

The new way of triathlon preparation in youth athletes

ZSOFIA PAPAI¹, MARTA WILHELM², ZSOLT SZAKALY³

^{1,2} Doctoral School of Biology and Sportbiology, University of Pécs, Pécs, HUNGARY

² Institute of Sport Sciences and Physical Education, Faculty of Sciences, University of Pécs

^{1,3} Faculty of Health and Sports Sciences, Széchenyi István University, Győr, HUNGARY

Published online: October 31, 2022

(Accepted for publication October 15, 2022)

DOI:10.7752/jpes.2022.10328

Abstract

The aim of our research was to find a way, based on international experience, to examine the training method that can be successfully used in youth age groups, and as a consequence, to increase the effectiveness of the sport of triathlon. In Hungary, the methods of preparing the younger age group (10-18 y) are not yet uniform. Hungarian triathletes do not dominate at the international level, neither in the junior age groups nor in the elite field. Two basic methods "fight" each other in Hungary, the so-called "threshold" training (training at the anaerobic threshold), the effectiveness of which has been proven by numerous studies in various sports. The aim of this study was to analyze the effectiveness of "Polarized" (Pol) and "Threshold" (TR) training in youth ages (15-18y). Male youth triathlete subjects taking part in systematic training ($n=10$, $n_{(Pol)}=5$; $n_{(TR)}=5$) were studied. Performance (time), physiological data from spirometry (vita maxima) tests and anthropometric features were measured in this longitudinal study (3 years). Performance improvement, relative oxygen uptake (rVO_{2max}) and aerobic time significantly increased ($p<0.05$) in Pol group, while differences of their anthropometric features did not change significantly during the research. No significant changes were found in any parameters of TR group. There were no significant differences of anthropometric and cardiovascular (Heart Rate) characteristics between the two groups in any assessment. The differences of rVO_{2max} and relative aerobic capacity at the anaerobic threshold were significant in the Pol group ($p<0.05$) at the second and third measurements. Performance improvement and time in aerobic zone increased more in the Pol group than in the TR group ($p<0.05$). The Pol training method proved to be more effective than the TR training of the studied group.

Keywords Polarized training, threshold training, relative oxygen uptake, triathlon, anthropometry

Introduction

Long Term Athlete Development (LTAD) is an optimized training process necessary on all stages of athlete development. This model was developed by coaches and experts. Its principles have been adopted by worldwide as a framework for the proper management of the growth and development processes of young and adolescent athletes, and critical periods of adaptation to training have been defined. Coaches who put this model into practice are more likely to develop athletes who reach their full potential in field of sport. Since it is essential to develop basic skills at a young age and refine competitive skills at a higher level. For young athletes, exposure to basic motor skills at an early stage is important ensuring the perfection of their skills before racing becomes the main focus (Balyi et al., 2013; Ortigosa-Márquez et al., 2018; Baker et al., 2019; Baker et al., 2020).

The training theory and methodology of the triathlon is well established; however, literature data mainly focus on the performance improvement of adults, and these training methods of youth (10-18 years) are not standardized yet in Hungary. At the international level the dominance of Hungarian triathletes is lacking, neither in youth nor in elite adult categories. In relation to the lack of outstanding results, Hungarian representatives from the sport continuously argue for the selection of age specific, appropriate training methods.

Two rival methods are used in Hungary, one of these is known as TR (Threshold) training method performed mainly at an exercise intensity corresponding to the lactate threshold (e.g., 4 mM blood lactate) or second ventilation threshold (ratio of ventilated air–exhaled CO₂ begin to rise), involves primarily continuous or intervals of moderate-intensity exercises and is often defined as "zone 2" training (Stöggl&Sperlich, 2014). Effectiveness of this method has been published in numerous studies in different sports (Faude et al., 2009; Beneke et al., 2011; Dalleck et al., 2010; Ziogas et al., 2011; Philp et al., 2008).

The other method is the Pol (Polarized) training which is basically very similar to Lydiard's method (Laursen, 2010). The Pol training consists of significant proportions of both high- and low-intensity training and only a small proportion of threshold training. The distribution between low and high intensity training is often quantified as 80:20%, or 75–80% with low intensity, 5% threshold intensity, and 15–20% as high intensity

training (Arne et al., 2009; Stöggl&Sperlich, 2015; Engel et al., 2018). Researchers have also demonstrated the effectiveness of polarized training in endurance sports as well (Yu et al., 2012; Gibala et al., 2012; Muñoz et al., 2014; Vesterinen et al., 2016; Gibala et al., 2013; Seiler et al., 2009; Seiler, 2010) but despite that, it is less common in Hungarian practice.

The main differences between TR training and Pol training were summarized by Seiler and Kjerland (Muñoz et al., 2014). With the aid of spiroergometric measurements they suggested three intensity zones (low-intensity, zone 1; moderate or threshold intensity, zone 2; high-intensity, zone 3).

The rapid performance-enhancing effect of intensity is evident, however high-intensity trainings bear a higher risk of injury, require longer recovery, and therefore, are to be applied to youth very carefully (Kellmann, 2010; DiFiori et al., 2014; Kostiukevych et al., 2018). The effectiveness of Pol training at younger ages has been demonstrated by several authors (Arne et al., 2009; Moreira et al., 2016; Laursen, 2010; Hoydal et al., 2016; Guellich et al., 2009).

Therefore if both methods are effective, which one should be chosen for developing the capabilities of youth triathletes? The aim of this study was to examine the effectiveness of Pol training and TR training for male youth triathletes.

Method

Subjects

Male youth triathletes were recruited ($n=10$ subjects, $age_{(Pol)}=15.63\pm1.25$ years; $age_{(TR)}=15.61\pm0.89$ years) in this study. The athletes took part in 8-10 trainings/ week, led by club coaches. Data collection and assessments were done at the end of March in 2014, 2015 and 2016. Limitations of the study were the number of subjects having identical ages and the clubs did not willingly modify their “well-established” training methods. Subjects and their parents were well informed of measurement procedures. The study was approved by the Ethics Committee and all subject’s parents gave their consent to participate in the study. Informed consent of University of Pécs, Institute of Sport Sciences and Physical Education was also given for this protocol.

Training methods

According to the Hungarian practice, after a longer break general trainings start in October-November and last until the end of March or beginning of April. After this period, the frequency of sport-specific trainings increase, resulting in more high-intensity trainings in the season.

The major difference between the two studied groups was the training intensity zones of the measured time frame. The Pol group trained in the following three intensity zones: Zone 1=85%; Zone 2=5%; Zone 3=15% (based on heart rate (HR) measurements), while the TR group exercised in 70%, 20%, and 10%, intensity zones respectively. Regarding the annual training load, the Pol group worked 80% of the training time in the low-intensity zone (Zone 1), 5% at the anaerobic threshold (AT, Zone 2), and 15% in high-intensity zone (Zone 3). The ratio of TR group in different zones was 60%, 30%, and 10%, respectively. The different training zones were controlled with Heart Rate (HR) monitors (Seiler & Tønnessen, 2009) in each training.

Anthropometric methods

Besides HR monitoring (resting HR, rHR; maximal HR, mHR) basic anthropometric characteristics such as body height (BH) and body weight (BW) were also recorded, relative muscle mass (rMM) and relative fat mass (rFM) were measured using an InBody 720 bioelectric impedance analyzer (Biospace).

Physiological parameters monitored

To characterize the effectiveness of the studied training methods, performance data of spiro-ergometry (vita maxima) tests were analyzed. Relevant parameters, like performed time and time under the anaerobic threshold (AT, time in aerobic zone), relative aerobic capacity (rVO_{2max}) and relative aerobic capacity at AT (rVO_{2at}) were also measured. Vita maxima tests were carried (Rigler, 2000; Szakály, 2013; Robertson et al., 2016; Armstrong et al., 2020) out on a treadmill ergometer (Marquette S2000) with SENSOR MEDICS Vmax29 C Gas analyzer and 12 lead EKG monitor. During the test protocol, the speed of the treadmill was $5\text{ km}\times\text{h}^{-1}$ for 2 minutes with a gradient of 0%, then $11\text{ km}\times\text{h}^{-1}$ at 3% for 2 minutes; then the grade of the treadmill increased 3% every 2 min with steady speed until complete fatigue.

Statistical methods

Statistica for Windows (version 12, StatSoft Inc., Tulsa, OK 74104, USA, 2013) was used to analyze collected data. General descriptive statistical measures for each group and test were used. Within groups the differences were investigated using repeated measures of ANOVA. Tukey’s post-hoc test was applied in the case of a significant F value. The level of statistical significance was set at $p<0.05$.

Results

Presented results of the collected data are analyzed in training groups. *Results of the Pol group*

Table 1 shows the anthropometric and cardiovascular characteristics of the Pol group.

Table 1. Measured parameters and mean differences of the Polarized group.

Parameters	1 st measurement		2 nd measurement		3 rd measurement		p		
	Mean	SD	Mean	SD	Mean	SD	I-II.	II-III.	I-III.
Age (year)	15.63	1.25	16.58	1.31	17.62	1.23	-	-	-
BH	178.40	6.16	181.10	3.44	182.00	3.69	NS	NS	NS
BW	62.42	9.47	67.10	9.14	67.66	8.69	NS	NS	NS
rMM	46.81	3.82	47.44	2.97	48.33	3.09	NS	NS	NS
rFM	11.02	4.39	8.87	1.59	8.36	1.30	NS	NS	NS
rHR	68.40	5.46	64.60	3.65	61.20	2.77	NS	NS	NS
AT	182.00	5.70	180.00	3.54	179.00	2.24	NS	NS	NS
mHR	198.80	8.53	197.60	8.53	199.80	3.56	NS	NS	NS

Notes: BH=body height (cm); BW=body weight (kg); rMM=relative muscle mass (%); rFM=relative fat mass (%); rHR=relative resting heart rate (beat $\times$ min⁻¹); AT=anaerobic threshold; mHR=maximal heart rate (beat $\times$ min⁻¹); NS=difference is not significant

Means of body height and body weight increased according to age-specificity, the differences were not significant (BH: $F = .830$, $p = .459$; BW: $F = .499$, $p = .618$), however standard deviations decreased. The means for rMM increased and rFM decreased, in addition to the decrements seen in standard deviations, but the differences were not significant (rMM: $F = .265$, $p = .771$; rFM: $F = 1.269$, $p = .316$). Relative rHR decreased, the means of mHR remained unchanged, although in every assessment period this parameter reached age-specific values, the differences were not significant (rHR: $F = 3.831$, $p = .051$; mHR: $F = .120$, $p = .892$). No significant differences were found between the means of AT (AT: $F = .700$, $p = .515$) also. The mean values and changes of $\text{relVO}_{2\text{max}}$ and relative aerobic capacity at AT ($\text{relVO}_{2\text{at}}$), being key factors in physical performance, are shown in Figure 1. In the Pol group, significant differences were found between measurements 1 and 3 in $\text{rVO}_{2\text{max}}$ (63.98 ± 6.29 ; 70.68 ± 3.77 ; 72.34 ± 2.95 ml $\times$ min⁻¹ $\times$ kg⁻¹; $\text{rVO}_{2\text{max}}$ $F = 4.703$, $p = .031$) and $\text{rVO}_{2\text{at}}$ (56.51 ± 5.96 ; 63.45 ± 4.26 ; 66.04 ± 4.21 ml $\times$ min⁻¹ $\times$ kg⁻¹; $\text{rVO}_{2\text{at}}$ $F = 5.138$, $p = .024$).

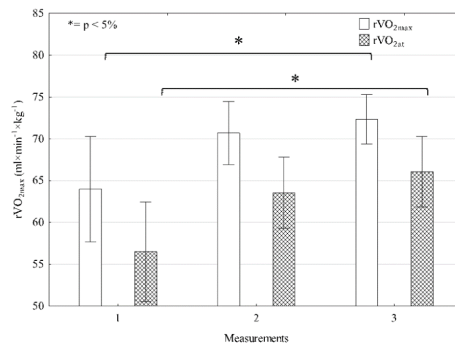


Figure 1. Changes in the relative aerobic capacity of the Polarized group during the studied period

The means of exercise time ($12:36.0 \pm 1:31.0$; $13:16.0 \pm 1:14.0$; $14:02 \pm 1:02.0$ min; $F = 3.353$, $p = .017$) and the time spent under AT (aerobic time: $9:26.0 \pm 1:11.0$; $10:36.0 \pm 1:27$; $11:28 \pm 1:19.0$ min; $F = 14.431$, $p = .000$) showed significant differences between each assessment period (Figure 2).

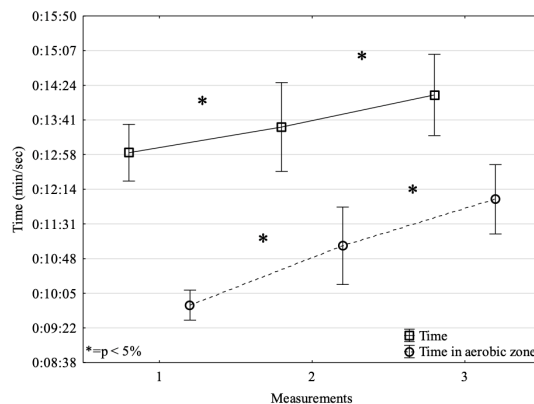


Figure 2. Changes in performance of the Polarized group

Results of the TR group

In Table 2 the anthropometric and basic cardiovascular characteristics of the TR group are presented at each time point. Similarly to the Pol group, no significant differences were found in any anthropometric or basic cardiovascular results (BH: $F=1.640$, $p=.234$; BW: $F=2.055$, $p=.170$; rMM: $F=.005$, $p=.994$; rFM: $F=.203$, $p=.818$; rHR: $F=.265$, $p=.771$; AT: $F=1.330$, $p=.299$; mHR: $F=.42$, $p=.664$). However, the changes in standard deviations are volatile – unlike in the Pol group.

Table 2. Measured parameters, characteristics of the Threshold group

Parameters	1 st measurement		2 nd measurement		3 rd measurement		p		
	Average	SD	Average	SD	Average	SD	I-II.	II-III.	I-III.
Age	15.61	0.89	16.69	0.81	17.71	0.74	-	-	-
BH	174.70	3.87	177.40	3.58	179.20	4.38	NS	NS	NS
BW	59.74	3.34	63.70	4.78	65.30	5.08	NS	NS	NS
rMM	50.88	4.81	50.96	4.14	51.15	3.77	NS	NS	NS
rFM	10.28	4.94	9.20	4.00	8.58	3.78	NS	NS	NS
rHR	64.20	4.87	64.60	7.57	61.80	6.98	NS	NS	NS
AT	181.00	2.24	181.00	2.24	179.00	2.24	NS	NS	NS
mHR	197.20	1.64	195.40	3.58	196.40	3.65	NS	NS	NS

Notes: BH=body height (cm); BW=body weight (kg); rMM=relative muscle mass (%); rFM=relative fat mass (%); rHR=relative resting heart rate (beat $\times$ min⁻¹); AT= anaerobic threshold; mHR=maximum heart rate (beat $\times$ min⁻¹);

Changes in rVO_{2max} and in exercise performance of the TR group are summarized in Figures 3 and 4. There were no significant differences in the means of rVO_{2max} (61.36 ± 6.64 ; 61.94 ± 5.70 ; 60.32 ± 7.05 ml $\times$ min⁻¹ $\times$ kg⁻¹; $F=.080$, $p=.923$) and $relVO_{2at}$ threshold (56.70 ± 6.48 ; 55.98 ± 5.78 ; 53.08 ± 6.96 ml $\times$ min⁻¹ $\times$ kg⁻¹; $F=.445$, $p=.651$).

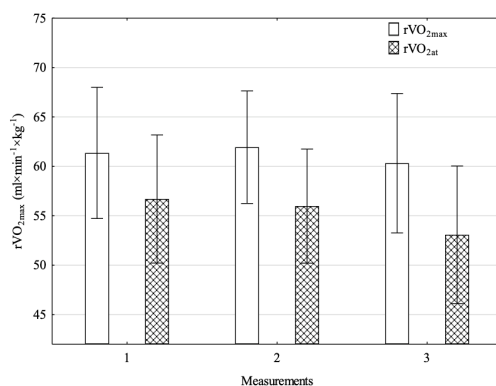


Figure 3. Changes in relative aerobic capacity of the “Threshold” group during the research

No significant changes were found again in total exercise time ($10:40.0\pm1:17.0$; $10:57.0\pm1:08.0$; $11:04.0\pm1:00.0$ min; $F=.161$, $p=.852$) and in exercise time under AT (aerobic time: $8:46.0\pm1:17.0$; $8:47.0\pm1:06.0$; $8:48.0\pm1:16.0$ min; $F=.009$, $p=.999$).

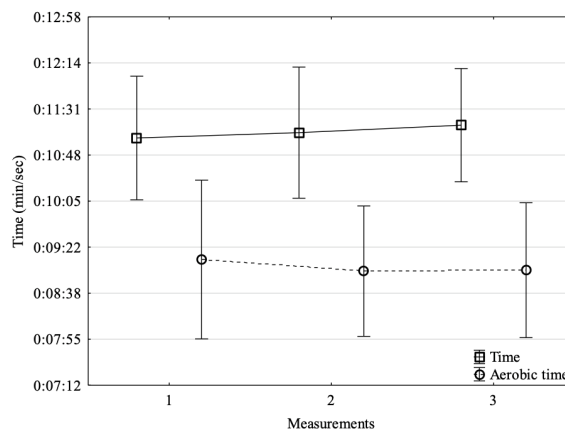


Figure 4. Changes in exercise performance of the Threshold group during the research

Results comparing the training methods

Comparison of anthropometric and cardiovascular characteristics of the two groups are summarized in table 3 for each assessment. No significant differences were found throughout the research.

Table 3. Comparison of the two studied groups. Results of the two-sample t-test

	1 st measurement				2 nd measurement				3 rd measurement			
	Mean "Polarized"	Mean "Threshold"	t-value	p	Mean "Polarized"	Mean "Threshold"	t-value	p	Mean "Polarized"	Mean "Threshold"	t-value	p
Age (year)	15.63	15.61	.0233	.98196	16.58	16.69	-.1538	.88153	17.62	17.71	-.1309	.89901
BH	178.40	174.70	1.1377	.28813	181.10	177.40	1.6680	.13385	182.00	179.20	1.0928	.30629
BW	62.42	59.74	.5967	.56716	67.10	63.70	.7371	.48209	67.66	65.30	.5244	.61416
rMM	46.81	50.88	-1.4835	.17623	47.44	50.96	-1.5469	.16047	48.33	51.15	-1.2952	.23136
rFM	11.02	10.28	.2492	.80946	8.87	9.20	-.1692	.86978	8.36	8.58	-.1219	.90593
rHR	68.40	64.20	1.2839	.23508	64.60	64.60	.0000	1.0000	61.20	61.80	-.1786	.86265
AT	182.00	181.00	.3651	.72446	180.00	181.00	-.5345	.60751	179.00	179.00	.0000	1.0000
mHR	198.80	197.20	.4122	.69114	197.60	195.40	.5317	.60937	199.80	196.40	1.4910	.17429

Notes: BH=body height (cm); BW=body weight (kg); rMM=relative muscle mass (%); rFM=relative fat mass (%); rHR=relative resting heart rate (beat×min⁻¹); AT=anaerobic threshold; mHR=maximum heart rate (beat×min⁻¹); NS= difference is not significant

Group-differences in values of rVO_{2max} and $relVO_{2at}$ are shown in Figures 5 and 6. For the second and third measurements, mean values of rVO_{2max} (1st measurement: $t = .64067$; $p = .539$; 2nd measurement: $t = 2.86073$, $p = .0211$; 3rd measurement: $t = 3.51513$, $p = .008$) and $relVO_{2at}$ (1st measurement: $t = .05079$; $p = .960$; 2nd measurement: $t = 2.35481$, $p = .0463$; 3rd measurement: $t = 3.56160$, $p = .007$) were significantly better in the Pol group compared to TR group.

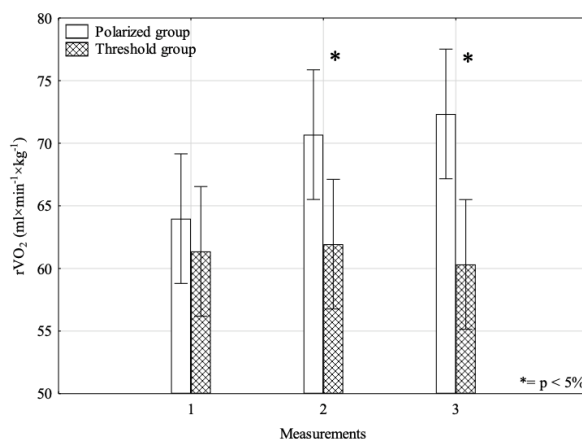


Figure 5. Differences in relative aerobic capacities between the two groups

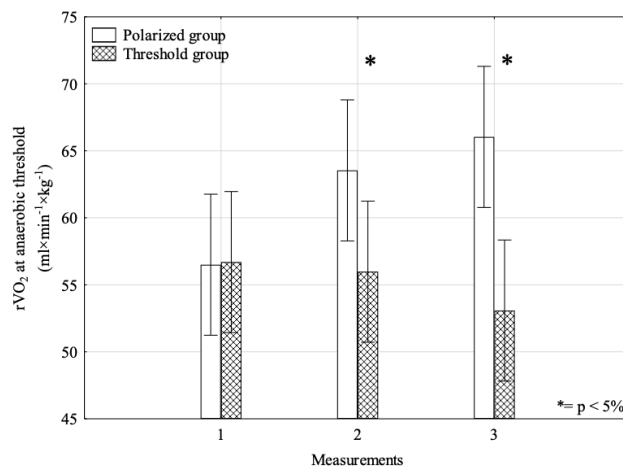


Figure 6. Differences in aerobic capacities at the anaerobic threshold between the two groups

Summarizing differences in exercise performances (Figures 7) of groups in the second and third measurements, the Pol method has proved to be significantly better in absolute performance during the research [(1st measurement: $t=4.42890$; $p=.002$; 2nd measurement: $t=4.30184$, $p=.003$; 3rd measurement: $t=5.93295$, $p=.001$) (Figure 7)]. Significant difference was also found in aerobic time in the second and third tests between the two groups [(1st measurement: $t=1.42313$, $p=.192$; 2nd measurement: $t=4.04127$, $p=.004$; 3rd measurement: $t=6.08699$, $p=.001$) (Figure 8)].

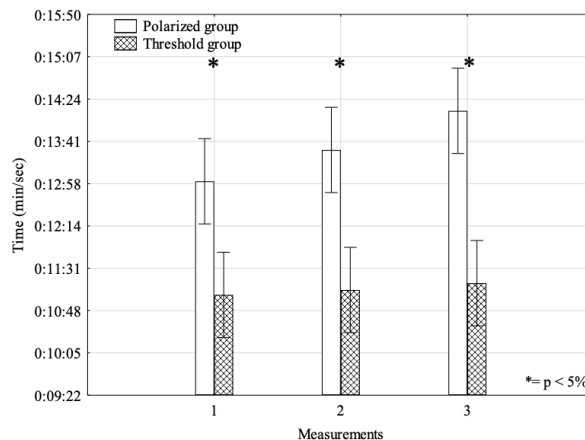


Figure 7. Differences in absolute performance between groups

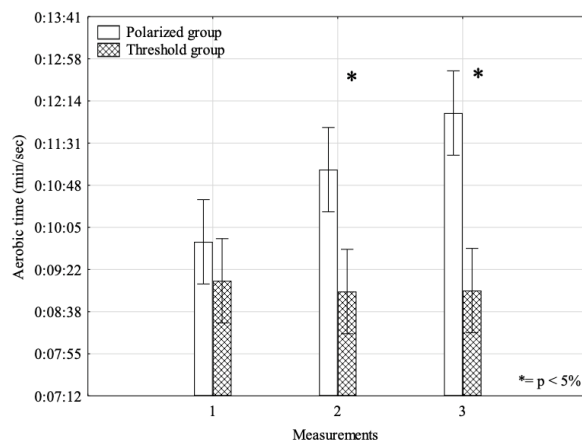


Figure 8. Differences in aerobic time between the measured groups

Discussion

The aims of our research were analyzing training methods relying on international experiences and hoping to successfully implement results in the training of young athletes improving performance and success in triathlon. However, analyzing data one must consider the limitations of the study resulting from the small sample and therefore should draw careful conclusions. Subject in our study (Pol training) were trainable effectively in endurance sports as it has been shown in earlier studies (Gibala et al., 2012; Plews et al., 2014; Muñoz et al., 2014; Sylta et al., 2014).

We have also characterized physiological parameters definitive in professional sport performance and body composition also as another influencing factor (Suriano et al., 2010). Anthropometric parameters (BH, BW) and body composition (rMM, rFM) of the measured athletes was optimal regarding successful triathlon training and competition (Landers et al., 2013; Bottoni et al., 2011; Brunkhorst&Kielstein, 2013; Tyrsy et al., 2020). In anthropometric parameters not any significant differences were found within groups, nor between groups in any assessment. The two groups have similar anthropometric data, therefore anthropometric features did not cause different adaptations and performance changes between the groups (Bilgin, 2016; Knechtle, 2014; Lepers et al., 2013).

The spiroergometry method is commonly accepted in international literature; many authors have verified that these types of laboratory performances are good predictors of real field performance (Suriano et al., 2010; Hausswirth& Brisswalter, 2008; Joyner&Coyle, 2008; Anta et al., 2008; Naisidou et al., 2017; Piacentini et al., 2019). The Pol group showed significant improvement in rVO_{2max} and rVO_{2at} , which are both primary

factors in sport performance (Suriano et al., 2010; Reilly et al., 2009; Millet et al., 2011; Walsh, 2019). Their physical performance also improved, including increments in aerobic time. In the TR group, we were not able to identify a significant change in any parameter measured during this research.

Based on the results of the two-sample t-test the Pol group performed significantly better at each assessment than the TR group. In factors characterizing the cardio-respiratory system ($\dot{V}O_{2\max}$; $\dot{V}O_{2at}$), significant differences were found between the two groups only from the second assessment. In our sample the Pol training method proved to be more effective than training of the TR group. Similar results were found by many authors using different samples, but applying the basic principles of Pol training to the maximum during the preparation of their athletes (Stöggl&Sperlich, 2014; Seiler, 2010; Neal et al., 2013; Muñoz et al., 2014).

Conclusions

This study was longitudinal focusing on performance improvement and its determining factors in young ages (15-18 years). The limitation factor in this research was the size of the sample. Therefore, an expansion of our sample population is important to provide further guidelines to triathletes. Despite this fact our findings are convincing that polarized training is an effective method for young triathletes. Hoping that our results prove to be interesting to coaches reading scientific studies and driving them towards further research, will be beneficial in training methodology for the triathlon or other sports in the future.

Experts have been debating the results of physiological adaptation from the application of different training methods for years. However, it can be concluded that those who applied the principles of the polarized method achieved a greater increase in the athletes' performance compared to threshold training. Modern triathlon encourages coaches and professionals to look for new periodization methods to help athletes reach their peak performance. Specialists still have to examine many things in terms of the various training intensity distributions, including endurance training periods, their effects on endurance athletes, as well as the mechanisms responsible for these effects. As a result, it can be said that this is a fruitful area for future research, which can contribute not only to the optimization of the endurance training program of athletes, but also to the understanding of the optimal ways to promote physiological adaptation.

Declaration of Conflicting Interests

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

References

- Anta, R.C., Turpin, J.A.P., Vicente, J.G.V., Tormo, J.M.C., Marroyo, J.A.R. (2008). An analysis of performance factors in sprint distance triathlon. *J Hum Sport Exerc*, 2(2), 1-25.
- Armstrong N, Welsman J. (2020). Traditional and new perspectives on youth cardiorespiratory fitness. *Med Sci Sports Exerc*. 52(12):2563-2573.
- Arne, G., Stephen, S., Eike, E. (2009). Training methods and intensity distribution of young world-class rowers. *Int J Sports Phys Perform*, 4(4), 448-460.
- Baker, J., Wattie, N., Schorer, J.(2019). A proposed conceptualization of talent in sport: The first step in a long and winding road. *Psychol. Sport Exerc*. 43, 27–33.
- Baker, J., Wilson, S., Johnston, K., Dehghansai, N., Koenigsberg, A., Steven de Vegt, S., Wattie, N. (2020). Talent Research in Sport 1990–2018: A Scoping Review. *Front. Psychol*. 11, 607710.
- Balyi, I., Way, R. and Higgs, C. (2013): *Long- Term Athlete Development*. Human Kinetics. Champaign, USA.
- Beneke, R., Leithäuser, R.M., Ochentel, O. (2011). Blood lactate diagnostics in exercise testing and training. *Int J Sports Phys Perform*, 6(1), 8-24.
- Bilgin, U. (2016). Effects of Body Composition on Race Time in Triathletes. *The Anthropologist*, 23(3), 406-413.
- Bottoni, A., Gianfelici, A., Tamburri, R., et al. (2011). Talent selection criteria for Olympic distance triathlon. *J Hum Sport Exerc*, 6, 293-304.
- Brunkhorst, L., Kielstein, H. (2013). Comparison of anthropometric characteristics between professional triathletes and cyclists. *Biol Sport*, 30, 269-273.
- Dalleck, L., Bushman, T.T., Crain, R.D., Gajda, M.M., Koger, E.M., Derksen, L.A. (2010). Dose-response relationship between interval training frequency and magnitude of improvement in lactate threshold. *Int J Sports Med*, 31(08), 567-571.
- DiFiori, J.P., Benjamin, H.J., Brenner, J.S., et al. (2014). Overuse injuries and burnout in youth sports: a position statement from the American Medical Society for Sports Medicine. *Br J Sports Med*, 48, 287-288.
- Engel, F. A., Ackermann, A., Chtourou, H. & Sperlich, B. (2018). High-intensity interval training performed by young athletes: a systematic review and meta-analysis. *Frontiers in Physiology*, 9, 1012.
- Faude, O., Kindermann, W., Meyer, T. (2009). Lactate threshold concepts. *Sports Med*, 39(6), 469-490.
- Gibala, M.J., Jones, A.M. (2013). Physiological and performance adaptations to high-intensity interval training. In *Nestle Nutr works Se* (76), 51-60. Karger Publishers.
- Gibala, M.J., Little, J.P., MacDonald, M.J., Hawley, J.A. (2012). Physiological adaptations to low-volume, high-intensity interval training in health and disease. *The J Phys*, 590(5), 1077-1084.

- Guellich, A., Seiler, K.S., Emrich, E. (2009). Training methods and intensity distribution of young world-class rowers. *Int J Sports Physiol Perform*, 4, 448–460.
- Hauswirth, C., Brisswalter, J. (2008). Strategies for improving performance in long duration events. *Sports Med*, 38(11), 881-891.
- Hoydal, K.L., Hareide, S. (2016). Evaluating and comparing the effect of high intensity interval training vs. low intense, longer-lasting training on endurance performance in recreational runners. *Int J Appl Sports Sci*, 28(2).
- Joyner, M.J., Coyle, E.F. (2008). Endurance exercise performance: the physiology of champions. *The J Physiol*, 586(1), 35-44.
- Kellmann, M. (2010). Preventing overtraining in athletes in high-intensity sports and stress/recovery monitoring. *Scand J Med Sci Sports*, 20, 95-102.
- Knechtle, B. (2014). Relationship of anthropometric and training characteristics with race performance in endurance and ultra-endurance athletes. *Asian J Sports Med*, 5(2), 73.
- Kostiukovich, V., Imas, Y., Borysova, O., Dutchak, M., Shynkaruk, O., Kogut, I., & Stasiuk, I. (2018). Modeling of the athletic training process in team sports during an annual macrocycle. *Journal of Physical Education and Sport*, 18, 327-334.
- Landers, G.J., Ong, K.B., Ackland, T.R., Blanksby, B.A., Main, L.C., Smith, D. (2013). Kinanthropometric differences between 1997 World championship junior elite and 2011 national junior elite triathletes. *J Sci Med Sport*, 16(5), 444-449.
- Laursen, P.B. (2010). Training for intense exercise performance: high-intensity or high-volume training? *Scand J Med Sci in Sports*, 20, 1-10.
- Lepers, R., Knechtle, B., Stapley, P.J. (2013). Trends in triathlon performance: Effects of sex and age. *Sports Med*, 43, 851-863.
- Millet, G.P., Vleck, V.E., Bentley, D.J. (2011). Physiological requirements in triathlon. *J Hum Sport and Exerc*, 6, No. 2. Suppl.
- Moreira, A., Gomes, R.V., Capitani, C.D., Lopes, C.R., Santos, A.R., Aoki, M.S. (2016). Training intensity distribution in young tennis players. *Int J Sports Sci Coach*, 11(6), 880-886.
- Muñoz, I., Cejuela, R., Seiler, S., Larumbe, E., Esteve-Lanao, J. (2014). Training-intensity distribution during an ironman season: relationship with competition performance. *Int J Sports Phys Perform* 9(2), 332-339.
- Naisidou, S., Kepesidou, M., Kontostergiou, M. & Zapartidis, I. (2017). Differences of physical abilities between successful and less successful young female athletes. *Journal of Physical Education & Sport*, 17(1), 294-299.
- Neal, C.M., Hunter, A.M., Brennan, L., et al. (2013). 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*, 114, 461-471.
- Ortigosa-Márquez, J.M.; Reigal, R.E.; Serpa, S.; Hernández-Mendo, A. (2018). Relative age effect on national selection process in triathlon. *Rev. Int. Med. Cienc. Act. Fis. Deporte*. 18, 199–211.
- Philp, A., Macdonald, A. L., Carter, H., Watt, P. W., & Pringle, J. S. (2008). Maximal lactate steady state as a training stimulus. *Int J Sports Med*, 29(06), 475-479.
- Piacentini, M.F., Bianchini, L.A., Minganti, C., Sias, M., Di Castro, A., Vleck, V. (2019). Is the bike segment of modern Olympic triathlon more a transition towards running in males than it is in females? *Sports* 7, 76.
- Plews, D.J., Laursen, P. B., Kilding, A.E., Buchheit, M. (2014). Heart-rate variability and training-intensity distribution in elite rowers. *Int J Sports Physiol Perform*, 9(6), 1026-1032.
- Reilly, T., Morris, T., Whyte, G. (2009). The specificity of training prescription and physiological assessment: A review. *J Sports Sci*, 27(6), 575-589.
- Robertson, S.J., and Gastin, P. (2016). “Metabolic Power Method Underestimates Energy Expenditure in Field Sport Movements Using a GPS Tracking System” *International Journal of Sports Physiology and Performance*, March .
- Seiler, K.S. (2010). What is best practice for training intensity and duration distribution in endurance athletes? *Int J Sport Physiol Perform*, 5, 276-291.
- Seiler, S., Tønnessen, E. (2009). Intervals, thresholds, and long slow distance: the role of intensity and duration in endurance training. *Sportsci*, 13, 32-53.
- Stöggl, T., Sperlich, B. (2014). Polarized training has greater impact on key endurance variables than threshold, high intensity, or high volume training. *Front Physiol*. 4 Feb 2014.
- Stöggl, T.L., Sperlich, B. (2015). The training intensity distribution among well-trained and elite endurance athletes. *Front Physiol*. Epub ahead of print 27 Okt 2015.
- Suriano, R., Bishop, D. (2010). Physiological attributes of triathletes. *J Sci Med Sport*, 13, 340-347.
- Sylta, Ø., Tønnessen, E., Seiler, S. (2014). From heart-rate data to training quantification: a comparison of 3 methods of training-intensity analysis. *Int J Sports Physiol Perform*, 9(1), 100-107.
- Tvrđy, M., Lednický, A., Peracek, P., Obetko, M., & Babic, M. (2020). Changes in the level of selected condition abilities of youth soccer players. *Journal of Physical Education and Sport*, 20 (4), 1706 – 1710

- Vesterinen, V., Nummela, A., Heikura, I., Laine, T., Hynynen, E., Botella, J., Häkkinen, K. (2016). Individual endurance training prescription with heart rate variability. *Med Sci Sports Exerc*, 48.
- Walsh, J.A. The rise of elite short-course triathlon re-emphasises the necessity to transition efficiently from cycling to running. *Sports* 2019, 7, 99.
- Yu, H., Chen, X., Zhu, W., Cao, C. (2012). A quasi-experimental study of Chinese top-level speed skaters' training load: threshold versus polarized model. *Int J Sports Phys Perform.*, 7(2), 103-112.
- Ziogas, G.G., Patras, K.N., Stergiou, N., Georgoulis, A.D. (2011). Velocity at lactate threshold and running economy must also be considered along with maximal oxygen uptake when testing elite soccer players during preseason. *The J Strength Cond*, 25(2), 414-419.