ORIGINAL ARTICLE

The effects of polarized training on time trial performance in trained and highly-trained triathletes

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ABSTRACT

The polarized training model (POL), with its unique training intensity distribution (TID), emerges as an effective alternative to improve time trial performance. This study aimed to evaluate the effects of 13 weeks of training by applying a POL model in trained and highly-trained triathletes, using a percentage of TID of 75/0/25 in zones 1, 2, and 3, respectively. To analyse training effects, the assessment was performed at the beginning and the end of the study on time trials: 200m swimming (T200m), 4 minutes (T4min) and 20 minutes (T20min) cycling, and 6 minutes (T6min) running. Analysis of covariance (ANCOVA), supplemented with post hoc tests, revealed that POL training did not produce significant changes: T200m (pre = 3.03 ± 0.58, post = 2.90 ± 0.53, *p* = .59), T4min (pre = 272.09 ± 55.91, post = 290 ± 69.33, *p* = .50), T20min (pre = 204.91 ± 51.3, post = 216.36 ± 56.6, *p* = .62) and T6min (pre = 15.71 ± 1.69, post = 15.86 ± 1.54, *p* = .82). Even though training time in Z1 and Z3 is relevant, our results suggest that optimal programs for trained and highly trained triathletes should not exclude training in Z2. Furthermore, to optimize the effects of the POL model, it is essential to consider the athlete's initial level of performance and the duration of the program.
Keywords: Performance analysis, Performance framework, Training intensity distribution, Overtraining, Physiological capacity.

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INTRODUCTION

In endurance sports, time-trial performance tests are considered one of the most effective methods of evaluating the effects of a training program. In addition, they allow the classification of the athlete's performance level in a sensitive and accessible form without using mathematical models or access to a laboratory (Valenzuela et al., 2021). These tests are characterized by the assessment of the athlete's ability to maintain maximum power or speed for a given period of time (Dolci et al., 2020), which makes it possible to establish a direct relationship between the physiological adaptations induced by training and performance in a specific sport discipline(Cerezuela-Espejo et al., 2018).

The polarized (POL) model has emerged as a highly effective alternative for the improvement and refinement of this type of testing (Rosenblat et al., 2019). This strategy, with its exclusive training intensity distribution (TID), is traditionally characterized by accumulating ∼75-80 % of training volume in the low intensity zone (Z1), ∼0-5 % in the moderate-intensity zone (Z2), and the remaining ∼15-20 % in the high-intensity zone (Z3) (i.e., Z1>Z3>Z2) (Treff et al., 2019). In this regard, recent studies have demonstrated that POL training has positive effects on modifying physiological responses related to performance enhancement in several elite athletes, including rowers (Treff et al., 2017), runners (Ingham et al., 2012), swimmers (Pla et al., 2019) and cyclists (Schneeweiss et al., 2022). Furthermore, research on the annual distribution employed by top world-class endurance athletes has indicated a tendency to utilize POL models (Casado et al., 2022; Seiler, 2010).

Several hypotheses have been proposed to elucidate the physiological mechanisms responsible for the effectiveness of the POL model in enhancing performance in endurance athletes. One of these is highlighted by the enhancement of mitochondrial capacity, and involves two signalling pathways that converge on the expression of peroxisome proliferator-activated receptor gamma coactivator 1 alpha (PGC-1α) (Casado et al., 2023). The first pathway is based on mitochondrial protein synthesis through calcium signalling and is related to low-intensity training at Z1, stimulated by high-volume steady-state sessions (Bishop et al., 2019). The second pathway is activated by an increase in the intramuscular ATP:ADP/AMP ratio and cellular energy depletion, leading to an accumulation of reactive molecules and energy intermediates that activate 5'-adenosine monophosphate-activated protein kinase (AMPK). Activation of this protein stimulates PGC-1α and thus generates mitochondrial biogenesis (Gibala et al., 2012). This signalling pathway is induced by Z3 training, which is carried out through intervallic sessions at intensities above the individual anaerobic threshold (IAT) or close to maximal oxygen uptake (VO2max) (van der Zwaard et al., 2021). However, a high volume of allocated training time in Z3 has been associated with negative cardiovascular, hormonal and metabolic consequences, as well as a decrease in performance (Bellinger, 2020). For this reason, to balance the positive and negative effects of high-intensity training, endurance athletes should consider combining Z3-regulated sessions with high volumes of Z1 training in order to optimize mitochondrial adaptations, physiological capacity and time trail and competition performance (Foster et al., 2022; van der Zwaard et al., 2021).

Despite the physiological mechanisms that explain the beneficial effects of POL model, there are significant inconsistencies and limitations in the evidence supporting the notion that this method is optimal (Burnley et al., 2022). This is particularly evident in lower-level endurance athletes (Silva Oliveira et al., 2024). In this sense, two recent studies conducted with trained endurance athletes (Festa et al., 2019; Röhrken et al., 2020) failed to demonstrate superior physiological adaptations and time trial performance improvements when comparing the effect of POL training with other TID models (pyramidal [PYR] and threshold [THR], respectively). Furthermore, a longitudinal case study of an elite trail runner (Rivera-Kofler et al., 2024) found that the greatest physiological changes were reported during the period when the athlete increased training volume in the Z2 (i.e., moderate intensity zone), which increased the internal training load with the measures of total training impulse (TRIMPs) and consequently improved the athlete's physiological capacity. However, the training volume reported in this study was significantly lower than that used by elite and world-class endurance runners (Casado et al., 2022; Haugen et al., 2022). It is important to note that such adaptations appear more common in trained and highly trained athletes, who have less time for long training days and must compensate for this lack of volume with regulated sessions in the moderate intensity zone (Z2). However, this tendency may lead to reduced adaptation as neither calcium-dependent nor AMPK pathways are likely sufficiently stimulated to increase mitochondrial capacity(Foster et al., 2022).

For this reason, although the POL model has been extensively validated in elite and world-class endurance athletes, its effectiveness in improving time trial performance, especially considering different performance levels, still needs to be explored. Therefore, this study aimed to evaluate the effects of 13 weeks of training by applying a POL model in trained and highly-trained triathletes, using a percentage of TID of 75/0/25 in zones 1, 2, and 3, respectively.

METHODS

Participants

Exclusion criteria were established for athletes who missed more than three training sessions per week or whose total training volume was less than 80% of the total training load. A total of 23 triathletes from Viña del Mar, Chile, participated in the study; 10 participants were excluded from the intervention due to health problems or other personal reasons. Their main goal for the season was to prepare for an Ironman 70.3 distance triathlon scheduled for 17 November 2024 in Valdivia, Chile. According to a 6-tiered classification framework that takes into account training volume and performance variables (McKay et al., 2022), all participants were classified into performance tiers 2 and 3, corresponding to trained/development and highly trained/national level athletes, respectively. Before the intervention, all subjects had been training consistently for >2 years (average experience 3.9 ± 2.2 years), with an average training volume of 10 h 30min ± 1 h 20 min per week, divided between swimming, cycling, and running. At the start of the study, the athletes were in the final phase of their overall seasonal preparation, characterized by a training volume predominantly in Z1.

Table 1. General characteristics of the participants before the study.

Characteristics of athletes	Total	Women (n = 4)	Men (n = 9)	*p*-value
Age (y)	32.08 ± 6.48	31.25 ± 3.5	32.44 ± 7.61	.77
Weight (kg)	66.42 ± 10.54	56.38 ± 11.95	70.89 ± 6.35	.01
Height (cm)	167.54 ± 7.07	160.50 ± 4.12	170.67 ± 5.74	.09
Body mass Index (kg/m^2)	23.57 ± 3.04	21.70 ± 3.45	24.40 ± 2.63	.14
VO_{2max} (mL/min/kg)	57.38 ± 5.87	54.85 ± 6.94	58.50 ± 5.387	.32
HRmax (bmp)	191.23 ± 8.26	190.25 ± 6.02	191.67 ± 9.39	.78
Bike 20 min. best (W/kg)	3.33 ± 0.97	2.75 ± 0.95	3.59 ± 0.91	.15
Run 10 km best (min)	44.38 ± 6.74	49.25 ± 7.45	42.22 ± 5.49	.08
Triathlon training experience (Years)	3.92 ± 2.21	2.50 ± 0.57	4.56 ± 2.40	

This intervention study is a randomized, controlled trial in which athletes were randomly assigned to a common training group that followed a POL intensity distribution trend for 13 weeks. Performance tests were assessed at baseline and post-intervention. Data confidentiality was ensured through the coding of

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participants' names, data were stored in the research computer with the principal investigator's login code. The research was conducted following the recommendations of the Helsinki declaration for human studies (World Medical Association, 2013).

Performance test and training intensity distribution

The performance tests and training intensity distribution for the three disciplines were presented based on the triphasic model (Skinner & Mclellan, 1980) and according to the relevant research literature (Arroyo-Toledo et al., 2021; Cerezuela-Espejo et al., 2018; Huerta Ojeda et al., 2018; Pinot & Grappe, 2014).

For swimming, the assessment was based on a 200m time trial (T200m) conducted in a 25-m indoor pool at 26º C. Z3 training was set at speeds above 86% of T200m; Z2 was set at speed between 76 and 85%, and Z1 below 75% of T200m test (Arroyo-Toledo et al., 2021).

For cycling, participants used their own bicycles equipped with an ergometer and pre-calibrated personal power meters. Performance was assessed on the basis of a 4-minute time trial (T4min). It was determined that Z3 training would be performed above 76% of the average power output of T4min; Z2 between 61% and 75%, and Z1 for power outputs below 60% (Pinot & Grappe, 2014). In addition, a 20-minute time trial (T20min) was also included for a more comprehensive assessment of performance, which has shown a strong correlation with direct identification of power at the IAT (Borszcz et al., 2018; Sitko et al., 2022; Valenzuela et al., 2021).

The assessment assigned for running was based on a 6-minute time trial (T6min) performed on a 400-m track. The training programmed proposed for Z3 was designed for speeds above 86% of the average T6min speed, while the Z2 training programme was designed for speeds between 66 and 85%. The Z1 training programme was designed for speeds below 65% of T6-min (Cerezuela-Espejo et al., 2018; Huerta Ojeda et al., 2018).

Prior to each application of the time trial performance tests, all triathletes were required to complete a standardized warm-up routine. The warm-up, comprising 20 minutes of exercise at Z1 intensity, followed by five minutes of specific activation exercises. The athletes were provided with explicit instructions regarding the duration and format of each test.

Additionally, based on the data from the time trial performance tests, their coach (TR) prescribed the training program based on time targets to track each zone and monitor the TRIMPs (Foster et al., 2001). Thus, heart rate (HR) and rate of perceived exertion (RPE) were mainly used for the prescription of long-duration and low-intensity training (i.e., Z1), and the speed-power, and RPE scales were used for the prescription of moderate and high-intensity training (i.e., Z2 and Z3). Athletes recorded all training sessions with their HR monitor (HR; Polar Electro, Kempele, Finland) and then uploaded their data into a specific analysis software (Training Peaks®, USA).

The three-zone model, related to HR and RPE, plays a crucial role in our performance assessment guidelines:

1. Z1: Low Intensity, <82%HRmax, RPE <4 points.
2. Z2: Moderate Intensity, 76-85% T200m; 61-75% T4min; 66-85% T6min; 82-92% HRmax; RPE >4, <7 points.
3. Z3: High Intensity, >86% T200m; >76%T4min; >86%T6min; >92% HRmax, RPE >7 points.

Training intervention
To reduce the effects of previous training, a pre-experimental period consisting of one week of detraining and 3 weeks of controlled training was proposed, with 95% of the prescribed sessions in Z1 and the remaining 5% in Z2.

The training program consisted of a combination of low and high-intensity sessions, Z1 and Z3, respectively. The sessions in Z1 lasted between 60 and 180 minutes, and those in Z3 between 40 and 60 minutes. Three sessions in Z3 were proposed weekly, one for each discipline interspersed with six training sessions in Z1 (Figure 1), assigning 75% of the training volume to Z1, 0% to Z2, and the remaining 25% to Z3. The intensity distribution was set according to the Polarization Index (PI): PI = log10 (Z1/Z2 x Z3*100) proposed by (Treff et al., 2019). If IP >2.00, the methodology can be defined as 'polarized'. Conversely, if IP is ≤ 2.00, the methodology is described as 'non-polarized'. This intervention presented a PI = 3.2, values in line with those proposed in the training of elite cyclists (Schneeweiss et al., 2022) but higher than studies conducted with recreational triathletes and elite runners (Filipas et al., 2022; Röhrken et al., 2020).

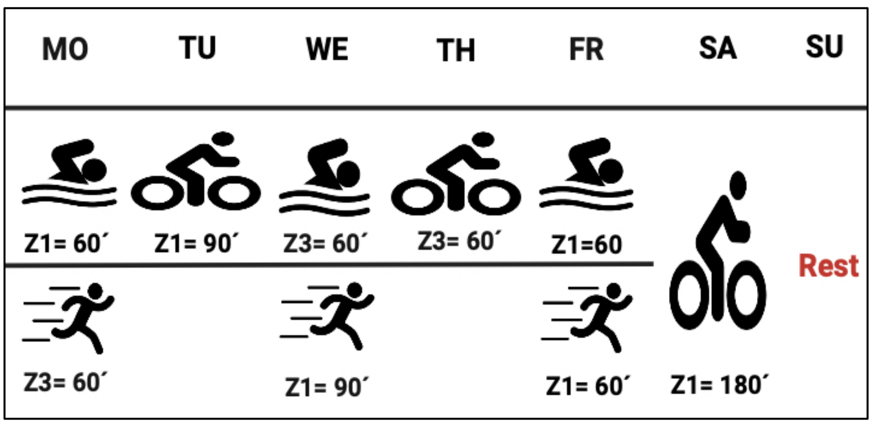

Figure 1. Weekly training programme that was implemented during the 13-week intervention period. The training programme consisted of two distinct intensity levels, designated as Z1 (low intensity) and Z3 (high intensity).

Statical analysis
JAMOVI® version 2.3.21 for Windows (Sydney, Australia) software was used for statistical analysis. Variables and standard deviations by pre- and post-test were presented to describe the study variables. The percentage of changes in the CRF variables (%Δ) was calculated using the following equation: ([post-test - pre-test]/pre-test) × 100%. First, a normality test was performed using the Kolmogorov and Smirnov test. Then an analysis of covariance (ANCOVA) was applied to establish differences between pre- and post-intervention for each test, with Bonferroni's post-hoc to establish the differences obtained by each group. In addition, the effect size was calculated using the partial eta-square test (η^2p), considering the following classification: <0.01 (small), >0.06 (moderate), >0.14 (large) and >2.0 (very large) (Richardson, 2011). In all tests, a value $p < .05$ was considered significant.

RESULTS

After the medical examination, 23 athletes were included in the study and assigned to an intervention group, POL (n = 23). Due to health complications, 10 athletes could not complete all assessment from the beginning to the end of the study. Finally, 13 data sets were comprehensively analysed.

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The results of a 13-week POL intervention program in the swim time on 200m showed a decrease in the duration of the test of 4.48%, throwing non-significant differences between the pre- and post-intervention results (*p* = .59). Power in Bike on 4 and 20 min increased 6.20% and 5.29%, however the difference was not significant (*p* = .50, *p* = .62) respectively. In the 6min run test there was an increase in running speed of 0.94%, but this difference was not significant either (*p* = .58) (Table 2).

Table 2. Performance data from the pre and post-test. Data are means (±SD).

Test and variable	Pre	Post	Dif.	(%∆)	*p*	n2p	Pb
Swim T200m. (min/s)	3.03 ± 0.58	2.90 ± 0.53	0.12	-4.48%	.59	0.01	0.592
Bike T4min. (power, W)	272.09 ± 55.91	290 ±69.33	18.4	+6.20%	.50	0.02	0.502
Bike T4min. (W/kg)	4.04 ± 0.78	4.27 ± 0.83	0.23	+5.38%	.50	0.02	0.502
Bike T20min. (power, W)	204. 91 ± 51.3	216.36 ± 56.6	11.5	+5.29%	.62	0.01	0.624
Bike T20min. (W/kg)	3.04 ± 0.67	3.18 ± 0.70	0.14	+4.40%	.62	0.012	0.627
Run T6min. (Km/h)	15.71 ± 1.69	15.86 ± 1.54	0.15	+0.94%	.82	0.002	0.825
HRmax. (bmp)	184.91 ± 8.0	187.09 ± 10.12	2.18	+1.16%	.58	0.015	0.583

Note: Pre, pre-test; Post, post-test, Dif, ; p, ; %, ; n2p: the partial eta-square test ; Pb: Bonferroni's post-hoc; Swim T200m (min/s), time on 200m test; Bike T4min, power on 4min test; Bike T20min, power on 20 min test; Run T6min (km/h), velocity on 6 min test. HRmax, maximal heart rate.

DISCUSSION

Our results, provide a comprehensive understanding of the effect of the POL model on time trial performance in athletes classified as trained and highly trained (tiers 2 and 3, respectively). We demonstrate that a 13-week training period using a POL TID (Z1 = 75%; Z2 = 0%; Z3 = 25%, IP: 3.2) did not significantly change time trial performance in any of the tests performed.

These findings contradict the results of the meta-analysis developed by (Rosenblat et al., 2019), where POL model demonstrated a positive impact and superiority over the THR training model in improving time trial performance. However, it is important to note that participant classification framework of the athletes included in our study was lower than that reported in the meta-analysis above. Consequently, the efficacy of the POL model has only been demonstrated in elite and world-class endurance athletes (tiers 4 and 5, respectively) (Pla et al., 2019; Yu et al., 2012). They are supported because these athletes, often professionals, tend to have more time to train and recover from training than lower- level endurance athletes, allowing them to complete a greater volume of training usually prescribed in Z1 (i.e., low-intensity zones) (Burnley et al., 2022). In addition, there are notable differences in how elite/ world class endurance athletes and non-elite athletes respond to endurance training programs (Silva Oliveira et al., 2024). Elite athletes can effectively tolerate high training volumes at Z3 due to their high physiological capacity (Magalhães et al., 2024). In contrast, for non-elite athletes with lower physiological capacity, these high training volumes at Z3 may result in inadequate recovery and increase the risk of non-functional overtraining (Meeusen et al., 2013). Therefore, while the POL approach may be optimal for athletes with high physiological capacity, lower-level endurance athletes may have better options.

Previous studies (Rønnestad & Hansen, 2018), suggest that 480-720 min per week of training in Z1 could be optimal for inducing performance improvements in elite cyclists (i.e., level 4). However, this claim does not have sufficient scientific support to be extrapolated to trained and highly trained athletes (i.e., tiers 2 and 3, respectively). In our study, the average weekly training volume allocated in Z1 was ∼540 min. However, we could not observe significant improvements in time trial performance in any of the tests evaluated. For this reason, increasing the training volume in Z2, traditionally associated with THR and PYR models, could effectively promote significant changes in sports performance in trained and highly trained athletes (tiers 2 and 3, respectively) (Festa et al., 2019).

Regarding physiological mechanisms, scientific evidence supports the use of Z2 training as a valid method to promote endurance adaptations and performance improvements in endurance athletes (Tønnessen et al., 2020). The evidence suggests that training volume at this specific intensity range optimizes lactate removal from muscle (Casado et al., 2023) and glucose utilization via the oxidative pathway during exercise (Casado et al., 2023). In addition, as with Z3 training, an increased in mitochondrial proliferation through PGC1α activity, mediated by elevated AMPK activation, has been evidenced (Gibala et al., 2012; Granata et al., 2018). However, it is possible that Z2 training will optimize the number of recruited motor units without the adverse effects associated with elevated catecholamine levels reported with Z3 training (Casado et al., 2022). In this regard, (Magalhães et al., 2024) have demonstrated a positive correlation between Z2 training time and the improvement in power output associated with 4 mmol lactate (P4) in a group of recreational cyclists after 16 weeks of training. Similar results were observed in trained triathletes after 13-weeks of training (Selles-Perez et al., 2019), in which time spent training in Z2 was associated with superior performance in a Half-Ironman race. Both programmed were designed using a PYR model (i.e., Z1>Z2>Z3) (Treff et al., 2019).

On the other hand, the analysis of the studies (Magalhães et al., 2024; Selles-Perez et al., 2019) indicates that the intervention period could also influence changes in performance capacity. In comparison to other TID models, longer training periods with a longer POL training report smaller improvements in endurance performance. In this sense, research development by (Silva Oliveira et al., 2024) has shown that the effectiveness of POL training in improving physiological capacity and endurance performance is greater when the intervention is shorter, at 12 weeks. Our results are in agreement with those obtained by these authors (Silva Oliveira et al., 2024), since we did not observe any significant changes in any of the variables studied during the 13 weeks of intervention. Similar results were observed by (Filipas et al., 2022), who compared the effects of 16 weeks of two different training intensity distribution models (POL and PYR) and two sequences of these modalities (POL+PYR and PYR+POL) on time trial performance in a 5 km race in highly trained runners (i.e., tier 3). All models improved performance in the 5 km test. However, only the POL group showed significant improvements in the first 8 weeks, which levelled off over time and were similar to the other models by the end of the study. These results suggest that when training interventions last 12 weeks or more, the effects of the POL training method on performance may be reduced.

In light of the existing literature, (Burnley et al., 2022; Foster et al., 2022; Silva Oliveira et al., 2024), coaches should exercise caution when employing the POL model to enhance time trial performance in trained and highly trained-level athletes (i.e.., tier 2 and 3, respectively). It has been observed that this methodology may not be effective, particularly in training programs that exceed 12 weeks in duration. Given the above, it is essential to consider that the methods that prove effective for world-class athletes may need to be more effective for trained and highly trained athletes.

Our study has some limitations that may affect the quality of this research:

1. We used short-duration tests (200-m in swimming, 4 and 20-min in cycling, and 6-min in running) before and after the training intervention. These protocols may not directly represent performance in longer distance events (e.g., Half Ironman Triathlon). However, they represent a practical, effective, and time-efficient form to quantify the effect of the training program.

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2. Throughout the intervention, we experienced a high drop-out rate of athletes (n = 10). This situation considerably reduced the sample size (n = 13) and weakened the study's statistical power.

3. We allocated a high percentage of the training volume to Z3 (25% of the total training time). These values are high when compared to other recent studies (Festa et al., 2019; Filipas et al., 2022; Röhrken et al., 2020).

4. No indirect calorimetry or blood lactate measurement assessments were carried out. Therefore, it was not possible to investigate the energy cost of sport-specific movement patterns (economy of movement in ml O2/kg/km), VO2max or the velocities and powers associated with the two physiological thresholds, which are considered to be the determining variables of endurance performance (Joyner et al., 2020; Midgley et al., 2007; Pate & Branch, 1992).

These limitations should be considered when interpreting the study's results and designing future research in this field.

CONCLUSSION

In the present study of trained and highly trained triathletes, a TID with a POL approach did not significantly improve any of the time trial performance tests studied after a 13-week training programme. Despite the importance of training time allocated to Z1 and Z3, our results suggest that optimal training programmes for this performance classification framework should not preclude the prescription of training in Z2. In this sense, to maximize the adaptations that POL training can produce, coaches should consider the athlete's initial level of performance as well as the intervention time of the POL model.

Future studies are needed to investigate the effect of different training intensity distributions models in groups with different performance levels and its impact on time trial and competition performance.

AUTHOR CONTRIBUTIONS

Study concept and design, article writing: Tomás Rivera-Kofler. Critical review: Guillermo Cortés-Roco, Tomás Rivera-Kofler, and Rodrigo Yañez-Sepulveda. Data collection: Tomás Rivera-Kofler, Rodrigo Yañez-Sepúlveda, and Guillermo Cortés-Roco. Analysis: Guillermo Cortés-Roco and Tomás Rivera-Kofler. Final approval of the version to be published: Tomás Rivera-Kofler, Rodrigo Yañez-Sepúlveda, Guillermo Cortés-Roco, Exal García-Carrillo, and Jorge Olivares-Arancibia.

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DISCLOSURE STATEMENT

No potential conflict of interest was reported by the authors.

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