BRIEF REVIEW

Polarized vs. Threshold Training Intensity Distribution on Endurance Sport Performance: A Systematic Review and Meta-Analysis of Randomized Controlled Trials

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Abstract

Rosenblat MA, Perrotta AS, and Vicenzino B. Polarized vs. threshold training intensity distribution on endurance sport performance: A systematic review and meta-analysis of randomized controlled trials. *J Strength Cond Res* 33(12): 3491–3500, 2019—The objective of this review was to systematically search the literature to identify and analyze data from randomized controlled trials that compare the effects of a polarized training model (POL) vs. a threshold training model (THR) on measurements of sport performance in endurance athletes. This systematic review and meta-analysis is registered with PROSPERO (CRD42016050942). The literature search was performed on November 6, 2016 and included SPORTDiscus (1800–present), CINAHL Complete (1981–present), and Medline with Full Text (1946–present). Studies were selected if they included: random allocation, endurance-trained athletes with greater than 2 years of training experience and $\dot{V}O_2$max/peak >50 ml·kg·min^{-1}, a POL group, a THR group, assessed either internal (e.g., $\dot{V}O_2$max) or external (e.g., time trial) measurements of endurance sport performance. The databases SPORTDiscus, Medline and CINAHL yielded a combined 329 results. Four studies met the inclusion criteria for the qualitative analysis, and 3 for the meta-analysis. Two of the 4 studies included in the review scored a 4/10 on the PEDro Scale and 2 scored a 5/10. With respect to outcome measurements, 3 studies included time-trial performance, 3 included $\dot{V}O_2$max or $\dot{V}O_2$peak, 2 studies measured time-to-exhaustion, and one study included exercise economy. There was sufficient data to conduct a meta-analysis on time-trial performance. The pooled results demonstrate a moderate effect (ES = −0.66; 95% CI: −1.17 to −0.15) favoring the POL group over the THR group. These results suggest that POL may lead to a greater improvement in endurance sport performance than THR.

Key Words polarized training, aerobic performance, time trial, time- to-exhaustion

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Introduction

There are a number of variables to consider when designing an exercise training program aiming to improve endurance sport performance. Some of these variables include training frequency, training duration, and training intensity (5). Previous investigations have identified training intensity to be an essential variable that can be manipulated to either positively or negatively alter markers of performance (27). Training intensity can be quantified by using different measurements including heart rate (1), blood lactate concentration (3), velocity at maximal oxygen uptake ($\dot{V}O_2$max) (4), and rating of perceived exertion (8). Previous literature has suggested that it is common for athletes to use standardized scales that group these measurements into a range of values to provide a description of different training zones (36). However, these methods may not accurately account for athlete-specific physiological differences, including those regarding the power or speed that can be maintained at specific thresholds (36).

In regard to the observed differences in physiological response at a given fraction of $\dot{V}O_2$max, practitioners have divided training intensity into 3 or more zones separated by physiological thresholds such as the lactate threshold, ventilatory thresholds (VTs), respiratory compensation threshold, and critical power (38). This approach improves the specificity for programming as each athlete's physiological thresholds can occur at a different percentage of their $\dot{V}O_2$max (36). One common approach is to divide intensity into 3 zones: a low-intensity zone below the first ventilatory threshold; a moderate-intensity zone occurring

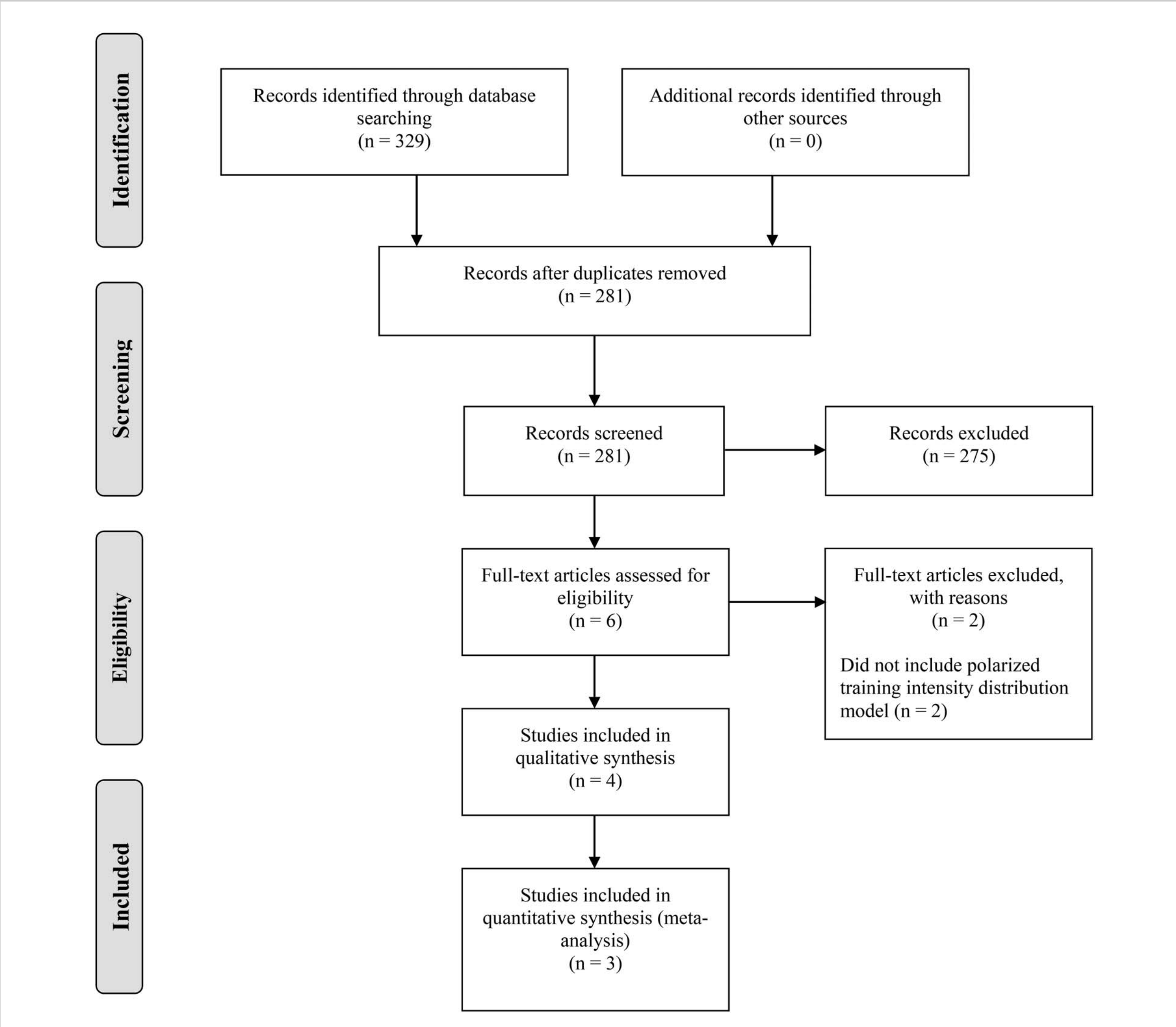

Figure 1. PRISMA flow diagram.

between the first and second ventilatory threshold, and a high-intensity zone residing above the second ventilatory threshold (25).

High-intensity training has been shown to lead to greater improvements in markers of endurance sport performance including $\dot{V}O_2$max, time-trial performance, exercise economy, and time-to-exhaustion in endurance-trained athletes (15,37). However, a high volume of high-intensity training can lead to inadequate recovery causing undesirable effects including a decrease in running performance and exercising heart rate, disturbed sleep, elevated perceived fatigue, and an increase in the incidence of respiratory tract infections (13,24). To balance the positive and negative effects of high-intensity training, it might be necessary to consider the distribution and frequency of high-intensity training to design an appropriate endurance training program.

A number of prospective cohort studies have identified how endurance athletes typically distribute the different training zones in their training program. These athletes (cross-country skiers, rowers, track runners, cross-country runners, marathoners, and ironman athletes) typically followed a program in which approximately 75–85% of total training volume was performed in the low-intensity zone, 5–10% in the moderate-intensity zone, and 15–20% in the high-intensity zone (9,29,31,38,41,43). The structure of training has been described as a polarized training intensity distribution (POL) model as proposed by Stephen Seiler (38). A threshold training intensity distribution (THR) model or more traditional training model, differs from a POL model in that a significant percentage of training (35–55%) is completed in the moderate-intensity zone with a smaller percentage of training (45–55%) completed in the low-intensity zone (38).

TABLE 1. Study characteristics.*

		Participants		Intervention			
Study	Study design	Sport	Characteristics (mean ± *SD*)	Group	TID % (Z1, Z2, Z3)	Workload (TRIMP/wk ± *SD*)	Outcome
Esteve-Lanao et al. (10)	Randomized controlled trial (5-mo)	Competitive, sub-elite male runners ($n = 20$)	Age = 27 ± 2 y, mass = 64 ± 1.1 kg, height = 174.6 ± 1.9 cm, $\dot{V}O_2max$ ($ml\cdot kg^{-1}\cdot min^{-1}$) = 69.5 ± 6.0, experience >5 y	POL ($n = 10$) THR ($n = 10$)	80, 10, 10 65, 25, 10	452 ± 23 460 ± 26	10.4-km running time (s), $\dot{V}O_2max$ ($ml\cdot kg^{-1}\cdot min^{-1}$)
Muñoz et al. (30)	Randomized controlled trial (10-wk)	Recreational runners ($n = 32$)	Age = 34 ± 28 y, mass = 69.2 ± 9.7 kg, height = 175 ± 6 cm, $\dot{V}O_2max$ ($ml\cdot kg^{-1}\cdot min^{-1}$) = 63 ± 7.9, experience >5.5 y	POL ($n = 16$) THR ($n = 16$)	75, 5, 20 45, 35, 20	330 ± 67 370 ± 98	10-km run time (min), $\dot{V}O_2max$ ($ml\cdot kg^{-1}\cdot min^{-1}$)
Neal et al. (32)	Randomized, crossover, within subject (6-wk)	Well-trained, competitive male cyclists ($n = 12$)	Age = 37 ± 6 y, mass = 76.8 ± 6.6 kg, height = 178 ± 6 cm, $\dot{V}O_2max$ ($ml\cdot kg^{-1}\cdot min^{-1}$) = NA, experience >4 y	POL ($n = 6$) THR ($n = 6$)	80, 0, 20 57, 43, 0	517 ± 90 633 ± 119	40-km cycling time (s), 95% PPO exercise capacity (s)
Stöggl et al. (39)	Randomized controlled trial (9-wk)	Competitive endurance athletes (48)	Age = 31 ± 6 y, mass = 73.8 ± 9 kg, height = 180 ± 8 cm, $\dot{V}O_2peak$ ($ml\cdot kg^{-1}\cdot min^{-1}$) = 62.6 ± 7.1, experience >8 y	POL ($n = 12$) THR ($n = 12$)	68, 6, 26 46, 54, 0	NA NA	$\dot{V}O_2peak$ ($L\cdot min^{-1}$), $VO_2submax$ (%$\dot{V}O_2peak$), $VO_2submax$ ($ml\cdot kg^{-1}\cdot min^{-1}$), ramp test

*TID = training intensity distribution; Z1 = training zone 1; Z2 = training zone 2; Z3 = training zone 3; TRIMP = training impulse; $\dot{V}O_2max$ = maximal oxygen uptake; POL = polarized training; THR = threshold training; PPO = peak power output; $\dot{V}O_2peak$ = peak oxygen uptake; TTE = time-to-exhaustion; NA = not available.

Table 2. Risk of bias in individual studies.*

Study	1	2	3	4	5	6	7	8	9	10	11	PEDro score
Esteve-Lanao et al. (10)	1	1	0	1	0	0	0	1	0	1	1	5
Muñoz et al. (30)	1	1	0	1	0	0	0	0	0	1	1	4
Neal et al. (32)	1	1	0	0	0	0	0	1	0	1	1	4
Stöggl et al. (39)	1	1	0	1	0	0	0	1	0	1	1	5

*(1) Eligibility; (2) randomization; (3) concealed allocation; (4) baseline comparison; (5) blind subjects; (6) blind therapists; (7) blind assessors; (8) adequate follow-up; (9) intention-to-treat analysis; (10) between group comparisons; (11) point estimates and variability. Eligibility is not included in the final 10-point score.

Current reviews (20,36,40) focusing on the capability of a POL and THR training model to influence endurance sport performance have proposed a POL model that may elicit superior training adaptations. However, there remains a lack of quantitative analyses examining the magnitude of variance in endurance performance measures when using each training model. As such, the objectives of this review were to (a) provide a systematic review of randomized control trials examining POL and THR training models and (b) to quantitatively examine the effect of using a THR or POL training model for improving endurance performance measures in trained endurance athletes using a meta-analysis.

Methods

Experimental Approach to the Problem

This systematic review is registered with PROSPERO (CRD42016050942) and follows the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRSIMA) guidelines protocol (28).

Subjects

Studies were selected if they included: random allocation, endurance-trained athletes with greater than 2 years of training experience and $\dot{V}O_2$max/peak >50 ml·kg^{-1}·min^{-1}, a POL group, a THR group, assessed either internal (e.g., $\dot{V}O_2$max) or external (e.g., time trial) measurements of endurance sport performance. Studies were excluded if participants were untrained or had pathology.

Procedures

An electronic search was conducted that included all publication years (up to November 6, 2016). To minimize selection bias and to perform a comprehensive search, 3 databases were used to conduct the literature search and included SPORTDiscus (1800–present), CINAHL Complete (1981–present), and Medline with Full Text (1946–present).

Search Strategy. The following search string (including all fields) was used: training intensity distribution OR polarized training OR polarized training OR threshold training.

Study Records: Data Management. Records were imported to Papers 3 (Labtiva, Inc.), a PDF management application, where they were reviewed for selection.

Selection Process. The titles and abstracts of the search results were independently assessed for suitability by 2 authors. Full-text articles were retrieved if the titles or abstracts met the eligibility criteria or if there was uncertainty. Disagreements were resolved through a discussion between the 2 authors, with a third to be consulted if the first 2 authors could not reach agreement. The rationale for excluding articles was documented.

Data Collection Process. A data collection form was created using the Cochrane Data Extraction and Assessment Form template. One author was responsible for collecting the data and the second author checked the extracted data. Disagreements were discussed between the 2 authors, with a third to be consulted if the first 2 authors could not reach agreement.

Data Items. The following data were extracted from each study included in the review: study methodology (study design, duration); participant characteristics (age, sex, height, mass, absolute and relative $\dot{V}O_2$max/peak, experience, sport); intervention and comparator description (exercise type, training-intensity distribution, periodization, intensity zone, workload); and outcome measures.

Outcomes and Prioritizations. The primary outcome assessed in this review is time-trial performance. Secondary outcomes include time-to-exhaustion, exercise economy, $\dot{V}O_2$max (L·min^{-1}), and $\dot{V}O_2$peak (L·min^{-1}).

Risk of Bias in Individual Studies. Two reviewers used the PEDro scale to assess the internal validity of the studies included in the review. The PEDro scale is a 10-point ordinal scale used to determine specific methodological components including: randomization, concealed allocation, baseline comparison, blind participants, blind therapists, blind assessors, adequate follow-up, intention-to-treat analysis, between-group comparisons, point estimates, and variability (21). Participant eligibility is also a component of the PEDro scale; however, it is not included in the final 10-point score.

Data Synthesis. Group data are reported as means and *SD*s with pooled data reported as the standardized mean difference and its 95% CI. The standardized mean difference, adjusted to account for small sample size bias, was calculated

TABLE 3. Results of individual studies.*

Outcome	Study	Measurement	Group	Pre	Post	Within-group change ± *SD*	Between-group difference (95% CI)
TT	Esteve-Lanao et al. (10)	10.4-km run (min ± *SD*)	POL ($n = 6$)	37.5 ± 2.1	34.9 ± NA	−2.6 ± 0.53	−0.60 (−0.74 to −0.46)
			THR ($n = 6$)	37.9 ± 2.1	35.9 ± NA	-2.0 ± 0.29	
	Muñoz et al. (30)	10-km run (min ± *SD*)	POL ($n = 15$)	39.3 ± 4.9	37.3 ± 4.7	−2.0 ± 1.5	−0.60 (−0.78 to −0.42)
			THR ($n = 15$)	39.4 ± 3.9	38.0 ± 4.4	−1.4 ± 1.2	
	Neal et al. (32)	40-km cycle (min ± *SD*)	POL ($n = 11$)	NA	NA	−2.3 ± 2.2	−1.90 (−2.4 to −1.4)
			THR ($n = 11$)	NA	NA	−0.40 ± 2.9	
$\dot{V}O_2$max/peak	Esteve-Lanao et al. (10)	$\dot{V}O_2$max (ml·kg^{-1}·min^{-1} ± *SD*)	POL ($n = 6$)	68.6 ± 5.9	NA	NA	NA
			THR ($n = 6$)	70.3 ± 9.7	NA	NA	
	Muñoz et al. (30)	$\dot{V}O_2$max (ml·kg^{-1}·min^{-1} ± *SD*)	POL ($n = 15$)	61.0 ± 8.4	NA	NA	NA
			THR ($n = 15$)	64.1 ± 7.3	NA	NA	
	Stöggl et al. (39)	$\dot{V}O_2$peak (L·min^{-1} ± *SD*)	POL ($n = 12$)	4.4 ± 1.0	4.9 ± 1.1	0.50 ± 0.40	0.60 (0.19 to 1.0)
			THR ($n = 8$)	4.4 ± 0.80	4.3 ± 9.2	−0.10 ± 3.30	
TTE	Neal et al. (32)	95% PPO (% ± *SD*)	POL ($n = 11$)	NA	NA	85.0 ± 43.0%	48.0% (40.2 to 55.8)
			THR ($n = 11$)	NA	NA	37.0 ± 45.0%	
	Stöggl et al. (39)	Ramp test (% ± *SD*)	POL ($n = 12$)	NA	NA	17.4 ± 16.1%	8.6% (5.9 to 11.3)
			THR ($n = 8$)	NA	NA	8.8 ± 8.6%	
EE	Stöggl et al. (39)	$\dot{V}O_2$submax (ml·kg^{-1}·min^{-1} ± *SD*)	POL ($n = 12$)	38.2 ± 5.5	39.7 ± 5.0	1.5 ± 2.2	2.5 (2.1 to 2.9)
			THR ($n = 8$)	34.7 ± 5.1	33.7 ± 4.4	−1.0 ± 2.4	

*SD = standard deviation; TT = time trial; POL = polarized training; THR = threshold training; NA = not available; $\dot{V}O_2$max = maximal oxygen uptake; $\dot{V}O_2$peak = peak oxygen uptake; TTE = time-to-exhaustion; PPO = peak power output; EE = Exercise economy.

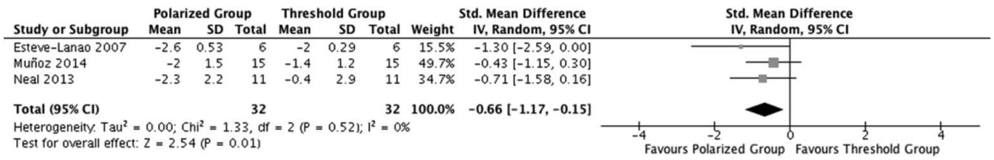

Figure 2. Forest plot of standardized mean difference in time-trial performance.

to establish an effect size (Hedges' adjusted *g*) (14). Effect size values of 0.2, 0.6 and 1.2 were interpreted as small, moderate and large effect sizes, respectively (17).

The authors of the included studies were contacted for data that were not presented in their publications (e.g., pre- and post-test data). Data expressed using the *SE* of the mean were converted to the standard deviation. Where possible, between-group comparisons were made by using the difference of means with the standard error expressed as a 95% CI.

Individual study results were combined using Review Manager 5.3 with a random-effect meta-analysis model. This method considers both within- and between-study variability and was used to accommodate for the differences in the interventions in the individual studies (22). An effect favoring the POL group is displayed as a positive value and an effect favoring the THR group is displayed as a negative value.

The consistency of the meta-analysis was assessed to determine the variability in excess of that because of chance. A chi-squared statistic (Cochrane Q) was used to evaluate the level of heterogeneity. The I^2 statistic was used to determine the percentage of the total variation in the estimated effect across studies.

Risk of Bias Across Studies. The relationship between the effect size and the sample size was determined visually using a funnel plot. Egger's test was used to quantitatively assess for small sample size bias.

Statistical Analyses

No additional analysis was completed.

Results

Study Selection

A literature search was conducted on November 6, 2016. The databases SPORTDiscus, Medline, and CINAHL yielded a combined 329 results. After the removal of 48 duplicates, 281 titles and abstracts were screened. A total of 6 full-text articles were screened for eligibility. Four studies met the inclusion criteria for the qualitative analysis and 3 studies were used in a meta-analysis (Figure 1).

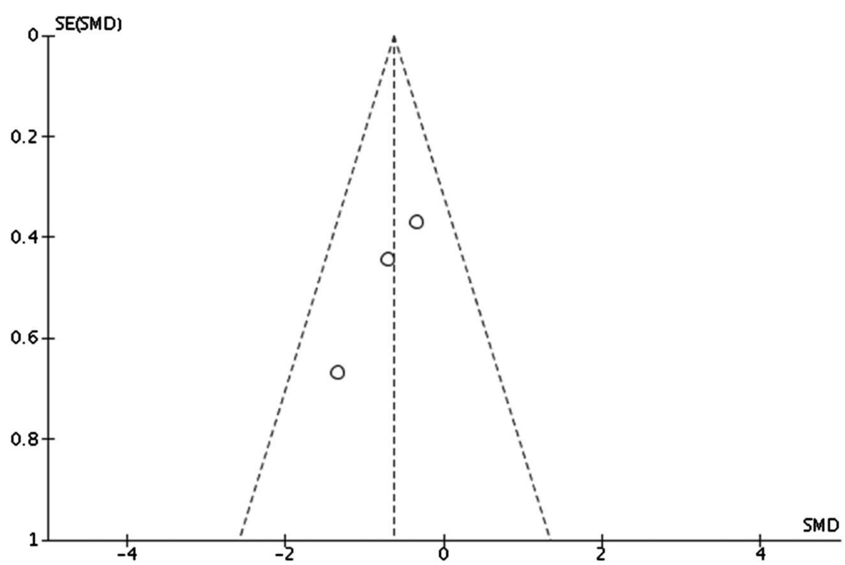

Figure 3. Funnel plot of the standardized mean difference vs. *SE* of time-trial performance.

Study Characteristics

All 4 studies included in the review were randomized controlled trials that ranged from 6-weeks to 5-months in duration (10,30,32,39). Participants were allocated to a POL intervention group or a comparison group. All studies included a THR group (10,30,32,39). One study also included a high-intensity interval training group and a high-volume low-intensity training group (10). Two of the studies included runners (10,30), one study included cyclists (32), and one incorporated cyclists, cross-country skiers, middle- or long-distance runners, and triathletes (39). All studies included internal and external measurements of performance. The external measurements include 10-km running time trial, 40-km cycling time trial, time-to-exhaustion, and exercise economy. Internal measurements include absolute and relative $\dot{V}O_2$max and $\dot{V}O_2$peak (Table 1).

Risk of Bias Within the Studies

Two of the 4 studies included in the review scored a 4/10 on the PEDro scale, and 2 scored a 5/10 (Table 2).

Results of Individual Studies

The studies included a total of 112 participants. All participants were randomly allocated to their respective groups before baseline data collection (10,30,32,39). The authors only included baseline and follow-up data for participants who completed the intervention programs (98 participants) (10,30,32,39). All authors of the studies were sent emails requesting individual and group data that were not published in their respective publications. Three of the 4 authors responded to the email (10,30,39), 2 of which provided additional data (30,39). Only data from one of the authors were incorporated into the results table (Table 3) (30).

Three studies included time-trial performance as an outcome measure (10,30,32), all of which showed a significant difference between the POL group and THR group in time-trial performance, favoring the POL group (Table 3). Three studies included $\dot{V}O_2$max/$\dot{V}O_2$peak (10,30,39), 2 of which did not include postintervention results (10,30). The one study that included follow-up results found a significant difference between the POL and THR groups, favoring the POL group (Table 3). Neal et al. and Stöggl et al. both compared POL and THR on time-to-exhaustion (32,39). Both studies found a greater improvement in time-to-exhaustion in the POL group (32). Only the study by Stöggl et al. (39) included exercise economy and found a POL model to be more beneficial than a THR model.

Data Synthesis

There was only sufficient data to complete a quantitative analysis on time-trial performance. A qualitative analysis of performance markers, including $\dot{V}O_2$max/peak, time-to-exhaustion, exercise economy and time trial, is examined in the discussion section. Three randomized clinical trials were included in the meta-analysis (10,30,32). There was a moderate effect favoring the POL group over the THR group (ES = −0.66; 95% CI: −1.17 to −0.15) (Figure 2).

Risk of Bias Across Studies

A funnel plot of the standard difference in mean vs. standard error indicates that there is no evidence of publication bias ($p = 0.52$) regarding the studies included in the meta-analysis (Figure 3).

Discussion

The pooled results demonstrate a significantly greater improvement in time-trial performance for the POL group when compared to the THR group (Figure 2). In a time-trial performance test, an athlete is required to complete a set amount of work or distance in the least amount of time possible (18). Time-trial test results have demonstrated to be significantly correlated to cycling ($R = 0.98$, $p < 0.05$) and running ($R = 0.95$, $p < 0.05$) race performance (33,34). There was a sufficient amount of data to complete a meta-analysis on time-trial performance.

The main difference between a POL model and a THR model is the percentage of time spent in the 3 training zones. Most notably, a POL model includes approximately 75–85% of total training in the low-intensity zone, whereas a THR model only includes about 35–55% of training in the low-intensity zone. A prospective cohort study by Esteve-Lanao et al. (9) found a positive relationship with training time in the low-intensity zone during a 6-month macrocycle and long-distance cross-country race performance in elite runners. Muñoz et al. (29) discovered a similar relationship with training time spent in the low-intensity zone and ironman race performance. However, Muñoz et al. (29) also found that ironman athletes spent approximately 58% of total race time in the moderate-intensity zone. These results appear to conflict with the principle of training specificity; therefore, a further understanding of the mechanisms behind a POL model is required.

One study in particular attempted to link specific peripheral adaptations with time-trial performance. Neal et al. (32) compared POL and THR on changes in lactate transporters (MCT1 and MCT4) to determine if intensity distribution affected muscle fiber type. MCT1 is found in type I oxidative (slow-twitch) muscles fibers, whereas MCT4 is only found in type II fast-twitch fibers (32). One could hypothesize that the large volume of low-intensity training would lead to an increase in MCT1 because of the specificity of the training model. However, the results of the study did not indicate a change in type I-specific transporters (32). The absence of oxidative fiber type changes may be due to the short duration of the intervention (6-weeks). Previous investigations have shown that it can take up to 5-months to increase type I muscle fiber density (12); therefore, studies of longer duration may be necessary to observe histological changes.

Current consensus has described $\dot{V}O_2$max as the maximal rate of oxygen that can be consumed, transported, and used by an individual (2). It is defined by either a plateau in oxygen utilization ($\dot{V}O_2$ changes $\leq$150 ml·min^{-1}) or a respiratory exchange ratio of greater than 1.15 (42). It has been suggested that if these physiological values are not reached between the last 2 stages of work, the test results would represent a $\dot{V}O_2$peak (19). $\dot{V}O_2$max/peak is a measurement that is commonly used to assess aerobic power (6) and it is highly correlated with 10-km running ($R = -0.95$, $p < 0.05$) and marathon ($R = -0.96$, $p < 0.05$) performance (11).

Three of the studies measured the effects of POL and THR on $\dot{V}O_2$max/peak (10,30,39). A meta-analysis could not be completed as a result of postintervention results only being provided in the study by Stöggl et al. (39). The results of their study indicate a significant difference in $\dot{V}O_2$peak favoring POL over THR (MD = 0.60 $L \cdot min^{-1}$; 95% CI: 0.19–1.0) (39).

As previously discussed, workload measurements such as $\dot{V}O_2$max/peak do not account for individual physiological differences (36). Lucia et al. (26) suggested that the percentage of $\dot{V}O_2$max at which the first and second VTs occur may be a better predictor of race performance over $\dot{V}O_2$max as a standalone measurement. A study by Coyle et al. (7) compared 40-km cycling time-trial performance in trained cyclists with the same $\dot{V}O_2$max (~69 $ml \cdot kg^{-1} \cdot min^{-1}$) but different VTs. The results of the study demonstrate that time-trial performance in cyclists with a higher relative VT were 10% faster than cyclists with lower relative VTs (7). Although $\dot{V}O_2$max/peak may be related to endurance sport performance (6,11), the proximity of VT_2 to $\dot{V}O_2$max appears to be a better measurement of endurance sport performance.

There are training adaptations that have yet to be investigated regarding metabolism and changes in physiological thresholds through POL training model. Hetlelid et al. (16) showed that well-trained runners have VTs (VT_1 and VT_2) that occur at a greater percentage of their $\dot{V}O_2$max when compared to recreationally trained runners. The study also indicates that well-trained athletes have the ability to metabolize approximately 3 times the amount of fatty acids during a session of high-intensity interval compared with recreationally trained runners (16). Because highly trained endurance athletes tend to follow a POL training model (9,29,31,38), there may be a link between a POL model with the ability of highly trained endurance athletes to metabolize fatty acids at a high rate (16). Additional studies investigating the effects of a POL training model on adaptations in fat metabolism and VT may provide insight into the mechanisms regarding improved race-pace performance at a moderate intensity.

Time-to-exhaustion is considered an open-looped test that may have less external validity than close looped tests (e.g., 40-km time trial) as such it may fail to provide a realistic indicator of athletic performance (18). Hopkins et al. (18) emphasizes that athletes may terminate the test as a result of feelings of boredom and lack of motivation rather than because of exercise-related fatigue.

Two studies examined the effects of a POL and THR training model on time-to-exhaustion (32,39). Neal et al. (32) examined time-to-exhaustion through having participants cycle at 95% of their predetermined PPO and Stöggl et al. (39) used the total time achieved on an incremental running or cycling ramp test. The results of both studies indicate that a POL model leads to a significantly greater improvement in time-to-exhaustion than a THR model (Table 3). Because of the methodological differences used to assess time-to-exhaustion, a meta-analysis was not conducted.

Exercise economy can be described as the energy demand for a given velocity or power output (35) and has been shown to be related to endurance sport performance (44). Only the study by Stöggl et al. examined the effects of POL and THR on exercise economy. They found a significant difference between POL and THR groups regarding the VO_2submax (%$\dot{V}O_2$peak) required to maintain a power output of 200 W during a submaximal cycling test (39). There was also a significant difference between the POL and THR groups in VO_2submax ($ml \cdot kg^{-1} \cdot min^{-1}$) favoring the THR group (MD = 2.50 $ml \cdot kg^{-1} \cdot min^{-1}$; 95% CI: 2.1–2.9) (Table 3).

To differentiate between the influence of anthropometric (e.g., changes in body mass) vs. physiological changes, exercise economy may be better demonstrated when measured using an absolute ($L \cdot min^{-1}$) $\dot{V}O_2$ value as opposed to relative ($ml \cdot kg^{-1} \cdot min^{-1}$) measurement. Because these values were not provided as absolute measurements, it may be difficult to conclude that a THR model is more effective than a POL model for improving exercise economy through physiological adaptations.

There are a number of limitations that may affect the quality of evidence included in this review. Only 4 randomized trials met the inclusion criteria, and only 3 could be used in the meta-analysis. In addition, the pooled results only included a sample size of 64 participants. The limited number of studies combined with a small sample size makes it difficult to definitively state that a POL model will lead to greater improvements in time-trial performance than a THR model.

Methodological design issues are evident as 2 of the studies scored a 4/10 on the PEDro scale and 2 scored a 5/10 on the PEDro scale. More specifically, issues such as the absence of participant blinding, assessor blinding, and concealed allocation are present in all studies included in the review. An intention-to-treat analysis was not included in any of the studies, possibly affecting the ability to control for confounding variables. The limitations in methodology may affect the internal validity of the included studies and increase the risk a bias.

Some of the studies included outcomes that were measured at baseline; however, postintervention results were not provided. The performance variables included in this review focused only on measures examined preintervention and postintervention. Furthermore, there was limited standardization of the training loads between the POL and THR groups. The lack of consistency in the training protocols may affect the strength of the results of the meta-analysis.

Although the design issues are important to consider when addressing the validity of the results, it is also necessary to consider the population from which the sample was taken. There are limited randomized trials that include highly trained endurance athletes, as such studies could alter their training program and negatively affect performance. Therefore, although the described limitations can influence the interpretation of the results, the scarcity of trials with this population should add significant value.

Polarized training model training has been discussed in great detail in the literature over the past decade. Further investigations involving a greater methodological approach are necessary to confidently determine the effects of a POL training model on endurance performance. As athletes prepare for competition, they tend to increase their total workload by manipulating both training duration and intensity (23). As such, future inquiries should address how training-intensity distribution before the taper period can influence event performance during a racing season. Because of the disconnect between a POL training model and the principle of specificity, additional studies should investigate the link between the physiological and metabolic adaptations that occur following a POL training model and race-pace performance.

Practical Applications

High-intensity aerobic training is a critical component in an exercise program to improve endurance sport performance (15,37). However, a high frequency of high-intensity training may lead to significant declines in sport performance (24). The findings of this meta-analysis indicate that a POL training model may lead to a significantly greater improvement in endurance performance than a THR training model. The methodological limitations of the included studies may affect their external validity; however, they are currently the highest level of evidence available on the topic. Endurance sport coaches should acknowledge that the distribution of training intensity may affect endurance sport performance and should consider a POL training model when structuring a training program.

A total of 4 randomized controlled trials have been published on the effects of a POL training model on endurance sport performance. The pooled results of all studies show a moderate effect that indicates that a POL model can lead to a greater improvement in time-trial performance time than a THR model.

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