JKES
Journal of Kinesiology and Exercise Sciences

E-ISSN: 2956-4581
Journal of Kinesiology and Exercise Sciences

105 (34): 1-10, 2024
ORIGINAL RESEARCH

(1.1) DOI: 10.5604/01.3001.0053.9657

ANALYSIS OF TRAINING LOADS IN POLISH ADOLESCENT ROAD CYCLISTS IN THE PREPARATORY PERIOD AND THEIR EFFECTS ON PHYSICAL FITNESS

Bartosz Zając [1]* ABCDEFG, Paulina Katarzyna Gaj [2] ABCDEFG, Tadeusz Ambroży [3] ACD

[1] Laboratory of Functional Diagnostics, Central Scientific and Research Laboratory, University of Physical Education in Kraków, Poland
[2] Cracow Academy of Track-and-Field Sports, Kraków, Poland
[3] Institute of Sport Science, University of Physical Education in Kraków, Poland

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

Received: 13.07.2023
Revised: 26.07.2023
Accepted: 09.10.2023
Published: 30.10.2023

Keywords: training loads; road cycling; aerobic fitness; anaerobic fitness

*Author for correspondence: bartosz.zajac@awf.krakow.pl

Abstract:

Background: Road cycling is one of the most extreme endurance sports. Professional road cyclists typically train ~20 hours per week and cover ~600 km a week. The longest 1-day race in men's cycling can be up to 300 km while the longest multiple-stage races can last up to 21 days. Twenty to seventy accelerations are performed during a race, exceeding maximal aerobic power. Training is a crucial component of athletes' preparation for competitions. Therefore, strong emphasis should be on recording the applied training loads and monitoring how they influence aerobic and anaerobic fitness, as well as performance. The aim of the study was to analyze the training loads in the preparatory period and their effects on aerobic and anaerobic fitness in adolescent road cyclists.

Materials and Methods: The study involved 23 highly trained/national elite male road cyclists. Of them, 16 athletes (age: 16.2±1.1 years; training experience: 5.0±2.1 years) fully completed all components of the study. Aerobic fitness was measured using cardiopulmonary exercise testing (graded exercise test to exhaustion), while anaerobic fitness was evaluated using the 30-second modified Wingate anaerobic test. Each recorded training session time was distributed across training and activity forms as well as intensity zones.

Results: The endurance training form used in the preparatory period was characterized by low-volume (~7.7h$\times$wk^{-1}), non-polarised (median polarization index 0.15) pyramidal intensity distribution (zone^1~68%; zone^2~26%; zone^3~1% total training volume). Endurance (specific and non-specific) and strength training forms accounted for ~95% and ~5% (respectively) of the total training time.

Conclusion: Low-volume, non-polarised pyramidal intensity distribution training is probably not an effective stimulus for improving physical fitness in adolescent road cyclists. Disregarding high-intensity exercises in training programs for adolescent cyclists may result in stagnation or deterioration of physical fitness.

Introduction

Road cycling competitions are very demanding in some respects. Analysis of road cycling races has shown that the average distance covered during a competition is 53km (1.4h) in youth, 77-94km (2.0-2.4h) in juniors, and 150km (3.9h) in elite cyclists [1,2]. Interestingly, during such long-lasting competitions, work intensity may be very high.

The percentage of the total flat race time in professional cyclists at an intensity below 70%, between 70 and 90%, and above 90% of maximal oxygen uptake (VO_2max), averages at approximately 70, 25, and 5%, respectively [3]. During the race, approximately 20 to 70 accelerations are performed at an intensity exceeding maximal aerobic power [4]. Moreover, male cyclists may generate power of over 1,200W ($17W \times kg^{-1}$) during final sprints [5]. What is more, data indicates that competitions in younger categories can be even more intense than those in elite cyclists in terms of internal intensity [2].

From a physiological perspective, sports performance in cycling competitions is determined by both aerobic [3,6] and anaerobic fitness [5,7]. The gold standard for evaluation of aerobic fitness is cardiopulmonary exercise testing (CPET), combining the measurement of: (i) physiological variables such as heart rate (HR), pulmonary ventilation (VE), volume of oxygen uptake (VO_2), and exhaled carbon dioxide (VCO_2); (ii) work rate (e.g. power output) and rating of perceived exertion (RPE) during the graded exercise test (GXT) to exhaustion [8]. For practitioners, the most important indices obtained from GXT are VO_2max and power output per kilogram of body mass at metabolic thresholds and VO_2max [9]. Furthermore, the Wingate anaerobic test (WAT) is widely used to assess anaerobic fitness [10]. Classic WAT requires pedaling for 30s at maximum speed against constant resistance. During the test, consecutive crank revolution times are recorded. Based on the obtained data, the following anaerobic fitness indices are calculated: peak (PP), mean (MP), and minimal (MinP) power (absolute and relative), time to obtain peak power (TOPP), and fatigue index (FI).

Training is a crucial component of athletes' preparation for competition. Therefore, strong emphasis should be on recording the applied training loads and monitoring how they influence physical fitness and performance. Training load can be categorized as either internal or external [11]. Internal training loads are defined as relative biological (both physiological and psychological) stressors imposed on an athlete during training or competition. Measures such as heart rate, blood lactate, oxygen consumption, and ratings of perceived exertion are commonly used to assess internal load. On the other hand, external training loads are objective measures of the work performed by an athlete during training or competition and are evaluated independently of internal workloads. Common measures of external load include power output, speed, acceleration, time-motion analysis, global positioning system, and accelerometer-derived parameters. An inexpensive and widely applied method of quantifying training loads in the practice of endurance sports is the time-in-zone approach [12]. This method is based on the measurement of HR and duration of training spent in 3 intensity zones determined individually in relation to HR at metabolic thresholds. However, the drawback of this method is the underestimated time of high-intensity training [12].

Reporting applied training loads and their effects on physical fitness or performance in various athlete populations using scientific approaches can be relevant for practitioners and scientists. Such data may provide a starting point for designing training programs and/or explaining their positive effects (performance improvement), and prevention of potential negative or no effects of the load used (injury, overtraining). To the best of our knowledge, researchers mainly concentrate on the analysis of internationally competitive training loads in adult cyclists, generally employing a retrospective study design [13–21], while there is a very limited amount of data from studies on adolescent road cyclists [22,23] or research in which the prospective scheme was employed [24]. Therefore, the aim of the study was to analyze training loads applied in the preparatory period and their effects on aerobic and anaerobic fitness in adolescent road cyclists.

Material and Methods

Study design

The study was conducted in Świdnica, Poland (at an elevation of 250 meters above sea level), in a ventilated gymnasium. Basic anthropometric indices and physical fitness were assessed (over the span of 4 days) before and after an 18-week preparatory period (PrPe) (November-March), during which training loads were recorded. GXT and MWAT were performed between 10:00 a.m. and 4:00 p.m. at an ambient temperature of 20 ± 1°C and relative humidity of 40 ± 5%. Athletes were tested at the same time of the day ($\pm$1h) before and after PrPe to avoid the influence of circadian rhythm. Participants were asked to remain well-hydrated, to refrain from consuming any stimulants for at least 24h before testing, and not to engage in strenuous exercise at least 48h prior to testing. Assessments were performed in the following order: anthropometric measurements (fasting and after using the toilet), GXT (minimum 2 hours after the last meal), and MWAT (minimum 1 hour after GXT). Before each test, the cyclists were familiarized with the testing procedures. Stress tests were performed on a Cyclus 2 ergometer (RBM electronic-automation GmbH, Germany) with the athlete's bike installed (the same bike on which the athlete trained and competed in races).

The ergometer was calibrated in accordance with the manufacturer's recommendations. All procedures were carried out in accordance with the 1964 Declaration of Helsinki and its subsequent amendments. Consent to perform testing was provided by the Bioethics Committee at the Regional Medical Chamber in Kraków (No. 249/KBL/OIL/2021).

Participants

The study involved 23 male road cyclists recruited from students of the Sports Championship School of Cycling in Świdnica, Poland. Finally, material for analysis was taken from 16 athletes (age: 16.2±1.1 years; training experience: 5.0±2.1 years) who fully completed all components of the study. The basic characteristics of the cyclists are presented in Tab. 1. Seven cyclists withdrew from the tests without giving a reason. The inclusion criteria were: (i) progression of biological development - minimum third pubic hair stage on Tanner's Scale [25]; (ii) "highly trained/ national elite" level according to McKay's participant classification framework for research in sports sciences [26]; (iii) having a current certificate from a sports medicine doctor regarding the ability to practice road cycling. The exclusion criteria were age above 18 years or the health status making it impossible to perform the stress tests. The participants and their legal guardians were informed about the research protocol in detail and gave their written informed consent to participate in the study.

Anthropometric measurements

Body height (BH) was measured using a Seca 213 stadiometer (Seca GmbH & co. kg, Germany) to the nearest 1 mm. Body mass (BM), fat mass (BF), and lean body mass (LBM) were evaluated by means of an MC 780 MA body composition multi-frequency (5kHz/50kHz/250kHz) octopolar analyzer (Tanita, Japan) using the method of electrical bioimpedance [27]. The measurements were conducted under conditions recommended by the analyzer's manufacturer.

Graded exercise test

The graded exercise test began with a 4-minute warm-up performed at 80W. Next, the load was increased by 40W every 2 minutes. The effort was continued until exhaustion, which was manifested in the inability to maintain a cadence higher than 70rpm. During testing, the following physiological variables were recorded breath-by-breath using a Quark CPET ergospirometer (Cosmed, Italy): VE, VO_2 and VCO_2, and HR. The data were averaged across 10-s intervals. The ergospirometer was calibrated according to the manufacturer's instructions. Rating of perceived exertion (RPE) was recorded in the last 15s of each 2-minute interval using the 6-20 Borg scale [28]. Anaerobic threshold (AT) and respiratory compensation point (RCP) were determined based on the dynamics of change in respiratory indices [29]. The following criteria [30] were used for VO_2max determination: an increase in VO_2 of $<150 mL \cdot min^{-1}$ with an increase in power, respiratory exchange ratio >1.10, RPE >18 on the Borg's scale, age-predicted maximal HR >90% calculated according to Tanaka [31].

Modified Wingate anaerobic test

At baseline, the participants performed a 4-minute warm-up at 90W. During the final 3-5s of the second and fourth of the warm-up, the athletes performed maximal accelerations. Two minutes after the warm-up, the maximal 30-s all-out effort with a stationary start was performed. The resistance applied during the test was set at 10% body mass [32]. At the "Go!" command, the task of the participant was to reach the maximum pedaling rate as quickly as possible and then maintain it in a seated position until the end of the effort (with strong verbal encouragement). Based on the MWAT, the following indices were evaluated: PP, TOPP, MP, MinP, and FI, calculated as ((PP-MinP)÷PP)×100%.

Training monitoring

Training load analysis was conducted based on the data recorded by the Edge 530 sport tester (Garmin, USA) and exported first to the Garmin Connect platform and then to Excel. Each recorded training session times were distributed across training form [33] (endurance, strength), activity form [33] (specific: spinning, road, track, or mountain cycling; non-specific: running, cross-country skiing, skating, swimming), and exercise intensity [34] ($zone^1$: below HR_{AT}; $zone^2$: between HR_{AT} and HR_{RCP}; $zone^3$: above HR_{RCP}) using a time-in-zone approach [12]. Moreover, the polarization index was calculated on a weekly basis according to Treff et al. [35].

Statistical analysis

Statistical analysis was carried out using Statistica 13.3 software (TIBCO Software Inc., Palo Alto, CA, USA). Changes in variables were evaluated with the two-tailed paired samples *t*-test or Wilcoxon signed-rank test depending on normal data distribution, which was examined with the Shapiro-Wilk test. The probability of type-I error below 0.05 was adopted as the level of significance. The effect size for the paired *t*-test samples was calculated by dividing the mean difference by the standard deviation of the difference, while the Wilcoxon signed-rank test, was calculated by dividing the z-value by the square root of the observation number [36]. Test power was calculated post-hoc using G*Power 3.1.9.7 software (input variables: 2-tail, effect size, $\alpha=0.05$, sample size=16).

Results

Anthropometric indices

After the 18-week PrPe, an increase in body mass was observed as a result of a rise in lean body mass. Detailed changes in anthropometric indices are presented in Table 1.

Table 1. Anthropometric characteristics (median (1st and 3rd quartiles)) of the cyclists studied

	pre-test	post-test	Difference (%) pre-post	*p*-value	ES	*p*
Body height (cm)	178.0 (174.3-180.5)	178.3 (174.8-180.8)	0.3 (-0.3-0.4)	0.738	0.24	0.23
Body mass (kg)	64.5 (59.8-68.1)	65.5 (62.4-69.9)	2.5 (0.9-4.6)	0.004*	0.87	0.95
Fat mass (kg)	10.1 (8.7-11.7)	9.8 (9.2-12.5)	2.5 (-3.2-8.22)	0.317	0.27	0.27
Fat mass (%BM)	15.6 (14.8-17.6)	15.9 (14.0-17.8)	-0.4 (-4.0-5.8)	0.947	0.02	0.05
Lean body mass (kg)	54.0 (50.7-57.7)	54.8 (52.3-59.4)	2.0 (1.0-4.7)	0.002*	0.99	0.98

p-value – probability of type-I error, * – statistically significant difference, ES – effect size, P – test power

Aerobic performance

Following the 18-week preparatory period, P_{AT} (W and W×kg^{-1}), P_{VO2MAX} (W), and VO_2max (L×min^{-1}) improved significantly. No changes in P_{AT} (W×kg^{-1}), P_{RCP} (W and W×kg^{-1}), or VO_2max (mL×kg^{-1}×min^{-1}) were found, whereas P_{VO2MAX} (W×kg^{-1}) deteriorated substantially. Detailed data regarding changes in aerobic fitness indices are shown in Table 2.

Table 2. Indices of aerobic performance (median (1st and 3rd quartiles)) before and after the 18-week preparatory period

	pre-test	post-test	Difference (%) pre-post	*p*-value	ES	*p*
P_{AT} (W)	200 (200-200)	200 (200-240)	16.7 (0-16.7)	0.012*	0.63	0.63
P_{AT} (W×kg^{-1})	3.0 (2.9-3.2)	3.3 (3.0-3.6)	12.9 (-1.4-16.6)	0.014*	0.75	0.80
P_{RCP} (W)	280 (280-320)	320 (280-320)	0.0 (0.0-12.5)	0.059	0.47	0.40
P_{RCP} (W×kg^{-1})	4.6 (4.2-4.7)	4.6 (4.4-5.0)	-0.4 (-3.3-9.1)	0.207	0.35	0.26
P_{VO2MAX} (W)	360 (360-400)	400 (400-400)	9.1 (0.0-10.0)	0.025*	0.56	0.53
P_{VO2MAX} (W×kg^{-1})	6.2 (6.0-6.5)	6.1 (5.8-6.3)	-2.3 (-4.6-(-0.7))	0.008*	-0.81	0.86
VO_2max^A	3.82 (3.65-3.94)	4.10 (3.85-4.14)	5.4 (1.6-7.6)	0.002*	1.02	0.97
VO_2max^R	58.5 (57.5-61.4)	60.5 (57.8-63.0)	2.5 (-2.9-5.3)	0.065	0.53	0.51

P – power, HR – heart rate, VE – pulmonary ventilation, VO_2 – oxygen uptake, AT – anaerobic threshold level, RCP – respiratory change point level, max – maximal level, ^{A} - L×min^{-1}, ^{R} - mL×kg^{-1}×min^{-1}, *p*-value – probability of type-I error, * – statistically significant difference, ES – effect size, *P* – test power

Anaerobic performance

After the preparatory period, no changes were found in PP (W), TOPP, or MP (W). Furthermore, relative PP, MP, and FI substantially decreased. Detailed data are shown in Table. 3.

Table 3. Anaerobic performance (median (1st and 3rd quartiles)) before and after the 18-week preparatory period

	pre	post	Difference (%) pre-post	*p*-value	ES	*p*
PP (W)	913 (889-974)	905 (851-983)	-1.8 (-7.6-2.3)	0.183	-0.36	0.27
PP (W×kg^{-1})	14.3 (13.9-14.9)	13.8 (13.0-14.2)	-5.3 (-10.7 to -1.5)	0.015*	-0.71	0.76
TOPP (s)	3.05 (2.40-3.77)	3.55 (2.95-4.40)	0.35 (-0.33-1.33)	0.133	0.41	0.34
MP (W)	736 (685-778)	724 (662-776)	-2.6 (-5.3-1.4)	0.134	-0.41	0.34
MP (W×kg^{-1})	11.4 (11.2-11.5)	10.9 (10.2-11.3)	-4.9 (-9.0 to -2.5)	0.002*	-0.99	0.96
FI (%)	42.9 (39.3-49.5)	38.6 (36.6-41.8)	-8.4 (-23.5-0.3)	0.004*	-0.89	0.91

PP – peak power, TOPP – time do obtain peak power, MP – mean power, FI – fatigue index, *p*-value – probability of type I error, * – statistically significant difference, ES – effect size, P – test power

Training loads

Numerical data for training volume across training forms, activity forms, and intensity zones are presented in Table 4. A graphical representation of training volume in 18 consecutive 7-day mesocycles for training forms, intensity distribution, and polarization index are presented in Figures 1 and 2.

Table 4. Training volume [h×wk^{-1}] (median (1st and 3rd quartiles)) distributed across training forms, activity forms, and intensity zones

Training form	Activity form	Zone^{1}	Zone^{2}	Zone^{3}	∑ Zone$^{1-3}$
Endurance	**Specific**	4.2 (3.7-6.7) 60.0%T	1.5 (1.2-2.4) 23.1%T	0.1 (0.0-0.1) 0.9%T	5.8 (5.0-9.2) 84.0%T
	Non-specific	0.4 (0.0-0.9) 7.6%T	0.3 (0.0-0.5) 3.5%T	0.0 (0.0-0.0) 0.4%T	0.7 (0.0-1.5) 11.5%T
	Overall	5.6 (4.1-7.0) 67.6%T	2.2 (1.5-2.5) 26.6%T	0.1 (0.1-0.1) 1.3%T	7.7 (5.5-9.5) 95.5%T
Strength	N/A	N/A	N/A	N/A	0.2 (0.1-0.6) 4.5%T
Total training volume (T) = 7.9 (6.5-10.0)			Polarization-Index = 0.15 A.U. (0.08-0.24)		

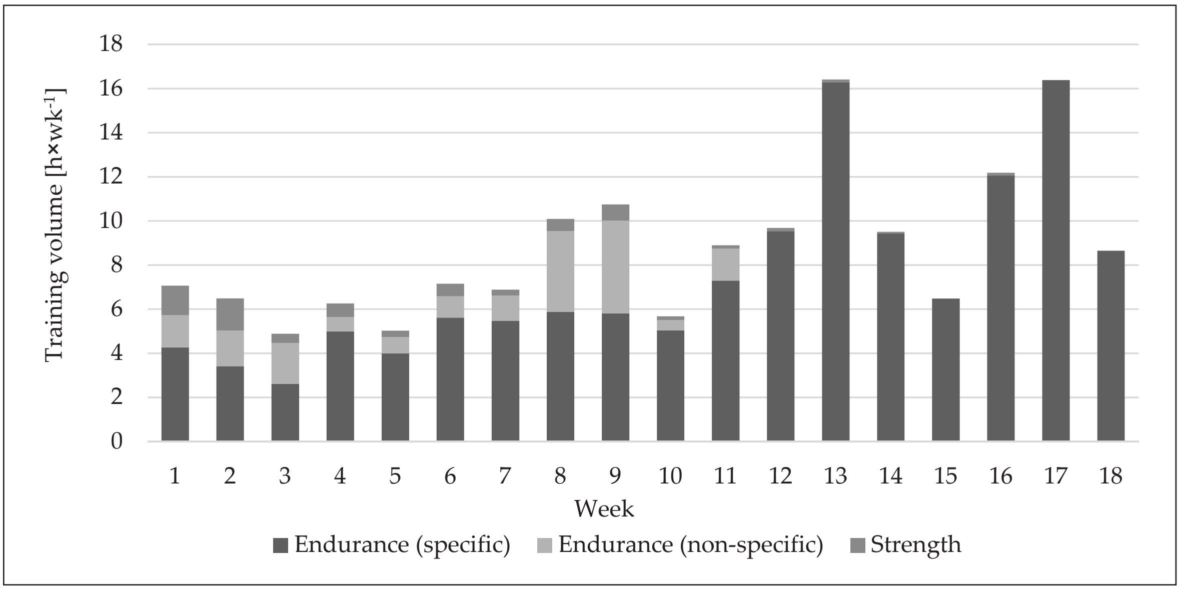

Figure 1. Endurance (specific, non-specific) and strength training volume during each 7-day mesocycle

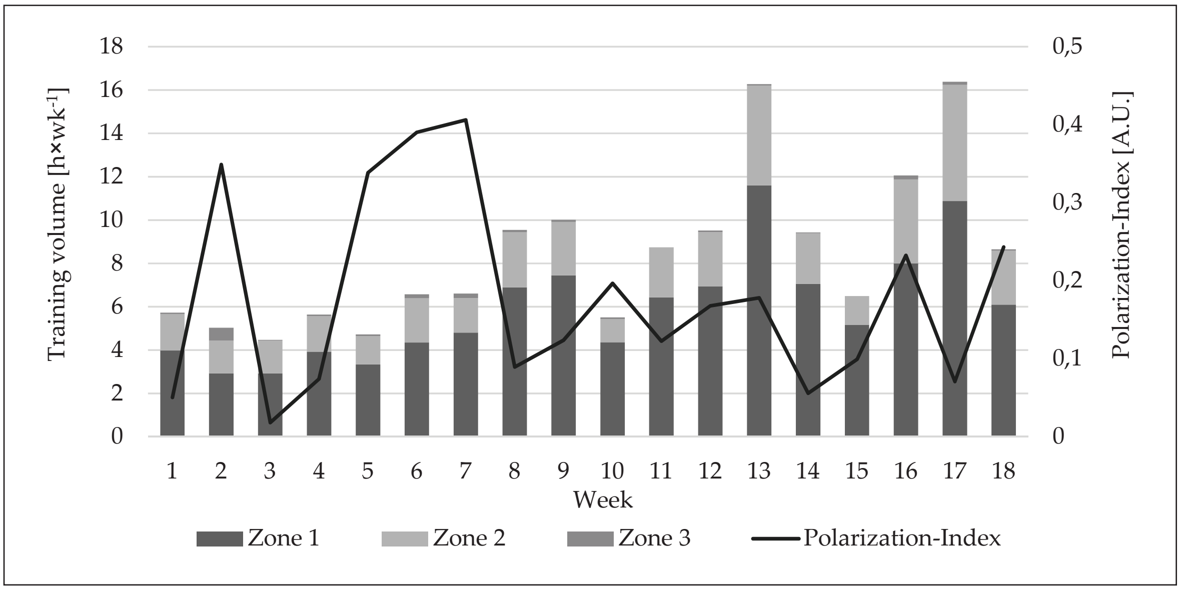

Figure 2. Training intensity distribution and polarization index during each 7-day mesocycle

Discussion

The main finding of this study was that training loads of Polish youth road cyclists in the PrPe period were characterized by low volume and non-polarized pyramidal intensity distribution. What is also significant, the training model implemented in this study had in general no positive effects on either aerobic or anaerobic fitness. To the best of our knowledge, this is one of the first studies in which training loads and their effects on physical fitness in adolescent road cyclists are assessed prospectively.

Training volume and intensity distribution are crucial parameters characterizing sports training. Endurance athletes typically train from 500 hours per year (~10h per week) (distance runners) [37–43] to over 1,000 hours per year (~20h per week) (rowing, swimming, cycling, triathlon) [21,22,44–50] in order to reach an international level. The adolescent road cyclists in the present study trained approximately for 7.9 hours per week during PrPe. Low training volume in the cyclists studied compared to other endurance athlete populations may result from sports level and/or age differences. Furthermore, it should be noted that the preparatory period fell in the winter season. In Poland at this time of the year, temperatures often fall below 0°C, which makes long bike rides difficult.

Many studies across a broad range of endurance sports that have analyzed training intensity distribution (TID) based on the binary approach were consistent with the finding that 75–90% of all endurance training time is performed at low intensity (below the first metabolic threshold). The remaining 10–25% is comprised of high-intensity training performed above the first metabolic threshold [21,33,37,38,49–51]. In the cyclist studied, endurance training time below and above AT accounted for approximately 68 and 27% (respectively) of total training time. The remaining 5% was intended for strength training. The polarization index (median 0.15) and 3 intensity zone approach (zone^1: ~68%, zone^2: ~26%, zone^3: ~1%) used in this study indicated non-polarised [31], pyramidal [9] TID, in which most training was at zone^1, with decreasing proportions of zone^2 and zone^3. This TID model seems to be commonly applied in elite cyclists. This has been shown in the research by Lucia et al. [19] (78%/17%/5%), Zapico et al. [21] (78%/20%/2%), and Schumacher and Mueller [20] (94%/4%/2%).

We believe that the simultaneous increase in P_{AT} (W and W×kg^{-1}), P_{VO2MAX} (W), VO_2max (mL×min^{-1}), plateau P_{AT} (W×kg^{-1}), P_{RCP} (W and W×kg^{-1}), and VO_2max (mL×kg^{-1}×min^{-1}); and decrease in P_{VO2MAX} (W×kg^{-1}), was the result of increased LBM. Kim et al. [52] and Maciejczyk et al. [53] demonstrated substantial positive correlations between LBM (the main component of which is muscle mass) and absolute indices of aerobic performance. We assume that the factor that was likely to increase LBM in the cyclists studied was strength training, which constituted approximately 5% of the total training volume. Such a combination of endurance (ET) and strength (ST) training is called concurrent training (CT). It stimulates both target peripheral (muscular) adaptations, i.e. hypertrophy and capillarisation [54]. In a meta-analysis performed by Wilson et al. [55], it was demonstrated that CT, compared to ET, produces substantially greater improvement in muscle hypertrophy (mean overall effect size of 0.85 [95%CI: 0.57-1.20] vs. 0.27 [95% CI:

-0.53-0.60]). Another plausible explanation for the increase in LBM is the passage of time (the pubertal period is characterized by dynamic tissue growth and maturation) [56], taking supplements promoting muscle hypertrophy [57], or an interaction effect of these factors [58]. Whatever the cause, the changes are adverse in the context of performance because each additional kilogram of BM produces metabolic heat [59] and requires the supply of energy substrates [60], which additionally burdens the body during long-lasting races.

Following the 18-week PrPe period, anaerobic fitness deteriorated in the studied cyclists. The reason for this is probably the characteristics of the applied training loads, with a small number of high-intensity exercises (analysis of cyclists' training loads showed that only approximately 1% of total training volume constituted exercises above RCP intensity). Low-intensity training is thought to be fundamental in the preparation for endurance events. This type of exercise improves VO_2peak by increasing stroke and plasma volume and inducing molecular adaptations for capillary and mitochondrial biogenesis, thereby improving the efficiency of key metabolic components for energy production [61,62]. However, it cannot be expected that this type of exercise will prepare athletes for anaerobic effort [63].

The practical conclusion of this study is that if, for some reason, coaches of adolescent road cyclists cannot include low-intensity training with a volume providing desirable adaptive changes or high volume, low-intensity training is ineffective. A good solution can be the implementation of a more polarised training model by adding high-intensity exercises (above RCP or VO_2max). In the meta-analysis performed by Engel et al. [64], it was suggested that young athletes performing high-intensity training can improve both aerobic and anaerobic performance. Moreover, young athletes may benefit from high-intensity training as it requires less time per training session, leaving more time for training sport-specific skills or school education.

The limitations of this study include (i) the small sample size which does not guarantee high test power (for 12 of the 20 indices, test power was below 80%), (ii) the lack of a control group, (iii) the method used to quantify training loads, which underestimates high-intensity training duration [12], (iv) a lack of detailed data about the applied strength training and supplementation.

Conclusions

Low-volume non-polarised pyramidal intensity distribution training is probably not an effective stimulus to improve physical fitness in adolescent road cyclists. Disregarding high-intensity exercises in training programs for adolescent cyclists may result in stagnation or deterioration of physical fitness.

Founding: The study was funded by the "Research of Young Scientists'' programme provided by the University of Physical Education in Kraków, project No. 144/MN/IS/2021.

Institutional Review Board Statement: All procedures were carried out in accordance with the 1964 Declaration of Helsinki and its subsequent amendments. Consent to perform testing was provided by the Bioethics Committee at the Regional Medical Chamber in Kraków (No. 249/KBL/OIL/2021).

Informed consent statement: The participants and their legal guardians were informed about the research protocol in detail and gave their written informed consent to participate in the study.

Data availability statement: The data presented in this study are available on request from the corresponding author.

Conflict of interest: There is a conflict of interest because one of the co-authors is an editor of the journal. We assure that in such cases, the manuscript has been processed by an independent editor in accordance with the principles of ethics, peer review, and publishing.

References:

[1] Rodríguez-Marroyo JA, Pernía R, Cejuela R, García-López J, Llopis J, Villa JG. Exercise Intensity and Load During Different Races in Youth and Junior Cyclists. J Strength Cond Res 2011;25:511–9. https://doi.org/10.1519/JSC.0b013e3181bf4426.

[2] Gallo G, Leo P, Mateo-March M, Giorgi A, Faelli E, Ruggeri P, et al. Cross-Sectional Differences in Race Demands Between Junior, Under 23, and Professional Road Cyclists. Int J Sports Physiol Perform 2022;17:450–7. https://doi.org/10.1123/ijspp.2021-0256.

[3] Lucia A, Hoyos J, Chicharro JL. Physiology of Professional Road Cycling. Sports Medicine 2001;31:325–37. https://doi.org/10.2165/00007256-200131050-00004.

[4] Ebert TR, Martin DT, Stephens B, Withers RT. Power Output During a Professional Men's Road-Cycling Tour. Int J Sports Physiol Perform 2006;1:324–35. https://doi.org/10.1123/ijspp.1.4.324.

[5] Menaspà P, Quod M, Martin DT, Peiffer JJ, Abbiss CR. Physical demands of sprinting in professional road cycling. Int J Sports Med 2015;36:1058–62.
[6] Impellizzeri FM, Marcora SM, Rampinini E, Mognoni P, Sassi A. Correlations between physiological variables and performance in high level cross country off road cyclists. Br J Sports Med 2005;39:747. https://doi.org/10.1136/bjsm.2004.017236.
[7] Baron R. Aerobic and anaerobic power characteristics of off-road cyclists. Med Sci Sports Exerc 2001;33:1387–93. https://doi.org/10.1097/00005768-200108000-00022.
[8] Mezzani A. Cardiopulmonary Exercise Testing: Basics of Methodology and Measurements. Ann Am Thorac Soc 2017;14:S3–11. https://doi.org/10.1513/AnnalsATS.201612-997FR.
[9] Stöggl TL, Sperlich B. The training intensity distribution among well-trained and elite endurance athletes. Front Physiol 2015;6. https://doi.org/10.3389/fphys.2015.00295.
[10] Castañeda-Babarro A. The Wingate Anaerobic Test, a Narrative Review of the Protocol Variables That Affect the Results Obtained. Applied Sciences 2021;11:7417. https://doi.org/10.3390/app11167417.
[11] Foster C, Rodriguez-Marroyo JA, de Koning JJ. Monitoring Training Loads: The Past, the Present, and the Future. Int J Sports Physiol Perform 2017;12:S2-2-S2-8. https://doi.org/10.1123/IJSPP.2016-0388.
[12] Sylta Ø, Tønnessen E, Seiler S. From Heart-Rate Data to Training Quantification: A Comparison of 3 Methods of Training--Intensity Analysis. Int J Sports Physiol Perform 2014;9:100–7. https://doi.org/10.1123/ijspp.2013-0298.
[13] Metcalfe AJ, Menaspà P, Villerius V, Quod M, Peiffer JJ, Govus AD, et al. Within-Season Distribution of External Training and Racing Workload in Professional Male Road Cyclists. Int J Sports Physiol Perform 2017;12:S2-142-S2-146. https://doi.org/10.1123/ijspp.2016-0396.
[14] Gallo G, Mateo-March M, Gotti D, Faelli E, Ruggeri P, Codella R, et al. How do world class top 5 Giro d'Italia finishers train? A qualitative multiple case study. Scand J Med Sci Sports 2022. https://doi.org/10.1111/sms.14201.
[15] van Erp T, Sanders D, de Koning JJ. Training Characteristics of Male and Female Professional Road Cyclists: A 4-Year Retrospective Analysis. Int J Sports Physiol Perform 2020;15:534–40. https://doi.org/10.1123/ijspp.2019-0320.
[16] Pinot J, Grappe F. A six-year monitoring case study of a top-10 cycling Grand Tour finisher. J Sports Sci 2015;33:907–14. https://doi.org/10.1080/02640414.2014.969296.
[17] Muriel X, Courel-Ibáñez J, Cerezuela-Espejo V, Pallarés JG. Training load and performance impairments in professional cyclists during COVID-19 lockdown. Int J Sports Physiol Perform 2021;16:735–8. https://doi.org/10.1123/ijspp.2020-0501.
[18] van Erp T, Hoozemans M, Foster C, de Koning J. Case Report: Load, Intensity, and Performance Characteristics in Multiple Grand Tours. Med Sci Sports Exerc 2020;52:868–75. https://doi.org/10.1249/MSS.0000000000002210.
[19] Lucía A, Hoyos J, Pardo J, Chicharro JL. Metabolic and Neuromuscular Adaptations to Endurance Training in Professional Cyclists. A Longitudinal Study. Jpn J Physiol 2000;50:381–8. https://doi.org/10.2170/jjphysiol.50.381.
[20] Schumacher YO, Muller P. The 4000-m team pursuit cycling world record: theoretical and practical aspects. Med Sci Sports Exerc 2002;34:1029–36. https://doi.org/10.1097/00005768-200206000-00020.
[21] Zapico AG, Calderon FJ, Benito PJ, Gonzalez CB, Parisi A, Pigozzi F, et al. Evolution of physiological and haematological parameters with training load in elite male road cyclists: a longitudinal study. Age (Years) 2007;20:20–1.
[22] Rauter S, Jurov I, Milić R. Training load and changes in physiological parameters among young cyclists. Kinesiologia Slovenica 2020;26:5–14.
[23] Gallo G, Leo P, March MM, Giorgi A, Faelli E, Ruggeri P, et al. Differences in Training Characteristics Between Junior, Under 23 and Professional Cyclists. Int J Sports Med 2022. https://doi.org/10.1055/a-1847-5414.
[24] Neal CM, Hunter AM, Brennan L, O'Sullivan A, Hamilton DL, DeVito G, et al. Six weeks of a polarized training-intensity distribution leads to greater physiological and performance adaptations than a threshold model in trained cyclists. J Appl Physiol 2013;114:461–71. https://doi.org/10.1152/japplphysiol.00652.2012.
[25] Taylor, Whincup, Hindmarsh, Lampe, Odoki, Cook. Performance of a new pubertal self-assessment questionnaire: a preliminary study. Paediatr Perinat Epidemiol 2001;15:88–94. https://doi.org/10.1046/j.1365-3016.2001.00317.x.
[26] McKay AKA, Stellingwerff T, Smith ES, Martin DT, Mujika I, Goosey-Tolfrey VL, et al. Defining Training and Performance Caliber: A Participant Classification Framework. Int J Sports Physiol Perform 2022;17:317–31. https://doi.org/10.1123/ijspp.2021-0451.
[27] Talma H, Chinapaw MJM, Bakker B, HiraSing RA, Terwee CB, Altenburg TM. Bioelectrical impedance analysis to estimate body composition in children and adolescents: a systematic review and evidence appraisal of validity, responsiveness, reliability and measurement error. Obesity Reviews 2013;14:895–905.
[28] Williams N. The Borg Rating of Perceived Exertion (RPE) scale. Occup Med (Chic Ill) 2017;67:404–5. https://doi.org/10.1093/occmed/kqx063.
[29] Beaver WL, Wasserman K, Whipp BJ. A new method for detecting anaerobic threshold by gas exchange. J Appl Physiol 1986;60:2020–7. https://doi.org/10.1152/jappl.1986.60.6.2020.
[30] Midgley AW, McNaughton LR, Polman R, Marchant D. Criteria for Determination of Maximal Oxygen Uptake. Sports Medicine 2007;37:1019–28. https://doi.org/10.2165/00007256-200737120-00002.
[31] Tanaka H, Monahan KD, Seals DR. Age-predicted maximal heart rate revisited. J Am Coll Cardiol 2001;37:153–6. https://doi.org/10.1016/S0735-1097(00)01054-8.

[32] Jaafar H, Rouis M, Coudrat L, Attiogbé E, Vandewalle H, Driss T. Effects of Load on Wingate Test Performances and Reliability. J Strength Cond Res 2014;28:3462–8. https://doi.org/10.1519/JSC.0000000000000575.
[33] Tønnessen E, Sylta Ø, Haugen TA, Hem E, Svendsen IS, Seiler S. The Road to Gold: Training and Peaking Characteristics in the Year Prior to a Gold Medal Endurance Performance. PLoS One 2014;9:e101796. https://doi.org/10.1371/journal.pone.0101796.
[34] Seiler S. What is best practice for training intensity and duration distribution in endurance athletes. Int J Sports Physiol Perform 2010;5:276–91.
[35] Treff G, Winkert K, Sareban M, Steinacker JM, Sperlich B. The Polarization-Index: A Simple Calculation to Distinguish Polarized From Non-polarized Training Intensity Distributions. Front Physiol 2019;10. https://doi.org/10.3389/fphys.2019.00707.
[36] Fritz CO, Morris PE, Richler JJ. Effect size estimates: Current use, calculations, and interpretation. J Exp Psychol Gen 2012;141:2–18. https://doi.org/10.1037/a0024338.
[37] Billat VL, Demarle A, Slawinski J, Paiva M, Koralsztein J-P. Physical and training characteristics of top-class marathon runners. Med Sci Sports Exerc 2001;33:2089–97.
[38] Billat V, Lepretre P-M, Heugas A-M, Laurence M-H, Salim D, Koralsztein JP. Training and bioenergetic characteristics in elite male and female Kenyan runners. Med Sci Sports Exerc 2003;35:297–304.
[39] Ingham SA, Fudge BW, Pringle JS. Training distribution, physiological profile, and performance for a male international 1500-m runner. Int J Sports Physiol Perform 2012;7.
[40] Stellingwerff T. Case Study: Nutrition and Training Periodization in Three Elite Marathon Runners. Int J Sport Nutr Exerc Metab 2012;22:392–400. https://doi.org/10.1123/ijsnem.22.5.392.
[41] Tjelta LI. A longitudinal case study of the training of the 2012 European 1500 m track champion. Int J Appl Sports Sci 2013;25:11–8.
[42] Tjelta LI, Tønnessen E, Enoksen E. A case study of the training of nine times New York Marathon winner Grete Waitz. Int J Sports Sci Coach 2014;9:139–58.
[43] Tjelta LI, Enoksen E. Training characteristics of male junior cross country and track runners on European top level. Int J Sports Sci Coach 2010;5:193–203.
[44] Schumacher YO, Mueller P. The 4000-m team pursuit cycling world record: theoretical and practical aspects. Med Sci Sports Exerc 2002;34:1029–36.
[45] Gao J. A study on pre-game training characteristics of Chinese elite swimmers. J Beijing Sport Univ 2008;31:832–4.
[46] Siewierski M. Volume and structure of training loads of top swimmers in direct starting preparation phase for main competition. Polish Journal of Sport & Tourism 2010;17.
[47] Fiskerstrand A, Seiler KS. Training and performance characteristics among Norwegian International Rowers 1970-2001. Scand J Med Sci Sports 2004;14:303–10. https://doi.org/10.1046/j.1600-0838.2003.370.x.
[48] Arne G, Stephen S, Eike E. Training Methods and Intensity Distribution of Young World-Class Rowers. Int J Sports Physiol Perform 2009;4:448–60. https://doi.org/10.1123/ijspp.4.4.448.
[49] Neal CM, Hunter AM, Galloway SDR. A 6-month analysis of training-intensity distribution and physiological adaptation in Ironman triathletes. J Sports Sci 2011;29:1515–23. https://doi.org/10.1080/02640414.2011.596217.
[50] Mujika I. Olympic Preparation of a World-Class Female Triathlete. Int J Sports Physiol Perform 2014;9:727–31. https://doi.org/10.1123/ijspp.2013-0245.
[51] Seiler KS, Kjerland GO. Quantifying training intensity distribution in elite endurance athletes: is there evidence for an “optimal” distribution? Scand J Med Sci Sports 2006;16:49–56. https://doi.org/10.1111/j.1600-0838.2004.00418.x.
[52] Kim C-H, Wheatley CM, Behnia M, Johnson BD. The Effect of Aging on Relationships between Lean Body Mass and VO2max in Rowers. PLoS One 2016;11:e0160275. https://doi.org/10.1371/journal.pone.0160275.
[53] Maciejczyk M, Więcek M, Szymura J, Szyguła Z, Wiecha S, Cempla J. The Influence of Increased Body Fat or Lean Body Mass on Aerobic Performance. PLoS One 2014;9:e95797. https://doi.org/10.1371/journal.pone.0095797.
[54] Docherty D, Sporer B. A Proposed Model for Examining the Interference Phenomenon between Concurrent Aerobic and Strength Training. Sports Medicine 2000;30:385–94. https://doi.org/10.2165/00007256-200030060-00001.
[55] Wilson JM, Marin PJ, Rhea MR, Wilson SMC, Loenneke JP, Anderson JC. Concurrent training: a meta-analysis examining interference of aerobic and resistance exercises. The Journal of Strength & Conditioning Research 2012;26:2293–307.
[56] Hulthén L, Bengtsson B-A, Sunnerhagen KS, Hallberg L, Grimby G, Johannsson G. GH Is Needed for the Maturation of Muscle Mass and Strength in Adolescents. J Clin Endocrinol Metab 2001;86:4765–70. https://doi.org/10.1210/jcem.86.10.7897.
[57] Valenzuela PL, Morales JS, Emanuele E, Pareja-Galeano H, Lucia A. Supplements with purported effects on muscle mass and strength. Eur J Nutr 2019;58:2983–3008. https://doi.org/10.1007/s00394-018-1882-z.
[58] Camera DM. Evaluating the Effects of Increased Protein Intake on Muscle Strength, Hypertrophy and Power Adaptations with Concurrent Training: A Narrative Review. Sports Medicine 2022;52:441–61. https://doi.org/10.1007/s40279-021-01585-9.
[59] Buresh R, Berg K, Noble J. Heat Production and Storage Are Positively Correlated With Measures of Body Size/Composition and Heart Rate Drift During Vigorous Running. Res Q Exerc Sport 2005;76:267–74. https://doi.org/10.1080/02701367.2005.10599298.

[60] Ettema G, Lorås HW. Efficiency in cycling: a review. Eur J Appl Physiol 2009;106:1–14. https://doi.org/10.1007/s00421-009-1008-7.
[61] Romijn JA, Coyle EF, Sidossis LS, Gastaldelli A, Horowitz JF, Endert E, et al. Regulation of endogenous fat and carbohydrate metabolism in relation to exercise intensity and duration. American Journal of Physiology-Endocrinology and Metabolism 1993;265:E380–91. https://doi.org/10.1152/ajpendo.1993.265.3.E380.
[62] Midgley AW, McNaughton LR, Wilkinson M. Is there an Optimal Training Intensity for Enhancing the Maximal Oxygen Uptake of Distance Runners? Sports Medicine 2006;36:117–32. https://doi.org/10.2165/00007256-200636020-00003.
[63] Laursen PB. Training for intense exercise performance: high-intensity or high-volume training? Scand J Med Sci Sports 2010;20:1–10. https://doi.org/10.1111/j.1600-0838.2010.01184.x.
[64] Engel FA, Ackermann A, Chtourou H, Sperlich B. High-Intensity Interval Training Performed by Young Athletes: A Systematic Review and Meta-Analysis. Front Physiol 2018;9. https://doi.org/10.3389/fphys.2018.01012.

Citation:
Zając B, Gaj PK, Ambroży T: Analysis of training loads in Polish adolescent road cyclists in the preparatory period and their effects on physical fitness. Journal of Kinesiology and Exercise Sciences. 2024; 105 (34): 1-10.