Peak velocity and its time limit are as good as the velocity associated with VO_{2max} for training prescription in runners

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ABSTRACT

This study compared the effects of 4 weeks of training prescribed by peak velocity (V_{peak}) or velocity associated with maximum oxygen uptake (vVO_{2max}) in moderately trained endurance runners. Study participants were 14 runners (18–35 years) randomized into 2 groups, named group VO_2 (GVO_2) and group V_{peak} (GVP). The GVO_2 had training prescribed by vVO_{2max} and its time limit (t_{lim}), whereas the GVP had training prescribed by V_{peak} and its t_{lim}. Four tests were performed on a treadmill: 2 maximum incremental for V_{peak} and vVO_{2max} and 2 for their t_{lim}. Performance (10 km) was evaluated on a 400 m track. Evaluations were repeated after 4 weeks of endurance training. The results showed a significant effect of training on V_{peak} [GVP (16.7 ± 1.2–17.6 ± 1.5 km·h^{-1}), GVO_2 (17.1 ± 1.9–17.7 ± 1.6 km·h^{-1})]; vVO_{2max} [GVP (16.4 ± 1.4–17.0 ± 1.3 km·h^{-1}), GVO_2 (17.2 ± 1.7–17.5 ± 1.9 km·h^{-1})]; and 10 km performance [GVP (41.3 ± 2.4–39.9 ± 2.7 min), GVO_2 (40.1 ± 3.4–39.2 ± 2.9 min)]. The V_{peak} highly correlated with performance in both pre- and post-training in GVP (−0.97;−0.86) and GVO_2 (−0.95;−0.94), as well as with vVO_{2max} in GVP (−0.82;−0.88) and GVO_2 (−0.99; −0.98). It is concluded that training prescribed by V_{peak} promoted similar improvements compared to training prescribed by vVO_{2max}. The use of V_{peak} is recommended due to its practical application and the low cost of determination.

Introduction

Success in endurance racing depends on an elaborate training prescription utilizing appropriate loads and recovery periods. Such prescriptions should be planned according to the needs of the individual athlete for achieving the highest level of adaptation possible prior to the competition [16, 22, 29]. For proper training prescription, it is necessary to use variables that control and monitor the intensity of effort and possible physiological adaptations resulting from this practice and, most importantly, that show a correlation with performance [7].

Currently, the velocity associated with the occurrence of maximum oxygen uptake (vVO_{2max}) is considered a good variable to predict performance and to monitor and prescribe endurance running training [2, 9, 27]. In addition, the application of its time limit (t_{lim}) may improve the prescription of the most adequate set duration for high-intensity interval workouts [2]. Previous studies show that training prescribed by vVO_{2max} and its respective t_{lim} promoted improvements in performance of 3, 5 and 10 km [9, 13, 34]. In addition, the training prescribed by these variables can promote improvements in VO_{2max}, running speed at the lactate threshold, and parameters related to heart rate (HR) among others [9, 13, 34]. However, the vVO_{2max} determination requires the use and handling of expensive and delicate equipment, as well as the interpretation of data, limiting its use to only a few research laboratories, coaches, and athletes. Moreover, the vVO_{2max} refers to estimating the minimum speed required to achieve VO_{2max}, as a result of calculating vVO_{2max} based on VO_{2max} determination, whereas the peak velocity (V_{peak}) is the maximum speed directly measured and associated with VO_{2max} [26].

Thus, V_{peak} is an attractive variable that has been gaining attention among researchers, trainers, and endurance runners due to its practicality and financial accessibility. Despite the fact that V_{peak} is associated with vVO_{2max} and is a great predictor of endurance performance in tests 3–90 km [25, 26, 30], it is necessary to test its applicability to endurance training prescription as well as the applicability of its t_{lim} to determine duration of high-intensity interval sets. Although the intra-individual differences between V_{peak} and vVO_{2max}

might be very small, the t_{lim} differences may be large, which would meaningfully change the duration of high-intensity interval sets.

Given that, as far as it is known, V_{peak} based training prescription for moderate intensity continuous training and high-intensity interval training has not been tested yet, the aim of this study was to evaluate the effect of 4 weeks of training prescribed by V_{peak}, vVO_{2max}, and their respective t_{lim} in moderately trained endurance runners. Our hypothesis was that both training models would improve aerobic, anaerobic, and performance parameters of moderately trained runners in a similar manner. We also hypothesized that V_{peak} would demonstrate a higher correlation with the 10 km performance than the vVO_{2max} before and after training, given that V_{peak} is the 'measured' speed associated with VO_{2max}, and vVO_{2max} is the 'estimated' speed associated with VO_{2max} [11, 26]. Should this be shown, it would demonstrate that the V_{peak} was a more sensitive variable to the effects of training for moderately trained runners.

Methods

Participants

Fourteen moderately trained endurance runners were recruited for participation in this study and showed average speed (AS) between 14 and 16 $km \cdot h^{-1}$ (≅62–71 % of the world record). They performed at least 5 training sessions per week. Their average training distance during the study was 40.9 ± 4.5 $km \cdot week^{-1}$, which was similar to their training distance before the study. Subjects had the following characteristics: (mean ± SD, age 29.2 ± 5.3 years, weight 71.9 ± 11.0 kg, height 175.1 ± 4.3 cm) with a minimum of 1 year of experience in competitive long distance races. Before the study, the subjects were informed about the testing and training and possible risks involved and provided written informed consent. This study was approved by the University's Human Research Ethics Committee (#1.022.468). All research was conducted ethically according to international standards and as required by the International Journal of Sports Medicine [15].

Experimental design

Runners were randomized into 2 groups using random numbers. One group was trained by V_{peak} (GVP; n = 8) and the other group by vVO_{2max} (GVO_2; n = 6). The experiment involved the implementation of 2 different endurance running training programs (GVP *vs.* GVO_2) using the prescribed external workload (%V_{peak} or %vVO_{2max}) for 5 sessions per week over a 4 week period, for a total of 20 sessions. Before and after the training intervention, in a counterbalanced order, the subjects were evaluated using 2 incremental tests on a treadmill to measure VO_{2max} and V_{peak} and 2 to determine their t_{lim}. Performance (10 km) was evaluated on an official running track (400 m). In addition, variables such as heart rate (HR), blood lactate concentration [LA], and rating of perceived exertion (RPE) were also evaluated during the tests. The tests were performed over 2 weeks, with a period of at least 48 h separating each of them.

Determination of V_{peak} and its t_{lim}

The V_{peak} was assessed on a motorized treadmill (Super ATL; Inbrasport, Porto Alegre, Brazil) (with the gradient set at 1 % [21]. After a 3 min warm-up walking at 8 $km \cdot h^{-1}$, the protocol started with an initial velocity of 10 $km \cdot h^{-1}$, followed by an increase of 1 $km \cdot h^{-1}$ every 3 min until volitional exhaustion (i. e., participant was unable to continue running). If the last stage was not completed, the V_{peak} was calculated on the partial time remaining in the last stage using the equation proposed by Kuipers et al. [23]: $V + (t/180 \times 1.0)$, where V was the last completed velocity ($km \cdot h^{-1}$) and t, the time (s) of the uncompleted step (180 s). The t_{lim} at V_{peak} was assessed after a 15 min warm-up at 60 % V_{peak}, when velocity was increased to V_{peak}. The subjects were verbally encouraged to run to volitional exhaustion [4].

Determination of VO_{2max} and its t_{lim}

The protocol used for determining the VO_{2max} was the same as that used for the determination of V_{peak}; additionally, exhaled gas was collected to determine the VO_{2max} using a portable gas analyzer ($k4b^{2,}$ Cosmed, Roma, Italy). The VO_{2max} was regarded as the maximum value obtained during the test, measured at an average of 15-s intervals, and when at last 2 of the following criteria were met: (1) $LA_{peak} \geq 8\ mmol \cdot L^{-1}$, (2) $HR_{max} \geq 100$ % of endurance-trained age-predicted HR_{max} using the age-based "206–0.7 × age" equation [37] and (3) $RPE_{max} \geq 18$ in the 6–20 Borg scale [6]. The vVO_{2max} was the minimal velocity at which the athlete was running when VO_{2max} occurred [2, 4]. To determine t_{lim} at $vVO_{2max,}$ the same protocol was applied as that used for determining the t_{lim} at V_{peak} using the values of vVO_{2max} as parameters.

Time trials of 10 km

Participants undertook 10 km time trials on a 400 m outdoor running track at 6:00 pm. The trial was preceded by a self-selected pace warm-up of 10 min duration. A hydration station was set up on the track with natural water. The participants were encouraged to achieve their best performance. Split times were registered at each 400 m and the average velocity of each section was calculated.

Determination [LA], HR, and RPE

Earlobe capillary blood samples (25 µl) were collected into a capillary tube at the end of the tests (time zero of recovery) and at the third, fifth, and seventh minutes of passive recovery with participants seated in a comfortable chair. From these samples, [LA] was subsequently determined by electroenzymatic methods using an automated analyzer (YSI 2300 STAT, Yellow Springs, Ohio, USA). Peak [LA] (LA_{peak}) was defined for each participant as the highest post-exercise [LA] value. RPE was also monitored during all tests by using a 6–20 Borg scale [6], and the highest RPE value was adopted as the peak RPE (RPE_{peak}). HR was monitored during all tests (Polar RS800sd; Kempele, Finland) and HR_{max} was defined as the highest HR value recorded during the test.

Training programs

All training sessions were held on a 400 m outdoor running track, between 5:00 and 9:00 pm hours due to the availability of participants and the fact that their performance would be better in the evening [10]. The training protocol consisted of 2 types of running training: continuous moderate-intensity and high-intensity interval training (short interval and long interval). The running intensity was prescribed based on the V_{peak} and t_{lim} for the GVP group, and the vVO_{2max} and t_{lim} for the GVO_2 group (▶ **Table 1**).

The GVO_2 and GVP training sessions were preceded by a 15 min warm-up consisting of 5 min of low intensity running at a self-select-

▶ **Table 1** Continuous and interval training prescribed for GVP and GVO_2 groups.

GVP and GVO_2	
Continuous training	45 * ± 2.5 min at 75 ± 4 % of V_{peak} or vVO_{2max}. (weeks 1 & 2) 60 ± 2.5 min at 75 ± 4 % of V_{peak} or vVO_{2max}. (weeks 3 & 4)
Short interval training	*X* *# sets at 120 ± 2 % of V_{peak} or vVO_{2max} with duration 10 % their respective t_{lim} and intervals (passive) with duration 30 % of t_{lim} at V_{peak} or vVO_{2max}.
Long interval training	*X* *# sets at 100 ± 2 % of V_{peak} or vVO_{2max} with duration 60 % their respective t_{lim} and intervals (passive) with duration 60 % of t_{lim} at V_{peak} or vVO_{2max}.

The number of series performed by each participant was adjusted so that the total duration of interval training session corresponded to 30 ± 2.5 min

* The intensity and duration of training was the same for both groups with differences only in the prescription variable: the GVO_2 had the training prescribed by vVO_{2max} and its respective t_{lim} and GVP had training prescribed by V_{peak} and its respective t_{lim}

Training was based on studies by Buchheit et al. [9]; Esfarjani and Laursen [13]; Smith; Coombes, and Geraghty, [34]; Billat et al. [2]

ed velocity, 5 min of stretching, and 5 min of running at 60 % of V_{peak} or vVO_{2max} [35]. After the warm-up, the main training session (continuous or interval training) was conducted, followed by a cool-down comprised of self-selected low-intensity running and stretching.

The training participants of both groups were trained 5 times per week for 4 weeks. They performed 10 sessions of continuous training and 10 of interval training. During the odd weeks, participants performed 3 sessions of continuous training and 2 sessions of interval training; and the reverse during even weeks. The training sessions of the groups were differentiated by the prescription method (V_{peak} and their respective t_{lim} to GVP and vVO_{2max} and their respective t_{lim} to GVO_2). The intensity and volume of training were maintained throughout the protocol, except for continuous training in weeks 3 and 4 when the duration was increased from 45 to 60 min for both groups.

Statistical analyses

All statistical analyses were performed using the SPSS software (v.20, SPSS Inc., Chicago, IL, USA). The variables are presented as mean ± standard deviation (SD). Data normality was verified by the Shapiro-Wilk test. The comparison between the pre- and post-training for the 2 groups was made by mixed ANOVA for repeated measures. Correlations between aerobic and anaerobic parameters with 10 km running performance were performed using the Pearson correlation coefficient. The differences (i. e., effect size [ES]) were considered small when ES ≤ 0.2, moderate when ES ≤ 0.5 and large when ES > 0.8. Furthermore, magnitude-based inferences were applied to estimate the chances of a true observed effect being positive, trivial or negative, considering the smallest worthwhile change per Hopkins et al. [18]. The probability of a positive/trivial/negative effect of the training programs was interpreted following the recommendations of Hopkins et al. [18]; effect: < 1 % almost certainly not; 1–5 % very unlikely; 5–25 % unlikely; 25–75 % possibly; 75–95 % likely; 95–99 % very likely; > 99 % almost certainly. When the chance of having positive or negative effects in an outcome were both above 10 %, the qualitative inference result was considered as unclear.

Results

The results show V_{peak} improvement in both groups after the 4 week training period: GVP = 0.9 [0.4–1.4] km · h⁻¹ (p = 0.01) and GVO_2 = 0.6 [0.2–1.0] km · h^{-1} (p = 0.03) (▶ **Table 2**). A significant increase in the total duration of the incremental test was observed in both groups: GVP = 2.8 [1.5–4.1] min (p = 0.01) and GVO_2 = 2.2 [0.4–3.9] min (p = 0.06) (▶ **Table 2**).

No significant differences were observed in either group between pre- and post-training for HR_{max}, RPE_{max}, t_{lim} at V_{peak}, t_{lim} at vVO_{2max}, and LA_{peak}.

After 4 weeks of training, we observed a significant improvement in vVO_{2max} only in the GVP group: 0.6 [−2.2–1.8] km · h^{-1}; (p = 0.01). In relation to the total duration of the test, a significant increase was observed in both groups: GVP = 1.7 [0.4–3.0] min (p = 0.036) and GVO_2 = 1.2 [0.2–2.2] min (p = 0.047) (▶ **Table 3**).

▶ **Table 4** shows the values of the variables both pre- and post-training obtained in the 10 km performance. In both groups, there was a significant reduction in the time it took to run a 10 km distance after the training program (GVP (– 1.4 [− 2.5 to − 0.3] min; p = 0.04) and GVO_2 (– 0.9 [−1.6–0.2] min; p = 0.048)). Furthermore, there was a significant increase in the AS after 4 weeks of training (0.6 [0.1–1.0] km · h^{-1} for GVP (p = 0.04) and 0.4 [0.1–0.6] km · h^{-1} for GVO_2 (p = 0.036)). The runners' AS was between 14 and 16 km · h^{-1} (≅62–71 % of the world record).

The effect size for the comparison between GVP and GVO_2 for the percentage variation after the 4 week running training period revealed a small effect for V_{peak} and 10 km time and a moderate effect for vVO_{2max}, all favorable to GVP (▶ **Fig. 1**).

The V_{peak} and vVO_{2max} were significantly correlated with the 10 km performance in both pre- and post-training time in both groups (▶ **Table 5**). The VO_{2max}, however, did not correlate with the 10 km performance at any time (▶ **Table 5**).

Discussion

The aim of the study was to evaluate the effect of 4 weeks of training prescribed by V_{peak}, vVO_{2max}, and their respective t_{lim} in moderately trained endurance runners.

The main finding of the study was that the training prescribed by V_{peak} or by vVO_{2max} promoted similar improvements for moderately trained endurance runners, which confirmed a previous hypothesis. Effect size analysis showed slightly favorable changes for GVP. A significant correlation was observed between the 10 km performance and the V_{peak} and vVO_{2max}, but our hypothesis was disproven because only in the pre-training time, the GVP showed a higher

▶ **Table 2** Mean ± standard deviation (SD) difference (90 % CI), magnitude of inference, and significance level for group × time interaction (P) for the variables: V_{peak}, ($km \cdot h^{-1}$) Total time of the incremental test (min), HR_{max} (bpm) RPE_{max} (AU), LA_{peak} ($mmol \cdot L^{-1}$) and t_{lim} at V_{peak} (min) obtained from the experimental protocol for determining the V_{peak}.

	GVP (n = 8)				GVO$_2$ (n = 6)				
Variable	**Pre**	**Post**	**Dif. (90 % CI)**	**Inference (P/T/N)**	**Pre**	**Post**	**Dif. (90 % CI)**	**Inference (P/T/N)**	**Group × time interaction (P)**
V_{peak} ($km \cdot h^{-1}$)	16.7 ± 1.2	17.6 ± 1.5 *	0.9 [0.4–1.4]	Very likely 98/2/0	17.1 ± 1.9	17.7 ± 1.6 *	0.6 [0.2–1.0]	Possible 72/28/0	0.352
Duration (min)	23.0 ± 3.7	25.8 ± 4.4 *	2.8 [1.5–4.1]	Very likely 99/1/0	24.3 ± 5.7	26.4 ± 4.7 *	2.2 [0.4–3.9]	Likely 81/19/0	0.566
HR_{max} (bpm)	189 ± 5.0	191 ± 6.0	1.6 [− 0.6–3.8]	Possible 66/32/2	183 ± 10.0	184 ± 12.0	1.8 [− 4.1–7.7]	Unclear 42/48/10	0.943
RPE_{max} (AU)	19.9 ± 0,4	19.9 ± 0.4	− 0.1 [− 0.6–0.3]	Unclear 20/23/57	19.7 ± 0.5	19.8 ± 0.4	0.2 [− 0.5–0.8]	Unclear 55/25/20	0.449
LA_{peak} ($mmol \cdot L^{-1}$)	9.3 ± 0.6	10.3 ± 0.8	0,9 [− 0.2–2.1]	Likely 81/15/3	8.0 ± 0.6	9.0 ± 1.0	1.1 [− 1.0–3.1]	Unclear 74/15/11	0.914
t_{lim} (min)	6.8 ± 1.6	6.7 ± 1.3	− 0.1 [− 0.6–0.4]	Unlikely 7/72/21	7.7 ± 1.8	6.8 ± 2.3	− 0.9 [− 1.7- − 0.1]	Likely 1/14/85	0.130

* P < 0.05 in relation to pre moment to the same group. Dif = Difference; (P/T/N) = Positive/Trivial/Negative

▶ **Table 3** Mean ± standard deviation (SD) difference (90 % CI), magnitude of inference, and significance level for group × time interaction (P) for the variables: VO_{2max} ($ml \cdot kg^{-1} \cdot min^{-1}$), vVO_{2max} ($km \cdot h^{-1}$), total duration of incremental test (min) HR_{max} (bpm) RPE_{max} (AU), LA_{peak} ($mmol \cdot L^{-1}$) and t_{lim} at vVO_{2max} (min) obtained from the determination of the protocol vVO_{2max}

	GVP (n = 8)				GVO$_2$ (n = 6)				
Variable	**Pre**	**Post**	**Dif. (90 % CI)**	**Inference (P/T/N)**	**Pre**	**Post**	**Dif. (90 % CI)**	**Inference (P/T/N)**	**Group × time interaction (P)**
VO_{2max} ($ml \cdot kg^{-1} \cdot min^{-1}$)	50.2 ± 3.5	50.0 ± 2.3	− 0.2 [− 2.2–1.8]	Unclear 19/52/29	49.0 ± 6.9	48.9 ± 6.1	− 0.1 [− 1.7–1.6]	Unlikely 4/90/6	0.957
vVO_{2max} ($km \cdot h^{-1}$)	16.4 ± 1,4	17.0 ± 1.3 *	0.6 [0.3–1.0]	Likely 93/7/0	17.2 ± 1.7	17.5 ± 1.9	0.3 [− 0.1–0.8]	Possible 37/62/1	0.317
Duration (min)	21.6 ± 4.8	23.3 ± 4.2 *	1.7 [0.4–3.0]	Likely 81/19/0	23.7 ± 5.9	24.9 ± 5.2 *	1.2 [0.2–2.2]	Possible 36/64/0	0.601
HR_{max} (bpm)	193 ± 11.0	190 ± 6.0	− 2.9 [− 9.0–3.3]	Possible 7/37/54	183 ± 8.0	182 ± 7.0	− 0.8 [− 4.2–2.5]	Possible 8/65/27	0.623
RPE_{max} (AU)	18.8 ± 2.1	19.5 ± 1.1	0.8 [0.0–1.5]	Possible 75/24/1	19.0 ± 1.7	19.3 ± 1.3	0.3 [− 0.3–1.0]	Possible 43/53/4	0.470
LA_{peak} ($mmol \cdot L^{-1}$)	9.1 ± 1.9	8.8 ± 1.3	0.5 [− 0.5–1.5]	Possible 67/24/9	8.4 ± 1.1	8.0 ± 2.5	− 0.8 [− 1.6–0.1]	Possible 1/28/71	0.911
t_{lim} (min)	7.5 ± 1.7	6.7 ± 1.1	− 0.8 [− 2.3–0.6]	Possible 8/21/72	6.3 ± 1.4	6.1 ± 2.1	0.5 [− 0.8–1.7]	Unclear 57/30/13	0.225

* P < 0.05 in relation to pre moment to the same group. Dif = Difference; (P/T/N) = Positive/Trivial/Negative

▶ **Table 4** Mean ± standard deviation (SD), difference (90 % CI), magnitude of inference, and significance level for group × time interaction (*P*) for the variables in the time trial of 10 km (min), average speed (AS) 10 km ($km \cdot h^{-1}$) HR_{max} (bpm), RPE_{max} (AU) and LA_{peak} ($mmol \cdot L^{-1}$), obtained from the 10 km track performance.

Variable	GVP (n = 8)				GVO_2 (n = 6)				Group × time interaction (*P*)
	Pre	Post	Dif. (90 % CI)	Inference (P/T/N)	Pre	Post	Dif. (90 % CI)	Inference (P/T/N)	
Time (min)	41.3 ± 2.4	39.9 ± 2.7 *	−1.4 [−2.5- −0.3]	Likely 1/8/91	40.1 ± 3.4	39.2 ± 2.9 *	−0.9 [−1.6–0.2]	Possible 0/37/63	0.517
AS 10-km	14.6 ± 0.9	15.1 ± 1.1 *	0.6 [0.1–1.0]	Likely 92/7/1	15.1 ± 1.3	15.4 ± 1.2 *	0.4 [0.1–0.6]	Possible 60/40/0	0.478
HR_{max} (bpm)	179 ± 8.0	179 ± 5.0	2.9 [−1.5–7.3]	Possible 58/39/3	171 ± 10.0	173 ± 8.0	6.5 [−1.0–14.0]	Likely 86/11/3	0.404
RPE_{max} (AU)	18.8 ± 1.9	18.8 ± 1.9	−0.1 [−0.8–0.5]	Unclear 15/49/35	18 ± 2.8	17.0 ± 2.6	0.0 [−0.5–0.5]	Unclear 15/70/15	0.792
LA_{peak} ($mmol \cdot L^{-1}$)	7.8 ± 2.0	7.7 ± 1.7	−0.1 [−1.7–1.5]	Unclear 27/39/34	6.7 ± 0.6	7.4 ± 0.8	0.7 [−0.2–1.6]	Likely 85/9/6	0.486

* $P < 0.05$ in relation to pre moment to the same group. Dif = Difference; (P/T/N) = Positive/Trivial/Negative

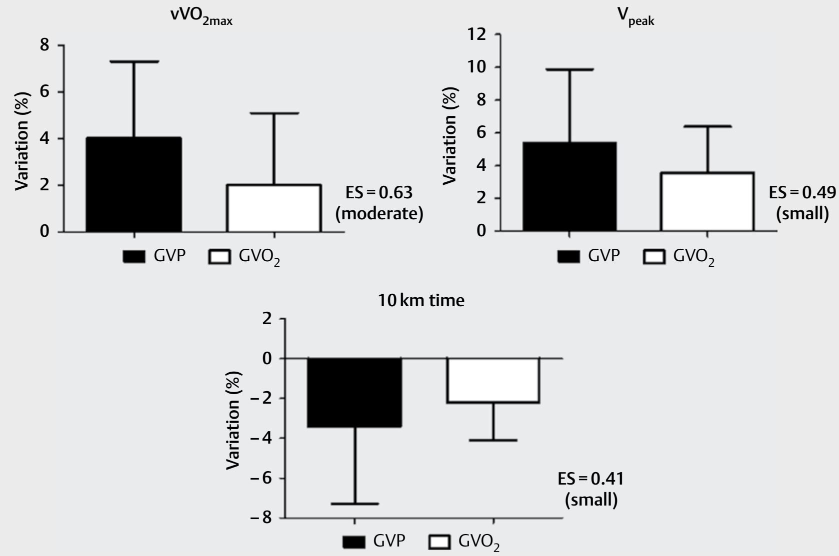
correlation of the V_{peak} with the 10 km performance compared with the vVO_{2max}.

For proper training prescription, it is necessary to use variables that can control and monitor the intensity of effort and possible physiological adaptations resulting from this practice and, most importantly, show a correlation with performance [7].

In our review, we found no previous studies that had used V_{peak} in the prescription of individualized endurance training. The GVP showed improvement in 10 km performance after 4 weeks of training, suggesting that V_{peak} is an effective variable for prescribing training and is able to promote improvements in performance after a period of training. The improvements found in performance caused by the training prescribed by V_{peak} were similar to those described by studies that used vVO_{2max} for training prescription [13, 35]. As for GVO_2, the improvements in the 10 km performance were similar to those observed for GVP after 4 weeks of training. This improvement in performance is in line with previous studies that used the same variable for training prescription [13, 35]. Esfarjani and Laursen [13] observed improvements in 3 000 m performance after applying a 10 week training in 17 moderately trained runners whose training sessions were prescribed by vVO_{2max} and their respective t_{lim}. Similar improvements observed in the 10 km performance by both prescription variables (V_{peak} and vVO_{2max}) can be explained by the fact that both variables are highly interrelated, as well as related to endurance performance [12, 25, 32]. This similarity is of great interest to coaches, athletes, and researchers, because currently vVO_{2max} is widely known as a variable to predict performance, monitoring, and training prescription [9, 24, 27]. However because it requires the use of expensive equipment, its use is limited to only a few research laboratories, coaches, and athletes. Thus, the V_{peak} is an attractive alternative variable because of its practicality and low financial cost.

Both the V_{peak} and vVO_{2max} groups showed improvement after the training program. This improvement is mainly associated with the prescription model used in the study for interval training sessions. The intensity of the V_{peak} and vVO_{2max} were related to VO_{2max}, which is considered the ideal intensity to utilize the maximum aerobic production system energy and maintain it as long as possible [31]. Moreover, the stimuli had a duration of 60 % of t_{lim} at V_{peak} and vVO_{2max}, which is considered the time required to achieve and maintain the VO_{2max}, resulting in an improvement in the prescription variable [5, 31]. No evidence was provided, however, about the existence of a limit to the improvement in prescription variables with training, or if they might be bettered by improving the performance test.

The improved V_{peak} demonstrates the sensitivity of this variable in that it is capable of accurately monitoring the changes caused by this type of training, which is one of the main requirements for an athletic training prescription variable [7]. Regarding vVO_{2max}, improvement was observed for post-training GVP, but no difference was found in the GVO_2 after the 4 weeks of training. It is noteworthy that even without a statistical difference in vVO_{2max}, there was significant improvement in the total duration of the incremental test when we observe the pre- and post-training duration (23.7 ± 5.9 vs. 24.9 ± 5.2 min, respectively). The improvement in test time and the absence of improvement in vVO_{2max} may be related to the methodology for its determination, which is to record the minimum intensity at which the occurrence of VO_{2max} was observed [2, 4]. In addition to being dependent on VO_{2max}, this estimation is not considered



▶ **Fig. 1** Effect sizes of the comparison between GVP and GVO_2 for the variation (%) of vVO_{2max} ($km \cdot h^{-1}$) V_{peak} ($km \cdot h^{-1}$) and the 10 km time after the 4 week running training period.

▶ **Table 5** Correlation between the performances of 10 km before and after 4 weeks of training with the variables: V_{peak} ($km \cdot h^{-1}$), VO_{2max} ($ml \cdot kg^{-1} \cdot min^{-1}$), vVO_{2max} ($km \cdot h^{-1}$).

	GVP (n = 8)		GVO_2 (n = 6)	
Variable (Pre and Post)	**Performance Pre**	**Performance Post**	**Performance Pre**	**Performance Post**
V_{peak} ($km \cdot h^{-1}$)	−0.97 *	−0.86 *	−0.95 *	−0.94 *
VO_{2max} ($ml \cdot kg^{-1} min^{-1}$)	−0.35	0.03	−0.64	−0.70
vVO_{2max} ($km \cdot h^{-1}$)	−0.82 *	−0.88 *	−0.99 *	−0.98 *

* $P < 0.05$

the total period of the test; therefore, even with the improvement in test duration, the occurrence of VO_{2max} can be observed at similar intensities between the pre- and post-training, with no change in vVO_{2max}. This does not occur with the V_{peak} when the Kuipers et al. [23] adjustment (which takes into account the precise length of the incomplete stage) is applied. This result shows that vVO_{2max} determined by this protocol is a less accurate alternative variable for monitoring training when possible adaptations are small. It also supports the use of V_{peak} as a variable for monitoring and training prescription because it is sensitive to small changes caused by training. This sensitivity is of great interest since the more highly trained the athletes, the smaller the improvements will be. Even detection of these small gains would warrant a new training protocol.

As for t_{lim} at V_{peak} and vVO_{2max}, no difference was found for these variables after the 4 week training program. This result deserves further consideration, however, because after the training program the participants have managed to remain at t_{lim} the same amount of time while exercising at higher intensities. These results were similar to those of Billat et al. [2], who also found no difference at t_{lim} after a 4 week training protocol. The t_{lim} seems to be a variable that does not follow the changes caused by training [24]. Despite that, the application of t_{lim} for prescribing interval training favors greater individualization of the duration of each high-intensity effort, given the large variation between subjects at t_{lim}, even if V_{peak} or vVO_{2max} do not show major differences between the subjects.

No improvements were seen at VO_{2max} in either group after the training program. Results from previous studies observed the effect of a training program on VO_{2max} in trained endurance runners with similar training prescriptions to those used in our study [2, 31, 35]. Even without changes in VO_{2max}, these studies have in common a significant improvement in performance, demonstrating that VO_{2max} seems to be a less sensitive training variable, which in turn suggests that the use of other variables for monitoring adaptations may be warranted [8, 20, 26].

No changes were observed in variables $HR_{max} \cdot LA_{peak}$, or RPE_{max}, either in the treadmill test or in track performance. The absence of change to these variables after training was expected because they are routinely used for the identification of physiological responses generated by the effort [17]. They serve as a parameter for identifying the maximum effort during the incremental test [14]. Thus, for already moderately trained runners such as our participants, the 4 week training period is a short time to promote changes in the said variables, especially in HR.

The correlation among V_{peak}, vVO_{2max}, and performance in the present study was also observed in previous studies [3, 26]. In the present study, the GVO_2 presented higher correlation of the performance with vVO_{2max} than with V_{peak}. The ability to predict performance by vVO_{2max} is related to the fact that it is a variable that shows the interaction between VO_{2max} and running economy (RE) [3, 12, 26], which are important variables for predicting performance. However, they are not able to predict the performance as isolated variables [19], especially in individuals with similar VO_{2max} and/or who have a high level of training [28]. Unlike the GVO_2, the GVP group showed a higher correlation between V_{peak} and 10 km performance in the pre-training time. Previous studies have also shown high correlations between V_{peak} and performance [11, 36]. Noakes et al. [30], in a study on expert runners over long distances (20 marathoners and 23 ultra-marathoners) with different performances, found that V_{peak} determined on a treadmill and lactate threshold (LT) were the 2 best performance predictors from 10- to 90 km running performances, concluding that V_{peak} is a great predictor of performance. Even in groups presenting different correlations of each variable (V_{peak} and vVO_{2max}) with performance, it was observed that both were able to predict performance, justified by the fact the 2 variables are highly interrelated [26].

Although studies show that VO_{2max} has a great capacity for performance prediction in races ranging from 3 km through ultramarathons [1, 26–28], in this study no correlation was found between VO_{2max} and 10 km performance in either the pre-training time or post-training time in either group. The fact that the runners present a similar VO_{2max} may indicate that the VO_{2max} is not as efficient a variable to predict the performance when individuals have similar VO_{2max} [12]. The results demonstrated in this study have important practical implications for teams, coaches, and athletes in obtaining information about the adaptations induced by training, especially its effects on performance, given that the V_{peak} is a variable of great practicality and low financial cost because it does not require expensive equipment (gas analyzer).

Based on the results of this study, it was concluded that the training prescribed by V_{peak} promoted improvements similar to the training prescribed by vVO_{2max} in moderately trained endurance runners. Therefore, we recommend the additional use of V_{peak} associated with its time limit for endurance training prescription in recreational runners with a similar training level to that of the study participants.

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