

Neuromuscular Adaptations, Performance, and Monitoring of Endurance Training Within Moderate Domain Intensities

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Abstract

Guimarães, MP, Foresti, YF, Papoti, M, and de Azevedo, PHSM. Neuromuscular adaptations, performance, and monitoring of endurance training within moderate domain intensities. *J Strength Cond Res* XX(X): 000–000, 2026—This study aims to find whether training at the upper limit of the moderate domain or below it (10–15%) differently affects neuromuscular and psychophysiological responses and performance. A total of 20 trained amateur runners participated in this 12-week study. In the first 4 weeks, subjects underwent familiarization with the tests and training. Then the subjects were divided into 2 groups ($n = 10$ per group, with 6 men and 4 women in each group): VL₁ and <VL₁, in which they were expected to train at the upper limit of the moderate domain and 10–15% below it for 6 weeks, respectively. The training was designed to be volume-equated between groups. Body composition, neuromuscular adaptations, and performance were evaluated, and the training and recovery sessions were monitored for psychophysiological factors. The groups showed no significant differences in neuromuscular and performance variables, although they improved from the pre- to post-intervention periods, except for D', which worsened in both groups. The psychophysiological variables differed between the groups at some times, being higher for the VL₁ but within acceptable limits. Training at the upper limit of the moderate domain or 10–15% below it similarly improves trained amateur runners' neuromuscular variables and performance.

Key Words: aerobic training, critical speed, training load, vertical jump

Introduction

The prescription of endurance training consists of external stimuli structured according to the management of variables such as training volume (kilometers or minutes), intensity (work, average speed, pace), and frequency (7). The manipulation of these stimuli and the control of the psychophysiological response can optimize the process of general adaptation syndrome (35). This strategy aims to mitigate fatigue, reduce the risk of injury, avoid overtraining, and increase sports performance (6).

However, debates persist on the optimal adjustment of volume and intensity within training endurance (13,27). The training intensity distribution (TID) in sports planning seems to configure an important factor to optimize performance and establish the physical and psychological integrity of endurance athletes (14). Several TID division models exist (7). Training intensity distribution may fall into moderate, heavy, and severe physiological domains (37). Some TID prescribe pyramidal (13), polarized (27), and threshold programs (23). Regardless of the model, most training occurs in the moderate domain. However, it remains unclear whether it is necessary to train at the upper end of moderate dominance (60) or if the stress at lower intensities (usually

used as recovery training) (14,16) can generate positive physiological adaptations and improve performance.

The continuous assessment of psychophysiological response and performance aids fine-tuning the training (54). Subjective rate of perceived exertion (RPE) (26), total quality of recovery (TQR) (45), the Hooper scale (36), jump height (3), and critical speed (CS) (41) serve to organize and control training loads. In addition, CS and countermovement jump (CMJ) and drop jump (DJ) height, for example, positively relate to long-distance runners' performance in 5- and 10-km races (25) and with adaptations to training (11). However, it remains unknown whether endurance athletes show different acute and chronic responses to these training monitoring indices under training with the same volume and varying relative intensity within the moderate domain or whether this modulates performance differently.

The combined analysis of neuromuscular, performance, and psychophysiological training variables can evince responses to endurance training. It is unclear how these parameters behave across different training methods within the moderate domain. This study aims to determine whether training at the upper limit of the moderate domain or below it affects performance and psychophysiological and neuromuscular responses differently in trained amateur runners. This research raised the following hypotheses: I—both groups would improve their performance according to the comparison between the pre- and post-

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intervention moments; II—the higher relative intensity of one group in relation to the other would generate different neuromuscular, performance, and psychophysiological responses.

Methods

Experimental Approach to the Problem

Figure 1 shows a schematic of the experimental design of this study.

This study lasted 12 weeks. At the first meeting 5 weeks before the start of the intervention, subjects familiarized themselves with the CS protocol and were instructed to perform all training sessions (5 times a week) in the moderate domain (14). The first 4 weeks were used to ensure that all subjects were at the same point in the training organization before the intervention started, thus avoiding possible interferences from individual annual planning. All subjects had experience with all the variables of this study. Thus, intensity was controlled by momentary RPE and the predicted speed in the 3200-m time trial test (64). Training sessions were conducted within the proposed parameters and controlled by an evaluator. During these 4 weeks, subjects familiarized themselves with the gas analyzer mask, the jump test, the GPS watch, effort and recovery scales, acquisition of retrospective volume data, and how to report training information.

After the 4-week equalization period, subjects attended an informational session detailing the subsequent study phases. After this, they were allocated into 2 groups based on their average weekly training volume: VL₁ and <VL₁. This allocation was a predetermined criterion of the study design to examine the relationship between training volume and performance. Thus, the 20 individual average weekly volumes were listed (individual 1: 62.4 km; individual 2: 62.1 km; individual 3: 60.3 km; individual 4: 60.3 km; individual 5: 54.7 km; individual 6: 54.6 km; individual 7: 51.8 km; individual 8: 51.4 km; individual 9: 49.2 km; individual 10: 48.9 km; individual 11: 47.3 km; individual 12: 47.0 km; individual 13: 44.5 km; individual 14: 44.5 km; individual 15: 42.7 km; individual 16: 42.6 km; individual 17: 41.8 km; individual 18: 41.4 km; individual 19: 37.7 km; individual 20: 36.1 km) based on the previous year of training. Odd numbers

were allocated to VL₁ and even numbers to <VL₁, except for numbers 19 and 20, who were swapped so the groups were homogeneous regarding previous training volume and performance.

The following 8 weeks were divided as follows: 1 week of testing (within the pre-intervention period); 6 weeks of training (intervention); and 1 week of retesting (post-intervention).

Pre-intervention. This moment comprised the 5 weeks before the start of the 6 weeks of training. The first 4 weeks were used to equalize the groups regarding initial performance, familiarization, and randomization. The pretesting moment began in the week after these 4 weeks, in which the following evaluations were made: on the first Sunday morning, the anthropometric evaluation and jump tests (CMJ, SJ, and DJ) were carried out in this sequence. On Wednesday, at individual times and according to subjects' availability, the maximal progressive treadmill test was performed to determine their $\dot{V}O_{2\max}$, VL₁, and VL₂. Finally, tests were carried out on Saturday to determine D' and CS. In all the tests, the temperature ranged from 16 to 22 °C, with a relative humidity varying from 40 to 65%.

Intervention. Intervention took place during the 6 weeks of training, which consisted of 5 sessions a week, totaling 30 sessions. Subjects sent their individual responses to the effort and recovery scales (session RPE, TQR, and Hooper scales) by messaging applications daily. They also sent GPS-recorded volume and intensity data. Subjects had to complete more than 90% of the prescribed sessions (15,54).

Post-intervention. Post-intervention comprised the week after the intervention. Test organization followed the pre-intervention structure.

Subjects

A total of 20 trained amateur runners (15,54), divided into VL₁ group (6 men and 4 women; mean $\pm$ SD: age = 35.2 $\pm$ 6.8 years [from 26 to 50], height = 1.71 $\pm$ 0.08 m, body mass = 70.1 $\pm$ 7.69 kg, fat percentage = 16.1 $\pm$ 1.71%, training time = 6.2 $\pm$

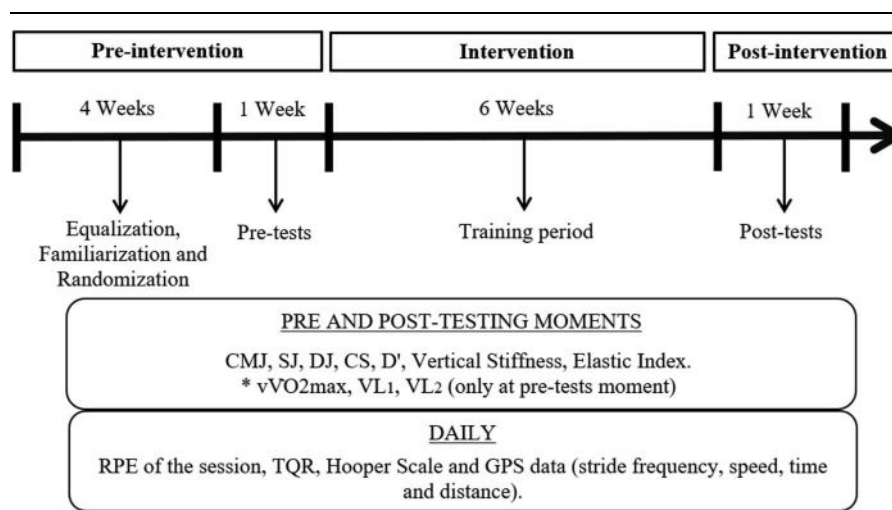


Figure 1. Schematic presentation of the study's experimental design. CMJ = countermovement jump; SJ = squat jump; DJ = drop jump; CS = critical speed; D' = maximum distance associated with anaerobic work capacity; RPE = rate of perceived exertion; TQR = total quality of recovery; $\dot{V}O_{2\max}$ = minimum speed associated with maximum oxygen consumption; VL₁ = velocity of the first physiological threshold; VL₂ = speed of the second physiological threshold.

1.7 years, and a mean weekly frequency = 5.0 ± 0.4 days) and <VL₁ group (6 men and 4 women; mean $\pm$ SD: age = 37.0 ± 7.9 years [from 25 to 48], height = 1.70 ± 0.10 m, body mass = 70.5 ± 7.21 kg, fat percentage = $16.2 \pm 1.50\%$, training time = 6.1 ± 1.8 years, and a mean weekly frequency = 5.1 ± 0.5 days), were recruited intentionally or by convenience from running teams and clubs. This number is in line with previous studies (15,59) that compared the performance of amateur runners between and within groups over time. Moreover, the Bayesian factor analysis in this study suffered little influence from sample size (50). Subjects inclusion criteria consisted of (a) men and women with a 10-km race time under 55 minutes; (b) having taken part in competitions in recent years; (c) having over 4 years of uninterrupted specific training in street or track running at distances ranging from 5 to 42.195 km; (d) having a weekly attendance of 5 training sessions in the last 3 months; and (e) having an age from 20 to 50 years. The adopted exclusion criteria were use of ergogenic substances and having cardiovascular and orthopedic pathologies. This project was submitted and approved by a Research Ethics Committee under number 3.183.845. All volunteers were informed about the research risks and signed an informed consent form before participating in this research.

Procedures

Anthropometric Evaluation. Sample characterization determined the height and body mass of subjects by a scale with a stadiometer (110 FF; Welmy, Santa Bárbara d'Oeste, Brazil). Body fat was estimated by a bioimpedance device (Quantum BIA-II; RJL Systems, Clinton Township). Data collection used tetrapolar electrodes (Bio Tetronic, Sanny, São Bernardo do Campo, Brazil). Subjects were instructed to abstain from alcoholic and/or caffeinated beverages and vigorous physical activity for at least 24 hours before the evaluation. Volunteers had to urinate 30 minutes before the assessment and rest for 5 minutes. All data were collected in the morning from euhydrated fasted subjects. Then, they were given a standard breakfast (black coffee, bread, butter, and bananas—runners' basic breakfast).

Vertical Jump Tests. Subjects completed a standard 10-minute warm-up consisting of running (5 minutes at the training speed of the previous 4 weeks, i.e., moderate dominance), dynamic lower-body stretches [$\sim$ 4 minutes for 30 seconds for each unilateral limb consisting of 4 exercises performed standing and starting from the anatomical position: (a) hip flexion with an extended knee trying to reach the foot with short movements (closed kinematic chain); (b) hip flexion and extension with the knee extended and wide movements—"kick forward and kick" (open kinematic chain); (c) flexion and extension of the knees with wide movements—touch the heel to the glutes (open kinematic chain); and (d) plantar flexion and ankle dorsiflexion with the knee extended and the help of a step (closed kinematic chain), and vertical jumps (1 of each type—CMJ, SJ, and DJ—with a 20-second break between them). Then, subjects performed 3 SJ, 3 CMJ, and three 40-cm DJ. The average value of the 3 attempts in all jumps was used for analysis (19). All jumps were performed with hands on hips. Takeoff and landing were standardized for full knee and ankle extension in the same location. Subjects were verbally instructed to jump as high as possible in all jumps. In the DJ, they were instructed to spend as little time as possible with their feet on the ground. Each jump was separated by a 2-minute passive rest period, whereas 5 minutes separated each type of jump. The logistics of the 10 individuals meant that the times were respected.

The application My Jump 2 was used for the calculations (10,34). The jumps were video recorded from about 1.5 m away from subjects. The length and height of the leg with the knees bent at about 90° were measured with a tape measure with a 0.1-cm accuracy. Lower limb length was measured from the anterior iliac spine to the tip of the feet in the lying position. Height at 90° was measured vertically from the anterior iliac spine to the ground in an optimal jumping performance position (the angle of about 90°) (10). The application also tracks vertical "stiffness" in DJ. After evaluating the CMJ and SJ, the elastic index (EI) of the groups was calculated, and the difference between the CMJ and SJ was calculated by the formula:

$$EI = (CMJ - SJ) \times 100/SJ.$$

$\dot{V}O_{2max}$, VL₁, and VL₂ Determination. $\dot{V}O_{2max}$, VL₁, and VL₂ were measured by a maximum incremental protocol on a treadmill (Super ATL Inbrasport and Lion Fitness model X4). Before starting it, subjects performed a specific 5-minute warm-up at 65% of the average speed of their 10-km race. After a 3-minute recovery break, the test began at 65% of their average 10-km race speed (20). From this initial speed, an increase of 1 km·h⁻¹ occurred at each 3-minute stage at a 1% incline (40). During the test, subjects received verbal encouragement from the lead researcher—such as "let's go" and "it's going great"—while they ran up to voluntary exhaustion (20). Oxygen uptake ($\dot{V}O_2$) was measured breath-by-breath using 2 gas analyzers (COSMED K4b², Rome, Italy, and COSMED QUARK CPET, Rome, Italy) and converted into 30-second averages. Half of the sample from each group was assessed with 1 analyzer and the other half of each group with the other analyzer, before and after the intervention. Before each test, we calibrated the gas analyzers according to the manufacturer's specifications using ambient air and a gas of known composition containing 12% O₂ and 5% CO₂. $\dot{V}O_{2max}$ was determined using a software (<https://exercisethresholds.com/>) (44). $\dot{V}O_{2max}$ evaluated the minimum speed at which subjects were running during $\dot{V}O_{2max}$ (8). $\dot{V}O_2$ at the first physiological threshold and its respective intensity were determined by increased ventilatory oxygen equivalent (VE/ $\dot{V}O_2$) and end-expiratory oxygen pressure (PETO₂) without a concomitant increase in ventilatory carbon dioxide equivalent (VE/ $\dot{V}CO_2$) (18,63). $\dot{V}O_2$ at the second physiological threshold and its respective intensity were determined by an increase in VE/ $\dot{V}O_2$ and VE/ $\dot{V}CO_2$ and a decrease in PETCO₂ (22,63). For these analyses, 2 experienced and independent researchers measured these variables. If the 2 disagreed, a third party would be called to give their opinion (which did not occur).

Critical Speed and D'. Each subjects completed 3 time trial runs on a flat 2-km track with an asphalt surface covering the distances of 3,600, 2,400, and 1,200 m in that order for all sessions. Subjects were instructed to complete each trial in the shortest time possible, and runs were manually timed (S141; Seiko, Tokyo, Japan) to the nearest second. All races were held on the same day with a 30-minute rest between them. No feedback was given on the subjects' performance. All volunteers performed the test individually (31). Critical speed was calculated as the linear relationship between the 3 distances and running times, corresponding to the slope of the linear regression line, in which D' (maximum distance that can be achieved when running just above CS) corresponded to the intercept of this line. The linear distance-time model is represented by: $d = (CS \cdot t) + D'$ in which: d = distance covered and t = running time (30,31,41).

Psychophysiological Response. The session RPE was obtained approximately 30 minutes after the training session ended to rate the global intensity of each session, in which volunteers answered the following question: “How was your workout?” (26), the answer to which was given by subjects based on the RPE scale (CR-10) (28). After classification, the internal training load was calculated by multiplying the RPE score of the session (0–10) by the total duration (min) of the training session, the data of which are shown in arbitrary units (AU) (26). Total weekly training load (sum of the daily loads of all training days), monotony (division of the average weekly load by the *SD* of the individual training sessions), and strain (multiplication of the total weekly training load by monotony) were calculated (57). The Hooper and TQR scales were always answered when individuals woke up. The Hooper scale comprises perceived sleep quality, stress, and muscle fatigue and soreness and is used to collect data from self-reported subjective measures of well-being. Each question was scored on a 7-point scale in which “1” and “7” represented “very, very good” and “very, very poor” well-being ratings, respectively. (36). The TQR scale is a scale that goes from 6 to 20, in which 6 is very, very poorly recovered and 20 is very, very well recovered (45). Weekly averages were used for these variables, which enabled comparisons of the groups in each week throughout the intervention.

Training Prescription. Figure 2 illustrates individuals’ 6-week training. VL₁ was instructed to follow the upper limit speed of the moderate domain and <VL₁, to follow 10–15% below it (this being the only difference between groups). We individually equalized training volumes according to kilometer history and weekly training time. Because of the time available for each session and the previous prescription model, training time was adopted as the daily volume. From the previous time and speed, we calculated the distance to equalize the groups. The first 2 weeks had lower volume than weeks 3 and 4, which were the most voluminous. Week 5 was planned to have similar volumes to the first 2 weeks, and the last week was planned to have the lowest volume. All training sessions were monitored by a *Garmin Forerunner 235* GPS watch, which has been scientifically validated for this purpose (39,54). We also collected stride frequency data from this equipment. Each subject had their own watch. The pyramidal TID in this study included ~70% of the total weekly volume in the moderate domain (VL₁ or below it) (61), ~17% of the total weekly training volume in the heavy domain (between VL₁ and VL₂) (7), and ~13% of the total weekly volume in the severe domain (between CS and $\dot{V}O_{2\max}$) (14,29,37). The 6-week intervention and each training sessions were organized based on previous studies (61). Throughout this study, subjects undertook no other complementary training (e.g., strength training or stretching). All moderate domain training sessions were done individually. Training times followed subjects’ availability and habits, most of which took place in the early morning. In all tests, the temperature ranged from 16 to 22 °C and the relative humidity, from 40 to 65%. Because data collection was divided into 2 stages (half of the sample from each group in the first stage and the other half of each group in the second stage), care was taken to ensure that both were performed in the same seasonal phase.

Statistical Analyses

A descriptive analysis was performed, the values of which are shown as mean values and *SD*s. To test the reliability of the CMJ,

SJ, and DJ jump data, we analyzed the intraclass correlation coefficient (ICC) and coefficient of variation (CV) from the 3 jumps at each time point. To verify the (Time + Group + Time × Group) interaction of the study variables, we performed a Bayesian repeated-measures ANOVA for: body weight, body fat, volume interaction in the first and sixth weeks, CS, 3600 m test, D’, CMJ, SJ, DJ, vertical stiffness, and EI. To verify the interaction of the group factor with the variables average volume 6 weeks in kilometers and minutes, and average volume 6 weeks stride frequency, we used the Bayesian Independent Samples T-Test. Finally, to verify the interaction of the group factor, in each of the weeks, with the variables monotony, strain, TQR scale, RPE session, and the sleep, stress, fatigue, and muscle soreness scales, we also used the Bayesian Independent Samples T-Test. The Bayesian factor tests the probability of the same results being repeated in the future (i.e., the magnitude of the evidence). Subsequent probabilities were corrected for multiple testing by setting the prior probability that the null hypothesis would hold across all comparisons to 0.5 (55). Pairwise comparisons were based on the standard *t* test with a previous Cauchy (0, $r = 1/\sqrt{2}$). The “U” in the Bayes factor denotes that it is uncorrected (55). Outcomes were classified as anecdotal ($BF_{10} = 1$ to 3), moderate (3–10), strong (10–30), very strong (30–100), and extreme (>100) favoring the alternative hypothesis or as anecdotal ($BF_{01} = 1$ to 0.33), moderate (0.33–0.1), strong (0.1–0.03), very strong (0.03–0.01), and extreme (<0.01), favoring the null hypothesis (Lee and Wagenmakers classification) (47,56). To calculate the probability of finding the same results, the actual value of BF_{10} was divided by $BF_{10} + 1$. All analyses were performed on the free software JAMOVI.

Results

Table 1 presents the mean ± *SD* of anthropometric variables, the average volume of the 6 weeks of training and interaction in the first and sixth weeks, stride frequency, performance, and neuromuscular variables for each group at each time point. Furthermore, it demonstrates intragroup and intergroup interactions (Time + Group + Time × Group) through BF_{10} values and difference chance.

Anthropometric variables showed no significant changes in both groups over time. There were no significant differences between the prior volume used for randomization of the groups and the average volume in kilometers of the 6 training weeks and in each of them between the groups. There was also no significant difference between the groups in the average training time in minutes, in the 6 training weeks and between each of them. However, despite not finding significance in this comparison, it is evident that individuals in the <VL₁ group trained for longer than those in the VL₁ group in the moderate domain sessions. This fact justifies the equalization of the groups by distance. Furthermore, there was no significant difference in stride frequency between the groups. Stride frequency data from 6 moderate-intensity training sessions in each group were analyzed, with 1 training session per week. The individual averages for the 6 weeks were used for group comparison. In all training sessions, the average steps per minute of individuals in both groups ranged from 158 to 167.

After the 6 weeks of training, the analysis of the average speeds of each session, individual, and group showed that the VL₁ had the distribution of 70.28% in VL₁, of 16.71% between VL₁ and VL₂, and 13.01% between CS and $\dot{V}O_{2\max}$; whereas <VL₁ had the distribution of 70.34% below VL₁, of 16.63% between VL₁

TRAINING PRESCRIPTION							
NAME:	XXX						
DAYS:	5x per week						
VL1: 10,2 km/h VL2: 12,2 km/h CS: 13,2 km/h vVO2max: 14,0 km/h							
1st Week	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
	60' of training on the flat in VL1	45' of training on the flat in VL1	20' of training on the flat at VL1 + 35' of training being: 50% of Tlim between CS and vWO2max for 50% of Tlim below VL1	45' of training on the flat in VL1	Day-off	15' of training on the flat in VL1 + 45' of training on a slight and flat slope and incline, between VL1 and CS	Day-off
2nd Week	60' of training on the flat in VL1	45' of training on the flat in VL1	20' of training on the flat at VL1 + 35' of training being: 50% of Tlim between CS and vWO2max for 50% of Tlim below VL1	45' of training on the flat in VL1	Day-off	15' of training on the flat in VL1 + 45' of training on a slight and flat slope and incline, between VL1 and CS	Day-off
3rd Week	65' of training on the flat in VL1	45' of training on the flat in VL1	20' of training on the flat at VL1 + 40' of training being: 50% of Tlim between CS and vWO2max for 50% of Tlim below VL1	45' of training on the flat in VL1	Day-off	15' of training on the flat in VL1 + 50' of training on a slight and flat slope and incline, between VL1 and CS	Day-off
4th Week	65' of training on the flat in VL1	45' of training on the flat in VL1	20' of training on the flat at VL1 + 40' of training being: 50% of Tlim between CS and vWO2max for 50% of Tlim below VL1	45' of training on the flat in VL1	Day-off	15' of training on the flat in VL1 + 50' of training on a slight and flat slope and incline, between VL1 and CS	Day-off
5th Week	60' of training on the flat in VL1	45' of training on the flat in VL1	20' of training on the flat at VL1 + 35' of training being: 50% of Tlim between CS and vWO2max for 50% of Tlim below VL1	45' of training on the flat in VL1	Day-off	15' of training on the flat in VL1 + 45' of training on a slight and flat slope and incline, between VL1 and CS	Day-off
6th Week	55' of training on the flat in VL1	45' of training on the flat in VL1	20' of training on the flat at VL1 + 30' of training being: 50% of Tlim between CS and vWO2max for 50% of Tlim below VL1	45' of training on the flat in VL1	35' of training on the flat in VL1 + 20' of training on a slight and flat slope and incline, between VL1 and CS	Day-off	Day-off

Figure 2. Example of an individual's training. VL₁ = speed at the first physiological threshold; VL₂ = speed at the second physiological threshold; CS = critical speed; T_{lim} = time limit; and vVO₂max = lower speed associated with maximum oxygen uptake.

and VL₂, and 13.03% between CS and vVO₂max. Thus, TID achieved its goal. The speeds of the moderate sessions followed the criterion of $\pm 0.3 \text{ km} \cdot \text{h}^{-1}$ for VL₁ and 10–15% below VL₁ for <VL₁. This study adopted the average speed of the session, and more than 98% of the data from the VL₁ remained within acceptable limits. The mean speed in <VL₁ equaled 12.06% < VL₁, with sessions ranging from 10.21 to 14.73% below VL₁.

The performance variables (CS, 3600 m test and D') and neuromuscular variables (CMJ, SJ, DJ, vertical stiffness, and EI) presented in Table 1 showed that the interactions of the time factor (pre and post) within the group had a 99% chance of mean improvement, except for the D' variable, which showed a 96%

chance of mean decrease. However, when analyzing the interactions between the groups for these same variables, we found a low chance of difference. For the CMJ, SJ, and DJ variables, in the pre- and post-intervention periods, the ICC and CV values were, respectively, all above 0.970 (0.963–0.990) and all below 3.0 (1.2–2.9).

Table 2 shows mean $\pm$ SD of variables: monotony; strain; TQR scale, RPE session; and the sleep, stress, fatigue, and muscle soreness scales. This study compared the groups at each of the 6 weeks of training. The following interactions between the groups over the 6 weeks were found: For the monotony variable, week 3 showed a 78% mean probability of the VL₁ group having

Table 1

Intragroup and intergroup comparison of the results of anthropometric, average volume of the 6 weeks of training, performance, and neuromuscular variables.*

	VL ₁ group		<VL ₁ group		Time factor		Group factor		BF _{Inclusion}	
	Pre	Post	Pre	Post	Pre × post		VL ₁ × <VL ₁		Group × time	
	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	BF ₁₀	DC (%)	BF ₁₀	DC (%)	BF ₁₀	DC (%)
Body mass (kg)	70.12 ± 7.72	70.13 ± 7.63	70.51 ± 7.41	70.52 ± 7.04	0.29	22	0.96	49	0.51	33
Body fat (%)	16.10 ± 1.72	16.00 ± 1.74	16.20 ± 1.40	16.20 ± 1.43	0.70	42	0.94	49	0.40	28
AVSW (km)	46.60 ± 8.20	46.70 ± 8.50	—	—	0.39	28	—	—	—	—
AVSW (min)	261.1 ± 47.37	278.30 ± 51.04	—	—	0.49	33	—	—	—	—
VIFSW (km)	45.99 ± 8.35	42.30 ± 7.61	46.05 ± 8.37	42.42 ± 7.94	>200	99	0.85	45	0.38	27
VIFSW (min)	259.3 ± 51.01	236.5 ± 42.60	274.2 ± 49.87	252.6 ± 49.87	>200	99	0.85	45	0.41	29
Stride frequency	160.8 ± 2.53	160.3 ± 2.66	—	—	0.42	29	—	—	—	—
CS (km·h ⁻¹)	13.30 ± 1.82	13.70 ± 1.83	13.30 ± 1.53	13.80 ± 1.55	>200	99	1.14	56	0.79	44
3600 m test (s)	928.31 ± 100.63	917.14 ± 98.83	929.81 ± 97.87	913.20 ± 91.23	>200	99	0.85	45	0.53	34
D' (s)	202 ± 65	188 ± 64	191 ± 50	166 ± 59	22.32	96	0.73	42	0.61	37
CMJ (cm)	28.10 ± 7.92	31.31 ± 7.14	30.05 ± 5.71	33.09 ± 6.14	>200	99	0.86	46	0.43	30
SJ (cm)	24.97 ± 6.80	26.37 ± 6.83	25.81 ± 4.78	27.29 ± 4.90	>200	99	0.95	49	0.38	28
DJ (cm)	28.07 ± 7.82	30.54 ± 8.22	29.53 ± 6.27	32.24 ± 6.50	>200	99	0.89	47	0.47	32
VS (kN·m ⁻¹)	4.38 ± 1.13	4.82 ± 1.17	4.43 ± 0.91	4.87 ± 0.92	>200	99	0.84	45	0.43	30
Elastic index (%)	12.81 ± 2.03	19.71 ± 4.31	16.44 ± 3.92	21.40 ± 6.11	>200	99	0.95	49	0.50	33

*BF = Bayes factor; DC = difference chance; AVSW = average volume 6 weeks; VIFSW = volume interaction in the first and sixth weeks; CS = critical speed; D' = maximum distance associated with anaerobic work capacity; CMJ = countermovement jump; SJ = squat jump; DJ = drop jump; VS = vertical stiffness.

higher values than the <VL₁ group; weeks 4 and 5 showed more than 90% of this same mean probability; and week 6 showed a 99% mean probability. For the strain variable, in weeks 2, 4, and 6, there was a 92, 81, and 77% mean probability, respectively, of the VL₁ group having higher values than the <VL₁ group; The TQR variable showed no interaction in any of the weeks; For the RPE session variable, in weeks 2, 3, 4, and 6, there was an 84, 93, 99, and 99% mean probability, respectively, of the VL₁ group having higher values than the <VL₁ group. Finally, for all variables included in the Hooper scale, only the fatigue variable showed interaction between the groups during the weeks: In weeks 3, 4, and 6, there was a 95, 91, and 99% mean probability, respectively, that the VL₁ group had higher values than the <VL₁ group.

Discussion

This study posed the following question: Will trained amateur runners have different neuromuscular, psychophysiological, and performance adaptations performing moderate domain training at VL₁ or <VL₁? How do internal training loads behave for both groups? This study confirmed its hypothesis that both groups would improve their performance between pre- and post-intervention. However, how the magnitudes of these improvements would behave in each group, along with the internal load, was still unknown.

The main results of this study showed that amateur runners trained in VL₁ or <VL₁ improved their performance with a similar magnitude between the groups. The pyramidal TID in this study showed proportions of about 70% in the moderate domain, 17% in the heavy one, and 13% in the severe one (54,65). Finally, VL₁ had a higher internal load value and lower recovery rates than <VL₁ in some training weeks. D' worsened in both groups.

To be included in the analyses, subjects had to have had adhered to more than 90% of training sessions (15,54). Only 4 subjects (2 in each group) failed to complete the 30 training sessions over the 6 weeks. However, they carried out more than 90% of the proposed training. The other 16 subjects completed 100%

of the training. Subjects also had to send all information regarding the control of the training load; completed all initial, intermediate (during the 6 weeks), and final tests; and showed no injuries or complaints of signs that would make it impossible for them to comply with training. In the end, the analysis included all subjects. Modified anthropometric data of weight and fat percentage over the 6 weeks could change the collected variables. As these runners have a long history of training and the diet recommendations in this study suggested maintaining their regular diet, athletes showed no change in body composition.

The biggest novelty of our study involves its comparison under controlled circumstances of the effects of intensity change within the moderate domain in trained amateur runners. Other studies have assessed heavy and severe domains (29,37), determined methods and variables associated with them (14), or prescribed training models in these more intense domains (9,12). However, it is important to better understand the physiological adaptations and load control in the face of training at the upper limit of the moderate domain and below it because more than 70% of runners' training volume lies in this domain. Our results suggest that the terms "regenerative training" or "active recovery," frequently used in the scientific literature (14,16) are mistaken because both groups improved their performance and neuromuscular variables by the same magnitude.

Another novelty of this study refers to its Bayesian statistics as they minimize dichotomous information in the pre- and post-intervention and intergroup analyses (whether the same or different), adding information on the probabilities of possible results if the study is replicated and directly transferring information to coaches (47,56).

Critical speed improved in both groups, with no significant differences between them. Its improvement reflects a higher rate of energy resynthesis by the oxidative pathway at the maximum speed that still enables the metabolic steady state (41,43), i.e., the upper limit of the heavy domain (29,37). Critical speed configures an important predictor of endurance performance in 5- and 10-km races (25,46) and marathons (42).

This study used 3 time trial tests in a single day (31). This method saves days of testing, bringing science closer to practice.

Table 2

Descriptive values of the variables monotony; strain; TQR scale; RPE session; and the sleep, stress, fatigue, and muscle soreness scales in each group over the 6 weeks.*

	Week 1			Week 2			Week 3			Week 4			Week 5			Week 6		
	VL ₁	Mean ± SD	<VL ₁	VL ₁	Mean ± SD	<VL ₁	VL ₁	Mean ± SD	<VL ₁	VL ₁	Mean ± SD	<VL ₁	VL ₁	Mean ± SD	<VL ₁	VL ₁	Mean ± SD	<VL ₁
Monotony (AU)	1.12 ± 0.1	1.08 ± 0.1	1.11 ± 0.1	1.15 ± 0.1	1.11 ± 0.1	1.11 ± 0.1	1.14 ± 0.1	1.11 ± 0.1	1.11 ± 0.1	1.19 ± 0.1	1.13 ± 0.1	1.13 ± 0.1	1.14 ± 0.1	1.10 ± 0.1	1.10 ± 0.1	1.12 ± 0.1	1.05 ± 0.1	1.05 ± 0.1
Strain (AU)	1.277 ± 0.347	1.060 ± 0.256	1.254 ± 0.193	1.573 ± 0.275	1.254 ± 0.193	1.254 ± 0.193	1.576 ± 0.221	1.449 ± 0.147	1.449 ± 0.147	1.779 ± 0.223	1.596 ± 0.115	1.596 ± 0.115	1.454 ± 0.141	1.339 ± 0.118	1.339 ± 0.118	1.199 ± 0.185	1.035 ± 0.155	1.035 ± 0.155
TQR scale (AU)	15.0 ± 1.4	16.1 ± 1.7	15.6 ± 1.2	14.8 ± 1.1	15.6 ± 1.2	15.6 ± 1.2	15.1 ± 1.0	15.5 ± 1.2	15.5 ± 1.2	15.9 ± 0.9	16.2 ± 1.4	16.2 ± 1.4	15.7 ± 0.8	16.0 ± 0.9	16.0 ± 0.9	17.8 ± 0.5	18.3 ± 1.0	18.3 ± 1.0
RPE session (AU)	4.0 ± 0.5	3.6 ± 0.6	4.2 ± 0.4	4.7 ± 0.5	4.2 ± 0.4	4.2 ± 0.4	4.7 ± 0.3	4.3 ± 0.2	4.3 ± 0.2	5.3 ± 0.2	4.9 ± 0.1	4.9 ± 0.1	4.6 ± 0.2	4.4 ± 0.2	4.4 ± 0.2	4.1 ± 0.3	3.5 ± 0.2	3.5 ± 0.2
Sleep (AU)	3.1 ± 0.8	2.8 ± 0.9	2.2 ± 0.7	2.3 ± 0.7	2.2 ± 0.7	2.2 ± 0.7	2.4 ± 1.5	2.3 ± 1.2	2.3 ± 1.2	2.5 ± 1.1	2.4 ± 0.9	2.4 ± 0.9	2.5 ± 0.9	2.4 ± 0.9	2.4 ± 0.9	1.9 ± 0.8	1.8 ± 0.7	1.8 ± 0.7
Stress (AU)	2.5 ± 1.5	2.1 ± 0.9	2.0 ± 1.1	2.5 ± 1.2	2.0 ± 1.1	2.0 ± 1.1	2.6 ± 1.3	2.2 ± 1.2	2.2 ± 1.2	2.4 ± 1.1	2.2 ± 1.1	2.2 ± 1.1	2.2 ± 0.9	2.2 ± 0.8	2.2 ± 0.8	1.7 ± 0.6	1.6 ± 0.5	1.6 ± 0.5
Fatigue (AU)	2.5 ± 0.5	2.5 ± 0.7	2.4 ± 0.9	2.8 ± 0.6	2.4 ± 0.9	2.4 ± 0.9	3.4 ± 0.5	2.6 ± 0.5	2.6 ± 0.5	3.4 ± 0.7	2.6 ± 0.5	2.6 ± 0.5	2.6 ± 0.4	2.4 ± 0.5	2.4 ± 0.5	1.9 ± 0.2	1.4 ± 0.3	1.4 ± 0.3
MS (AU)	2.4 ± 0.7	2.2 ± 0.8	2.2 ± 0.8	2.6 ± 0.2	2.2 ± 0.8	2.2 ± 0.8	2.7 ± 0.5	2.4 ± 0.7	2.4 ± 0.7	2.9 ± 0.6	2.4 ± 0.7	2.4 ± 0.7	2.4 ± 0.5	2.0 ± 0.3	2.0 ± 0.3	1.8 ± 0.5	1.5 ± 0.4	1.5 ± 0.4

*VL₁ = VL₁ group; <VL₁ = <VL₁ group; AU = arbitrary units; TQR = total quality of recovery; RPE = rate of perceived exertion; MS = muscle soreness.

Other positive points of using this variable is that it is cheap and simple and offers ecological validity for training prescriptions (31). This method could evaluate D' because it hypothetically represents the maximum distance in runs just above CS (41). The union of these variables, which can include prescription and control of training, provides coaches and physical trainers with an important tool to organize training.

The improvement in CS from the pre- to post-intervention moment in both groups shows the efficacy and sensitivity of this variable as a marker of performance in trained amateur runners in a relatively short period of training (6 weeks). The literature has used CS as a marker of performance in an endurance training program (24).

The similarity of improvement in CS between the groups occurred in the study by Galbraith et al. (30). The authors of this 1-year study found that the total volume of training in kilometers and the percentage of training time in the heavy and severe domain explained 33% of peak speed variation. They suggested that interval and continuous training can effectively increase CS, specially by increasing the volume of training above the second physiological threshold (30,41). We showed that training in the moderate domain or below it also effectively improved CS in a pyramidal TID. Approximately 30% of the weekly volume lied in the heavy and severe domains. Because the change between the groups only occurred in the moderate domain, it suggested that adaptations primarily from the heavy and severe domains were the same between groups. As continuous training in the heavy domain usually occurred at a race pace, intensity may have exceeded the second physiological threshold at certain times. Thus, training in the moderate domain or 12% below in a pyramidal distribution equally and positively modulates CS.

The D' of both groups decreased at the end of the 6 weeks by similar magnitudes. Thus, the training organization in this study worsened trained amateur runners' anaerobic capacity. This result holds importance as previous studies have shown that this variable can be decisive in the final moments of races or in changes of pace (41). Other studies have shown that 2 sessions of high-intensity interval training (HIIT) per week and power training could maintain or increase the D' of untrained subjects by up to 49% (38), unlike our method and our results. An explanation for the decrease in D' together with the increase in CS refers to the pyramidal model with only 1 HIIT a week, which seems to favor the improvement of aerobic capacity and power. Thus, we can suggest that athletes with prominent imbalances between peak speed and D' (aerobic and anaerobic capacity, respectively) use the pyramidal model at some moment of a sports season as our data suggest that this model would favor the increase of aerobic fitness and performance. On the other hand, power and sprint training are suggested to improve D' (38). Moreover, in highly trained athletes, a decrease of about 24% in D' occurred over 1 year of training (30), agreeing with our data and showing that only systematic training can reduce D'. Thus, as with other variables, no difference in the magnitude of change occurred between the groups, which we attributed to the equality of training in the heavy and severe domains because these could change D' in different proportions.

The performance improvements in both groups were mainly attributed to mechanical factors. However, we are unable to rule out peripheral biochemical (e.g., increased mitochondrial density, citrate synthase activity, and decreased peak inorganic phosphate) and vascular (e.g., increased capillarization and fiber/capillary ratio) changes because this study did not address these factors.

Vertical jump height has served as a sensitive parameter for adaptations to training (11) and neuromuscular status in runners (3). The reliability of the CMJ, SJ, and DJ data, represented by the ICC and CV, is in accordance with the scientific literature for the sample in question (1,21). In addition to CMJ, SJ, and DJ, this study evaluated vertical stiffness and EI by a scientifically tested and validated mobile application (10,34,54).

Neuromuscular parameters can positively influence trained amateur runners' performance (4,49,53). This improvement seems to be related to the lower activation of the muscles of the lower limbs during propulsion, improvement of agonist-antagonist co-activation of the thigh muscles, greater pre-activation of the muscles, and greater stiffness of the lower limbs, the latter showing a positive association with the improvement of running economy (49). In fact, race economy is strongly correlated with endurance race performance (11) and seems to suffer great influence from lower limb rigidity (4,11,49).

Our hypothesis that jump height and vertical stiffness would improve between pre- and post-intervention agrees with some studies (2,3,49). However, jump height in trained amateur runners is contradictory. The study by Nuutila et al. (54), for example, evaluated recreational runners for 10 weeks and found no differences in CMJ height. However, it analyzed 2 groups that increased, after a base period, volume (volume group), and intensity (intensity group). However, our study only changed the intensity within the moderate domain. A possible explanation for such differences refers to the structuring of training because the groups in the study by Nuutila et al. (54) progressively increased the volume and intensity under a polarized TID, unlike our study. However, corroborating our study, Mikkola et al. (51) found an increase in CMJ height and performance of recreational runners after 8 weeks of running-specific training associated with 2 strength training sessions per week.

Several explanations can be given for the increases in neuromuscular variables in both groups because each test to assess neuromuscular performance has specific characteristics. Countermovement jump and DJ take advantage of the stretching-shortening cycle, a neural and structural mechanism with elastic and active components (48). However, SJ first induces hysteresis, which dissipates the energy of the elastic components into heat. Thus, a balance between eccentric and concentric actions could influence markers of runner performance because the eccentric contractions that store elastic energy are less expensive than energy-releasing concentric contractions (4). Specifically in running, the elastic energy stored during the eccentric contractions of running contributes substantially to propulsion as the subsequent concentric contractions release it. A higher ratio of eccentric to concentric activity is associated with lower metabolic demand, i.e., better running economy (4). Li et al. (48) concluded that superior running economics in long-distance runners may be related to greater eccentric strength, elastic energy use, and stiffer lower limbs during running but not to maximal muscle strength per se. Cavagna et al. (17) estimated that the $\dot{V}O_2$ during running can be 30–40% higher without contributions from elastic storage and energy return. At higher running speeds, the return of elastic energy prevails over the contractile machinery and accounts for most of the work (4). Because of no differences in jump height, vertical stiffness, and EI between the groups, we concluded that the adaptations to training at the upper limit of the moderate domain and below it showed the same magnitude. The difference in speed from one group to another (even if it only totals 12%) also increases stress or mechanical load (32), especially when added to the weekly moderate volume.

Although the total training volume (in kilometers) was the same between the groups, the mechanical load profile was likely different. The groups had different speeds in the moderate-intensity training sessions (VL₁ group with an average of 10.1 km·h⁻¹ and <VL₁ group with an average of 9.1 km·h⁻¹—unpublished data from our group). Thus, the VL₁ group trained for less time than the <VL₁ group in most sessions, although this difference was not significant. In addition, we found no differences in stride frequency between the groups during these sessions. Previous studies have shown that, at lower speeds like ours, stride frequency was around 160 steps per minute, corroborating our findings (33,62). Furthermore, they found significant increases in stride length with increased speed, suggesting that the difference between the groups may lie in this increase. Therefore, biomechanical parameters such as ground reaction force, ground contact time, stride length, and impulse (the integral of the force-time curve) should also be discussed for a better understanding of the results. When stride length increases at different speeds while stride frequency remains constant, ground reaction force also increases (52). However, ground contact time is substantially shorter (33). The literature indicates that the increase in ground reaction force exceeds the reduction in contact time as speed increases (58). Consequently, the impulse per contact tends to be greater at higher speeds. Because in our study the running speeds of the groups were not very different, the total training time was also not very different, the stride frequencies were equalized, and the volume in kilometers was equalized, we suggest that the VL₁ group experienced a greater mechanical stimulus in sessions with these characteristics. In fact, this greater temporal exposure may have benefited the <VL₁ group, whereas the increased mechanical stress because of the mileage covered in 70% of the training sessions may have benefited the VL₁ group. This hypothesis shows the importance of equalization by weekly kilometers. Finally, we understand that both groups showed a similar magnitude of improvement under different mechanisms. One limitation of our data concerns our measurements of vertical stiffness using an app that has only been validated for heel height.

The transfer of the values and metrics for jump tests fails to fully reflect the mechanisms that will be applied in the race, configuring a limitation of this study. Jumps express only the vertical component of the race, leaving aside the horizontal one. However, several studies have shown the associations of jumps as a variable to monitor and control training (3,11). These associations fail to imply a cause-and-effect relationship by themselves. However, simply discarding some relationships in variables with high construct validity can cause researchers and trainers to miss an important point of information (5).

The optimal effort/recovery ratio has been described as key to improving performance (6,35). This study equalized the total weekly volume between groups and planned progressions. It planned its training protocols so that the training volume would progressively increase (54) up to the fourth week, decreasing in the fifth week (values close to the first and second week), and showing the lowest training volume in the sixth and last week (65). When we compared the responses of the training load between the groups over the 6 weeks, we see that, for some variables and in some weeks, VL₁ had higher load values and lower recovery values than <VL₁ (from strong to the very strong). These data show the importance of monitoring the effort/recovery relationship between the groups because they experienced different intensities in 70% of the kilometers traveled during the 6 weeks.

Finally, we understand that generalizing the results should be approached with caution because the sample size consisted of 12 men and 8 women.

We concluded that training at the upper limit of the moderate domain or 10–15% below it similarly improves trained amateur runners' neuromuscular variables and performance. The group that trained at the upper limit of the moderate domain had higher values of internal training load, which remained within tolerable values.

Practical Applications

Because of the same performance improvement in both groups and less mechanical stress for $<VL_1$, physical trainers and running coaches can organize training during certain periods thinking about goals such as less impact or mechanical stress on lower limbs. Moreover, if trainers need to increase the weekly volume for individuals with limited training time (only 1 hour of training per session), they can opt for the upper moderate limit because this alternative allows for greater session volume and an internal load within tolerable limits. Furthermore, future research could delve deeper into comparing other percentages below the upper limit of the moderate domain, to detect possible differences in the physiological responses of amateur runners under their coach. Finally, it would be interesting to observe these responses in a longer training program, for example, more than 10 weeks.

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