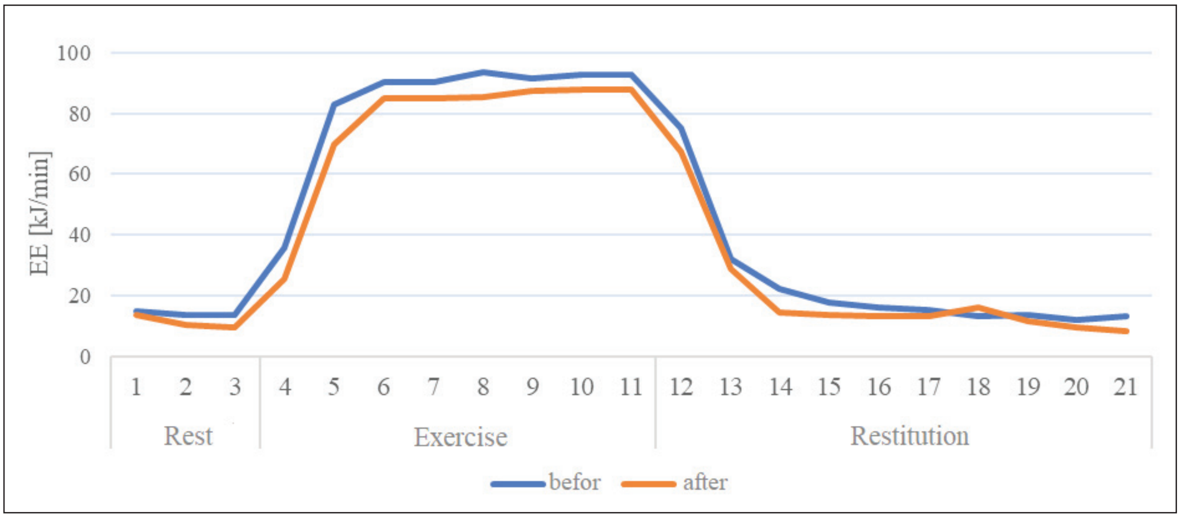


**Fig. 2.** Evaluation of energy cost of run – before and after implementing training programme

- Threshold zone 160-167 bpm / 15.01-15.79 km/h
- Supra-threshold zone> 167 bpm / > 15.79 km/h

### Energy cost of the run

In Table 3, Figure 2, a summary is presented regarding the average values of physiological indices obtained in the final 4 minutes of the run with a threshold speed of 15.79 km/h before and after the training programme. A reduction in running energy expenditure (EE) by 5.5 kJ/min (6.32%) was observed. The amount of oxygen consumption (VO2) in absolute terms decreased by 0.29 L/min (6.77%), relativised by 4.07 mL/kg/min (6.77%), while ventilation per minute (VE), by 11.2 L/min (11.41%). In addition, there was a decrease in the ventilatory-oxygen index (VE-VO2) by 1.018 (4.36%) and heart rate (HR) by 3 bpm (1.71%). In the case of

**Table 4.** Intensity zones of loads in consecutive mesocycles of training programme

| Mesocycle | Intensity zones | | | | | | | | Total | % |
|---|---|---|---|---|---|---|---|---|---|---|
| | Regeneration | | Sub-threshold | | Threshold | | Supra-threshold | | | |
| | min | % | min | % | min | % | min | % | | |
| I | 1343 | 69.2 | 338 | 17.4 | 144 | 7.5 | 115 | 5.9 | 1940 | 22.4 |
| II | 1507 | 70.9 | 274 | 12.9 | 209 | 9.8 | 136 | 6.4 | 2126 | 24.5 |
| III | 1560 | 75.7 | 317 | 15.4 | 0 | 0.0 | 183 | 8.9 | 2059 | 23.8 |
| IV | 1244 | 87.0 | 0 | 0.0 | 30 | 2.2 | 155 | 10.8 | 1430 | 16.5 |
| V | 835 | 75.4 | 0 | 0.0 | 34 | 3.1 | 239 | 21.5 | 1108 | 12.8 |
| **Total** | **6489** | **74.9** | **929** | 10.7 | 418 | 4.8 | 826 | 9.5 | 8663 | 100 |

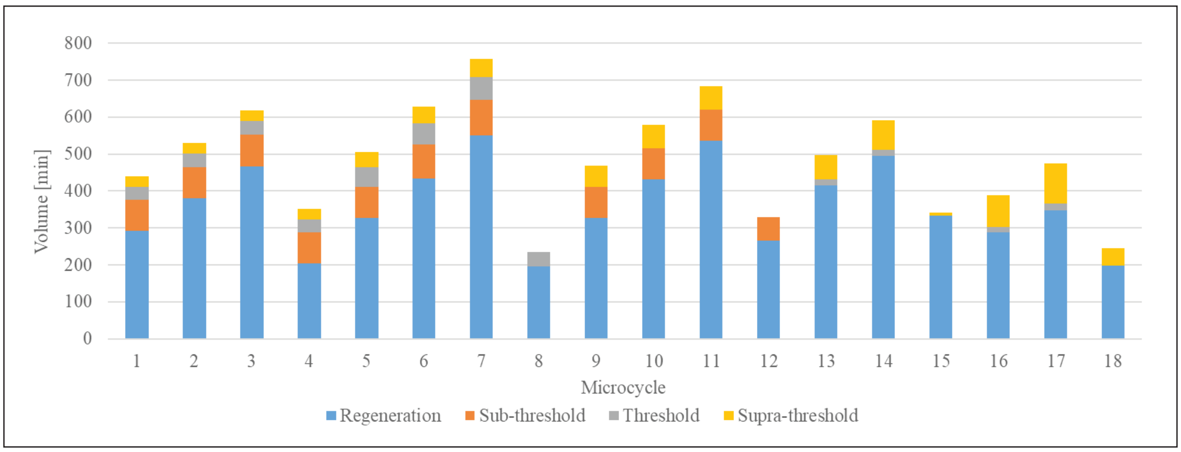


**Fig. 3.** Training volume in week-long mesocycles considering intensity zones

respiratory exchange rate (RER) and the oxygen-ventilatory index (VO2/VE), increases of 0.01 (1.64%) and 0.002 (4.20%) were recorded, respectively.

### Training loads

In Table 4 and Figure 3, a detailed analysis is given of the exercise loads performed as part of the training programme. The total volume of work performed during 18 weeks was 8,663 min (1,797 km). This equals an average weekly value of 481.3 min (99.8 km). Analysis of training load composition, taking intensity ranges into account, showed that 74.9% of the total volume regarded work in the regeneration zone, 10.7% - sub-threshold, 4.8% - threshold and 9.5% - supra-threshold.

### Start in 10-km street run

During the competition over a distance of 10 kilometres, the participant obtained a time of 35.1 min, which gives an average running speed of 17.094 km/h (108% vLT). During the competition, the average registered heart rate was 182 bpm (109% hrLT).

## Discussion

The implemented training programme resulted in a reduction of running energy with a threshold speed of 6.32%. This indicates the beneficial effects of the work on economics of movement and confirms the reports by other authors regarding the modifiability of this functional ability in response to training [16-18].

Economics of movement are determined by a number of factors that were not observable. The training programme used could, for example, contribute to the optimisation of biomechanical structure (technique) of the run. Perhaps the efficiency of using the elastic properties of the motor apparatus has increased. The applied loads may have improved neuromuscular coordination. The reduction of running energy cost could have also been the result of an increase in respiratory muscle performance [4]. In connection with the above, it is necessary to conduct a more thorough penetration of the object in order to obtain information on how training loads affect factors conditioning running economy, leading to its improvement.

During the competition over a distance of 10 km - lasting 35.1 min, the examined athlete achieved an average heart rate and running speed corresponding to 109% and 108% (respectively) of the threshold values for the indicated parameters. For comparison, an athlete of the international championship class in race-walking, during a competition over a distance of 10 kilometres (effort lasting ~ 40 minutes), was able to maintain an average intensity of 114% hrLT/110% vLT [19]. Considering that the running section was shorter, its average speed as well as the average heart rate should be at an even higher level than in the case of race-walking [13].

The observed discrepancies may result from differences in sports level or training experience. This would indicate the validity of the hypothesis that the more experienced an athlete, the more s/he is able to maintain a higher intensity of work during a specific period of time [20].

Weather conditions (air temperature and humidity, wind strength) in which the competition took place were not subject to control. These variables have confirmed impact on exercise-related physiological indicators and sports results, and thus, may have distorted the obtained results [21-22].

It should also be taken into account that the achieved results may have been disturbed by factors such as the amount of time spent on sleep, biological regeneration or per-exercise nutrition strategy, which is well-documented within the context of exercise capacity [21-22]. The lower level of registered intensity indices of the subject's effort during the competition - in relation to the aforementioned walker - may also be the result of errors in the training programme which did not allow the full use of his potential.

Sport theorists point out that direct start preparation is usually a 4-8 week period. This cycle or its equivalents may sometimes be extended up to 12-15 weeks [23]. In the case of the observed training programme, 18 week-long microcycles were planned – therefore, slightly longer than those recommended.

The sum of work performed by the subject was 8,663 min (1,797 km), which gives an average weekly volume of 481 min (99.8 km). This is not much compared to the amount of work done by more advanced athletes. Billat, Lepretre and Heugas [24] observed the exercise loads of 13 Kenyan long-distance runners presenting a high level of sport for 8-9 weeks (each participant was placed on the list of top 30 Kenyan Cross-Country Champions in 2002). Implementing the training model "small volume - high intensity", 6 of them covered an average of 158 ± 19 km/week. The remaining, training according to the "high volume - low intensity" principle, had an average amount of work at the level of 174 ± 17 km/week. Rabadan, Diaz and Calderon [24] registered an average training volume of 160-180 km/week during the preparatory period in a group of 32 Hispanic long-distance runners at national and international levels.

Analysis of the loads conducted in terms of the distribution of work in individual intensity zones showed that regenerative measures accounted for 74.9%, subthreshold measures - 10.7%, threshold measures - 4.8%, and supra-thresholds - 9.5% of the total volume of work performed. Comparing their own observations with data obtained by other authors, this showed that competitors with a higher sports level used a proportionally very similar amount of effort in the supra-threshold zone, while they spent much more time working in the threshold zone, at the expense of regenerative work [24-26].

To work on special endurance, the intermittent method was applied in the training programme - implementing repetitions no longer than 2 km. On the other hand, Zbigniew Zaręba, a classic of Polish medium- and long-distance runs, indicates that the optimum length of pace sections for a 10,000 m run is 3-4 km repetitions [27]. In connection with the above, it seems that the units used in the training programme, the assumption of was to shape special strength, were designed based on too short pace sections.

## Conclusions

1. The proposed 18-week training programme had positive effects on the economics of running at a threshold speed. The research results indicate the need for further scientific penetration of the subject in order to explain how the stress loads affect the factors determining the economics of movement, leading to its improvement.
2. It was shown that the average heart rate and average test speed during the 10-km race exceeded the threshold values of the mentioned parameters by 9 and 8%, respectively.
3. Comparison of the authors' observations with reports by other authors provides information to optimise training loads.

**Institutional Review Board Statement**: The study was conducted in accordance with the Declaration of Helsinki, and approved by the Institutional Ethics Committee

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