Effect of aerobic training volume on VO_{2max} and time trial of runners: A systematic review

RHENNAN RODRIGUES BARBOSA[1], RAPHAEL JOSÉ PERRIER MELO[1], JORGE LUIZ DE BRITO GOMES[2], FERNANDO JOSÉ DE SÁ PEREIRA GUIMARÃES[3], MANOEL DA CUNHA COSTA[1]

[1]*Higher School of Physical Education. University of Pernambuco. Recife, Brazil.*

[2]*Department of Physical Education. Federal University of Vale do São Francisco. Petrolina, Brazil.*

[3]*Department of Medical Graduation. Olinda Medical School. Olinda, Brazil.*

ABSTRACT

Several conditioning indicators are necessary when performing running events, such as: the ability to sustain speed during a test and obtain good competitive rates in medium and long distance events. Purpose: This systematic review was to verify the distribution of weekly training volume during the preparatory phase of recreational runners and analyse the effect of this volume on maximum oxygen consumption and time-trial running. Results: The seven studies included analysed the training volume effect. A total of 120 adult participants were included with age of 27.80 ± 5.52 years, VO_2 of 47.45 ± 7.82 ml/kg/min^{-1}. All presented different aerobic training methods: HIIT, undulatory training, Linear, Reverse and Sprints. The interventions had an average duration of 10.00 ± 3.57 weeks. Training volume at the beginning of the interventions of 30 ± 7.21 km/week. A total of 59 adult participants with experience in road running and with performance in the 10 km and 1 km distances of 44.22 ± 8.43 min and 5.17 ± 0.24 min. Conclusion: The present review indicates that adjustments in training volume, specifically increments of up to 42% during the preparatory phase, can produce significant improvements in VO_{2max} and time trial performance.

Keywords: Endurance, Peak oxygen uptake, Sports performance, Physical exercises, Running.

Cite this article as:
Rodrigues Barbosa, R., Perrier Melo, R. J., de Brito Gomes, J. L., de Sá Pereira Guimarães, F. J., & da Cunha Costa, M. (2024). Effect of aerobic training volume on VO_{2max} and time trial of runners: A systematic review. *Journal of Human Sport and Exercise, 19*(4), 1139-1150. https://doi.org/10.55860/90apnb26

Corresponding author. *Higher School of Physical Education, University of Pernambuco, Recife, Zip code: 50100-130. Brazil.*
E-mail: rhennan.rodrigues@hotmail.com
Submitted for publication May 10, 2024.
Accepted for publication June 28, 2024.
Published August 02, 2024.
JOURNAL OF HUMAN SPORT & EXERCISE ISSN 1988-5202.

doi: https://doi.org/10.55860/90apnb26

INTRODUCTION

Road races are among the sports with the greatest mass participation. Their popularity is attributed to the variety of environments, terrains, climates, and the diversity of age groups involved (Cuk et al., 2019), with participation rates ranging between 12.5% and 25% of the population (Tejero-González, 2015; Videbæk et al., 2015). It also offers opportunities for races of various distances, catering to runners of different competitive levels, from recreational to elite. Recreational athletes (Damsted et al., 2017) typically have between two to ten years of experience in the sport, train two to six times per week, run at an intensity of 4 to 7 minutes per kilometre, and/or cover a weekly distance of 10 to 65 kilometres (Kozlovskaia et al., 2019).

Several conditioning indicators are necessary for performing well in races. These include the ability to sustain speed during a race and achieve competitive times in medium and long-distance events. These abilities are influenced by physiological, anthropometric, neuromuscular, and psychological factors (Olaya-Cuartero et al., 2023). The best predictors of good performance in races, regardless of the athlete's competitive level, traditionally include maximum oxygen consumption (VO_{2max}), anaerobic threshold, and running economy (Bernans et al., 2023). Additionally, variables related to training strategies, such as volume, intensity, frequency, and rest, play a significant role (Fredette et al., 2022).

Therefore, it is known that variables such as intensity and weekly training volume, which are related to training planning and periodization, are essential for coaches and running athletes to monitor (Casado et al., 2022), as they are associated with performance development, particularly in terms of maximum oxygen consumption and time trial performance (Midgley et al., 2007). Thuany et al. (2020) found that, in a study with Brazilian recreational runners, greater volume and frequency of weekly aerobic training were four times more likely to produce superior performance compared to runners with lower training volumes (Thuany et al., 2020).

However, in practice, it appears that there is a certain negligence in controlling and adjusting these variables based on the objective and phase of the runner's periodization, which can increase non-functional overload (fatigue associated with a drop in performance or injury). A lack of proper adjustment can also harm the performance of recreational runners (Ramskov et al., 2018). Moreover, training volume is an excellent predictor of endurance performance (Suwankan et al., 2024). There is little experimental evidence demonstrating whether there is a minimum aerobic training volume capable of generating positive adaptations in terms of maximum oxygen consumption and improving runners' times (García-Pinillos et al., 2017). Through a systematic review of randomized studies, Campos et al. (2021) demonstrated that recreational runners cover an average of 30 to 120 km per week. However, there is no control over the runners' profiles or preparation phases (Campos et al., 2021).

Thus, there is no consensus on the ideal training volume to start a running program, much less on the necessary increments throughout an aerobic training program to optimize maximum oxygen consumption and improve race performance. Therefore, the aim of this systematic review was to examine the distribution of weekly training volume during the preparatory phase of recreational runners and analyse the effect of this volume on maximum oxygen consumption and time-trial performance.

METHODS

Study design

This systematic review followed the guidelines of the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) (Liberati et al., 2009). The study protocol was registered in the International Prospective Register of Systematic Reviews (PROSPERO) under the protocol CRD42023453769.

Search strategy

Original articles published in journals indexed in electronic databases including PubMed, Web of Science, EMBASE, Scopus, and Cochrane CENTRAL were searched up to May 2023 (Figure 1), without language restrictions. Advanced search tools were utilized to combine descriptors and terms.

The search strategy involved two blocks: one for training strategies and another for outcomes. The training strategy block included terms such as "*long distance runners*," "*endurance runners*," "*middle distance runners*," "*half marathon runners*," "*endurance running*," "*distance runners*," "*recreational runners*," and "*marathoners*." The outcome block included terms like "*training volume*," "*load*," "*volume*," "*training load*," "*training volumes*," and "*distance running*." These blocks were combined using the Boolean operator "*AND*" during the search process.

Inclusion and exclusion criteria

Study Design

The search process included chronic, randomized comparative studies with pre/post evaluative monitoring, and progressive sequential detailing of the modulation of changes in the intervention concerning outcome variables. Acute studies and intervention studies involving animals were excluded.

Characterization of participants

The review included studies involving recreational runners with an average of 2.8 ± 1.82 years of racing experience. The participants were adults aged 26.73 ± 9.13 years, engaging in an average of 3.39 ± 1.43 training sessions per week. They had a body mass index (BMI) of 24.5 ± 2.45 kg/m² and a VO_{2max} of 49.46 ± 9.0 ml/kg/min. Participants of both genders were included in the preparatory and/or conditioning phases of testing.

Intervention type

Participants were categorized based on their running profile as average or long distance (Midgley et al., 2007), ensuring homogeneity in the analysis of intervention protocols for recreational athletes. Volumes within the preparation phases were classified according to different Training Intensity Distributions (TID) for comparison (Bellinger et al., 2020), aiming to enhance VO_{2max} conditioning and time trials for runners. The three-phase model served as a framework for prescribing and monitoring runners using cardiorespiratory and conditioning indicators, quantified through training zones (Festa et al., 2020).

Zone 1 is defined as a light domain (<2 $nmol.L^{-1}$; <First Lactate Threshold – LT1; <Ventilatory Threshold 1 – VT1), corresponding to a subjective Rating of Perceived Exertion (RPE) of 1 to 4, indicating low intensity. Zone 2 is moderate and continuous (>2 $nmol.L^{-1}$ and <4 $nmol.L^{-1}$; > LT1 and < LT2; > VT1 and < VT2 or Respiratory Compensation Point - RCP), with an RPE between 5 and 6. Zone 3 is characterized by high intensity (>4 $nmol.L^{-1}$; > LT2; > VT2 or RCP), with an RPE > 7 (Clemente-Suarez et al., 2018).

This intensity model quantifies distribution using the following strategies: 1. **Polarized:** Applies 80% of the training volume in Zone 1, with most of the remaining 20% in Zone 3, and minimal training in Zone 2 (80% Zone 1 + 0–5% Zone 2 + 20% Zone 3) (Muñoz et al., 2014). 2. **Undulatory:** Alternates volumes with moderate fluctuations, incorporating 10% to 30% increments of external training load (Casado et al., 2022). 3. **Linear:** Stabilizes volume and intensity throughout the training (Seiler, 2010). 4. **Sprint/High Intensity Interval Training (HIIT):** Involves multiple series of short (6–30s) or long (30–240s) stimuli at vigorous intensity (>80% - 100% of maximum heart rate [HR], heart rate reserve [HRR], maximum oxygen consumption [VO_{2max}], peak oxygen consumption [VO_{2peak}], and peak power [Ppeak]), followed by brief or extended periods of recovery (passive and/or active) (Buchheit & Laursen, 2013). Sprints are typically very short (<20s) and involve maximal effort, emphasizing high-intensity applications.

Analysis of outcome

The primary outcome assessed was VO_{2max} in the specific preparation of recreational runners, including average values and their variation amplitudes (Δ) from the initial phase to the end of preparation. Secondarily, time trial performance variables were analysed across several distances (1 to 10 km) against the clock, with mean values and standard deviations reported for each training strategy (interval and/or continuous).

Risk of bias evaluation

The methodological quality of the studies was assessed and classified using a quality scale (Van Velzen et al., 2006). This scale evaluates internal and external study validity across 15 criteria, which are detailed in Table 1. Each criterion was scored as YES (1.0), NOT CLEAR (0.5), or NO (0), contributing to a maximum score of 15 points based on the total number of indicators (Marocolo et al., 2019).

Table 1. Quality criteria and score assigned to studies.

Studies	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	Q11	Q12	Q13	Q14	Q15	*Score*	%
Esfarjani et al., 2007	1	1	1	1	1	1	1	1	0.5	1	1	1	1	0	1	13.5	90.00
Munoz et al., 2014	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	15	100.00
Vesterinen et al. 2015	1	1	0.5	1	1	1	1	1	1	1	1	1	1	1	1	14.5	96.67
Lum et al., 2016	1	1	1	0.5	1	1	1	1	0.5	1	1	1	1	1	1	14	93.33
Bradbury et al., 2018	1	1	0	0.5	1	1	1	1	1	1	1	1	1	0	1	12.5	83.33
Costa et al., 2019	1	1	1	0.5	1	1	1	1	1	1	1	1	1	1	1	14.5	96.67
Faelli et al., 2019	1	1	1	1	1	1	1	1	1	1	1	1	1	0	1	14	93.33

Legend: Q1: Is the hypothesis/objective of the study clearly described? Q2: Are the key results to be measured clearly described in the introduction? Q3: Are the characteristics of the subjects included in the study clearly described? Q4: Are the interventions of interest clearly described? Q5: Are the main findings of the study clearly described? Q6: Does the study provide estimates of the random variability of the data for the main results? Q7: Were the testing instruments reliable? Q8: Was the duration of follow-up sufficiently described and consistent in the study? Q9: Was the number of participants included in the study findings? Q10: Have actual probability values been reported (e.g. .035 rather than <.05) for the main outcomes, except where the probability value is less than .001? Q11: Was there a statement adequately describing or referencing all statistical procedures used? Q12: Were the statistical analyses used adequate? Q13: 13. Was the presentation of results satisfactory? Q14: Were confidence intervals given for the main results? Q15: Is the conclusion drawn from the statistical analysis justified?

RESULTS

Included studies

As shown in Figure 1, a total of seven potential articles were identified through the search process and eligibility criteria application. These studies analysed the effect of training volume on maximum oxygen consumption and/or time trial performance during the specific preparation period for recreational runners.

Effect of training volume on maximum oxygen consumption

Six studies investigated the effect of training volume on maximum oxygen consumption as the primary outcome, with no reported adverse effects. The studies collectively included 120 adult participants (110 men and 22 women) with a mean age of 27.80 ± 5.52 years, mean BMI of 24.77 ± 2.48 kg/m², pre-intervention

VO2max of 47.45 ± 7.82 ml/kg/min, and average running experience of 2.59 ± 2.12 years. VO_{2max} was evaluated using ergospirometry in all studies conducted in a controlled laboratory environment.

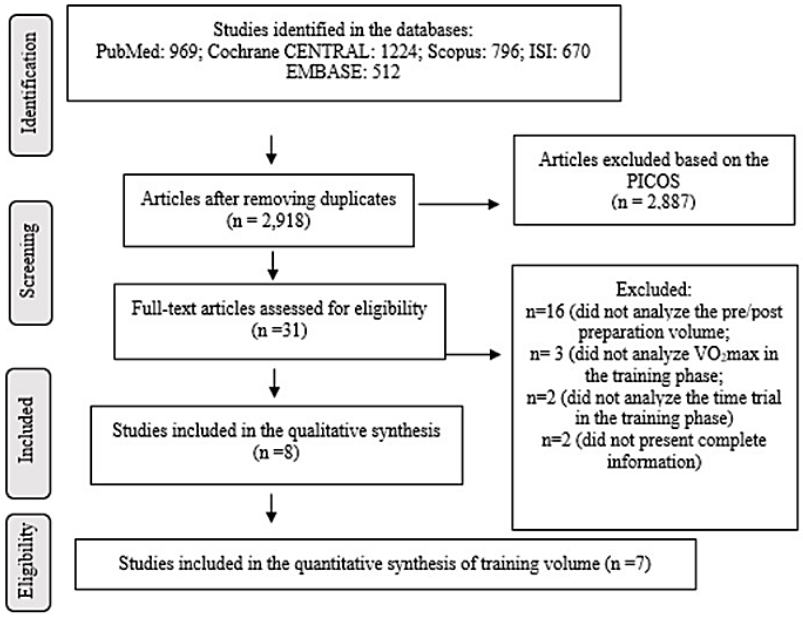

Figure 1. Flowchart of the stage for included articles.

Among the six studies included in this review, each utilized distinct aerobic training methodologies, resulting in a total of six interventions: high-intensity interval training (Faelli et al., 2019; Vesterinen et al., 2016), undulatory training (Costa et al., 2019), Linear training (Bradbury et al., 2018), Reverse training (Bradbury et al., 2018), and Sprint training (Lum et al., 2016). These interventions spanned an average duration of 10.00 ± 3.57 weeks, ranging from six to 16 weeks. Initial training volumes at the onset of interventions averaged 30 ± 7.21 km/week, with a range of 15 to 38 km/week, conducted at a frequency of 3.74 ± 1.40 days per week on average.

Changes in training volume, calculated as post-intervention minus pre-intervention values, are presented as mean ± standard deviation. Results indicated that an average 32.11% increase in training volume over approximately 10 weeks led to a notable improvement in maximum oxygen consumption by 10.44%.

Effect of training volume on time trial

Three studies (Faelli et al., 2019; Lum et al., 2016; Muñoz et al., 2014) investigated the impact of training volume on time trial performance as a secondary outcome, with no reported adverse effects. A total of 59 adult participants (mean age 33.52 ± 3.33 years, average BMI 22.88 ± 0.62 kg/m²) with experience in races (5.12 ± 2.02 years) and performance times of 44.22 ± 8.43 minutes for 10 km and 5.17 ± 0.24 minutes for 1 km distances were included. All studies evaluated time trials conducted on asphalt (track or test).

Each of the three studies employed different aerobic training methods, totalling four interventions: high-intensity interval training (Faelli et al., 2019), sprints (Lum et al., 2016), polarized training (Muñoz et al., 2014), and cross-threshold training (Muñoz et al., 2014). The interventions averaged 8 weeks in duration (ranging from 6 to 10 weeks). Initial training volumes averaged 32.54 ± 17.50 km/week (ranging from 15 to 50 km/week), conducted at a frequency of 2.8 ± 0.5 days per week on average.

Regarding periodization models and manipulation of intensity and volume variables, two studies increased training volume (Faelli et al., 2019; Muñoz et al., 2014), while two others focused on increasing training intensity and reducing volume (Faelli et al., 2019; Lum et al., 2016).

Table 2. Characterization of runners and training protocols.

Intervention	Author	Participants	Program
Interval Training	Esfarjani et al., 2007 (a)	G1 – n = 6; HIIT	HIIT G1 - completed five to eight intervals at VO_{2max} for a duration equal to 60% Tmax, with a 1:1 work: recovery ratio. The HIT sessions for G1 included high-intensity running bouts at 15,7 ± 0.7 kmh^{-1} for 3.5 ± 0.7 min followed by low-intensity recovery runs at 7.8 ± 0.3 km/h^{-1} for 3.5 ± 0.7 min.
	Esfarjani et al., 2007 (b)	G2 – n = 6 (19 ± 2 years, 73 ± 3 kg, 1.72 ± 0.04 m);	HIIT G2 - seven to twelve 30 s bouts at 130% VVO_{2max} separated by 4,5 min of recovery. This equated to a supramaximal run at 19,9 ± 0,6 km/h^{-1} for 30 s followed by a recovery run at 7.8 ± 0.3 km/h^{-1} for 4,5 min
	Vesterinen et al., 2015	HIIT – n = (35 years) (M =7, F =7)	HIT replaced three low-intensity training sessions during each intense training week with three moderate- or high-intensity (HR above lactate threshold 2, LT2) training sessions: (a) constant speed run 20–40 min at 80–90% HRmax; (b) 4 × 4 min at 90–95% HRmax, with 3 min of recovery at intensity below LT1; and (c) 6 × 2 min at 100% RSpeak, with 2 min of recovery at intensity below LT1, whereas training volume was maintained the same.
	Lum et al., 2016	Sprint – n = 7 (28.9 ± 3.4 years; 66.3 ± 6.8 kg; 1.71 ± 0.06 m)	Sprint = training plan of ∆ 3x 3x 10-m sprint / ∆ 4x 3x 50-m sprint
	Faelli et al., 2019 (a)	HIIT 10/20/30 – n = 11 (32.54 ± 3.05 years; 69.83 ± 2.76 kg; 1.74 ± 0.01 m)	HIIT 10/20/30 - 10 min warm-up at a low intensity, followed by 5 min running period, interspersed by 2 min of rest. Each 5 min running period consisted of five consecutive 1 min intervals, divided into 30, 20, and 10 s, at an intensity corresponding to 30, 60, and 90–100% of MAS, respectively.
	Faelli et al., 2019 (b)	HIIT 30/30 – n = 11 (38.18 ± 3.57 years; 68.11 ± 2.68 kg; 1.69 ± 0.02 m)	HIIT 30/30 - consisted of a standardized 10 min warm-up at a low intensity, followed by the 30–30 interval training, that consisted of 30 s at 90–100 % MAS interspersed with 30 s of active recovery (50% MAS)
High volume training	Vesterinen et al., 2015	HVT – n = 14 (35 years) (M =7, F =7);	HVT were instructed to increase their training volume by 30–50% whereas training intensity remained same as during PREP.
Undulatory	Costa et al., 2013	Undulatory-Undulatory – n = 18 (27 ± 9.3 years, 25.8 ± 4.6 kg/m^2);	Undulatory (training plan of ∆ 70% - 90% loads volume + ∆ 70% - 100% loads volume + 70% loads intensity)
		Undulatory-Linear – n =19 (26.3 ± 6.5 years, 25.8 ± 5.2 kg/m^2);	Staggered (training plan of ∆ 70% - 100% loads volume + 70% loads intensity)
		Staggered-Linear – n = 18 (24.3 ± 4 years, 25.9 ± 4.6 kg/m^2);	Linear (∆ 20% - 0% loads volume).
Linear	Bradbury et al., 2018	LP – n = 11	LP = training plan of ∆ 31.7 ± 3.86 km / 19.5 ± 2.51 km + ∆ 1075 ± 188 min*RPE / 548 ± 68 min*RPE
		RPG – n = 11	RPG = training plan of ∆ 31.8 ± 3.97 km / 19.1 ± 2.42 km + ∆ 739 ± 93 min*RPE / 556 ± 78 min*RPE
Polarized	Muñoz et al., 2014	BThET – n = 15 (34 ± 7 years, 67 ± 10.4 kg, 1.73 ± 0.07 m);	BThET = training plan of 1: followed a training plan designed to achieve a total percentage distribution in zones 1, 2, and 3 of ~45/35/20 (mean of ~350 TRIMPs/wk.)
		PET – n = 15 (34 ± 9 years, 71.4 ± 8.9 kg, 1.77 ± 0.05 m)	PET = training plan of 1: was designed to achieve a total percentage distribution in zones 1, 2, and 3 of ~75/5/20 based on HR distribution (mean of ~350 TRIMPs/wk.).

*Legend. *HVT: High Volume Training; HIIT: High Intensity Interval Training; BThET: Between-thresholds endurance training program; PET: Polarized endurance-training; LP: Linear periodization; RLP: Reverse Linear periodization.*

Munoz et al. (2014) and Faelli et al. (2019) demonstrated that a 26.97% increase in training volume over a nine-week period resulted in a 7.3% improvement in time trial performance. Conversely, Lum et al. (2016) and Faelli et al. (2019) reported that reducing training volume by 17.19% initially, followed by a progressive increase up to the final week, with intensity ranging from 33% to 112%, led to a 28.51% improvement in time trial performance compared to other training strategies. Changes in training volume [post-intervention minus pre-intervention] were calculated for each study and expressed as mean ± standard deviation (Faelli et al., 2019; Lum et al., 2016).

Table 3. Table of internal and external performance load indexes for recreational street runners.

Authors	**Pre-volume (km)**	**Post-volume (km)**	**∆ Volume variation in km (%)**	***p*-value**	**Pre-VO_{2max} (ml/kg/min)**	**Post-VO_{2max} (ml/kg/min)**	**∆ VO_{2max} variation ml.kg.min^{-1} (%)**	***p*-value**
The VO_2 response to training volume								
Esfarjani et al., 2007_HIIT_G1	38	43.6	↑ ∆ = 5.6 (↑ 14.73 %)	<.05	51.3	56	↑ ∆ = 4.7 (↑9.16%)	<.05
Esfarjani et al., 2007_HIIT_G2	38	36.6	↓∆ = -1.4 (↓ - 3.68 %)	>.05	51.7	54.9	↑ ∆ = 3.2 (↑6.18%)	<.05
Vesterinen et al. 2015_HVT	35	47	↑ ∆ = 12 (↑ 34.28 %)	<.001	49.3	50.5	↑ ∆ = 1.2 (↑ 2.43 %)	>.05
Vesterinen et al. 2015_HIIT	33	39	↑ ∆ = 6 (↑ 18.18 %)	>.05	50.7	52.8	↑ ∆ = 2.1 (↑ 4.14 %)	<.01
Lum et al., 2016_Sprint	32.7	28.8	↓∆ = -3.9 (↓ - 11.92 %)	=.03	53.9	54.6	↑ ∆ = 0.7 (↑ 1.29%)	=.47
Bradbury et al., 2018_LP	31.7	19.5	↓∆ = -12.2 (↓ -38.48 %)	<.05	59.46	62.09	↑ ∆ = 2.63 (↑ 4.42 %)	>.05
Bradbury et al., 2018_RLP	31.8	19.1	↓∆ = -12.7 (↓ -39.93 %)	<.05	59.95	62.52	↑ ∆ = 2.57 (↑ 4.28%)	>.05
Costa et al., 2019_UND	30.1	43	↑ ∆ = 12.9 (↑ 42.85 %)	<.05	37.9	46.3	↑ ∆ = 8.4 (↑ 22.1 %)	=.01
Costa et al., 2019_LINEAR	30.1	43	↑ ∆ = 12.9 9↑ 42.85 %)	<.05	38.9	45.2	↑ ∆ = 6.3 (↑ 16.19 %)	=.02
Costa et al., 2019_ Staggered-undulatory	30.1	43	↑ ∆ = 12.9 (↑ 42.85 %)	<.05	41.3	46.1	↑ ∆ = 4.8 (↑ 11.62 %)	=.02
Costa et al., 2019_ Staggered-linear	30.1	43	↑ ∆ = 12.9 (↑ 42.85 %)	<.05	38.6	42.9	↑ ∆ = 4.3 (↑ 11.13 %)	=.04
Faelli et al., 2019_HIIT 10/20/30	15	11.63	↓∆ = -3.37 (↓ -22.46 %)	=.002	43.01	46	↑ ∆ = 2.99 (↑6.95%)	<.001
Faelli et al., 2019_HIIT 30/30	15	15.14	↑ ∆ = 0.14 (↑ 0.93 %)	>.05	40.77	43	↑ ∆ = 2.23 (↑5.46%)	<.001
The time trial response to volume of training								
Time trial 10,000 meters								
Muñoz et al., 2014_BthET	50	70	↑ ∆ = 20 (↑ 40 %)	<.05	2364	2280	↓∆ = -84 (↓- 3.55 %)	<.001
Muñoz et al., 2014_PET	50	70	↑ ∆ = 20 (↑ 40 %)	<.05	2358	2220	↓∆ = -138 (↓- 5.85 %)	<.0001
Lum et al., 2016_Sprint	32,7	28.8	↓∆ = -3.9 (↓ - 11.92 %)	=.03	3237	3117	↓∆ = -120 (↓- 3.7 %)	=.03
Time trial 1,000 meters								
Faelli et al., 2019_HIIT 10/20/30	15	11.63	↓∆ = -3.37 (↓ -22.46 %)	=.002	300	460	↑ ∆ = 160 (↑53.33 %)	<.05
Faelli et al., 2019_HIIT 30/30	15	15.14	↑ ∆ = 0.14 (↑ 0.93 %)	>.05	320	280	↓∆ = -40 (↓- 12.5 %)	<.05

Legend: ↑ = Increased running volume; ↓ = Decrease in running volume; ∆ = Variation pre (Baseline) / post (Training). *HVT: High Volume Training; HIIT: High Intensity Interval Training; BThET: Between-thresholds endurance training program; PET: Polarized endurance-training; LP: Linear periodization; RLP: Reverse Linear periodization.

DISCUSSION

To our knowledge, this is the first systematic review to analyse the impact of training volume distribution on maximum oxygen consumption (VO_{2max}) and time trial performance in recreational runners. Key findings from this study include: i) Aerobic training programs with an initial volume ranging from 15 to 50 km/week, conducted at a frequency of 3.7 ± 1.4 days/week over intervention periods lasting 6 to 16 weeks, were sufficient to elicit positive adaptations in maximum oxygen consumption (ml/kg/min-1); and; ii) Aerobic training programs with an initial volume of 15 to 50 km/week, conducted at a frequency of 2.8 ± 0.5 days/week and lasting between 6 and 10 weeks, were effective in improving time trial performance (seconds).

Effect of training volume on VO_{2max}

VO_{2max} stands as a pivotal measure in assessing the competitive proficiency of runners and evaluating post-training athletic performance. Training volume is widely recognized as a critical variable in aerobic training protocols that can significantly influence VO_{2max}, thereby enhancing overall runner performance. However, there remains a paucity of studies that rigorously control this variable throughout the entirety of a training cycle.

The findings of this review revealed considerable variability regarding the optimal volume adjustments across training programs, lacking standardization. Nonetheless, it was observed that moderate increments of approximately 10% in training volume were sufficient to yield significant improvements in VO_{2max} among recreational runners. Conversely, interventions prescribing larger increases in volume demonstrated more pronounced improvements.

Our findings align with prior research (Billat et al., 2003), which investigated the impact of high-intensity aerobic interval training programs featuring incremental weekly volume adjustments in professional Kenyan runners, resulting in notable increases in VO_{2max}%. Similar outcomes were reported in a systematic review conducted by Campos et al. (2021), underscoring that aerobic training programs incorporating higher weekly volumes elicited greater enhancements in VO_{2max} among recreational runners across various competitive levels.

It is crucial to prioritize higher weekly training volumes during the preparatory phase, emphasizing moderate to vigorous intensities and preferably incorporating interval stimuli. This approach aims to foster both central and peripheral adaptations associated with endurance capacity. Although none of the included studies specifically analysed the mechanisms through which high-volume aerobic training enhances VO_{2max}, these mechanisms are well-documented in the literature. They include increased capillarization of muscle fibres and mitochondrial density, as well as enhancements in systolic volume and circulating haemoglobin concentration (Thompson, 2017). These adaptive changes contribute to an improved tolerance to [H+] accumulation during intense sections of races, whether influenced by elevation, temperature, or competitive conditions (Casado et al., 2023).

Effect of training volume on time trial

Time-trial running serves as a crucial measure for assessing physical conditioning progress and simulating physiological demands akin to competitive races. Additionally, it correlates significantly with endurance performance (Russell et al., 2004). Recent systematic reviews have explored the impact of different aerobic training intensity distributions on time trials among recreational runners (Campos et al., 2021; Rosenblat et al., 2019). These reviews suggest that pyramidal and polarized training models are particularly effective in enhancing time-trial performance.

Despite extensive research on training intensity, there remains no consensus regarding the effect of training volume on time trials. Some studies indicate that higher volumes correlate with improved running speed (Rust et al., 2011). However, systematic reviews have highlighted that weekly volume increases exceeding 65 km for men and 48 to 63 km for women are associated with higher injury rates (Fokkema et al., 2020), underscoring a direct relationship between training volume and injury risk. In our study, aerobic training programs ranging from 15 to 70 km per week were found to produce a significant 12.5% improvement in time-trial performance. These findings suggest that reducing training volume by more than 22.4% may not yield substantial improvements in time-trial running.

We encountered challenges in determining optimal training volumes for recreational runners due to the intricate interplay of associative factors. Variables such as experience, age, and gender (Knechtle et al., 2011) serve as foundational elements in training regimen customization. However, our review highlighted a scarcity of literature addressing the specific needs of recreational runners, with existing recommendations predominantly derived from professional or elite athletes, often misaligned with the practical realities and aspirations of these participants (Kozlovskaia et al., 2019).

The transformation of these findings into actionable insights is pivotal for runners aiming to optimize performance efficiency. This involves leveraging predictive biomechanical metrics to identify and rectify energy expenditure inefficiencies on the track, thereby mitigating injury risks.

Practical applications

This systematic review offers practical insights to guide training strategies for recreational runners. It emphasizes the importance of mapping out preparation strategies that optimize performance indices while mitigating the risks of excessive training loads, thereby promoting longevity in sport and preserving structural integrity. Specifically, starting with a weekly training volume ranging from 15 to 50 km over approximately 8 weeks has been found effective in significantly improving maximum oxygen uptake (VO_{2max}) and time trial performance. Moreover, a moderate increase of about 10% in training volume has shown to enhance VO_{2max} levels. To minimize injury risks, it is essential to maintain a balanced approach between training volume and intensity, especially when weekly volumes exceed 65 km for men and 48 km for women. Coaches are advised to consider individual factors such as experience, age, and gender when adapting these recommendations, ensuring personalized training adjustments that optimize outcomes.

CONCLUSION

We conclude that improving the preparation of recreational runners hinges on understanding training volume distribution. This review demonstrates that adjusting training volume, with increases of up to 42% during the preparatory phase, significantly enhances VO_{2max} and time trial performance. The identified average of 32.7 km/week establishes a starting point for medium-distance runners, potentially increasing to 38.15 km/week. Coaches must consider these findings, adapting them to each runner's needs and characteristics, prioritizing health, injury prevention, and continual performance improvement.

These insights aim to enhance the effectiveness and safety of training programs tailored for recreational runners, facilitating sustainable improvements in performance metrics and overall athletic development.

AUTHOR CONTRIBUTIONS

Rhennan Rodrigues Barbosa: Scientific methods, scientific writing and data collection. Raphael José Perrier Melo: Scientific methods, scientific writing and data collection. Jorge Luiz de Brito Gomes: Scientific writing and statistical data analysis. Fernando José de Sá Pereira Guimarães: Scientific writing and statistical data analysis. Manoel da Cunha Costa: Scientific writing and general review.

SUPPORTING AGENCIES

Coordenação de Aperfeiçoamento de Pessoal de Nível Superior - Brazil (CAPES) - Finance Code 001.

DISCLOSURE STATEMENT

No potential conflict of interest was reported by the authors.

REFERENCES

Bellinger, P., Arnold, B., & Minahan, C. (2020). Quantifying the training-intensity distribution in middle-distance runners: The influence of different methods of training-intensity quantification. International Journal of Sports Physiology and Performance, 15(3), 319-323. https://doi.org/10.1123/ijspp.2019-0298

Bernans, E., Abolins, V., & Lanka, J. (2023). Does step frequency as a single factor affect running economy? A systematic review. Journal of Human Sport and Exercise, 18(3), 743-754. https://doi.org/10.14198/jhse.2023.183.20

Billat, V., Lepretre, P. M., Heugas, A. M., Laurence, M. H., Salim, D., & Koralsztein, J. P. (2003). Training and bioenergetic characteristics in elite male and female Kenyan runners. Medicine and Science in Sports and Exercise, 35(2), 297-304. https://doi.org/10.1249/01.MSS.0000053556.59992.A9

Bradbury, D. G., Landers, G. J., Benjanuvatra, N., & Goods, P. S. R. (2018). Comparison of linear and reverse linear periodized programs with equated volume and intensity for endurance running performance. Journal of Strength and Conditioning Research, 34(5), 1345-1353. https://doi.org/10.1519/JSC.0000000000002805

Buchheit, M., & Laursen, P. B. (2013). High-intensity interval training, solutions to the programming puzzle: Part II: Anaerobic energy, neuromuscular load and practical applications. Sports Medicine, 43(10), 927-954. https://doi.org/10.1007/s40279-013-0066-5

Campos, Y., Casado, A., Vieira, J. G., Guimarães, M., Sant'Ana, L., Leitão, L., Silva, S. F. da, Azevedo, P. H. S. M. de, Vianna, J., & Domínguez, R. (2021). Training-intensity Distribution on Middle- and Long-distance Runners: A Systematic Review. Int J Sports Med, 43(04), 305-316. https://doi.org/10.1055/a-1559-3623

Casado, A., Foster, C., Bakken, M., & Tjelta, L. I. (2023). Does Lactate-Guided Threshold Interval Training within a High-Volume Low-Intensity Approach Represent the "Next Step" in the Evolution of Distance Running Training? International Journal of Environmental Research and Public Health, 20(5). https://doi.org/10.3390/ijerph20053782

Casado, A., González-Mohíno, F., González-Ravé, J. M., & Foster, C. (2022). Training Periodization, Methods, Intensity Distribution, and Volume in Highly Trained and Elite Distance Runners: A Systematic Review. International Journal of Sports Physiology and Performance, 17(6), 820-833. https://doi.org/10.1123/ijspp.2021-0435

Clemente-Suarez, V. J., Dalamitros, A., & Nikolaidis, P. T. (2018). The effect of a short-term training period on physiological parameters and running performance: intensity distribution versus constant-intensity exercise. The Journal of Sports Medicine and Physical Fitness, 58(1), 1-7. https://doi.org/10.23736/S0022-4707.16.06756-6

Costa, P., Simão, R., Perez, A., Gama, M., Lanchtermacher, R., Musialowski, R., Braga, F., de Mello Coelho, V., & Palma, A. (2019). A Randomized Controlled Trial Investigating the Effects of Undulatory, Staggered, and Linear Load Manipulations in Aerobic Training on Oxygen Supply, Muscle Injury, and Metabolism in Male Recreational Runners. Sports Medicine - Open, 5(1). https://doi.org/10.1186/s40798-019-0200-5

Cuk, I., Nikolaidis, P. T., Markovic, S., & Knechtle, B. (2019). Age differences in pacing in endurance running: Comparison between marathon and half-marathonMen and Women. Medicina (Lithuania), 55(8). https://doi.org/10.3390/medicina55080479

Damsted, C., Parner, E. T., Sørensen, H., Malisoux, L., & Nielsen, R. O. (2017). Design of ProjectRun21: a 14-week prospective cohort study of the influence of running experience and running pace on running-related injury in half-marathoners. Injury Epidemiology, 4(1). https://doi.org/10.1186/s40621-017-0124-9

Faelli, E., Ferrando, V., Bisio, A., Ferrando, M., Torre, A. La, Panasci, M., & Ruggeri, P. (2019). Effects of Two High-intensity Interval Training Concepts in Recreational Runners. International Journal of Sports Medicine, 40(10), 639-644. https://doi.org/10.1055/a-0964-0155

Festa, L., Tarperi, C., Skroce, K., La Torre, A., & Schena, F. (2020). Effects of Different Training Intensity Distribution in Recreational Runners. Frontiers in Sports and Active Living, 1, 70. https://doi.org/10.3389/fspor.2019.00070

Fokkema, T., van Damme, A. A. D. N., Fornerod, M. W. J., de Vos, R. J., Bierma-Zeinstra, S. M. A., & van Middelkoop, M. (2020). Training for a (half-)marathon: Training volume and longest endurance run related to . In PLoS Medicine performance and running injuries. Scandinavian Journal of Medicine and Science in Sports, 30(9), 1692-1704. https://doi.org/10.1111/sms.13725

Fredette, A., Roy, J. S., Perreault, K., Dupuis, F., Napier, C., & Esculier, J. F. (2022). The Association between Running Injuries and Training Parameters: A Systematic Review. Journal of Athletic Training, 57(7), 650-671. https://doi.org/10.4085/1062-6050-0195.21

García-Pinillos, F., Soto-Hermoso, V. M., & Latorre-Román, P. A. (2017). How does high-intensity intermittent training affect recreational endurance runners? Acute and chronic adaptations: A systematic review. Journal of Sport and Health Science, 6(1), 54-67. https://doi.org/10.1016/j.jshs.2016.08.010

Knechtle, B., Knechtle, P., Barandun, U., Rosemann, T., & Lepers, R. (2011). Predictor variables for half marathon race time in recreational female runners. Clinics, 66(2), 287-291. https://doi.org/10.1590/S1807-59322011000200018

Kozlovskaia, M., Vlahovich, N., Rathbone, E., Manzanero, S., Keogh, J., & Hughes, D. C. (2019). A profile of health, lifestyle and training habits of 4720 Australian recreational runners-The case for promoting running for health benefits. Health Promotion Journal of Australia, 30(2), 172-179. https://doi.org/10.1002/hpja.30

Liberati, A., Altman, D. G., Tetzlaff, J., Mulrow, C., Gøtzsche, P. C., Ioannidis, J. P. A., Clarke, M., Devereaux, P. J., Kleijnen, J., & Moher, D. (2009). The PRISMA statement for reporting systematic reviews and meta-analyses of studies that evaluate health care interventions: Explanation and elaboration (Vol. 6, Issue 7). https://doi.org/10.1371/journal.pmed.1000100

Lum, D., Tan, F., Pang, J., & Barbosa, T. M. (2016). Effects of intermittent sprint and plyometric training on endurance running performance. Journal of Sport and Health Science, 8(5), 471-477. https://doi.org/10.1016/j.jshs.2016.08.005

Marocolo, M., Simim, M. A. M., Bernardino, A., Monteiro, I. R., Patterson, S. D., & da Mota, G. R. (2019). Ischemic preconditioning and exercise performance: shedding light through smallest worthwhile change. European Journal of Applied Physiology, 119(10), 2123-2149. https://doi.org/10.1007/s00421-019-04214-6

Midgley, A. W., Mcnaughton, L. R., & Jones, A. M. (2007). Training to Enhance the Physiological Determinants of Long-Distance Running Performance Can Valid Recommendations be Given to Runners and Coaches Based on Current Scientific Knowledge? Sports Med, 37(10), 857-880. https://doi.org/10.2165/00007256-200737100-00003

Muñoz, I., Seiler, S., Bautista, J., España, J., Larumbe, E., & Esteve-Lanao, J. (2014). Does polarized training improve performance in recreational runners? International Journal of Sports Physiology and Performance, 9(2), 265-272. https://doi.org/10.1123/ijspp.2012-0350

Olaya-Cuartero, J., Plaza-Morales, D., Jimenez-Olmedo, J. M., & Lipinska, P. (2023). Sensor analysis for the assessment of biomechanical parameters in endurance runners: a systematic review. Journal of Physical Education and Sport, 23 (9), 2385-2393.

Ramskov, D., Rasmussen, S., Sørensen, H., Thorlund, E., Lind, M., Nielsen, R., & Lagerloefsvej, S. (2018). Progression in running intensity or running volume and the development of specific injuries in recreational runners. Run Clever a randomized trial using competing risks. Journal of Orthopaedic & Sports Physical Therapy, 48(10), 740-748. https://doi.org/10.2519/jospt.2018.8062

Rosenblat, M. A., Perrotta, A. S., & Vicenzino, B. (2019). Polarized vs. Threshold Training Intensity Distribution on Endurance Sport Performance: A Systematic Review and Meta-Analysis of Randomized Controlled Trials. Journal of Strength and Conditioning Research, 33(12), 3491-3500. https://doi.org/10.1519/JSC.0000000000002618

Russell, R. D., Redmann, S. M., Ravussin, E., Hunter, G. R., & Larson-Meyer, D. E. (2004). Reproducibility of Endurance Performance on a Treadmill Using a Preloaded Time Trial. Medicine and Science in Sports and Exercise, 36(4), 717-724. https://doi.org/10.1249/01.MSS.0000121954.95892.C8

Rust, C. A., Knechtle, B., Knechtle, P., Barandun, U., Lepers, R., & Rosemann, T. (2011). Predictor variables for a half marathon race time in recreational male runners. Open Access Journal of Sports Medicine, 113. https://doi.org/10.2147/OAJSM.S23027

Seiler, S. (2010). What is Best Practice for Training Intensity and Duration Distribution in Endurance Athletes? BRIEF REVIEW. International Journal of Sports Physiology and Performance, 5, 276-291. https://doi.org/10.1123/ijspp.5.3.276

Suwankan, S., Suwankan, S., Theanthong, A., & Kemarat, S. (2024). Prediction of 10 km running time by physical and training characteristics in recreational runners. Journal of Human Sport and Exercise, 19(1), 193-201. https://doi.org/10.14198/jhse.2024.191.17

Tejero-González, C. M. (2015). The number of runners in Spain increased during the first decade of the 21st century. Apunts. Educacion Fisica y Deportes, 120, 73-75. https://doi.org/10.5672/apunts.2014-0983.es.(2015/2).120.10

Thompson, M. A. (2017). Physiological and biomechanical mechanisms of distance specific human running performance. Integrative and Comparative Biology, 57(2), 293-300. https://doi.org/10.1093/icb/icx069

Thuany, M., Gomes, T. N., & Almeida, M. B. (2020). Validação de um instrumento para caracterização e verificação de fatores associados ao desempenho de corredores de rua. Scientia Plena, 16(3). https://doi.org/10.14808/sci.plena.2020.032801

Van Velzen, J. M., Van Bennekom, C. A. M., Polomski, W., Slootman, J. R., Van Der Woude, L. H. V., & Houdijk, H. (2006). Physical capacity and walking ability after lower limb amputation: A systematic review. Clinical Rehabilitation, 20(11), 999-1016. https://doi.org/10.1177/0269215506070700

Vesterinen, V., Häkkinen, K., Laine, T., Hynynen, E., Mikkola, J., & Nummela, A. (2016). Predictors of individual adaptation to high-volume or high-intensity endurance training in recreational endurance runners. Scandinavian Journal of Medicine & Science in Sports, 26(8), 885-893. https://doi.org/10.1111/sms.12530

Videbæk, S., Bueno, A. M., Nielsen, R. O., & Rasmussen, S. (2015). Incidence of Running-Related Injuries Per 1000 h of running in Different Types of Runners: A Systematic Review and Meta-Analysis. Sports Medicine, 45(7), 1017-1026. https://doi.org/10.1007/s40279-015-0333-8