

Chronic effects of plyometric training on VO₂max in recreational male runners with low aerobic fitness

Efeitos crônicos do treino pliométrico no VO₂máx em corredores recreacionais do sexo masculino com baixa aptidão aeróbia

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Abstract

Running has long been a popular sport, leading to a steady rise in marathon participation and in research exploring the physiological parameters that determine performance. The aim of this study was to investigate the chronic effects of plyometric training on maximal oxygen uptake (VO₂max) in male recreational road runners with baseline VO₂max values below 50 ml·kg⁻¹·min⁻¹. Sixteen men participated (84.28 ± 10.70 kg; 178 ± 8.28 cm; 35.12 ± 2.93 years; 3.66 ± 1.36 years of running experience). Participants were monitored over thirty-four non-consecutive days, comprising the intervention phase (sessions 3–33) and post-intervention retesting (session 34). Statistical analysis was conducted using SPSS v22.0 (IBM, Chicago, IL). Paired and independent t-tests were used to identify differences between and within experimental groups for VO₂max (p < 0.05). Significant within-group increases in VO₂max were found for both the plyometric-training group (p = 0.001; df = 7) and the traditional-training group (p = 0.003; df = 7). However, no significant differences were observed between groups (p > 0.05). These findings suggest that, in recreational runners with low aerobic fitness, plyometric training does not provide additional improvement in VO₂max beyond that achieved with traditional endurance training.

Keywords: Oxygen Consumption; Plyometric Training; Running.

Resumo

A corrida tem sido, há muito, um desporto popular, o que tem conduzido a um aumento constante da participação em maratonas e da investigação que explora os parâmetros fisiológicos determinantes do desempenho. O objetivo deste estudo foi investigar os efeitos crônicos do treino pliométrico no consumo máximo de oxigénio (VO₂máx) em corredores recreacionais de estrada do sexo masculino com valores basais de VO₂máx inferiores a 50 ml·kg⁻¹·min⁻¹. Participaram dezasseis homens (84,28 ± 10,70 kg; 178 ± 8,28 cm; 35,12 ± 2,93 anos; 3,66 ± 1,36 anos de experiência em corrida). Os participantes foram acompanhados ao longo de trinta e quatro dias não consecutivos, compreendendo a fase de intervenção (sessões 3–33) e a reavaliação pós-intervenção (sessão 34). A análise estatística foi realizada utilizando o SPSS v22.0 (IBM, Chicago, IL). Foram utilizados testes t emparelhados e independentes para identificar diferenças intra e intergrupos no VO₂máx (p < 0,05). Verificaram-se aumentos intra-grupo significativos no VO₂máx tanto no grupo de treino pliométrico (p = 0,001; gl = 7) como no grupo de treino tradicional (p = 0,003; gl = 7). No entanto, não foram observadas diferenças significativas entre os grupos (p > 0,05). Estes resultados sugerem que, em corredores recreacionais com baixa

aptidão aeróbia, o treino pliométrico não proporciona melhorias adicionais no $\text{VO}_2\text{máx}$ para além das obtidas com o treino tradicional de resistência.

Palavras-Chave: Consumo de Oxigénio; Corrida; Treino Pliométrico.

1. Introduction

Running is among the most practiced forms of exercise worldwide, and participation in road races and marathons has increased steadily, stimulating scientific research into the physiological, biomechanical, and neuromuscular determinants of running performance (Li et al., 2021; Telles Roth et al., 2020). Metabolic parameters such as maximal oxygen consumption (VO_2max), running economy, and lactate threshold are well established as key contributors to endurance performance (Li et al., 2021; Lum et al., 2019; Marcello et al., 2017).

Neuromuscular factors also play an essential role by enhancing intramuscular and intermuscular coordination, muscle-tendon stiffness, and motor-unit recruitment and firing rates (Eihara et al., 2022; Llanos-Lagos et al., 2024). These adaptations can be promoted through strength and plyometric training, both of which have been associated with improved running economy (Eihara et al., 2022; Filipas et al., 2023). Plyometric training, characterized by rapid eccentric-concentric actions that exploit the stretch-shortening cycle (SSC), enhances the mechanical efficiency of elastic-energy utilization (Eihara et al., 2022; Filipas et al., 2023). The SSC, facilitated by the myotatic reflex, supports higher running speeds and may improve endurance performance by enhancing running economy, though findings on its effect on VO_2max remain inconsistent (Lum et al., 2019).

An important consideration is that exercise-induced muscle damage resulting from resistance and plyometric training may negatively affect subsequent aerobic exercise performance, particularly during longer running sessions (Gutiérrez-Vargas et al., 2020; Marcello et al., 2017). Therefore, running performance may depend on the recovery interval between resistance or plyometric training sessions and subsequent running sessions (Marcello et al., 2017). Prolonged and/or high-intensity exercise increases muscle glycogen utilization and lactate production, leading to greater hydrogen ion (H^+) accumulation and muscle damage, as reflected by increases in biomarkers such as creatine kinase (CK), creatine phosphokinase (CPK), and lactate dehydrogenase (LDH) (Gutiérrez-Vargas et al., 2020; Marcello et al., 2017).

Elevated H^+ concentrations reduce calcium binding to troponin, impairing muscle contraction, decreasing force production, and consequently reducing running performance (Brooks, 2018; Marcello et al., 2017; Tornero-Aguilera et al., 2022). In addition, increased H^+ concentrations decrease hemoglobin affinity for oxygen, potentially increasing the oxygen demand of the working muscles (Brooks, 2018; Marcello et al., 2017; Tornero-Aguilera et al., 2022). Neuromuscular fatigue associated with exercise-induced muscle damage following neuromuscular-oriented training may also reduce musculotendinous stiffness and impair running economy in the short term (Marcello et al., 2017; Tornero-Aguilera et al., 2022).

Previous studies show divergent outcomes depending on training status. In novice or low-fit individuals, plyometric training has been shown to improve VO_2max but not necessarily running economy, despite favorable biomechanical adaptations in stride patterns (Gómez-Molina et al., 2018). Conversely, in intermediate-level runners with similar VO_2max values ($\sim 55 \text{ ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$), plyometric training did not increase aerobic capacity, but reduced total time to complete 10 km (Lum et al., 2019). In highly trained athletes ($\text{VO}_2\text{max} > 60 \text{ ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$), both strength and plyometric training tend to improve running economy without significant changes in VO_2max (Li et al., 2019; Li et al., 2021). This plateau effect suggests that individuals below their maximal cardiorespiratory capacity may still experience aerobic improvements from plyometric exercise (Gómez-Molina et al., 2018; Lum et al., 2019).

Thus, plyometric training may elicit different physiological responses depending on the runner's training status (Gómez-Molina et al., 2018; Lum et al., 2019). The present study aimed to compare the chronic effects of plyometric training and traditional running training on VO_2max in recreational male road runners with a baseline

VO₂max below 50 mL·kg⁻¹·min⁻¹. We hypothesized that the training protocol incorporating plyometric exercises would elicit greater improvements in VO₂max than the traditional running training protocol without plyometric exercises.

2. Materials And Methods

2.1. Participants

Sixteen recreational male road runners (age: 35.12 ± 2.93 years; body mass: 84.28 ± 10.70 kg; height: 178 ± 8.28 cm; running experience: 3.66 ± 1.36 years) voluntarily participated in the study. The following inclusion criteria were adopted: (1) regular running training for at least 12 months; (2) participation in resistance training for at least 5 months; (3) minimum weekly frequency of 3 running sessions; (4) minimum of 3 weekly strength-training sessions; and (5) age between 30 and 45 years; (6) male sex.

Exclusion criteria included: (1) any cardiovascular or respiratory disease; (2) musculoskeletal injury preventing training; (3) a positive PAR-Q screening. Additionally, runners with baseline VO₂max values above 50 mL·kg⁻¹·min⁻¹ were excluded from the statistical analysis.

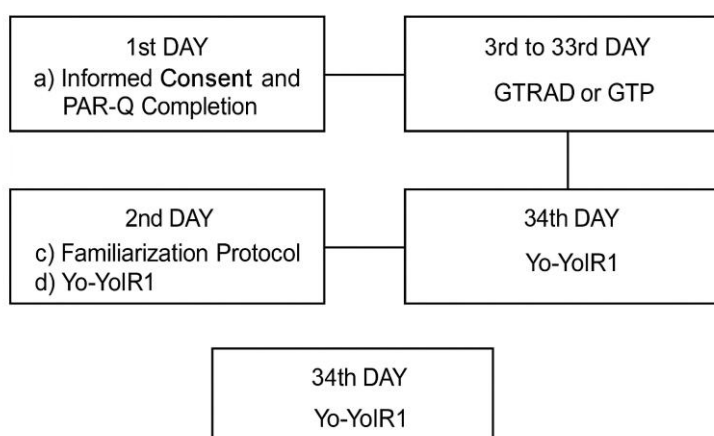
All participants signed an informed consent form prior to participation. The study adhered to the ethical standards of the Declaration of Helsinki and was approved in accordance with Resolution 466/12 of the Brazilian National Health Council (CONSELHO NACIONAL DE SAÚDE, 2012).

2.2. Experimental Design

Participants were monitored over a total of 34 nonconsecutive days. On Day 1, written informed consent was obtained, the Physical Activity Readiness Questionnaire (PAR-Q) was completed, and anthropometric measurements were collected. On Day 2, participants attended a familiarization session, performed a standardized warm-up, and completed the Yo-Yo Intermittent Recovery Test Level 1 (Yo-Yo IR1) (Bangsbo et al., 2008). From Days 3 to 33, participants underwent the intervention protocols over a 10-week period. Post-intervention assessments were conducted on Day 34. Thus, Days 3–33 corresponded to the 10-week intervention period, whereas Days 1, 2, and 34 were dedicated to baseline, familiarization, and post-intervention testing, respectively.

Body mass and stature were assessed using a calibrated digital scale and stadiometer (Filizola Beyond Technology, São Paulo, Brazil).

Figure 1: Experimental Design.



Participants were randomly assigned to one of two groups: a traditional training group (GTRAD) and a plyometric training group (GTP).

All participants completed a standardized 10-minute warm-up prior to each training session, consisting of five 2-minute running drills: butt kicks, straight-leg bounds, low skipping, high skipping, and ankle hops (Santos et al., 2020). Intensity was maintained at a light level (RPE = 10–12) according to Borg’s 6–20 scale. The main training loads were prescribed using perceived exertion ratings between 6 and 20 points (Bath et al., 2012).

Traditional Running Protocol (GTRAD)

Each session consisted of 35 minutes of moderate-intensity continuous running (RPE = 13–15), three times per week (Monday, Wednesday, Friday). Each workout ended with a 5-minute recovery jog at a light intensity (RPE = 8–11). Twice weekly (Monday and Friday), participants performed continuous running, while once weekly (Wednesday) they performed a fartlek session (2 minutes at RPE 13–15 alternating with 1 minute at RPE 10–12).

Plyometric Training Protocol (GTP)

The GTP followed the same running program as GTRAD, with the addition of plyometric sessions three times per week for 10 weeks (total = 30 sessions).

Each session included 2 to 4 sets of 10–15 repetitions per exercise, performed with body weight only. Rest intervals were 90 seconds between sets and 120 seconds between exercises.

The progression followed three phases (Vretaros, 2003):

- Adaptation phase (sessions 1–6 counted with 10 repetitions each exercise and two sets each exercise)
- Intermediate phase (sessions 7–19 counted with 12 repetitions each exercise and three sets each exercise), and
- Advanced phase (sessions 20–30 counted with 15 repetitions each exercise and four sets each exercise).

Table 1: Plyometric training program applied to the experimental group (GTP).

Phase	Sessions	Exercises	Reps	Sets
Adaptation	1–6	Vertical jumps; unilateral vertical jumps; horizontal jumps	10	2
Intermediate	7–19	Box jumps; in-out hops (15 × 15 cm); alternating hops with displacement	12	3
Advanced	20–30	Vertical jumps; unilateral jumps; horizontal jumps	15	4

Yo-Yo Intermittent Recovery Test 1 (Yo-Yo IR1)

The Yo-Yo IR1 test was used pre- and post-intervention to assess maximal aerobic capacity (VO₂max). It was performed on an indoor multisport court with a minimum of 25 m available space. Two cones were placed 20 m apart, with an additional 5 m recovery zone behind each cone.

Participants ran back and forth between the cones according to audio signals, with speed increasing progressively. Each running bout (40 m) was followed by 10 seconds of active recovery. The test was terminated when the participant failed twice to reach the line in time or voluntarily stopped due to exhaustion (Lizana et al., 2014).

Total distance covered was recorded, and VO₂max (ml·kg⁻¹·min⁻¹) was indirectly estimated using the equation:

$$\text{VO}_{2\text{max}} = (\text{distance in meters} \times 0.0084) + 36.4$$

(Bangsbo et al., 2008).

Table 2: VO₂max values (mean ± SD) before and after 10 weeks of training in the traditional training group (GTRAD) and the plyometric training group (GTP).

Group	VO ₂ max Pre (ml·kg ⁻¹ ·min ⁻¹)	VO ₂ max Post (ml·kg ⁻¹ ·min ⁻¹)	p-value
GTRAD	47.2 ± 2.4	49.1 ± 2.6	0.003
GTP	47.5 ± 2.2	49.5 ± 2.1	0.001
Between-group (post)	—	—	0.129

2.3. Statistical Analysis

Statistical analyses were performed using SPSS software (version 22.0; IBM Corp., Chicago, IL). Data normality was verified with the Shapiro–Wilk test. With normality confirmed, paired t-tests were used to compare pre- and post-intervention VO₂max values within each group, while independent t-tests were used to compare between groups.

All data are presented as mean ± SD, and the significance level was set at $p < 0.05$.

While the statistical approach appears appropriate, the inclusion of effect size measures and confidence intervals would further strengthen the interpretation of the practical significance of the findings.

3. Results

Table 2 presents the mean and standard deviation values of VO₂max for both groups (GTRAD and GTP) before and after the intervention.

Significant within-group differences were observed for both training conditions. The plyometric training group (GTP) showed a significant improvement in VO₂max ($p = 0.001$; $df = 7$), as did the traditional training group (GTRAD) ($p = 0.003$; $df = 7$). However, when comparing post-intervention results between the two experimental groups, no significant differences were found ($p > 0.05$).

4. Discussion

The aim of this study was to investigate the effects of a 10-week plyometric training program on VO₂max in recreational male runners with baseline values below 50 ml·kg⁻¹·min⁻¹. The main finding was that both the plyometric training (GTP) and traditional endurance training (GTRAD) protocols significantly improved VO₂max, but without between-group differences. For recreational runners with aerobic fitness below 50 ml·kg⁻¹·min⁻¹, adding plyometric training to a running program may not yield further improvements in maximal aerobic capacity.

These results are consistent with previous research suggesting that aerobic adaptations to plyometric training are more evident in less-trained individuals (Gómez-Molina et al., 2018; Lum et al., 2019). According to Eihara et al. (2022), runners with VO₂max below 50 ml·kg⁻¹·min⁻¹ are typically classified as recreational and still present adaptive potential in both metabolic and neuromuscular domains. In this context, both moderate-intensity endurance running and body-weight plyometric training can stimulate meaningful improvements in aerobic capacity.

Gómez-Molina et al. (2018) observed that concurrent plyometric and running training increased VO₂max in novice athletes engaged in different sports (e.g., judo, tennis, handball), though running economy remained unchanged. Similarly, Li et al. (2021) found that combined complex training—consisting of strength and plyometric exercises performed in the same session—improved running economy, jumping performance, and neuromuscular function, yet did not affect VO₂max in trained runners. These findings may indicate that

plyometric training is more effective for enhancing neuromuscular efficiency and running economy than for eliciting additional cardiorespiratory adaptations once a certain aerobic threshold is reached.

The absence of between-group differences in the current study suggests that, in recreational runners, the stimulus provided by the running program alone was sufficient to increase VO_2max . This is likely because these individuals had not yet reached a plateau in their aerobic development. Plyometric exercise may thus act as a complementary rather than a primary driver of aerobic adaptations at this stage of training (Filipas et al., 2023).

However, in highly trained endurance runners ($\text{VO}_2\text{max} > 60 \text{ ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$), plyometric training seems to improve performance mainly through biomechanical and neuromuscular mechanisms, such as increased tendon stiffness, improved stretch–shortening cycle efficiency, and reduced ground-contact time (Beattie et al., 2017; Markovic & Mikulic, 2010). In this population, VO_2max typically remains stable, but running economy improves (Denadai & Greco, 2022; Loturco et al., 2015). Filipas et al. (2023) demonstrated that when plyometric training was combined with high-intensity endurance work—above the second ventilatory threshold—elite runners improved both running speed at $4 \text{ mmol}\cdot\text{L}^{-1}$ of lactate and time to exhaustion. This reinforces that the degree of aerobic adaptation is highly dependent on training status and program intensity.

The current findings also align with evidence that training intensity and volume must be carefully matched to the athlete's level. High-intensity plyometric programs may produce excessive neuromuscular stress and limited aerobic benefit in less-trained runners (Eihara et al., 2022), whereas low- to moderate-intensity protocols can improve VO_2max by stimulating peripheral adaptations (e.g., capillary density and mitochondrial efficiency) without overloading the musculoskeletal system.

An important limitation of the present study is the absence of direct measurements of maximal oxygen uptake. Compared to an incremental test using a gas analyzer, the Yo-Yo IR1 is known to underestimate VO_2max (Lizana et al., 2014). Nevertheless, because the protocol involved recreational athletes and exercise intensity was prescribed using the Borg Scale (Bath et al., 2012) rather than VO_2max , the reliability of the Yo-Yo IR1 is deemed acceptable for this context (Bangsbo et al., 2008). Nonetheless, since indirect testing has its limitations, future studies should incorporate direct measurements of oxygen uptake.

Another limitation was the lack of lower-limb power assessments (e.g., countermovement jump or squat jump), which would help determine the extent of neuromuscular adaptations following plyometric training. Similarly, no lactate or ventilatory-threshold data were collected, which would provide insight into metabolic adaptations related to running economy. Future studies should combine cardiorespiratory, biomechanical, and neuromuscular measures to clarify how plyometric and concurrent training influence endurance performance across different levels of aerobic fitness.

5. Conclusion

This study demonstrates that traditional endurance training, whether performed alone or supplemented with plyometric training, effectively improves VO_2max in recreational male runners with a baseline aerobic fitness below $50 \text{ ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$. However, no significant between-group differences were observed regarding VO_2max .

The results suggest that runners can use both methods to develop maximal oxygen uptake: traditional running training and concurrent training. Therefore, there is no problem in using body-weight plyometric exercises together with running protocols. Even though neuromuscular tests were not used in this study, the discussion of the literature shows that plyometric training may contribute to other performance-related adaptations, such as improved running mechanics and neuromuscular efficiency. Thus, this type of training should be encouraged among athletes.

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Declaração Ética

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