Comparing the effects of simultaneous execution versus isolated training on oxygen consumption during exercise

Comparación de los efectos de la ejecución simultánea versus el entrenamiento aislado sobre el consumo de oxígeno durante el ejercicio

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Abstract

Introduction: Resistance training (RT) influences metabolic demand and training efficiency. Oxygen consumption (VO_2) represents a central physiological marker linking exercise structure to energy expenditure, yet the effects of simultaneously engaging upper and lower body musculature remain underexplored.
Objective: To compare the acute physiological responses to simultaneous versus isolated execution of RT exercises, focusing on VO_2.
Methodology: Ten recreationally resistance-trained men (25.0±3.97 years) participated in a randomized crossover design. Participants performed two protocols: simultaneous execution (SS) of incline dumbbell press and 45º leg press, and isolated execution (SI) of the same exercises in separate sets, both at 70% of one-repetition maximum. VO_2 (absolute and relative), heart rate (HR), and respiratory exchange ratio (RER) were continuously measured. Linear mixed-effects models were applied to compare conditions.
Results: SS elicited significantly higher VO_2 than SI (VO_2A: 1.58±0.06 $L.min^{-1}$ vs 1.23±0.06 $L.min^{-1}$; VO_2R: 20.91±0.42 $ml.kg^{-1}.min^{-1}$ vs 16.38±0.55 $ml.kg^{-1}.min^{-1}$; $p<0.001$), with very large effect sizes. HR was also higher in SS ($p<0.001$), whereas RER was significantly higher in SI ($p<0.001$).
Discussion: The elevated VO_2 during SS likely reflects faster VO_2 uptake kinetics driven by greater concurrent muscle mass activation and reduced metabolic recovery periods, increasing systemic ATP turnover and cardiorespiratory demand. These findings highlight exercise configuration as a key modulator of physiological load beyond traditional variables such as intensity and volume.
Conclusions: Simultaneous upper and lower body RT execution enhances VO_2 per unit of time and represents a time-efficient strategy to increase metabolic stress, with practical implications for optimizing RT prescription in health and performance settings.

Keywords

Oxygen consumption; strength training; simultaneous execution.

Resumen

Introducción: El entrenamiento de fuerza (EF) influye en la demanda metabólica y a la eficiencia del entrenamiento. El consumo de oxígeno (VO_2) es un marcador clave que relaciona la estructura del ejercicio con el gasto energético, sin embargo, los efectos de ejecución simultánea del tren superior e inferior siguen poco explorados.
Objetivo: Comparar las respuestas fisiológicas agudas a la ejecución simultánea frente a la aislada de ejercicios de EF, con énfasis en el VO_2.
Metodología: Diez hombres recreacionalmente entrenados (25.0±3.97 años) participaron en un diseño cruzado aleatorizado. Realizaron dos protocolos: ejecución simultánea (SS) de dos ejercicios de EF versus los mismos ejercicios aislados en series separadas, ambos al 70% de 1RM. El VO_2 (absoluto y relativo), la frecuencia cardíaca (FC) y el cociente respiratorio (RER) se midieron de forma continua. Se utilizaron modelos lineales de efectos mixtos.
Resultados: El protocolo SS mostró valores de VO_2 significativamente superiores al SI (VO_2A: 1.58±0.06 vs 1.23±0.06 $L{\cdot}min^{-1}$; VO_2R: 20.91±0.42 vs 16.38±0.55 $ml{\cdot}kg^{-1}{\cdot}min^{-1}$; $p<0.001$), con tamaños del efecto muy grandes. La FC también fue mayor en SS ($p<0.001$), mientras que el RER fue superior en SI ($p<0.001$).
Discusión: El mayor VO_2 en SS se explica por una mayor activación muscular simultánea y menor recuperación intra-sesión, aumentando la demanda metabólica.
Conclusiones: La ejecución simultánea del tren superior e inferior aumenta el VO_2 por unidad de tiempo, siendo una estrategia eficiente para incrementar el estímulo metabólico en EF.

Palabras clave

Consumo de oxígeno; entrenamiento de fuerza; ejecución simultánea.

Introduction

Aerobic training (AT) and resistance training (RT) remain cornerstone exercise strategies for improving cardiometabolic health and body composition, including in populations with overweight/obesity (Ignarro et al., 2007; Ozemek et al., 2025). Contemporary evidence indicates that AT, RT, and combining training all contribute to clinically meaningful reductions in adiposity-related outcomes, with modality-specific trade-offs (e.g., AT often yielding larger absolute fat-mass reductions, while RT and combining training better preserve or increase lean mass) (Hickson et al., 1984; Phillips and Ziuraitis, 2004; Bloomer, 2005; Vilaça Alves et al., 2012; Yarizadeh et al., 2021). In this context, oxygen consumption (VO_2) during and after exercise is not merely a descriptive physiological variable, but a mechanistic bridge linking session design to energy expenditure, substrate oxidation, and training efficiency, precisely the “dose–response” logic that informs time-efficient prescriptions (Faleiro et al., 2025).

The present study is conceptually grounded in bioenergetic principles of exercise physiology, which posit that oxygen uptake during exercise is determined by the interaction between active muscle mass, contraction intensity, and metabolic demand for ATP resynthesis. Simultaneous activation of large muscle groups may therefore accelerate oxygen uptake kinetics and increase VO_2 during resistance exercise (Hunter et al., 1998; João et al., 2021; Nyberg and Jones, 2022).

However, the metabolic cost of RT is highly sensitive to how the session is structured. Small manipulations in load, repetition scheme, density (work:rest), and exercise ordering can meaningfully alter VO_2 dynamics and total energy expenditure, even when the movement pattern is ostensibly “the same” (João et al., 2021; Del-Cuerpo et al., 2025). This sensitivity is also methodological: quantifying RT energy expenditure and VO_2 requires careful attention to the non–steady-state nature of RT and to the contribution of recovery VO_2 kinetics (e.g., capturing the fast component of post-exercise oxygen uptake) (Mitchell et al., 2024). Accordingly, although the literature has progressed from simplistic “RT vs AT” comparisons to more nuanced evaluations of RT configurations, substantial heterogeneity persists in how protocols are operationalized and how metabolic outcomes are estimated (João et al., 2021; Mitchell et al., 2024).

Taking into account the studies that manipulated the aforementioned variables, it is presumed that VO_2 increases with: alternating exercises involving the upper and lower limbs (Hickson et al., 1984), the use of exercises involving large muscle masses (Bloomer, 2005), the use of multiple series (Haddock & Wilkin, 2006; Phillips and Ziuraitis, 2004), and the use of workloads around 70% 1RM (Hunter et al., 1998). Thus, executing upper and lower limb RT exercises simultaneously, meets the criteria of using large muscle masses and alternating exercises for the upper and lower limbs which both have been shown to increase VO_2 during a training session. Generally, when upper and lower limb RT exercises are performed at the same time, the absolute load lifted by the upper limbs is almost always less than that lifted by the lower limbs. Considering the load and the muscle mass involved, two important factors for augmenting VO_2 during exercise (Hunter et al., 1998), the 45º leg press machine (LP45º) at 70% 1 RM and the incline dumbbell chest press (IDCP) at 70% 1 RM were chosen as the two RT exercises.

From a physiological standpoint, increasing the active muscle mass and reducing intra-session “dead time” are two robust levers for elevating VO_2 during predominantly resistance-based tasks. This rationale is consistent with evidence that exercise engaging larger muscle mass imposes greater systemic demands and tighter matching requirements between O_2 delivery and O_2 utilization, especially when the transition dynamics of O_2 uptake are considered (Nyberg and Jones, 2022). In parallel, applied RT research shows that time-efficient prescriptions (e.g., supersets and other condensed formats) can preserve mechanical outcomes while increasing internal load/physiological strain, highlighting that how exercises are sequenced may matter as much as which exercises are selected (Zhang et al., 2025). Yet most existing studies have examined sequencing approaches that are still serial (exercise A then exercise B), leaving an important applied question under-addressed: what happens when upper and lower limb RT exercises are executed simultaneously rather than in isolation?

Therefore, the purpose of the present study was to verify if there are significant differences between performing two RT exercises simultaneously (SS) versus isolating (SI) the exercises on VO_2. This question has practical relevance because it addresses a pragmatic design problem faced by coaches and clinicians, maximizing metabolic stimulus and time efficiency without compromising exercise quality or feasibility. Considering emerging evidence that distinct high-intensity and circuit-based formats can amplify post-exercise energy expenditure and substrate oxidation, clarifying whether simultaneous upper–lower execution meaningfully elevates VO$_2$ during the session may refine how practitioners operationalize “efficient” RT prescriptions in both performance and health-oriented settings.

Method

Participants

The sample consisted of 10 recreationally RT men (25.0 ± 3.97 years, 177.3 ± 4.99 cm, 75.1 ± 7.61 kg, 5.04 ± 4.14% body fat estimated) with at least six months of RT experience and reported engaging in RT approximately 2-4 sessions per week. Their training routines typically included global and isolated exercises (e.g., incline leg press, bench press with dumbbells, squat, lat pulldown, biceps curl and triceps pushdown). Table 1 lists the descriptive data for the sample, observing the means and standard deviations for age, body mass, stature and the estimated percentage of fat body.

Table 1. Mean and standard deviation for age, body mass, height and % estimated body fat mass.

Variable	N	Minimum	Maximum	Mean	Standard deviation
Age (yr)	10	21.00	32.00	25.00	3.97
Body mass (kg)	10	61.00	86.00	75.10	7.60
Height (cm)	10	168.00	183.00	177.30	4.98
% Estimated body fat	10	0.09	11.62	5.04	4.14

Procedure

This was a randomized crossover design. The data collection took place in a laboratory over the course of four different sessions, and there was a seven-day washout period between the third and fourth sessions. The first session entailed an interview, which comprised collecting a Par-Q test questionnaire, signing an informed consent, and collecting baseline anthropometric measurements (height [cm], body mass [kg], and percent estimated body fat). In addition, repetition maximum (1RM) was collected for the selected exercises: The LP45º (Panatta, 45º Leg Press with lever, Apiro, Italy) and the IDCP. In the second session, which occurred 72 hours after the first session, the investigators re-assessed the participant’s 1RM for the same exercises to ensure validity and reliability. In the third session, participants were randomly assigned to one of the following protocols: a) simultaneous (SS): 3 sets of 10 repetitions of LP45º and IDCP, both at 70% 1RM, performed simultaneously, at a cadence of 60 beats.min^{-1}, with 60 seconds of rest between series; b) separated (SI): 3 sets of 10 repetitions of LP45º at 70% 1RM, followed by 3 sets of 10 repetitions of IDCP at 70% 1RM. Exercise cadence was controlled using a metronome (Korg MA-30, USA) at 60 beats.min^{-1}, where each beat corresponded to a movement phase, resulting in an approximate repetition tempo of 1s concentric and 1s eccentric phases. For the fourth session, participants performed the other protocol; they acted as their own controls. In the SS protocol, data collection lasted a total duration of 4 minutes (20 seconds during the execution of each set (1 minute total) plus 60 seconds between sets (3 minutes total); in SI protocol total duration was 8 minutes (20 seconds per each set (2 minutes) plus 60 seconds interval between sets (6 minutes).

To improve data reliability, the following controls were enforced. All sessions, for all participants of the sample, were held between 17:00 – 18:30. Participants were asked not to consume alcohol or caffeine within 12 hours before they were scheduled to report for data collection, and not to perform physical exercise within 72 hours before data collection. In addition, participants were asked to record their food intake during the 24 hours before the third study session so that they could repeat the same caloric intake and eating habits before the fourth session to control for confounding variables that could be affected by energy status between the third and fourth data collection sessions.

Maximal Strength Testing

1RM (kg) for both exercises was assessed using the protocol described by Kraemer and Fry (1995): Perform 5-10 repetitions with a load between 40-60% of the perceived maximum, followed by 1 minute rest. Next, perform 3-5 repetitions with a load 60-80% of the perceived maximum, followed by 2 minutes of rest. Then, try a load close to perceived maximum; and then in a conservative manner, attempt a 1RM. After this attempt, whether successful or not, allow 5 minutes of rest, before increasing or decreasing the load. The maximum load was the weight that allowed the participants to perform only a single repetition. This procedure was repeated after 72 hours to ascertain more precisely the participant 1RM. The 1RM values and protocols were always performed on the same leg press machine. The 1RM test and re-test values of the selected exercises for this study are shown in Table 2, revealing an intraclass correlation of r = 0.93 for the IDPC and of r = 0.98 for the LP45º.

Table 1. Mean and standard deviation of 1RM test and re-test.

Variable (Kg)	N	Minimum	Maximum	Mean	Standard Deviation
RM IDCP	10	28.00	40.00	35.20	4.44
RRM IDCP	10	28.00	45.00	36.50	4.60
RM LP45º	10	140.00	240.00	188.00	31.55
RRM LP45º	10	145.00	280.00	202.00	39.17

RM IDCP – one-repetition maximum incline dumbbell chest press test; RRM – one-repetition maximum incline dumbbell chest press retest
RM LP45º- one-repetition maximum 45º Leg press test; RRM LP45º- one-repetition maximum 45º Leg press retest

Oxygen Consumption Assessment

Respiratory indicators were determined by an open circuit system, the portable spirometer K4b^2 (COSMED® K4b^2, Rome, Italy), and values of time (minutes), respiratory rate (breaths per minute), total volume (L), ventilation (VE [L/min]), oxygen consumption (VO$_2$ [ml.Kg^{-1}.min^{-1}]), carbon dioxide production (VCO$_2$ [mL.Kg^{-1}.min^{-1}]), heart rate (HR [bpm]) and VCO$_2$/VO$_2$ ratio were recorded. The participants used the portable spirometer immediately before the beginning of the exercise protocol, and respiratory variables were recorded continuously throughout the execution of the exercise sets and the rest intervals between sets.

Heart Rate Assessment

The Heart Rate (HR) was monitored continuously during all study sessions through a heart rate transmitter (Polar Wireless Double Electrode, Kempele, Finland) placed on the subjects' chest, duly adjusted to their anthropometric measurements, and the values were continuously recorded by K4b^2.

Data analysis

Data are presented as mean ± standard deviation. The normality of the data distribution was assessed using Shapiro-wilk test. To compare physiological responses between protocols, linear mixed-effects models were used. In these models, protocol (SS vs. SI) was included as a fixed factor, while participant was included as a random effect to account for the crossover design and the within-subject correlation of repeated measurements. The order of protocol execution was randomized, and participants completed the protocols in a counterbalanced sequence to minimize potential order effects. When significant main effects were detected, estimated marginal means were used to determine pairwise differences between protocols. Mean differences and their corresponding 95% confidence intervals (CI) were calculated to quantify the magnitude and precision of the observed effects. Additionally, effect sizes were calculated using Cohen´s d for paired samples, based on the mean and standard deviation of the within-subject differences (Lakens, 2013). Effect sizes were interpreted according to conventional thresholds proposed by Cohen (1988) (small = 0.2, moderate = 0.5, large = 0.8). All statistical analyses were performed using SPSS version 30 (IBM Corp., Armonk, NY, USA). The level of statistical significance was set at $p<0.05$.

Results

Table 3 shows the mean and standard deviation obtained from both protocols for VO$_2$A, VO$_2$R, RER and HR. The linear mixed-effects model revealed significant differences between protocols for all physiological variables analysed. Oxygen consumption was significantly higher in the SS protocol compared with the SI protocol. Specifically, VO$_2$A was significantly higher in SS ($p<0.001$), with a mean difference of 0.29 L.min^{-1} (95% CI: 0.20 to 0.38). The magnitude of this difference was very large (paired Cohen´s d=2.28). Similarly, VO$_2$R was significantly higher in the SS condition ($p<0.001$), with a mean difference of 3.73 $ml.kg^{-1}.min^{-1}$ (95% CI: 2.52 to 4.93) and a very large effect size (d=2.21). Heart rate was also higher during the SS protocol compared with SI ($p<0.001$), with a mean difference of 13.25 $beats.min^{-1}$ (95% CI: 1.27 to 27.77), corresponding to a moderate effect size (d=0.65). In contrast, the RER was significantly higher in the SI protocol compared with SS ($p<0.001$). The mean difference between conditions was -0.10 (95% CI: -0.18 to -0.02), representing a large effect size (d=-0.92).

Table 2. Protocol comparison of mean and standard deviation for absolute vo_2, relative vo_2, respiratory exchange ratio and heart rate.

Protocol	VO_2A ($L.min^{-1}$)	VO_2R ($ml.Kg^{-1}.min^{-1}$)	RER	HR ($beat.min^{-1}$)
(SS) Simultaneous	1.58 ± 0.06	20.91 ± 0.42	1.30 ± 0.01	145.93 ± 5.62
(SI) Isolated	1.23 ± 0.06	16.38 ± 0.55	1.39 ± 0.04	131.75 ± 6.74

Discussion

To our knowledge, this study is one of the first studies to observe the acute effects on VO_2, triggered by the simultaneous execution of two RT exercises. Thus, for methodological reasons, it is difficult to compare the present findings with those of other studies. In the present study, the SS protocol produced higher VO_2A and VO_2R values than the SI protocol (1.58 ± 0.06 $L.min^{-1}$ vs 1.23 ± 0.06 $L.min^{-1}$ and 20.91 ± 0.42 $ml.kg^{-1}.min^{-1}$ and 16.38 ± 0.55 $ml.kg^{-1}.min^{-1}$, VO_2A and VO_2R, respectively). The VO_2A values observed in the SI protocol are consistent with those by Vilaça Alves et al. (2012) which assessed the squat, bench press, sit-ups, overhead shoulder press, lat pull-down, and lumbar extension exercises (1.26 ± 0.11 $L.min^{-1}$). However, comparing the results of the Vilaça Alves et al. (2012), with the present study is not representative because the study by Vilaça Alves et al, (2012), used multiple muscle groups, whereas the present study assessed two, thus the VO_2 values are not relative.

Ballor et al. (1989), Farrar et al. (2010), and Lagally et al. (2009), performed studies seeking similar investigational aims as the present study. Ballor et al. (1989) used RT circuit training with hydraulic machines, at different velocities, and observed VO_2 values of 2.00 ± 0.39, 1.98 ± 0.29 and 1.93 ± 0.29 $L.min^{-1}$, with high, low and medium velocities, respectively. In turn, Farrar et al. (2010), observed a VO_2 of 34.31 ± 5.67 $ml.kg^{-1}.min^{-1}$ during two-handed swings, using a 16kg Kettlebell for 12 minutes. Similarly, Lagally et al. (2009), observed VO_2 values of 27.8 ± 5.4 $ml.kg^{-1}.min^{-1}$ during a 28.5-minute continuous functional exercise workout. The higher VO_2 values in the studies referred to above may be attributed to the circuit training design (duration and exercises selected) and lower relative loads. These types of protocol designs use volumes and intensity levels that predominantly tax the aerobic metabolic pathway. Contrary to this modality, the present study followed a protocol design that predominantly stresses the anaerobic metabolic pathway. This is further confirmed by comparing the observed RER that was 1.00 ± 0.05 in Farrar et al. (2010) study and 1.39 ± 0.04 for the SS protocol in the present study.

In the present study, the responses observed under a short-interval configuration reinforce a practical principle for time-constrained sessions: maximizing active muscle mass per unit time is a key determinant of VO_2 during RT. Contemporary methodological evidence indicates that the metabolic cost of RT is highly sensitive to exercise selection and work density, particularly when recovery is constrained and VO_2 remains elevated across transitions (Mitchell et al., 2024). Moreover, relative intensity (Hunter et al., 1998) meaningfully modulates VO_2 kinetics and total energetic load, given its effects on motor-unit recruitment, intramuscular tension, and the balance between aerobic and anaerobic contributions (João et al., 2021). Within this framework, emphasizing large lower-limb musculature, and, when feasible, combining it with concurrent upper-limb work, should increase VO_2 by amplifying systemic ATP resynthesis demands and recovery VO_2 (Del-Cuerpo et al., 2025). Evidence from time-efficient resistance formats (e.g., supersets/condensed sequencing) further supports session architecture as a legitimate lever to elevate physiological strain without necessarily compromising mechanical outputs (Zhang et al., 2025). Collectively, these findings support the applied inference that brief, high-density configurations centred on large-muscle recruitment and sufficient intensity represent an effective strategy to increase VO_2 when training time is limited.

The higher VO_2A and VO_2R observed in the SS condition, together with the higher HR, are physiologically coherent with an acute increase in active muscle mass per unit time and a reduction in “metabolic downtime” between efforts (Mitchell et al., 2024; Mang et al., 2025; Zhang et al., 2025). When upper and lower limb actions are performed concurrently, the body must sustain a larger total demand for ATP turnover, ion pumping, and phosphocreatine resynthesis, which accelerates VO_2 on-kinetics and maintains oxygen uptake at a higher plateau across the bout (Pogliaghi et al., 2023). In parallel, the concurrent engagement of large lower-limb musculature with upper-limb work amplifies the muscle pump, venous return, and consequently cardiac output requirements, which is typically expressed as a higher HR for a given session duration (Heinonen, 2025). Because the SS protocol involves a greater amount of active muscle mass within the same time frame, the overall metabolic demand of the exercise bout is increased, which helps explain the higher oxygen consumption observed during the protocol compared with the isolated execution condition.

It is important to note that the SS protocol had a shorter total duration compared with the SI protocol. Therefore, although SS elicited higher VO_2 values per unit of time, total energy expenditure across the entire session may differ between protocols due to the longer duration of SI protocol (8 min vs 4 min, SI and SS, respectively). From an applied perspective, the SS protocol may represent a time-efficient strategy to increase metabolic demand when training time is limited, however sequential execution may result in greater total energy expenditure when longer sessions are feasible.

The higher RER values observed in SI protocol likely reflect a greater reliance on anaerobic glycolysis and increased CO_2 production associated with bicarbonate buffering of metabolic acidosis. During high-intensity muscular contractions, the accumulation of metabolic by-products such as H^+ and lactate stimulate buffering mechanisms, increasing ventilatory drive and CO_2 output, which may elevate RER values without necessarily indicating a greater oxidative metabolism (de Oliveira et al., 2022; Mougin et al., 2025). The longer duration of the SI protocol may have further promoted the accumulation of these metabolic by-products, thereby amplifying buffering responses and increasing RER. In contrast, the SS protocol appears to increase VO_2 primarily through a greater amount of active muscle mass and higher systemic metabolic demand. Consequently, SS may elevate oxygen uptake predominantly through whole-body metabolic demand, whereas SI may increase RER through more localized glycolytic stress and buffering related CO_2 production (João et al., 2021; de Oliveira et al., 2022; Mougin et al., 2025).

In practical terms, the present findings suggest that the simultaneous execution of upper and lower limb RT exercises may represent an effective strategy to increase oxygen consumption during RT sessions. By increasing the amount of active muscle mass within the same time frame and reducing intra-session downtime, this configuration appears to enhance the metabolic demand of the exercise bout. Therefore, simultaneous RT exercise execution may be particularly relevant for time-efficient training prescriptions aimed at increasing the cardiometabolic stimulus of RT without necessarily increasing session duration.

The present study has some limitations that should be acknowledged. First, the findings may not be generalizable to other populations. Although the crossover design allowed each participant to serve as their own control, thereby reducing inter-individual variability, future studies should include larger and more diverse samples to confirm the observed responses. In addition, perceptual measures such as rating of perceived exertion were not collected in the present investigation. Including such measures could provide additional insight into the subjective demands associated with simultaneous versus isolated execution of RT exercises and help further interpret the physiological responses observed.

Conclusions

Based on the results of the present study, we can conclude that the simultaneous execution of the two RT exercises selected resulted in higher VO_2 during exercise, per unit time, compared to the isolated execution. The benefits of simultaneous execution of two RT exercises, specifically performing an upper and lower limb exercise at the same time, may represent a practical strategy to increase metabolic stimulus while reducing session duration.

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