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Original Investigation

Effects of a 6-week period of polarized or threshold training on performance and fatigue in elite swimmers

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Abstract

Purpose: To quantify the impact of a polarized distribution of training intensity on performance and fatigue in elite swimmers. ***Methods:*** Twenty-two elite junior swimmers (12 males: age 17 ± 3 yrs, and 10 females: age 17 ± 3 yrs) participated in a cross-over intervention study over 28 weeks involving 2 x 6-week training periods separated by 6 weeks. Swimmers were randomly assigned to a training group for the first period: polarized (POL) (81% in zone 1: $[La]_b \leq 2$ mmol·L^{-1}; 4% in zone 2: 2 mmol·L^{-1} $< [La]_b \leq 4$ mmol·L^{-1}; 15% in zone 3: $[La]_b > 4$ mmol·L^{-1}) or threshold (THR) (65%/25%/10%). Before and after each period, they performed a 100 m maximal swimming test to determine performance, maximal blood lactate concentration ($[La]_{max}$) and oxygen consumption ($\dot{V}O_2$), and an incremental swimming test to determine speed corresponding to $[La]_b = 4$ mmol·L^{-1} (V4mmol·L^{-1}). Self-reported indices of well-being were collected with a daily questionnaire. ***Results:*** POL training elicited small to moderately greater improvement than THR on 100 m performance (0.97% ± 1.02%; within-group change: ± 90% CI vs. 0.09% ± 0.94% respectively) with less fatigue and better quality of recovery. There was no substantial gender effect. No clear differences were observed in physiological adaptations between groups. ***Conclusion:*** In elite junior swimmers, a 6-week period of polarized training induced small improvements in 100 m time-trial performance, and in combination with less perceived fatigue, forms a viable option for coaches preparing this cohort of swimmers for competition.

Keywords: training zones, swimming performance, intensity distribution, training periodization

Introduction

The training load is one of the major parameters that swimming coaches manipulate to improve elite performance. Over the past 20 years, many observational studies and technical reports have described the training prescribed by high-level coaches.[1-4] These sources have highlighted the training models specific to distance, middle-distance and sprint swimmers. In the last ten years, the training of middle-distance swimmers (200–400 m) has been characterized by a predominantly aerobic distribution, with 55–70% below the first lactate threshold (Zone 1; V2 $\text{mmol}\cdot\text{L}^{-1}$, blood lactate: $[\text{La}]_b \leq 2\ \text{mmol}\cdot\text{L}^{-1}$) and 30–40% between 2 $\text{mmol}\cdot\text{L}^{-1}$ and 4 $\text{mmol}\cdot\text{L}^{-1}$ (Zone 2; V4 $\text{mmol}\cdot\text{L}^{-1}$, $[\text{La}]_b \leq 4\ \text{mmol}\cdot\text{L}^{-1}$).[1,2] In sprint swimming (50–100 m), there are two primary two models employed by world-class sprinters and Olympic medalists, with the first showing a large proportion of aerobic (Zone 1) and threshold training (Zone 2) (about 90% of the total training time),[2] and the second showing high intensity (Zone 3; above V4 $\text{mmol}\cdot\text{L}^{-1}$) that is close to the distribution of the so-called polarized model (volume in Zone 1 higher than 70% and volume in Zone 3 tending toward 15%).[4] From an experimental point of view, Arroyo-Toledo performed the only swimming study comparing the performance responses of regional swimmers for different training distributions and reported improvement in the pure performances with a low volume and a distribution (49, 33, 18%) compared with moderate-volume periodization (69, 25, 6%).[5] Most other studies have compared high-volume training (aerobic and threshold) with high-intensity training.[6] It appears that progressive volume increases over several weeks or months with stable intensity is associated with performance decreases and a possible elevation in the concentration of biological markers of fatigue. Conversely, lower volume decreases with maintenance or elevation of the intensity were associated with maintained or improved performances with no loss in the physiological qualities.

In the past 15 years, several studies have shown that many internationally-ranked endurance athletes (cyclists,[7] runners,[8] rowers,[9] cross-country skiers,[10] orienteerers,[11] and triathletes[12]) use the polarized training model. With this model, the training volume under a 2 mmol·L^{-1} blood lactate concentration is high and accounts for approximately 75-80% of the total volume, with 15-20% at or well above the speed (or power) corresponding to 4 mmol·L^{-1}. Experimental studies have confirmed the effectiveness of the polarized model, with performance improved by 4-8% and physiological capacity improved by 5-10% ($\dot{V}O_{2max}$, second lactate threshold) following 6- to 52-week of training. [7,8,13-15]

The two likely explanations for the greater effectiveness of the polarized model are a larger increase in physiological capacities and the lower risk of fatigue that it engenders. In polarized training, the high volume of training < 2 mmol·L^{-1} fosters development of peripheral muscle endurance (mitochondrial genesis, lactate exchange and removal), whereas high-intensity interval training develops the central factors of endurance ($\dot{V}O_{2max}$ and cardiac output).[14,15] Training volume reduced by 5 to 15% in mixed moderate intensities (2-4 mmol·L^{-1}) can reduce neurovegetative fatigue while preserving high power and velocity at submaximal intensities.[10] More detailed analysis of the patterns and magnitude of performance improvements in highly trained swimmers with a polarized organization of training are required to inform coaching practices.

The aim of this study was to compare the changes in the 100 m swim time and an incremental swim test on the performance and physiological adaptations, and the perceived well-being and fatigue, in 22 elite swimmers during two 6-week cross-over periods of threshold and polarized training. We expected that the polarized training would promote larger improvements in performance and physiological adaptations, with less fatigue.

Methods

Participants

Thirty elite junior swimmers participated in this study (Table 1). In the 6 months preceding the study, all participants trained 15–18 hours with 8 ± 2 sessions of swimming per week. Swimmers were excluded if they had an injury or illness requiring medical treatment or had missed training for more than one week. The final cohort was 22 swimmers (10 women and 12 men, comprising 9 freestyle, 5 breaststroke, 4 butterfly and 4 backstroke swimmers). The experimental study was conducted in accordance with the Declaration of Helsinki. After comprehensive verbal explanations, all participants signed an informed consent form to participate.

The study followed a cross-over design with a total duration of 28 weeks (Figure 1). To minimize the delayed effects of prior training, a pre-experimental period was imposed, consisting of one week of no training, one week of moderate load training, and 3 weeks of controlled training. We conducted preliminary tests to familiarize the swimmers with the measurement procedures. The study had two 6-week periods to which the swimmers were randomly assigned. For the initial 6-week intervention, 13 participants were assigned to the threshold (THR) group and 9 to the polarized (POL) training group. The two groups were similar for age, level and gender. The swimmers then crossed over to complete the other arm of the study design.

Training categorization

As Mujika, we tested the swimmers for $[La]_b$ concentration during a 5 x 200 m incremental test in the period preceding the intervention study.[3] This test consisted of 200 m swims at a progressively increasing pace (using an audible signal), determined from each swimmer's best competition time in that distance. Blood samples for $[La]_b$ concentration determination were taken from a fingertip during the 1-min rest interval after each 200 m swim.[3] We established three training intensity levels according to the results of this test: Z1: below ~2 mmol·L^{-1}, Z2: between 2 and 4 mmol·L^{-1} at the onset of blood lactate accumulation, Z3: above 4 mmol·L^{-1}. All workouts over the period were timed for each swimmer and the intensity was categorized according to the three intensity levels. We presented the intensity distribution as the percentage of the volume swum at each intensity over the total distance. We then corrected the speeds corresponding to each intensity level to account for the swimming distance and rest intervals using Olbrecht's method.[16] The training out of the water (strength, conditioning, flexibility) – apart from the prescribed POL or THR - was the same for all participants for the 6-week periods.

Performance, physiological testing and fatigue questionnaire

The physiological and performance tests were conducted before and after each 6-week intervention period. Prior to every test session, the swimmers were asked to maintain the same diet for the 24 hours preceding the test. The training session the day before the pre-test was standardized, with 90 min of light aerobic swimming. The time between the meal and testing was identical for each test. Participants did not drink caffeine or alcohol for at least 3 hours before each test session.

Maximal performance test

The participants performed a standardized swimming warm-up involving general, arm, and leg work, with a progressive-intensity specialty set, finishing with some low-intensity aerobic swimming. After 30 min of rest, they swam 100 m at maximal speed in their specialty stroke in conditions similar to competition. When the test was finished, capillary samples for blood lactate were collected at the finger with a Lactate Pro 2 analyzer (Arkray Factory, Inc., Japan) to measure maximal blood lactate concentration $[La]_{max.}$ Gas analysis for energy expenditure was conducted immediately using backward extrapolation and a K4b2 gas analyzer (Cosmed, Italy) connected to a face mask (Hans Rudolph, Inc., USA). As soon as the swimmer's head was out of the water, the mask was put on the swimmer for 30 s. The first 20 sec were used for the analysis to determine $\dot{V}O_2$.[17]

Incremental test until exhaustion

The incremental test was conducted two hours after the 100 m performance. The active swimming recovery between tests was controlled for each swimmer (600 m light aerobic swimming for active recovery before ~75 min of passive recovery). The swimmers performed an incremental test in crawl to determine the speed corresponding to 4 $mmol\cdot L^{-1}$ ($V4mmol\cdot L^{-1}$).[3] This test consisted of swimming 5 x 200 m with final 200 m swum at maximal effort, with increments of 0.05 $m.s^{-1}$ and 1 min of rest between each 200 m stage. Every 200 m, capillary samples for blood lactate $[La]_b$ were collected with the same method described before.

Well-being and sleep assessment

The swimmers completed a short wellness questionnaire, as described by Noon,[18] every morning before breakfast for the 6 weeks of intervention. We monitored their perceptions of well-being on seven items: motivation to train, quality of the previous night's sleep, perceived recovery, appetite, perceived fatigue, stress and muscle soreness. To facilitate data collection in the cohort of young swimmers, we asked them to download a cell phone application and practice moving the cursor on a scale of 1 to 100. The best perception for each item was 100 and the worst perception was 1. This questionnaire was chosen because pilot trials indicated it to be practical for the swimmers to use every morning of the study. This technique was tried by the swimmers during the entire month prior to the first pre-test.

Statistical analyses

Data were analyzed using magnitude-based inferences.[19] All data were log transformed before analysis to reduce bias arising from non-uniformity of error. The magnitude of the percentage change in time was interpreted by using values of the typical variation (coefficient of variation, CV) between the two pre-tests as 1.6%, with values of 0.5% (small), 1.4% (moderate), 2.6% (large), 4.0% (very large) and 6.4% (extremely large) established as criterion differences in the change in performance time between tests.[20] For all the other parameters, the smallest worthwhile change (SWC) was defined as a small standardized effect based on Cohen's effect size (ES) principle (0.2 x between-athlete standard deviation).[21] Threshold values for ES statistics were ≤ 0.2 (trivial), > 0.2 (small), > 0.6 (moderate), > 1.2 (large), > 2.0 (very large), and > 4.0 (extremely large).[19] Quantitative chances of higher or lower differences were evaluated qualitatively as follows: <1%, almost certainly not; 1%–5%, very unlikely; 5%–25%, unlikely; 25%–75%, possible; 75%–95%, likely; 95%–99%, very likely; and > 99%, almost certain. If the chance of having positive/beneficial or negative/harmful performances were both > 5%, the true difference was assessed as unclear.

Results

Polarized versus threshold training

The total volume in kilometers and the training load were similar between POL and THR training (Table 2). The intensity distribution was 81/4/15 for POL and 65/25/10 for THR with substantially more training undertaken in zone 2 for the THR group (large effect size).

A likely small increase in performance was observed in POL (0.97% ± 1.02%; mean ± 90% confidence limits), while the change in performance in THR was unclear (0.09% ± 0.94%) (Figure

2). The improvement in performance was possibly higher after POL training than THR training (0.89 ± 1.31 %, small). There was no substantial effect of gender.

The changes observed for $[La]_{max}$ were unclear for POL (12.4 ± 4.2% *vs.* 12.9 ± 3.7% $mmol \cdot L^{-1}$, within-group change ± 90% CL at pre- and post-, respectively) and THR (11.8 ± 3.6% *vs.* 12.5 ± 3.6%, at pre- and post-, respectively) (Table 3). No clear difference in the change in $[La]_{max}$ was evident between POL and THR (2.0 ± 14.4%). We observed a possibly small larger improvement with THR for $V4mmol \cdot L^{-1}$ (0.7 ± 1.6%) and $\dot{V}O_2$ (5.8 ± 9.8%), whereas the results were unclear with POL.

The self-reported swimmer well-being indices are shown in Table 4. The main finding is that swimmers undertaking POL training reported that recovery was likely to very likely better than in THR training in the final three weeks of the 6-week training intervention. No clear difference was observed for the other well-being indices.

Discussion

In this study, we expected that POL would be associated with faster performances, greater physiological adaptations and less fatigue. We observed larger improvements in swimming performance after polarized training for 6 weeks compared with threshold training. However we observed no additional physiological adaptations with POL training. Self-reported well-being indices were better for POL than for THR in the final weeks of the training period.

The physiological and performance responses to the two training models were compared with an incremental test of 5 x 200 m and a maximal test of 100 m performed as a swimming time-trial. The small beneficial effect of POL on performance improvement confirms the effectiveness of this training approach in elite swimmers. These results are in accordance with the results of earlier studies in triathlon,[8] cycling[7] and rowing,[9] where most of the athletes who progressed trained in POL. But as opposed to the other studies, the improvements in swimming performance were not associated with physiological adaptations. These studies reported improvements in $\dot{V}O_{2max}$ after POL training,[9,10,13,14] in V4mmol·L^{-1},[7,9,13,14] whereas we observed no clear differences in our study. Six weeks of polarized training with an 81/4/15% distribution yielded an 1% improvement in performance compared with threshold training, without a change in physiological capacities.

To our knowledge, this study is the first to systematically compare indices of well-being and recovery in polarized and threshold training. The indices were higher in the swimmers who trained in POL. For the THR group, the quality of recovery decreased until the fifth training week and self-reported feelings of fatigue were higher than in POL group. Perceived fatigue generally increases during periods of overload training and has been described as an index of an overreaching state.[22] An increase in fatigue is also correlated with overload training without overexertion.[23] Chatard[24] used a short fatigue questionnaire with swimmers and showed that fatigue scores were strongly correlated with differences in performance and training load – the swimmers with the highest fatigue scores had the lowest performances. In our study, the swimmers in the THR group may have accumulated too much fatigue to improve their performance, whereas in the POL group most of the swimmers who improved their performance did so with less fatigue. This pattern of responses supports the contention that polarized training is less fatiguing.

The performance improvement in POL was accompanied by more time spent in race pace training compared with THR (15% vs 9%). A recent study also highlighted the importance of training at or around race pace intensities.[25] Pacing strategies may underpin the benefits of various intensity distribution models in complement to the physiological adaptations. A training regime incorporating a large proportion in high-velocity pace swimming seems to shift the stroke rate-velocity relationship toward one in which the body travels greater distances per stroke, improving maximal stroke rate, maximal aerobic power, anaerobic power and anaerobic capacity.[26] Taken together, these results provide evidence in support of evaluating and prescribing the proportion of the race pace training in elite swimmers. Coaches should consider the potentially positive technical and physiological impacts of race pace training.

We observed substantial differences between the two training conditions regarding their effect on swimming 100 m time-trial performance. In elite adult swimmers who train daily, various studies have reported magnitudes of improvement in performance, $\dot{V}O_{2max}$ and speed at 4 $mmol \cdot L^{-1}$ lower than or equal to those observed in our study.[6] It would be interesting to observe the effects on performance with a larger increase in training load, a longer training intervention and a longer taper period. Indeed, in most of the studies that have compared polarized and threshold training, the increase in training load was moderate to large during the intervention period compared with the pre-experimental training period (often the off-season period or without load). Conversely, the training load in our study was increased by 10% over the 6 weeks. This small increase is arguably more appropriate for elite-level swimmers, but could be one explanation why only ~55% of all the swimmers in our study progressed during the experimental period. Most of the studies on the time course of physiological adaptations have provided strong evidence in support of training intervention periods lasting at least 9 weeks.[8,9,13] In our study, the post-tests were performed one week after the peak load of the macrocycle, which is likely to have induced an increase in biological fatigue, as observed in previous studies of swimmer populations with the same characteristics.[27,28] Moreover, the taper period in our study was short (3 to 5 days), which is another factor that may have limited improvement in performance. It is likely that at the end of a 2- to 3-week taper, as recommended by experts[2], the improvements would have been greater and the effects of the two models more marked. In the present study, polarized training modality induced substantial changes in the patterns of load, volume and intensity with regard to the usual training routines. This variability in training should therefore be established as one of the factors of progress.[29] Our study tested a model of endurance training in swimmers who were mainly 100 to 200 m freestyle and form stroke swimmers using a short endurance test (5 x 200 m). Future research should experimentally test this model in middle-distance, medley and distance swimmers (400 to 1500 m). An additional limitation of this study is that we did not present and compare the technical and kinematic responses induced by the two training distributions. Indeed, other studies in swimming[26,30] have suggested that these adaptations are strongly related to the energetic characteristics and swimming speeds used during training.

Practical applications

The results of this study should help coaches to gain a sharper understanding of how the training load components (load increase, intensity distribution, period duration, taper) interact to improve performance. Polarized training may be a good option for sprinters as this type of training, when implemented appropriately (progressive load increases, sufficient macrocycle duration, and a well-conducted taper), should yield improvements in competition performance.

Conclusions

The current study is the first systematic evaluation of the effects of polarized training versus threshold training on swimmers’ energetics, perceptions of fatigue and recovery, and time-trial performance. Only a small positive improvement on 100 m performance was observed for the swimmers who trained with POL compared with those who trained with THR. The performance improvements with the polarized modality may relate to a greater proportion of the training at the race pace, which is physiologically and technically a more specific type of training. The swimmers with polarized training also reported less fatigue. For the swimmers who trained in the threshold mode, additional fatigue may have been induced by the cumulative impacts of threshold and high-intensity training. Swimmers should be monitored closely during periods of increased training loads.

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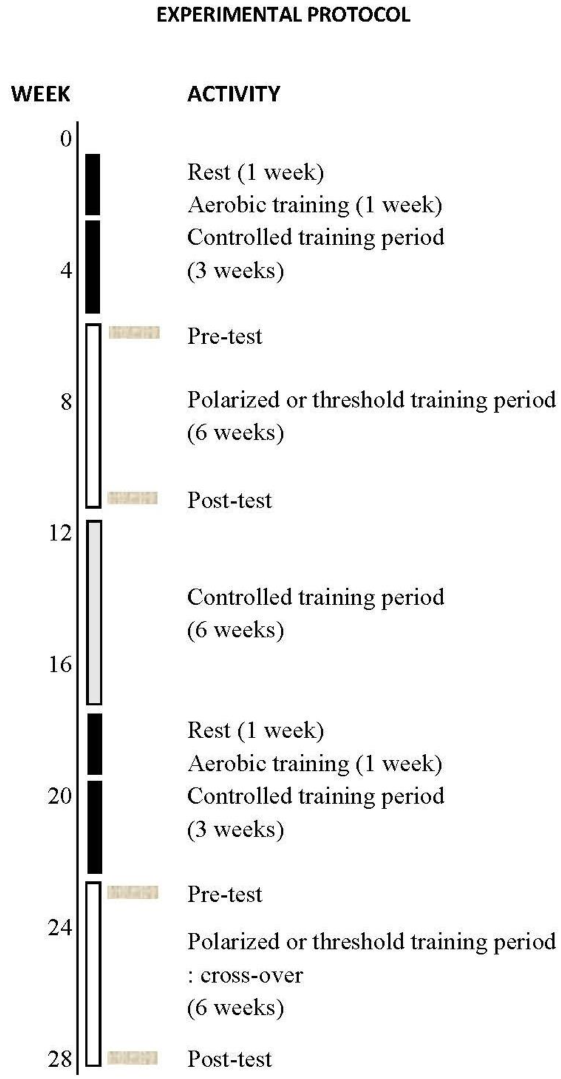

Figure 1. Study design schematic detailing the timeline for each period of the study including the testing weeks.

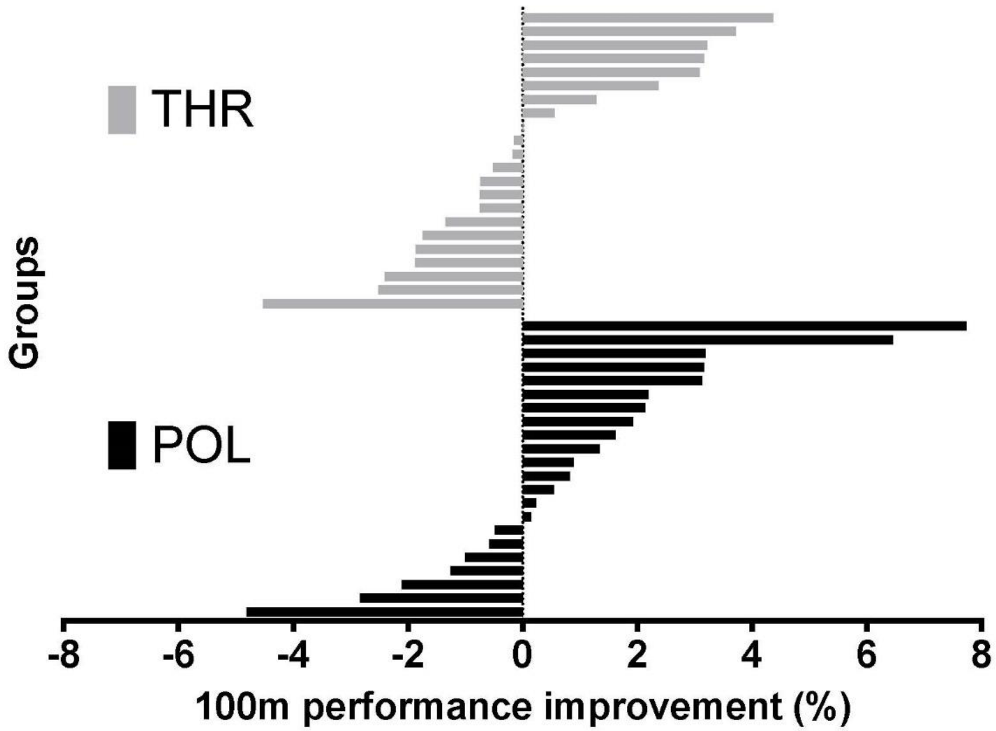

Figure 2. Performance time changes (pre-test 100 m vs post-test 100 m in POL and THR) classed in decreasing order by group. Abbreviations: POL, polarized training; THR, threshold training.

Table 1: Baseline characteristics of 22 elite swimmers. Mean ± SD.

Variables	Males (n=12)	Females (n=10)
Age (years)	17 ± 3	17 ± 3
Body height (cm)	178 ± 10	170 ± 6
Body Mass (kg)	64 ± 9	59 ± 9
BMI	20.2 ± 1.4	20.5 ± 2.4
Training experience (years)	8 ± 2	8 ± 2
FINA points	485 ± 92	498 ± 75

Table 2: Total training volume completed during baseline training and six weeks of polarized and threshold training. Mean ± SD

	Units	Base	POL	THR
Total Training Volume	Kilometers per week	37 ± 3	42 ± 4	42 ± 4
Volume in Zone 1	% of training volume	70 ± 6	81 ± 3	66 ± 5*
Volume in Zone 2	% of training volume	20 ± 4	4 ± 1	25 ± 2*
Volume in Zone 3	% of training volume	10 ± 2	15 ± 2	9 ± 3*

Abbreviations: Base, 3 weeks period before training intervention; POL, polarized training; THR, threshold training.

*Substantial differences between POL vs THR

Table 3: Performance and physiological adaptations Pre and Post Test to POL and THR including the differences in the changes between POL and THR

Variable	Group	Pre	Post	Pre to post changes			Differences in the changes between POL and THR		
		Mean ± SD	*Mean ± SD*	*% mean ± IC*	*Change H/T/B*	*Outcome*	*Δ%mean ± 90% IC*	*Difference H/T/B*	*Outcome for POL*
100m (s)	POL	68.74 ± 7.97	68.07 ± 7.96	-0.97 ± 1.02	1/19/80	Likely small decrease	0.89 ± 1.31	4/25/70	Possibly small positive effect
	THR	68.40 ± 8.31	68.37 ± 8.58	-0.09 ± 0.90	14/64/22	Unclear			
[La] max (mmol·L^{-1})	POL	12.4 ± 4.2	12.9 ± 3.7	7.4 ± 10.9	1/59/46	Possibly trivial increase	2.0 ± 14.4	11/65/23	Unclear
	THR	11.8 ± 3.6	12.5 ± 3.6	5.3 ± 9.5	2/62/36	Possibly trivial increase			
V4mmol·L^{-1} (m.s^{-1})	POL	1.32 ± 0.07	1.33 ± 0.08	0.89 ± 1.3	1/64/35	Possibly trivial increase	-0.72 ± 1.60	38/58/5	Possibly small negative effect
	THR	1.32 ± 0.06	1.34 ± 0.06	1.61 ± 1.0	0/15/85	Likely small increase			
$\dot{V}O_2$ (ml.min.kg)	POL	56.0 ± 11.3	55.9 ± 13.6	-0.9 ± 7.5	17/74/9	Unclear	-5.8 ± 9.8	58/39/3	Possibly small negative effect
	THR	56.4 ± 12.4	58.7 ± 9.7	5.2 ± 6.5	1/44/55	Possibly small increase			

Abbreviations : Pre, pre-test; Post, post-test, POL, polarized training; THR, threshold training; Time, Time on 100 m test; $[La]_{max}$, maximal blood concentration on 100 m; V4mmol•L^{-1}, speed corresponding at $[La]_b$ = 4 mmol•L^{-1} during the incremental test; $\dot{V}O_2$, oxygen consumption on 100 m ; H/T/B show likelihood of changes being harmful, trivial and beneficial.

Table 4: Mean values (± SD) of perceived fatigue and perceived recovery for POL and THR across the 6 weeks period

Variable	Group	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6
Fatigue	POL	69 ± 24	65 ± 18	64 ± 27	59 ± 25	63 ± 23*	66 ± 21
	THR	63 ± 26	65 ± 27	63 ± 31	59 ± 24	53 ± 27	57 ± 31
Recovery	POL	40 ± 17	42 ± 16#	44 ± 15#	41 ± 13*##	44 ± 16*##	51 ± 17*#
	THR	43 ± 17	40 ± 19	41 ± 18	35 ± 17	35 ± 18	43 ± 18

Abbreviations: POL, polarized training; THR, threshold training. Between-group difference versus THR, **likely*, ***very likely*. Between-group difference in the changes from Week 1 versus THR, #*likely*, ##*very likely*.