European Journal of Sport Science

ISSN: 1746-1391 (Print) 1536-7290 (Online) Journal homepage: http://www.tandfonline.com/loi/tejs20

The effects of two different swimming training periodization on physiological parameters at various exercise intensities

Vicente Javier Clemente-Suárez, Athanasios Dalamitros, João Ribeiro, Ana Sousa, Ricardo J. Fernandes & J. Paulo Vilas-Boas

To cite this article: Vicente Javier Clemente-Suárez, Athanasios Dalamitros, João Ribeiro, Ana Sousa, Ricardo J. Fernandes & J. Paulo Vilas-Boas (2017) The effects of two different swimming training periodization on physiological parameters at various exercise intensities, European Journal of Sport Science, 17:4, 425-432, DOI: 10.1080/17461391.2016.1253775

To link to this article: https://doi.org/10.1080/17461391.2016.1253775

European Journal of Sport Science, 2017
Vol. 17, No. 4, 425–432, http://dx.doi.org/10.1080/17461391.2016.1253775

ORIGINAL ARTICLE

The effects of two different swimming training periodization on physiological parameters at various exercise intensities

VICENTE JAVIER CLEMENTE-SUÁREZ[1], ATHANASIOS DALAMITROS[2], JOÃO RIBEIRO[3], ANA SOUSA [3], RICARDO J. FERNANDES [3,4], & J. PAULO VILAS-BOAS [3,4]

[1]*Department of Sport Science, European University of Madrid, Villaviciosa de Odón, Spain;* [2]*School of Physical Education, Aristotle University of Thessaloniki, Thessaloniki, Greece;* [3]*Faculty of Sport, Centre of Research, Education, Innovation and Intervention in Sport (CIFI2D), University of Porto, Porto, Portugal &* [4]*Porto Biomechanics Laboratory (LABIOMEP), University of Porto, Porto, Portugal*

Abstract
This study analysed the effects of two different periodization strategies on physiological parameters at various exercise intensities in competitive swimmers. Seventeen athletes of both sexes were divided to two groups, the traditional periodization (TPG, $n = 7$) and the reverse periodization group (RPG, $n = 10$). Each group followed a 10-week training period based on the two different periodization strategies. Before and after training, swimming velocity (SV), energy expenditure (EE), energy cost (EC) and percentage of aerobic (%Aer) and anaerobic (%An) energy contribution to the swimming intensities corresponding to the aerobic threshold (AerT), the anaerobic threshold (AnT) and the velocity at maximal oxygen uptake (vVO_2max) were measured. Both groups increased the %An at the AerT and AnT intensity ($P \leq .05$). In contrast, at the AnT intensity, EE and EC were only increased in TPG. Complementary, %Aer, %An, EE and EC at vVO_2max did not alter in both groups ($P > .05$); no changes were observed in SV in TPG and RPG at all three intensities. These results indicate that both periodization schemes confer almost analogous adaptations in specific physiological parameters in competitive swimmers. However, given the large difference in the total training volume between the two groups, it is suggested that the implementation of the reverse periodization model is an effective and time-efficient strategy to improve performance mainly for swimming events where the AnT is an important performance indicator.

Keywords: *Energy cost, energy expenditure, energy contribution, aerobic and anaerobic threshold, velocity at maximum oxygen uptake*

Introduction

To optimize athletic preparation and, consequently, competitive performance, a variety of different training periodization strategies have been applied (Clemente Suarez & González-Ravé, 2014; Clemente-Suárez, González-Ravé, & Navarro-Valdivielso, 2014). Towards this direction, the traditional training periodization model has been extensively used, based on developing high-volume and low-intensity training during the first periods of the macrocycle, with progressive increases in training intensity and simultaneous decreases in training volumes of the consecutive periods (Matveyev, 1977).

According to the reverse training periodization model, athletes can begin their training preparation with high-intensity and low-volume training, while gradually decrease intensity and increase volume or, depending on the sport, maintain intensity and increase volume during the following training periods (Arroyo-Toledo, Clemente, Gonzalez-Rave, Ramos Campo, & Sortwell, 2013). A different approach, emphasizing the limitations of the traditional training periodization, has also been employed representing an opposite pattern and previous studies examining the potential benefits of the reverse training periodization have demonstrated increases in maximum strength and endurance performance in trained athletes (Ebben et al., 2004; Rhea, Ball, Phillips, & Burkett, 2003).

In addition, the effectiveness of high-intensity and low-volume training programmes, characterizing the

---

Correspondence: Vicente Javier Clemente-Suárez Department of Motricity, Human Performance and Sport Management, Faculty of Sport Sciences, European University of Madrid, Calle Tajo, s/n, 28670 Villaviciosa de Odón, Spain. E-mail: vctxente@yahoo.es

reverse periodization, have previously been investigated indicating significant improvements to a similar level to that attained when performing low-intensity endurance training, namely; (i) the fatty acid oxidation enzyme activity in skeletal muscle; (ii) the muscle oxidative capacity; (iii) the muscle buffering capacity; (iv) the muscle glycogen content; (v) the glucose transporter type 4 content and (vi) the maximal glucose transport activity in skeletal muscle (Gibala et al., 2006; Terada et al., 2001; Terada, Tabata, & Higuchi, 2004).

Moreover, these adaptations can also affect the energy cost (EC) of exercise, defined as the total energy required per unit body mass to move a given distance (Barbosa, Fernandes, Keskinen, & Vilas-Boas, 2008). This parameter is considered to be one of the most important physiological determinants of performance in several forms of human locomotion (Capelli, 1999). The EC increases as a function of exercise intensity and depends, among other factors, on the athletes' technical skill. Complementary, the percentage of aerobic (%Aer) and anaerobic (%An) energy contribution have been previously described in a variety of swimming events (Zamparo, Capelli, & Pendergast, 2010). However, the effects after the implementation of different training periodization strategies on the energy expenditure (EE), the EC and the energy systems contribution has been poor studied, since only recent studies in athletes have been conducted (Ghiani et al., 2015; Wiewelhove et al., 2015), but in swimming are still unknown. Thus, the purpose of the present study was to analyse the modifications on the afore-mentioned parameters during swimming at intensities corresponding to the aerobic threshold (AerT), the anaerobic threshold (AnT) and the velocity at maximal oxygen uptake (vVO_2max), following a 10-week swimming training period of either a traditional or a reverse periodization model.

Methods

Participants

Seventeen swimmers of both sexes, recruited from two different swimming clubs, were divided to the traditional periodization group (TPG) (*n* = 7; 4 female: age 18.5 ± 1.9 years, body mass 62.5 ± 6.8 kg, height 1.76 ± 0.06 m and BMI 20.2 ± 0.9 m/kg^2; 3 male: age 17.3 ± 0.6 years, weight 71.0 ± 3.5 kg, height 1.79 ± 0.01 m and BMI 22.1 ± 1.0 m/kg^2) and the RPG (*n* = 10; 5 female: age 15.8 ± 2.6 years, weight 54.2 ± 4.2 kg, height 1.66 ± 0.08 m and BMI 19.7 ± 2.1 m/kg^2; 5 male: age 19.3 ± 3.0 years, body mass 76.0 ± 6.2 kg, height 1.79 ± 0.08 m and BMI 23.9 ± 2.8 m/kg^2). Each group was composed only of swimmers from the same club. Participants had an average training experience of 6.5 ± 4.9 years, and were all competing at the national level. Prior to participation, all swimmers were informed about the experimental procedures, indicating the right to withdraw from the study at any time and providing written informed consent. In addition, swimmers below the age of 18 years provided written parental consent. The study was conducted in accordance with the Declaration of Helsinki and approved by the Porto University ethical committee.

Experiment design

The tested parameters were analysed during three different swimming exercise intensities: AerT (2.5 mmol^{-1} of blood [La$^-$]), AnT (4 mmol^{-1} of blood [La$^-$]) and vVO_2max, before (pre) and after (post) completing the 10-week training period, in both groups. For this reason, swimmers performed a 5 × 200 m intermittent incremental protocol with increments of 0.05 m s^{-1} and 30 s rest intervals between each steps. Prior to testing, a standardized warm-up of 1500 m on a moderate self-paced swim was executed. All tests were performed in a 25 m indoor pool with in-water starts and open turns and under the same pool conditions (27–28°C). The pre-determined velocity of the last step was calculated according to the swimmers' individual 400 m best performance, minus seven increments of velocity (Fernandes et al., 2006). Swimming velocity (SV) was measured using a stopwatch (Seiko, 5141), and was controlled through acoustic signals for each 25 m. Capillary blood samples (5 μl) for blood lactate concentration analysis (Lactate Pro analyser, Arkay, Inc, Kyoto, Japan) were collected from the earlobe during the rest intervals and immediately after the end of each exercise step.

VO_2 assessment

The swimmers breathed through a respiratory snorkel and valve system (AquaTrainer II Snorkel®, Cosmed, Rome, Italy), recently validated (Baldari et al., 2012), connected to a telemetric portable gas analyser (K4b2, Cosmed, Rome, Italy) to directly measure oxygen uptake (net VO_2). Expired gas concentrations were measured breath by breath and averaged every 5 s. VO_2 was calculated subtracting the resting VO_2 from the exercise measured VO_2.

Energy cost and energy expenditure assessment

EC was calculated as the ratio between the EE and the mean SV. EE was obtained through the sum of the contributions of the aerobic and anaerobic energy systems. The %Aer in each step was measured from the time integral of the net VO_2, being later expressed in kJ assuming an energy equivalent of 20.9 kJ l O_2^{-1}. Net VO_2 was calculated subtracting the resting VO_2 from the measured VO_2 in the last minute. The expression for aerobic EC was as follows:

$$\text{Aer} = (\text{VO}_2\text{net}\ T\ m)\quad 20.9, \qquad (1)$$

where VO_2net is the difference between the VO_2 measured during the effort and the basal VO_2, T is the time duration of the effort and m is the mass of the subject. The %An was obtained by the sum of the energy derived from glycolysis (An):

$$\text{An} = b[\text{La -}]_{\text{net}} \cdot m, \qquad (2)$$

where $[\text{La}]_{\text{net}}$ is the net accumulation of blood lactate after exercise, b is the energy equivalent for lactate accumulation in the capillary blood (2.7 ml O_2 mmol^{-1} kg^{1}), and m is the mass of the subject. %An was then expressed in kJ assuming an energy equivalent of 20.9 kJ L O_2^{-1} (Zamparo et al., 2010).

Swimming velocity at different exercise intensities

The SV at the intensity corresponding to the AerT was assessed by the 2.5 mmol^{-1} value (Pyne, Maw, & Goldsmith, 2000), while the SV corresponding to the AnT was assessed by the conventional 4 mmol^{-1} value, obtained by linear interpolation taking into account the $[\text{La}^-](t)$ function assessed through several stages immediately before and after the 2.5 and 4 mmol^{-1} (Mader et al., 1976). vVO_2max was considered to be the minimal velocity that elicits VO_2max (Fernandes et al., 2003).

Training zones

Three different training zones were used to control and quantify the volume and the exercise intensity during the training periods (Seiler, 2010): Zone 1 (Z_1), AerT training, <3 mmol^{-1} of blood [La-]; Zone 2 (Z_2), AnT training, 3 to 4 mmol^{-1} of blood [La-]; and Zone 3 (Z_3), high-intensity training, >4 mmol^{-1} of blood $[\text{La}^-]$. TPG began the 10-week period with higher training volumes during Z_1 and Z_2, and then gradually proceeded to Z_3. In contrast, RPG initiated the training period by performing swimming intensities in Z_3, followed by an increased training volume in Z_2 during the middle term of the period. Hence, TPG made a progression from high-training volume (Z_1 and Z_2), to more intense swimming sessions (Z_3) in subsequent weeks, whereas, RPG started with a high-intensity training that was maintained throughout the 10-week period. This period was divided to four periods, according to previous literature (Arroyo-Toledo et al., 2013; Issurin, 2010; Rhea et al., 2003). The RPG performed 133,600 ± 350 m in Z_1, 12,500 ± 150 m in Z_2, 12,925 ± 80 m in Z_3 and a total volume of 159,024 ± 360 m. The TPG performed 293,666 ± 1100 m in Z_1, 8300 ± 220 m in Z_2, 35,085 ± 680 m in Z_3 and a total volume of 337,051 ± 1890 m. In Figure 1 the weekly distribution in each training zone is shown.

Statistics

Data were analysed using the SPSS v.17.0 statistical package. The Shapiro–Wilk normality test was used to test homogeneity of each variable. The statistical power of the analysis performed was higher than 0.8 for all the variables studied. A two-way analysis of variance for repeated measures with a Bonferroni *post hoc* test was used to analyse the differences between the pre- and post-training samples in RPG and TPG. An independent samples t-test was used to compare differences between groups. The effect size (ES) was calculated using Cohen's d (d = Post-test mean – Pre-test mean / Pre-test SD). Data are presented as mean ± s and statistical level was set at $P \leq .05$.

Results

Initial values of SV at the AerT intensity, did not alter after the training period in both groups. In contrast, a significant increase in %An in both RPG and TPG was obtained at the same exercise intensity. In addition, %Aer, EE and EC also increased, but not significantly in both groups (Table I). Values of % Aer and EE were significantly higher in TPG, compared to RPG at post training. Values regarding EE, EC and SV during the 5 × 200 m incremental protocol are presented in Figure 2.

At the AnT intensity, SV remained almost unchanged in both groups. However, %An increased in both groups. EE and EC showed significant increase only in TPG. Values of %Aer and EE, were higher in TPG compared to RPG at post training (Table I). No significant changes were observed for all the parameters tested at the vVO_2max intensity in both groups (Table I).

Furthermore, no significant changes were observed between the pre- and post-conditions for both groups

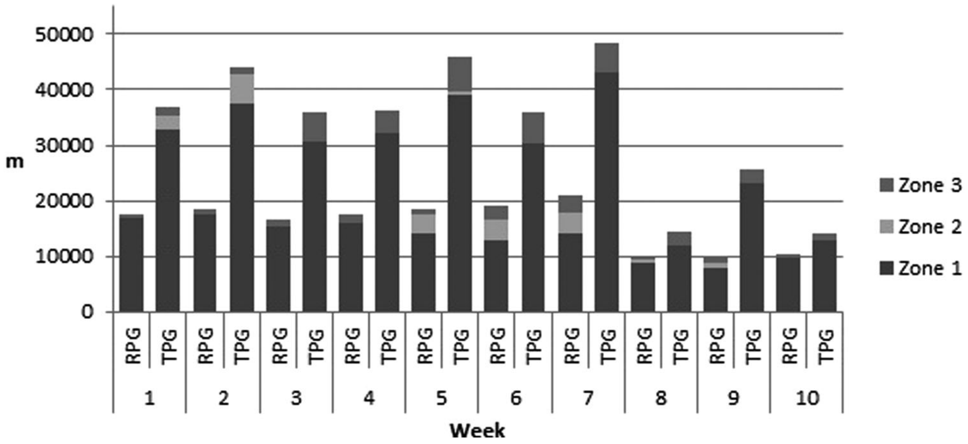

Figure 1. Weekly training volume of each group during the 10-week program. RPG, reverse periodization group; TPG, traditional periodization group.

at the percentage of the energy systems contribution for the intensities corresponding to the AerT, AnT and vVO_2max (Table I).

Discussion

The aim of the present research was to analyse the changes on EE, EC and percentage of aerobic and anaerobic energy contribution to the exercise intensities corresponding to the AerT, AnT and vVO_2max, following two different swim training periodization strategies during a 10-week period in competitive swimmers. One of the key findings was that SV at all three intensities observed after both periodization schemes was not significantly increased. This fact indicates the subtlety of changes in specific physiological parameters in trained swimmers and, presumably, the exquisiteness of the training strategy required eliciting them. These trivial variations in SV measured after completing the training periods are similar to those previously reported for highly trained (Mujika et al., 1995) and elite swimmers (Pyne, Lee, & Swanwick, 2001). Furthermore, values of EE presented a linear increase with SV. This result appears to contradict the study of Kjendlie, Ingjer, Madsen, Stallman, and Stray-Gundersen (2004), in which a cubic relationship between those two parameters was revealed. Nevertheless, Fernandes et al. (2003) and Vilas-Boas (1996) also reported a linear relationship, which might be explained by an increase in swimming efficiency at higher velocities, possibly due to a reduction of intracyle velocity variations.

After completing the 10-week training period, swimmers' energy contribution, EE and EC were altered depending on the periodization strategy followed. Specifically at the intensity corresponding to the AerT, the pre-training values of %Aer and %An, EE and EC presented no significant differences between RPG and TPG. In contrast, values obtained in the post training condition exhibited marked differences between groups on %Aer and EE, with the increases obtained at the TPG been greater compared to the RPG. However, only %An increased significantly in both groups after the training period. An increase in EE values in RPG was somewhat expected, since swimmers performed a lower volume of aerobic training, compared to TPG. Nevertheless, results differed as EE and %Aer were slightly increased in both groups. This finding could be explained by considering that the mitochondrial activity cannot be enhanced only by performing high-volume training sessions (Dudley, Abraham, & Terjung, 1982). In contrast, it is necessary to perform strenuous training sessions, indicating that a greater exercise stress is needed to bring about significant increases in the enzyme's activity of the mitochondrial electron transport chain (Holloszy & Coyle, 1984).

Data obtained at the intensity of the AnT in the pre-training condition also presented no significant differences between RPG and TPG. In contrast, at the post-training condition %Aer and EE were significantly higher in TPG compared to RPG. It is important to note that significant increases were obtained for %An for both groups after the training periods, while EC and EE showed marked differences only in TPG. While both groups showed small increases in SV, TPG also presented an increase in EE that was higher compared to RPG. A previous study reported that these kinds of alterations in the velocity of the AnT in athletes were associated with changes in the oxidative enzyme activity (Coyle, Martin, Bloomfield, Lowry, & Holloszy, 1985). In the same line, an increase in the mitochondrial

Table I. Mean ± *s* values for SV, aerobic, anaerobic energy contribution, total EE and EE measured at the intensities of aerobic threshold, anaerobic threshold, and VO_2max for pre- and post-conditions.

		Aerobic threshold			Anaerobic threshold			VO_2max		
Intensity	Group	Pre	Post	ES	Pre	Post	ES	Pre	Post	ES
SV (m s^{-1})	RPG	1.08 ± 0.05	1.08 ± 0.04	0.00	1.12 ± 0.05	1.13 ± 0.06	0.17	1.22 ± 0.05	1.26 ± 0.08	0.50
	TPG	1.22 ± 0.05	1.23 ± 0.04	0.25	1.27 ± 0.03	1.28 ± 0.04	0.25	1.35 ± 0.05	1.39 ± 0.04	1.00
%Aer (kJ)	RPG	124.7 ± 34.5	129.7 ± 26.9	0.19	144.8 ± 32.7	148.0 ± 28.4	0.11	158.9 ± 26.2	145.6 ± 73.2	−0.18
	TPG	134.7 ± 24.2	139.6 ± 23.8†	0.21	146.8 ± 21.5	157.2 ± 21.5†	0.48	157.6 ± 28.5	159.6 ± 24.0	0.08
%An (kJ)	RPG	4.8 ± 1.0	9.2 ± 1.8*	2.44	10.3 ± 1.6	14.7 ± 2.8*	1.57	29.0 ± 11.5	24.7 ± 12.4	−0.35
	TPG	4.8 ± 1.3	9.3 ± 1.0*	4.50	10.4 ± 1.7	14.9 ± 1.6*	2.81	24.8 ± 6.3	26.6 ± 6.9	0.26
E (kJ)	TPG	129.5 ± 34.7	138.8 ± 28.2	0.33	155.1 ± 33.9	162.7 ± 30.5	0.25	187.9 ± 33.1	170.4 ± 84.0	−0.21
	TPG	139.5 ± 24.2	148.9 ± 24.4†	0.39	157.2 ± 22.0	172.1 ± 22.7*†	0.66	182.4 ± 6.3	186.2 ± 29.1	0.13
C (kJ)	RPG	120.2 ± 32.2	128.1 ± 22.5	0.35	138.9 ± 29.6	143.4 ± 22.4	0.20	153.6 ± 24.8	134.4 ± 67.5	−0.28
	TPG	114.4 ± 19.2	121.5 ± 21.4	0.33	123.9 ± 18.4	134.3 ± 20.0*	0.52	135.1 ± 27.2	134.3 ± 21.1	−0.04
%Aer	RPG	96.3 ± 1.0	93.4 ± 0.9	−3.33	93.3 ± 1.2	91.7 ± 1.3	−1.23	84.6 ± 0.9	85.5 ± 1.1	0.82
	TPG	96.6 ± 1.1	93.8 ± 1.0	−2.80	93.4 ± 1.1	91.3 ± 1.2	−1.75	86.4 ± 1.1	85.7 ± 1.2	−0.58
%An	RPG	3.7 ± 0.2	6.6 ± 0.2	14.50	6.7 ± 0.6	8.3 ± 0.5	3.20	15.4 ± 1.1	14.5 ± 1.2	−0.75
	TPG	3.4 ± 0.1	6.2 ± 0.2	14.0	6.6 ± 0.3	8.7 ± 0.4	5.25	13.6 ± 0.8	14.3 ± 1.1	0.64

Notes: *$P \leq .05$ vs. respective pre values. †$P \leq .05$ TPG vs. respective RPG values; TPG, traditional periodization group; RPG, reverse periodization group; ES: effect size (d); SV, swimming velocity; %Aer, percentage of aerobic energy contribution; %An, percentage of anaerobic energy contribution; E, total energy expenditure; C, energy cost.

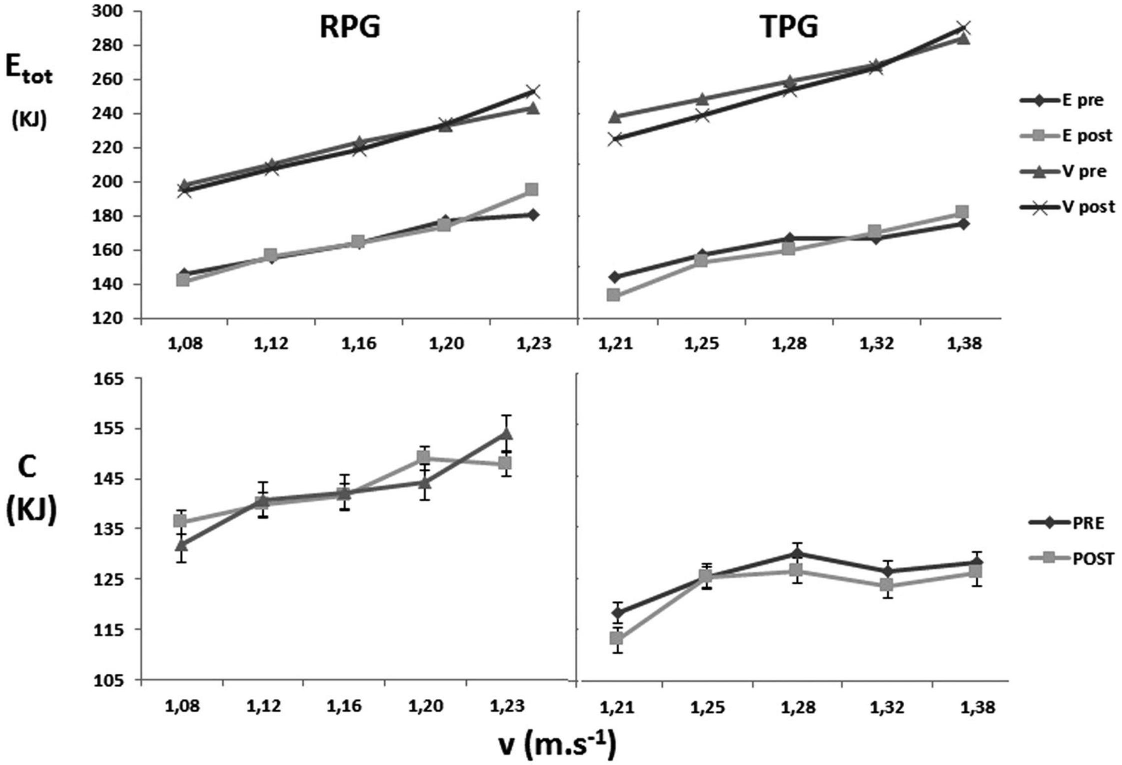

Figure 2. Schematic representation of energy cost (EC), total energy expenditure (EE) and swimming velocity (SV) during the 5 × 200 m incremental protocol, for pre- and post-conditions.

content and oxidative enzyme activity is reported as the most important training adaptation responsible for reducing muscle glycogen breakdown and lactate formation (Holloszy & Coyle, 1984). In fact, alterations in lactate threshold in well-trained endurance athletes are accompanied with changes in the oxidative enzyme activity (Coyle et al., 1985), while the main modifications in the AnT are related with increases in the mitochondrial content and the oxidative enzymes activity (Holloszy & Coyle, 1984).

Regarding the vVO_2max, %Aer plays an essential role as previous studies have reported (Figueiredo, Zamparo, Sousa, Vilas-Boas, & Fernandes, 2011; Gastin, 2001). The %Aer measured in the current study was between 84.6% and 86.4% for both groups (RPG and TPG, respectively). These values were similar to a 400 m maximal swimming trial (Rodríguez & Mader, 2000), but also higher compared to a 200 m maximal race (65.9–72%) (Coyle et al., 1985; Zamparo et al., 2010). These variations could be explained by the fact that the exercise effort performed by both RPG and TPG had a higher temporal duration compared to previous studies. All the changes obtained during the post-training condition, were non-significant for both groups at this exercise intensity. However, RPG presented a greater increase in the swimming economy compared to TPG, as the EC values decreased by 19.2 kJ (vs. 0.8 kJ for the TPG) after the training period. The decrease in EE after the 10-week period was higher in RPG compared to TPG, as a high-intensity workload (Z_3) was prescribed in the RPG from the first to the last week, representing a characteristic of the reverse periodization, also proposed by Costill et al. (1991) and Mujika et al. (1995). In these cases, exercise intensity, rather than training volume, was demonstrated as the most important factor improving swimming performance. Similarly, the physiological adaptations that accompany a low-volume and high-intensity training period were equal or greater compared to those obtained during a period characterized by long-distance extensive training (Terada et al., 2001). Thus, training based on high-intensity performed from the first weeks of a training period, could be more effective to improve EE and EC at vVO_2max intensity, compared to high-volume training with gradual increases in exercise intensity.

A possible limitation can be addressed regarding the relatively small number of swimmers participating in this study. Conducting training studies using competitive level populations usually includes this type of limitation, highlighting however, the benefit to generalize the results to the practice of competitive sports.

Another limitation is related to the experimental design of the current research and specifically the lack of examining the second training mesocycle, that is, changing the training strategy that each group was submitted to. We had to choose this research approach as one of the groups chose not to modify its traditional periodization model. In this study, effort was made to reproduce the actual training process that occur during typical swimming conditions as well as applying training schemes regularly used by swim coaches.

The current investigation revealed that a 10-week swim training period, regardless the periodization strategy followed, caused significant alterations in the percentage of anaerobic contribution to the intensities related to both the aerobic and anaerobic threshold in competitive level swimmers. However, none of the training strategies modified the percentage of aerobic contribution at any of the studied intensities, nor the anaerobic contribution, the EE and the EC of swimming at the velocity at VO_2max. Importantly, EE and EC were significantly increased at the anaerobic threshold intensity only in the TPG. Finally, the SV at all three intensities showed only slight increases in both groups. The data presented in this study are expected to provide new insights into the interesting topic of investigating different periodization strategies in competitive swimming. Still, a generalization concerning other individual sports should not be made, as the particularities of each sport should be taken under consideration as well as the fact that a large variety of training methods and characteristics can be applied during an annual macrocycle.

Disclosure statement

No potential conflict of interest was reported by the authors.

ORCID

Ana Sousa http://orcid.org/0000-0001-7790-732X
Ricardo J. Fernandes http://orcid.org/0000-0002-5811-0443
J. Paulo Vilas-Boas http://orcid.org/0000-0002-4109-2939

References

Arroyo-Toledo, J. J., Clemente, V. J., Gonzalez-Rave, J. M., Ramos Campo, D. J., & Sortwell, A. (2013). Comparison between traditional and reverse periodization: Swimming performance and specific strength values. *International Journal of Swimming Kinetics*, *2*, 87–96.

Baldari, C., Fernandes, R. J., Meucci, M., Ribeiro, J., Vilas-Boas, J. P., & Guidetti, L. (2012). Validity of a new Aquatrainer® Snorkel for gas exchange measurements. *International Journal of Sports Medicine*, *34*, 336–344. doi:10.1055/s-0032-1321804

Barbosa, T., Fernandes, R. J., Keskinen, K., & Vilas-Boas, J. P. (2008). The influence of stroke mechanics into energy cost of elite swimmers. *European Journal of Applied Physiology*, *103*, 139–149.

Capelli, C. (1999). Physiological determinants of best performances in human locomotion. *European Journal of Applied Physiology and Occupational Physiology*, *80*, 298–307.

Clemente Suarez, V. J., & González-Ravé, J. M. (2014). Four weeks of training with different aerobic workload distributions–effect on aerobic performance. *European journal of sport science*, *14* (sup1), S1–S7. doi:10.1080/17461391.2011.635708

Clemente-Suárez, V. J., González-Ravé, J. M., & Navarro-Valdivielso, F. (2014). Short-term periodized aerobic training does not attenuate strength capacity or jump performance in recreational endurance athletes. *Acta Physiologica Hungarica*, *101*(2), 185–196. doi:10.1556/APhysiol.101.2014.002

Costill, D. L., Thomas, R., Robergs, R. A., Pascoe, D., Lambert, C., Barr, S., & Fink, W. J. (1991). Adaptations to swimming training: Influence of training volume. *Medicine and Science in Sports & Exercise*, *23*, 371–377.

Coyle, E. F., Martin, W. H., Bloomfield, S. A., Lowry, O. H., & Holloszy, J. O. (1985). Effects of detraining on responses to submaximal exercise. *Journal of Applied Physiology*, *59*, 843–859.

Dudley, G. A., Abraham, W. M., & Terjung, R. L. (1982). Influence of exercise intensity and duration on biochemical adaptations in skeletal muscle. *Journal of Applied Physiology*, *53*, 844–850.

Ebben, W., Kindler, A., Chirdon, K., Jenkins, N., Polichnowski, A., & Ng, A. V. (2004). The effect of high-load vs. high-repetition training on endurance performance. *Journal of Strength and Conditioning Research*, *18*, 513–517. doi:10.1519/R-12722.1

Fernandes, R. J., Billat, V. L., Cruz, A. C., Colaço, P. J., Cardoso, C. S., & Vilas-Boas, J. P. (2006). Does net energy cost of swimming affect time to exhaustion at the individual's maximal oxygen consumption velocity? *Journal of Sports Medicine and Physical Fitness*, *46*, 373–80. doi:10.1007/s00421-011-2126-6

Fernandes, R. J., Cardoso, C., Soares, S., Ascensão, A., Colaço, P., & Vilas-Boas, J. P. (2003). Time limit and VO2 slow component at intensities corresponding to VO2max in swimmers. *International Journal of Sports Medicine*, *24*, 576–581. doi:10.1055/s-2003-43274

Figueiredo, P., Zamparo, P., Sousa, A., Vilas-Boas, J. P., & Fernandes, R. J. (2011). An energy balance of the 200 m front crawl race. *European Journal of Applied Physiology*, *111*, 767–77. doi:10.1007/s00421-010-1696-z

Gastin, P. (2001). Energy system interaction and relative contribution during maximal exercise. *Sports Medicine*, *31*, 725–741. doi:10.2165/00007256-200131100-00003

Ghiani, G., Marongiu, E., Melis, F., Angioni, G., Sanna, I., Loi, A., … Tocco, F. (2015). Body composition changes affect energy cost of running during 12 months of specific diet and training in amateur athletes. *Applied Physiology, Nutrition, and Metabolism*, *40*(9), 938–944.

Gibala, M., Little, J. P., Van Essen, M., Wilkin, G. P., Burgomaster, K., Safdar, A., … Tarnopolsky, M. (2006). Short-term sprint interval versus traditional endurance training: Similar initial adaptations in human skeletal muscle and exercise performance. *Journal of Physiology*, *575*, 901–911. doi:10.1113/jphysiol.2006.112094

Holloszy, J., & Coyle, E. F. (1984). Adaptations of skeletal muscle to endurance exercise and their metabolic consequences. *Journal of Applied Physiology*, *56*, 831–838.

Issurin, V. (2010). New horizons for the methodology and physiology of training periodization. *Review Sports Medicine*, *40*, 189–206. doi:10.2165/11535130-000000000-00000

Kjendlie, P. L., Ingjer, F., Madsen, Ø, Stallman, R. K., & Stray-Gundersen, J. (2004). Differences in the energy cost between children and adults during front crawl swimming. *European Journal of Applied Physiology*, *91*, 473–80. doi:10.1007/s00421-003-1022-0

Mader, A., Liesen, H., Heck, H., Philippi, H., Rost, R., Schurch, P., & Hollman, W. (1976). Zur beurteilung der sportsartspezifishen Ausdauerleistungsfihigkeit im Labor. *Sport Sportsmedizin*, *4*, 80–88.

Matveyev, L. (1977). *Osnovy sportivnoy trenirovki* [Fundamentals of sport training]. Moscow: Progress Publishers.

Mujika, I., Chatard, J., Busso, T., Geyssant, A., Barale, F., & Lacoste, L. (1995). Effects of training on performance in competitive swimming. *Canadian Journal of Applied Physiology*, *20*, 395–406. doi:10.1080/026404100750017805

Pyne, D., Maw, G., & Goldsmith, W. (2000). Protocols for the physiological assessment of swimmers. In *Physiological test for elite athletes* (pp. 372–382). Champaing: Human Kinetics.

Pyne, D. B., Lee, H., & Swanwick, K. M. (2001). Monitoring the lactate threshold in world-ranked swimmers. *Medicine and Science in Sports & Exercise*, *33*, 291–297. doi:10.1097/00005768-200102000-00019

Rhea, M. R., Ball, S., Phillips, W. T., & Burkett, N. (2003). A comparison of linear and daily undulating periodized programs with equated volume and intensity for local muscular endurance. *Journal of Strength and Conditioning Research*, *17*, 82–87. doi:10.1519/JSC.0b013e3181c03548

Rodríguez, F., & Mader, A. (2000). Energy metabolism during 400 and 100 m crawl swimming: Computer simulation based on free swimming measurement. In J. C. Chatard (Ed.), *Biomechanics and medicine in swimming IX* (pp. 373–378). Saint-Étienne: Publications de L'Université de Saint-Étiene.

Seiler, S. (2010). What is best practice for training intensity and duration distribution in endurance athletes? *International Journal of Sports Physiology and Performance*, *5*, 276–291. doi:10.1111/j.1600-0838.2010.01117.x

Terada, S., Tabata, I., & Higuchi, M. (2004). Effect of high-intensity intermittent swimming training on fatty acid oxidation enzyme activity in rat skeletal muscle. *Japan Journal of Physiology*, *54*, 47–52. doi:10.2170/jjphysiol.54.47

Terada, S., Yokozeki, T., Kawanaka, K., Ogawa, K., Higuchi, M., Ezaki, O., & Tabata, I. (2001). Effects of high-intensity swimming training on GLUT-4 and glucose transport activity in rat skeletal muscle. *Journal of Applied Physiology*, *90*, 2019–2024. doi:10.1007/s12576-011-0170-y

Vilas-Boas, J. P. (1996). Speed fluctuations and energy cost of different breastroke techniques. In J. P. Troup, A. Hollander, D. Strasse, S. Trappe, J. Cappaert, & T. Trappe (Eds.), *Biomechanics and medicine in swimming VII* (pp. 167–171). London: E & F Spon.

Wiewelhove, T., Raeder, C., Meyer, T., Kellmann, M., Pfeiffer, M., & Ferrauti, A. (2015). Markers for routine assessment of fatigue and recovery in male and female team sport athletes during high-intensity interval training. *PloS one*, *10*(10), e0139801.

Zamparo, P., Capelli, C., & Pendergast, D. (2010). Energetics of swimming: A historical perspective. *European Journal of Applied Physiology*, *111*, 367–378. doi:10.1007/s00421-010-143