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Effectiveness of different training models for running performance in female youth triathletes

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Abstract

Study aim: The aim of this study was to analyze the effectiveness of polarized (Pol) and threshold (TR) training in youth triathletes (15–18 years).
Material and methods: Female youth triathlete subjects taking part in systematic training (n = 42, $n_{(Pol)}$ = 21; $n_{(TR)}$ = 21; at the beginning age$_{(Pol)}$ = 14.63 ± 1.25 years; age$_{(TR)}$ = 14.61 ± 0.89 years) were studied. In this 3-year-long research, anthropometric characteristics and performance were measured, using a spiroergometric, maximal exercise test. Run time spent on a treadmill and physiological data were analyzed.
Results: There were no significant differences in anthropometric variables during the study period, but a difference was observed between the two groups in heart rate at the third year. Relative oxygen uptake (rVO_2), ventilation (VE) and performance (Time) increased significantly ($p < 0.05$) in the Pol group, suggesting that this method can also be successful in youth training.
Conclusions: Our study results support other research findings demonstrating the effectiveness of polarized training. Further expansion of our sample is necessary to provide guidance for youth triathlon training.

Keywords: Polarized training – Threshold training – Youth female triathletes – Anthropometry – Endurance training

Introduction

The theory and methodology of triathlon training are well developed, but they have focused mostly on the performance enhancement of adults. Nowadays, training methods are not uniform in the youth age group (10–18 years). With a few exceptions, triathletes do not dominate at international level, either in the junior age groups or in the adult elite field, resulting in a constant debate among national representatives about the best training method.

At present, two ”competing” types of training methods are used by coaches: threshold (TR) training (mostly training at anaerobic threshold, Figure 1), the effectiveness of which has been demonstrated by several authors in different sports (Denis et al., 1984; Gaskill et al., 2001; Helgerud et al. 2007; Kindermann et al., 1979; Londeree, 1997), and polarized (Pol) training (Billat et al., 2001; Schumacher & Mueller, 2002; Steinacker et al., 1998), which is very similar in principle to Lydiard's method (1962). The effectiveness of Pol training (Figure 1) has also been demonstrated by several researchers in endurance sports (Esteve-Lanao et al., 2007; Foster et al., 2001; Midgley et al., 2007; Pichot et al., 2000; Seiler, 2010; Seiler & Kjerland, 2006; Seiler & Tonnessen, 2009), but it is less common in practice. Figure 1. Characteristics of the two methods.

The zone between VT_1–VT_2 and LT_1–LT_2 indicates the aerobic-anaerobic transition. The zones are thus follows: zone 1 – below anaerobic threshold; zone 2 – aerobic-anaerobic transition; zone 3 – above anaerobic threshold. These zones are used in the two training modalities with different ratios (Figure 2).

If both methods are effective, as several studies have shown, the question remains which one should be chosen for the training of young athletes. It is well established that intensity is a rapid performance enhancer, although intense training has a higher risk of injury, requiring longer recovery times and should be used with caution in youth

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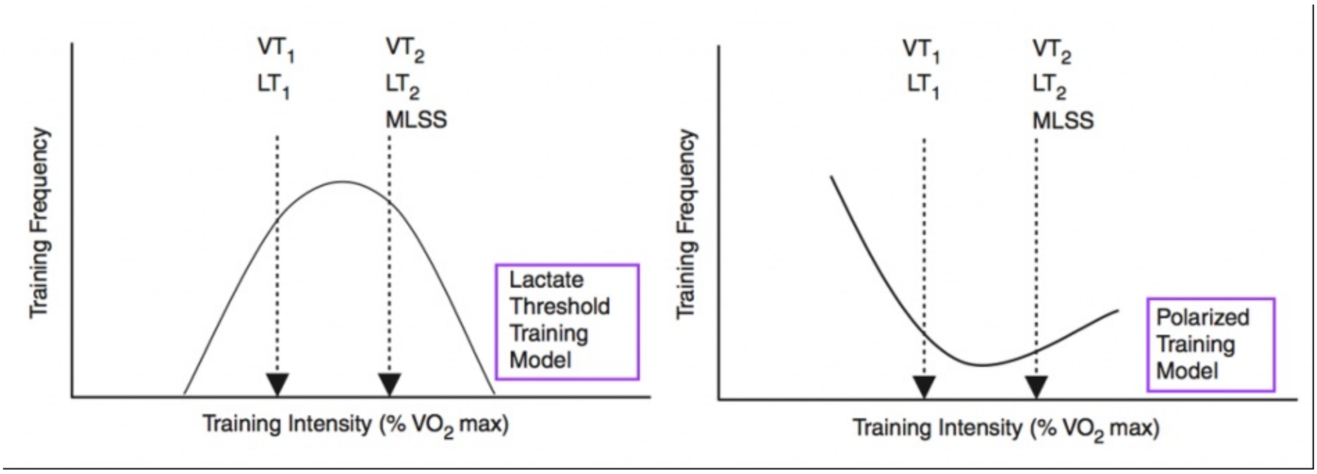

Figure 1. Basic characteristics of threshold and polarized training (Seiler & Kjerland, 2006)

LT_1 = lactate level starts to increase; LT_2 = lactate level increases exponentially; MLSS = lactate steady state; VT_1 = ventilated air-volume when O_2 ratio starts to increase exponentially; VT_2 = ventilated air-volume CO_2 ratio starts to increase exponentially

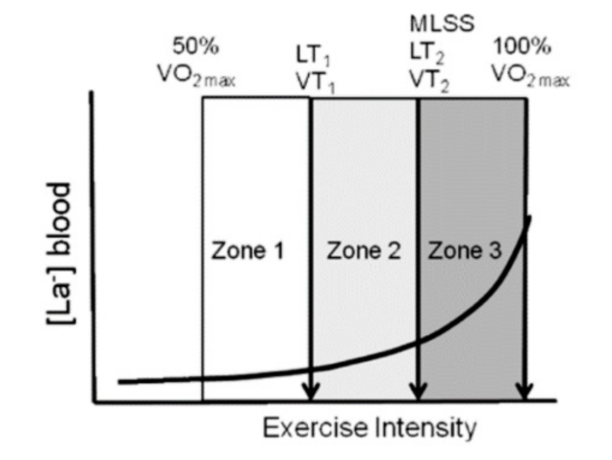

Figure 2. Training zones (Seiler & Tonnessen, 2009)

age groups (Rogers et al., 2014). For younger age groups, several authors have demonstrated the effectiveness of Pol training (Evertsen et al., 1997, 1999, 2001; Pápai et al., 2022; Steinacker et al., 1998). According to other data, the effectiveness of the Pol training method is not optimal at all. Some authors did not find any difference between the two methods, or only found differences in endurance athletes (skiers, biathletes, rowers) (Burnley et al., 2022), while others state that Pol training is more optimal for elite endurance athletes (Foster et al., 2022; Pápai et al., 2022; Stöggl & Sperlich, 2014). Others reported that with Pol training of endurance athletes, a decrease in fat mass both in the arms and trunk, and an increase in lean body mass were observed (Sellés-Pérez et al., 2024). Pérez et al. (2020) found that both Pol and TR training had a positive effect on fat loss, and increased muscle mass in endurance athletes over a 12-week period. The effectiveness of Pol and TR training was investigated even with obese subjects, resulting in weight loss with both training methods, and respiratory functions also improved with Pol training (D'Alleva et al., 2024).

Consequently, our aim was to examine whether Pol training proves to be more effective in the triathlon sport for young ages. Several authors have already shown that VO_2 and ventilation are closely related to performance, since the more optimal these parameters are, the better athletes can perform (Bassett et al., 1997; Bassett et al., 2000; Burnley & Jones, 2007; Kollias & Buskirk, 1974). Although other parameters also influence performance, these are the two main variables, measured and estimated even during track conditions, showing a close correlation with effectiveness. In our research protocol, these data were analyzed to compare the Pol and TR methods.

In addition to the impact of training methods concerning performance, it is also influenced by body composition (Selléz-Pérez et al., 2024; Vleck et al., 2014).

Considering the possibilities and choices of trainers, the aim of our research was to investigate the effectiveness of Pol training in young female triathletes for running performance. We sought to answer the following questions:

1. Can any effect be detected in body composition, and does it depend on the method used?
2. Can any difference be detected between the Pol and TR groups after the study period?

Material and methods

The study was conducted in accordance with the principles of the Declaration of Helsinki. The subjects included in the study were informed in advance and provided parental consent. Participation in the study was anonymous and voluntary. Participants were informed in detail about the research ethics. The examined persons will not be identified in the publications.

Subjects

Subjects were selected among female athletes ($n_{(Pol)}$ = 21; $n_{(TR)}$ = 21) participating in triathlons, aged 14–16 years (at the beginning $age_{(Pol)}$ = 14.63 ± 1.25 years; $age_{(TR)}$ = 14.61 ± 0.89 years). Sample selection was limited by the number of girls in the same age group and the reluctance of clubs and coaches to change their 'tried and tested' training methods. Data were collected annually during the study period for 3 years. At the beginning of our analysis, there was no difference between the two groups.

Training methods

According to practice, after a longer break, general training start in October-November and lasts until the end of March or the beginning of April. After this period, the frequency of sport-specific training increases, resulting in more high-intensity training sessions 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 (80%); 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 the high-intensity zone (Zone 3). The ratio of the TR group in different zones was 60%, 30%, and 10%, respectively. The different training zones were monitored with heart rate (HR) devices (Seiler & Tonnessen, 2009) in each training session.

Physiological parameters tested

To test the effectiveness of training methods, a spiroergometric maximal exercise test (VO max test) on a treadmill ergometer (Marquette S2000, using a SENSOR MEDICS Vmax29 C Gas Analyser and a 12-lead ECG monitor) was conducted, and physiological parameters having a decisive role in long-term physical performance were analyzed. During the protocol, treadmill speed was 5 km×h^{-1} for 2 min, slope 0%, then 10 km×h^{-1} at 3% for 2 min, then the slope was increased by 3% every 2 min with the same treadmill speed until complete exhaustion.

The protocol we use was developed in the diagnostic laboratory of the Hungarian National Youth Education Institute. The purpose of the protocol, which is widely used (in several sports), is to diagnose the physiological parameters of athletes in each sport, and to compare the physiological parameters of athletes in different sports.

The test protocol we used conforms to the standards of a maximal exercise test (VO max test). In sports physiology, a maximal exercise test assesses an athlete's performance at the point of volitional exhaustion, when they can no longer maintain the workload. This level of exertion corresponds to the athlete's maximum oxygen consumption (VO max) and represents their peak cardiovascular and aerobic capacity. During the test, the workload is progressively increased until the athlete reaches their maximum performance limit.

Statistical methods

Statistical analysis of measured and calculated data was performed using the Statistica for Windows software package (version 7.1, StatSoft Inc., Tulsa, OK 74104, USA, 2013). First, conventional descriptive statistical characteristics (mean, standard deviation and range of variation) were calculated, and then the independent-samples T-test was applied. The level of statistical significance was set at $p < 0.05$.

Results

The results of our study are presented in tables and graphs.

There were no significant differences between the two groups in any variables at the beginning of our analysis (Table 1), but minimal differences were already observed in variables determining the effectiveness in endurance sports (rVO_2, VE, Time).

Results of the second measurement are shown in Table 2. Significant differences in relative aerobic capacity (rVO_2), the main determinant of physical performance, and in time spent on the treadmill (Time) were found in favor of the Pol group. For the other variables, we did not detect any significant difference.

Table 1. Basic characteristics and differences between the means of the two studied groups at the first survey

	„Polarized"	„Threshold"	*t*-value	*p*	ES
BH	162.43 ± 5.22	161.43 ± 8.40	0.27	0.7937	0.08
BW	49.63 ± 8.36	45.40 ± 5.15	1.14	0.2767	0.35
rHR	82.86 ± 10.24	87.00 ± 8.70	−0.82	0.4305	−0.25
LA1	1.40 ± 0.12	1.48 ± 0.09	−1.42	0.1822	−0.44
rVO_2	62.61 ± 8.73	57.60 ± 2.67	1.45	0.1719	0.45
mHR	194.00 ± 8.08	201.43 ± 4.96	−2.07	0.0604	−0.64
O_2 pulse	15.41 ± 1.50	15.43 ± 0.79	1.54	0.1499	0.48
VE	108.91 ± 11.87	100.23 ± 7.13	1.66	0.1228	0.51
VT	1.90 ± 0.12	1.90 ± 0.12	0.11	0.9154	0.03
RR	55.29 ± 2.93	50.86 ± 4.98	2.03	0.0653	0.63
LA2	10.86 ± 1.79	10.96 ± 2.60	−0.08	0.9346	−0.02
Time	11:29.00 ± 0:34.12	11:27.35 ± 0:35.00	−0.08	0.9399	−0.02

Notes: BH = body height (cm); BW = body weight (kg); LA1 = resting lactate level; LA2 = maximal lactate level; mHR = maximal heart rate (beats×min^{-1}); rHR = relative resting heart rate (beats×min^{-1}); RR = respiratory rate; rVO_2 = relative oxygen uptake; Time: running time spent on treadmill; VE = ventilation; VT = breathing threshold

Table 2. Differences found between the two groups at the second data collection

	„Polarized"	„Threshold"	*t*-value	*p*	ES
BH	166.28 ± 3.09	164.42 ± 8.06	0.57	0.5797	0.18
BW	55.42 ± 12.28	49.05 ± 4.66	1.28	0.2234	0.40
rHR	82.48 ± 14.42	83.14 ± 5.27	−0.12	0.9043	−0.04
LA1	1.78 ± 0.39	1.67 ± 0.48	0.49	0.6343	0.15
rVO_2	**67.08 ± 1.95**	**60.30 ± 2.20**	**6.12**	**<0.0001**	**1.89**
mHR	196.85 ± 8.38	195.28 ± 9.11	−1.80	0.0966	−0.56
O_2 pulse	15.75 ± 1.71	15.62 ± 1.53	0.15	0.8844	0.05
VE	117.44 ± 11.69	109.51 ± 7.19	1.53	0.1524	0.47
VT	2.01 ± 0.14	1.90 ± 0.28	0.93	0.3728	0.29
RR	53.28 ± 6.32	55.27 ± 4.68	−0.67	0.5137	−0.21
LA2	11.57 ± 2.90	8.92 ± 4.26	1.36	0.1999	0.42
Time	**12:01.51 ± 0:28.16**	**10:28.00 ± 0:53.02**	**–4.13**	**0.0014**	**–1,27**

Notes: BH = body height (cm); BW = body weight (kg); LA1 = rest lactate; LA2 = maximal lactate; mHR = maximal heart rate (beats×min^{-1}); rHR = relative resting heart rate (beats×min^{-1}); RR = respiratory rate; rVO_2 = relative oxygen uptake; Time: runtime spent on treadmill; VE =ventilation; VT = breathing threshold

At the third measurement, significant differences were found in relative-resting heart rate (rHR) (the lowest HR measured at rest before test), relative aerobic capacity (rVO_2), ventilation (VE) and Time (time spent on treadmill) between the two groups, the Pol group performing better. Significant differences in running times between the two groups were detected (Fig. 3). While average time of the TR group (11:27.35; 10:28.00; 10:38.51) showed a slight deterioration, the performance of the Pol group (11:29.00; 12:01.51; 12:02.51) improved.

Differences in rVO_2, significantly determining athlete performance, are illustrated in Figure 4. At the first and second measurement, performance improved in both groups, but averages of the TR group are below the other group (Pol), although no differences were detected between them at the first measurement. It is noteworthy that $relVO_2max$ of the Pol group improved at each survey, while it did not in the other group.

Table 3. Differences found between the two groups at the second data collection

	„Polarized"	„Threshold"	*t*-value	*p*	ES
BH	168.86 ± 6.41	165.43 ± 6.24	1.61	0.1330	0.50
BW	53.34 ± 5.04	52.26 ± 5.81	0.38	0.7142	0.12
rHR	**74.29 ± 12.05**	**87.43 ± 9.00**	**–2.32**	**0.0391**	**–0.72**
LA1	1.74 ± 0.47	1.60 ± 0.69	0.46	0.6508	0.14
rVO_2	**68.01 ± 7.18**	**56.53 ± 6.83**	**3.09**	**0.0094**	**0.95**
mHR	196.57 ± 6.18	198.71 ± 6.87	–0.62	0.5474	–0.19
O_2 pulse	17.07 ± 3.29	15.71 ± 1.00	1.88	0.0851	0.58
VE	**128.16 ± 5.09**	**114.06 ± 8.35**	**3.84**	**0.0024**	**1.19**
VT	2.11 ± 0.14	2.03 ± 0.33	0.57	0.5764	0.18
RR	52.86 ± 7.36	53.29 ± 5.77	–0.12	0.9049	–0.04
LA2	11.11 ± 2.35	11.41 ± 2.91	–0.22	0.8328	–0.07
Time	**12:02.51 ± 0:24.38**	**10:08.51 ± 0:37.48**	**–2.81**	**0.0157**	**–0.87**

Notes: BH = body height (cm); BW = body weight (kg); LA1 = rest lactate; LA2 = maximal lactate; mHR = maximal heart rate (beats×min^{-1}); rHR = relative resting heart rate (beats×min^{-1}); RR = respiratory rate; rVO_2 = relative oxygen uptake; Time: runtime spent on a treadmill; VE = ventilation; VT = breathing threshold

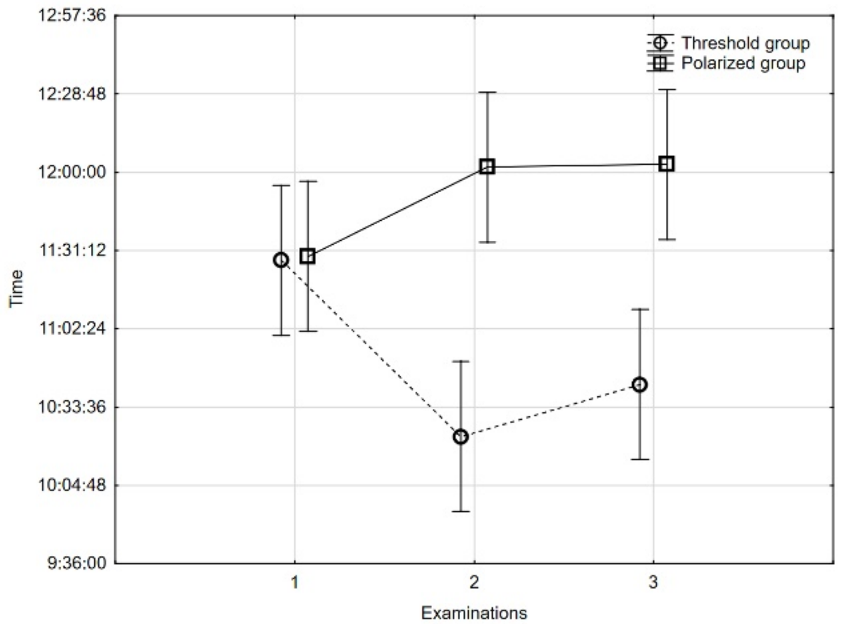

Figure 3. Differences in running times spent on treadmill of tested groups

Discussion

The aim of our study was to investigate the effectiveness of polarized and threshold training in female youth athletes to further improve their success in the triathlon. Our data support the effectiveness of Pol training in the youth age group, showing that the Pol group performed significantly better than the TR group in terms of physical performance (Time) after 3 years of training. In a cardio-respiratory performance variable (rVO_2), we also detected significant differences, again in favor of the Pol group, while performance (Time) and ventilation (VE) also increased significantly ($p < 0.05$) in this group. There were no significant differences in the anthropometric variables; however, a difference was observed between the two groups in rHR at the third year. The effectiveness of Pol training has already been demonstrated in some endurance sports (Billat et al., 1999; Esteve-Lanao et al., 2007; Foster et al., 2001;

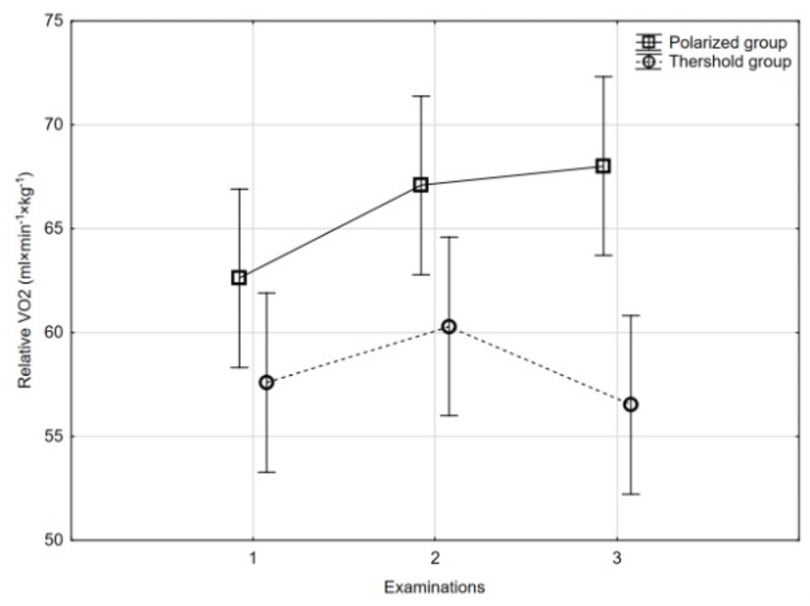

Figure 4. Differences in relative aerobic capacity between groups

Seiler et al., 2007), although considering the low number of subjects, one should be cautious in drawing conclusions.

We did not analyze body composition directly, but both groups showed optimal levels for triathlon performance, and no significant difference was detected between the training models in this respect. Body composition, being a major determinant of sport performance, was found to be optimal for successful triathlon performance in our study, similarly to earlier findings (Beunen, 2003; Bottoni et al., 2011; Brunkhorst & Kielstein, 2013; dos Anjos et al., 2003).

Our results confirmed that differences measured between the two groups are related to the training method rather than the test method used. Several authors have demonstrated that performance in spiroergometric tests is a good predictor of sport performance (Cejuela et al., 2008; Schabort et al., 2000; Suriano & Bishop, 2010; Van Schuylenbergh et al., 2004), so the differences observed between groups are not the consequences of the test method chosen.

The Pol group showed significant improvements in relative aerobic capacity (rVO_2), playing a significant role in athletic performance (Butts et al., 1991; O'Toole & Douglas, 1995; Suriano, & Bishop, 2010), and an increase in running Time. In the TR group, no significant change was detected in any variable over the 3-year period. Potential biological effects in adolescence were not investigated in this study, but one cannot exclude possible changes in personal goals and motivation, especially in the TR group, which might have negatively affected performance development.

In our sample, the Pol training method proved to be more effective than the TR training method. The measured data are consequences of the fundamental differences between the two training models, based on the amount of training spent in different zones. Similar findings have been documented in several studies, using different testing strategies, while maximizing the principles of Pol training (Boullosa et al., 2010; Muñoz et al., 2014; Neal et al., 2013; Papai et al., 2022; Seiler, 2010; Stöggl & Sperlich, 2014).

Our study contributes to the limited data of youth adaptations, as most findings are based on research involving adults. Many studies describe the adaptation of adults (Bell et al., 1991; Häkkinen et al., 2003; McCarthy et al., 2002), whereas research on young people is negligible, despite the fact that this age is important in sport adaptation (Zemková & Hamar, 2018). Children show a significant increase in muscle strength before puberty and during adolescence (up to 13–30%), and anaerobic performance of youngsters improves with age, although the mechanisms behind it are still unclear (Matos & Winsley, 2007).

Our data suggest that VO_2max of youth and anaerobic performance can also be improved depending on training type, especially during puberty. Scientists discussing the effectiveness of aerobic training agree that VO_{2max} of children increases, although its magnitude depends on the type of training, suggesting that a cross-training effect may occur in young people (Buttar et al., 2019; McManus et al., 1997). Similar results were obtained in the case of anaerobic parameters measured in strength-speed tests, in which aerobic performance was approximated. Improvement by 23% was observed, mostly attributable to optimal strength increase during puberty (Obert et al., 2001), demonstrating that children are able to improve their anaerobic power.

According to our results, differences in training zone distribution played a key role in the superior effects of Pol training. Pol training has been analyzed by several authors (Billat et al., 2001; Esteve-Lanao et al., 2007; Röhrken et al., 2020; Schumacher & Mueller, 2002; Seiler & Kjerland, 2006; Steinacker et al., 1998), showing that the annual training program of endurance athletes is performed around or above the lactate threshold level (75% in Olympic athletes) and only a small percentage below that. Data show that running speed around the lactate threshold caused the improvement of VO_2max (Helgerud et al., 2001; McMillan et al., 2005).

The present data reinforce the notion that systemic adaptations are more pronounced following Pol training compared to TR training. Neal et al. (2013) reported that in cyclists, six weeks of Pol training resulted in a higher level of systemic adaptation compared to TR training. Rosenblat et al. (2019) examined potential reasons for the effectiveness of Pol training, examining 112 manuscripts. They found that some variables (VO_2max, pre-specified maximal exercise testing protocol, VT_2/LT_2) were strongly associated with endurance performance, confirming the effectiveness of Pol training.

We observed improved VO2max in the Pol group, likely due to combined central and peripheral aerobic adaptations. The results showed that VO_2max was higher for Pol training than for other training intensity distributions (Silvia et al., 2024), with low heterogeneity but a small effect size. Pol proved to be more effective in increasing VO_2max, as athletes combine high and low intensity training, suitable for the development of central and peripheral aerobic adaptation (Bartlett et al., 1985). A major factor in adaptation to endurance training is an increase in cardiac output (Jones & Carter, 2000; Rosenblat et al., 2022). Low-intensity aerobic training has been shown to effectively increase cardiac output and plasma volume (Pollock, 1977), but higher intensity is even more effective for this purpose (Helgerud et al., 2007; Milanovic et al., 2015). It has already been shown that intensity is of key importance in exercise-induced hypervolemia, and higher exercise intensity contributes to a rapid increase in plasma volume. Results proving that high-intensity exercise increased blood volume more quickly also support our data suggesting that the Pol training method is more effective in improving VO_2max, even after a short intervention (Silva et al., 2024). The VO_2max improvement is also strongly related to adaptational changes of the peripheral skeletal muscle, increasing both capillary oxygen extraction and the uptake by mitochondria (van der Zwaard et al., 2021).

In our study, higher-intensity training led to more efficient peripheral adaptations than low- or medium-intensity training. Additionally, Pol training was more effective in promoting increases in VO_2max. Several authors have found that higher-intensity training improves endurance faster (Driller et al., 2009; Ní et al., 2017), and the degree of peripheral adaptation is more efficient than during low- or medium-intensity training (Schubert et al., 2017), which might be due to type II muscle fibers, positively affecting oxidative capacity (Conwit et al., 1999; Poole et al., 1985; Torma et al., 2019). Additionally, our research is supported by studies showing that during high-intensity training (around VO_2max) the oxidative capacity of type IIx muscle fibers increases (Dubley et al., 1982), suggesting that high-intensity training might develop both central and peripheral adaptation faster, thereby further increasing VO_2max.

Although our study focused on performance outcomes, we acknowledge the importance of avoiding early sport specialization in adolescents. Despite the physical changes athletes experience in youth, training spent below the aerobic-anaerobic zone has high efficiency in physical performances. Too early sport-specific training might be harmful in adolescence, so premature sports specialization generates many controversies. To avoid these issues, a long-term athlete development strategy was developed (Jayanthi et al., 2013).

A major limitation of the study is the relatively small sample size, which might limit the generalizability of the results, warranting cautious interpretation. Despite the limitations, the longitudinal design of the study over a three-year period and the real-world training context are significant advantages, enhancing ecological validity. Objective physiological measures, including relative VO and ventilation, further support the robustness of our findings. From a practical perspective, these data have important implications for coaches, sports scientists, and youth sports development programs. The use of a polarized training approach in adolescent endurance athletes may facilitate greater improvements in aerobic capacity and performance while also supporting long-term athlete development. These results reinforce the effectiveness of strategically varying training intensities to optimize adaptation and minimize risks associated with early sport specialization.

In summary, our findings provide compelling evidence that polarized (Pol) training is more effective than threshold (TR) training, enhancing physical performance and cardiorespiratory fitness among adolescent female triathletes over a three-year period. The Pol group demonstrated significant improvements in relative VO (rVO), running time, and ventilation (VE), supporting previous research highlighting the superior adaptive effects of combining high- and low-intensity training. While no significant anthropometric changes were observed, the lower resting heart rate (rHR) in the Pol group at the third year further suggests improved cardiovascular efficiency. These results align with prior studies in adult populations and emphasize the potential of Pol training to elicit meaningful adaptations even in youth athletes. Given the small sample size, conclusions must be drawn with caution; however, our data add valuable insights to the limited literature on long-term training effects in young endurance athletes. Future research should further explore the interplay between biological maturation, motivation, and training response to optimize developmental strategies in youth sports.

The authors hope that this work will attract the attention of coaches interested in scientific studies and inspire further research, ultimately benefiting triathlon and potentially other sports.

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