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# Acute responses of muscle oxygen saturation during different cluster training configurations in resistance-trained individuals

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**ABSTRACT:** This study compared the perceptual responses, physiological indicators and technical parameters between different training protocols focused on upper body exercises. A randomized crossover design was performed, and 12 trained individuals (age: 27.1 ± 5.7 years; height: 173.7 ± 10.7 cm; BMI: 23.9 ± 2.3) completed three resistance training sessions under different protocols separated by at least 72 h: traditional training (TT) (4 x 6 repetitions at 85% of 1RM with 120 s of rest between sets), cluster 1 (CL1) (4 x 2+2+2 repetitions at 85% of 1RM with 15 s of intra-rep rest and 80 s between sets), and cluster 2 (CL2) (24 repetitions at 85% of 1RM with 15 s of inter-set recovery). Before training, arterial blood pressure (BP) and repetitions to failure of pull-up and push-up (FT) were collected. Muscle oxygen saturation ($SmO_2$) in the chest and movement velocity were evaluated in barbell bench press during the training session. After finishing, lactate, BP, rate of perceived exertion and FT were assessed. The percentage of velocity loss (TT: 19.24%; CL1: 5.02% and CL2: 7.30%) in the bench press and lactate concentration (TT: 8.90 $mmol \cdot l^{-1}$; CL1: 6.13 $mmol \cdot l^{-1}$ and CL2: 5.48 $mmol \cdot l^{-1}$) were significantly higher ($p < 0.05$) for TT compared to both CLs. RPE values were higher ($p < 0.05$) in TT compared to CL1 (7.95 a.u. vs. 6.91 a.u., respectively). No differences ($p > 0.05$) were found between protocols for $SmO_2$, BP, FT, pain or heart rate between set configurations. Cluster configurations allow one to maintain higher movement velocity and lower lactate and RPE values compared to a traditional configuration, but with similar concentrations of $SmO_2$.

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Fatigue
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$SmO_2$
Movement velocity

## INTRODUCTION

In recent decades, the popularity of strength training has increased in both contexts, sport performance and physical fitness and health. Strength training programmes cause body adaptations increasing muscle strength, power, hypertrophy, or endurance, depending on the specific prescription [1]. However, the mechanisms of adaptation of the neuromuscular system to the different stimuli generated by strength training depend on a series of variables such as muscle activation, exercise loading and volume, type and order of exercise, rest periods, density, repetition velocity, and frequency [2]. These variables must be monitored and carefully considered during programming to achieve the proposed objectives and avoid overtraining [3].

The manipulation of the different strength training variables, such as the relationship between work and rest (i.e., density), has led to a new set of configurations such as cluster training. In this type of training, a 10–30 s rest between repetitions is usually prescribed [4]. This rest time could be allocated between each repetition performed (inter-repetition rest) or between groups of two or more repetitions (intra-set rest), within the set [5]. Normally, in traditional training (TT), the sets are carried out continuously and the rest is usually prescribed at the end of each set. However, carrying out continuous repetitions within the same set causes progressive loss of performance that may lead to a decrease in movement velocity [6]. In relation to this, cluster training has been proposed as a method that allows each repetition of the sets to be performed with the highest quality [7].

Although TT has been associated with greater strength gains due to the high metabolic stress it generates [8, 9], several studies have shown similar gains in strength [10–12] and lower performance decremental effects when less fatiguing protocols during training were selected [13–16]. Moreover, shorter set configuration causes a reduction in metabolic impact [17], a smaller impact on the cardiovascular response [18], and a higher mechanical performance during the course of exercise compared to longer set configurations [12, 14]. However, it is important that the rest time between repetitions will be the only independent variable to evaluate, since the inclusion of other variables, such as different rest times between sets, load intensities, or numbers of repetitions per set, could affect the different adaptations caused by this type of training. García-Ramos et al. [19] examined different set configurations (two traditional and three cluster protocols) with different total session times between them. Their results reported that the training protocols with a lower session duration (TR1: 3x10 with 5 min of inter-set rest and CL5: 3x10 with 5 s of inter-rep rest and 5 min of inter-set rest) were associated with the largest velocity loss and blood lactate concentration. Moreover, in a recent study conducted by Cuevas-Arbuto et al. [20] both cluster and rest-redistribution configurations allowed for higher velocities and lower RPE values than traditional training during bench press and squat exercises.

Regarding training fatigue, the rate of perceived exertion (RPE) method is becoming increasingly popular to provide a global rating difficulty of an entire training session [21]. Thus, cluster set configurations could reduce RPE when the total session duration is equalized with respect to traditional training [22]. Different investigations have shown lower RPE values after cluster training compared to TT [20, 23, 24]. However, we can find other parameters that can indicate the fatigue accumulated during a training session or during the development of several sets of the same exercise. Thus, Takaishi et al. [25] demonstrated that near infrared reflectance spectroscopy (NIRS) technology serves as a useful measure to provide information on muscle metabolic changes. In relation to this, the measure of the muscle oxygen saturation ($SmO_2$) can provide real-time fatigue feedback on the relationship between oxygen consumption in the muscle and oxygen supply to the muscle [26]. Although different investigations have measured $SmO_2$ during resistance training [27–30], only one investigation has reported $SmO_2$ values comparing different set configurations [31]. In this, Tufano et al. [31] reported that the rest-redistribution protocol applied (20 sets of 2 repetitions with 15 s inter-set rest) resulted in significantly greater total haemoglobin concentration (tHB) and $SmO_2$ values than TT (4 sets of 10 repetitions with 95 s inter-set rest). However, to the best of our knowledge, no previous research has studied the influence of cluster training on upper-body $SmO_2$. Previous studies have explored the influence of different set configurations in specific exercises of the upper and lower body (bench press, back squat, power clean, etc). Nevertheless, the present study proposes different set configurations in a whole session of the upper-body exercises.

Therefore, the aim of this study was to compare the perceptual responses, physiological indicators and mechanical parameters between three different set configurations in well-trained individuals. It was hypothesized that traditional training would elicit higher mechanical fatigue, metabolic, and perceptual responses than both cluster set configurations.

## MATERIALS AND METHODS

### *Experimental design*

A randomized, counterbalanced, crossover study design with familiarization was used. The independent variable was intervention, with intra-set rest (i.e., cluster 1), inter-repetition rest (i.e., cluster 2), or rest between sets (i.e., TT). Dependent variables were divided into three groups: physiological (arterial blood pressure, heart rate (HR), $SmO_2$, and post-exercise blood lactate concentration [La]), mechanical

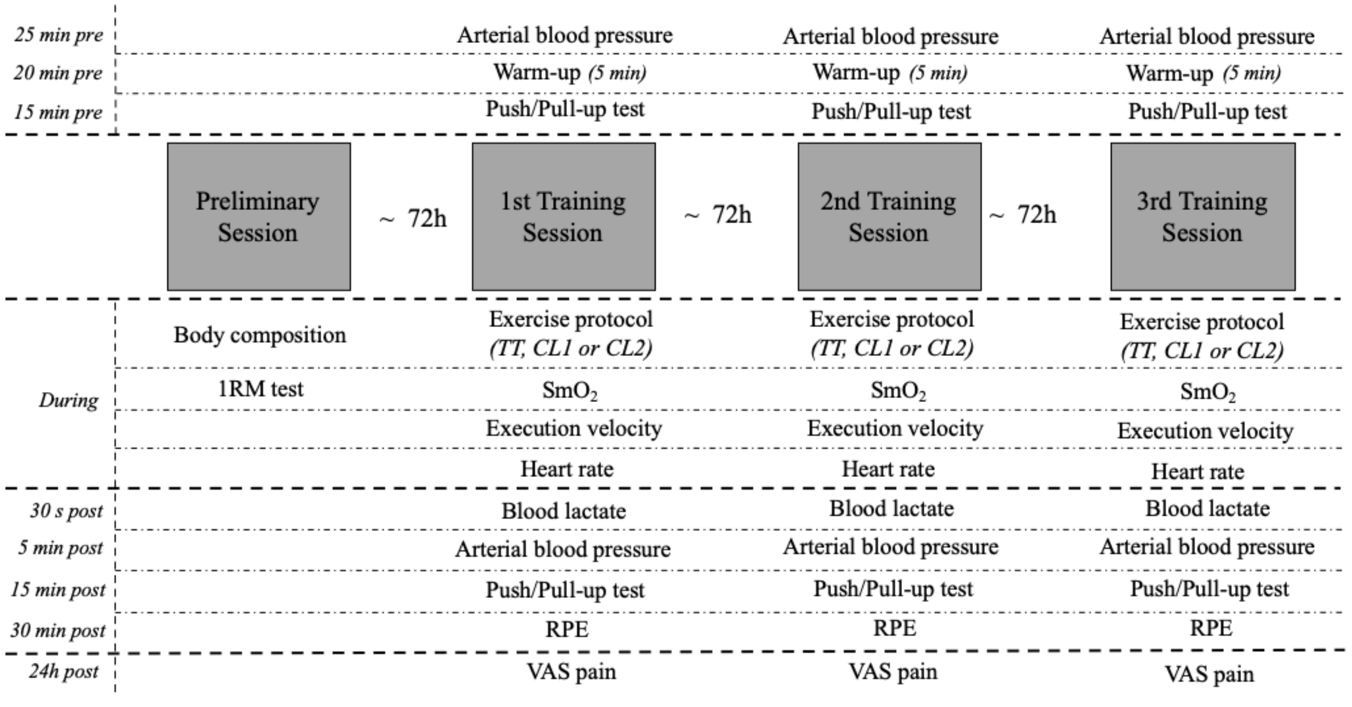

**FIG. 1.** Chronological assessment of the variables throughout the study.

(number of repetitions performed and movement velocity) and perceptual (subjective perception of effort (RPE), subjective perception of pain). Figure 1 shows the chronological assessment of the variables throughout the study. All measurements were conducted at the same time of day for each subject and by the same investigators before and after the intervention. Room temperature was maintained at 21–24°C and relative humidity [RH] 40–50% throughout the study. In addition, participants were instructed to maintain their regular dietary consumption and not practise any intense exercises within 24 h before each session.

### *Subjects*

Twelve healthy (eight males and four females) subjects with more than two years of continuous resistance training experience (age 27.10 ± 5.70 years; weight 72.30 ± 13.45 kg; height 173.69 ± 10.66 cm; BMI 23.93 ± 2.28 kg/m$^2$; fat percentage 22.68 ± 4.20%) volunteered to participate in this study. During the first visit, all experimental procedures were explained to the participants, and written informed consent was obtained from each subject. Participants had at least two years of resistance training experience and exercised three times per week. In addition, subjects reported that they did not take ergogenic aids or medications that might influence performance, and only participants without musculoskeletal injuries in the previous six months or cardiorespiratory disorders were included. They were free to withdraw from the study at any time. The study was conducted according to the Declaration of Helsinki (1964; revised in 2014) and approved by the Institutional Review Board. Figure 2 shows the flow diagram of the present crossover study according to CONSORT guidelines.

### *Procedures*

### *Physiological variables*

*Arterial blood pressure*. Systolic (SBP) and diastolic (DBP) arterial blood pressure was obtained through a manual sphygmomanometer (Moore Medical, New Britain, CT, USA). We ensured proper arm cuff size by aligning target marks indicating appropriate cuff size and recorded the blood pressure of the relaxed right arm with the subject supine.

*Heart rate.* The maximum and average HR values were recorded by an HR monitor (Garmin Forerunner 735XT).

*Blood lactate.* Post-workout [La] was determined from a blood drop from the fingertips, with the participant in a seated position. Calibration of the lactate testing device (Lactate Scout+, SensLab GmbH, Germany) was performed prior to use, according to the procedures outlined by the manufacturer. The first drop of blood was discarded. The second drop of blood was applied to an assay strip and inserted into the lactate testing device. This analyser uses an enzymatic–amperometric detection method that requires only 0.5 $\mu$L of blood.

*Muscle oxygen saturation.* To measure SmO$_2$, a portable NIRS device (Moxy-I, Profusa Inc., South San Francisco, CA, USA) was placed in the fourth intercostal space [32]. This device uses light from the near-infrared wavelength spectrum (light from about 670

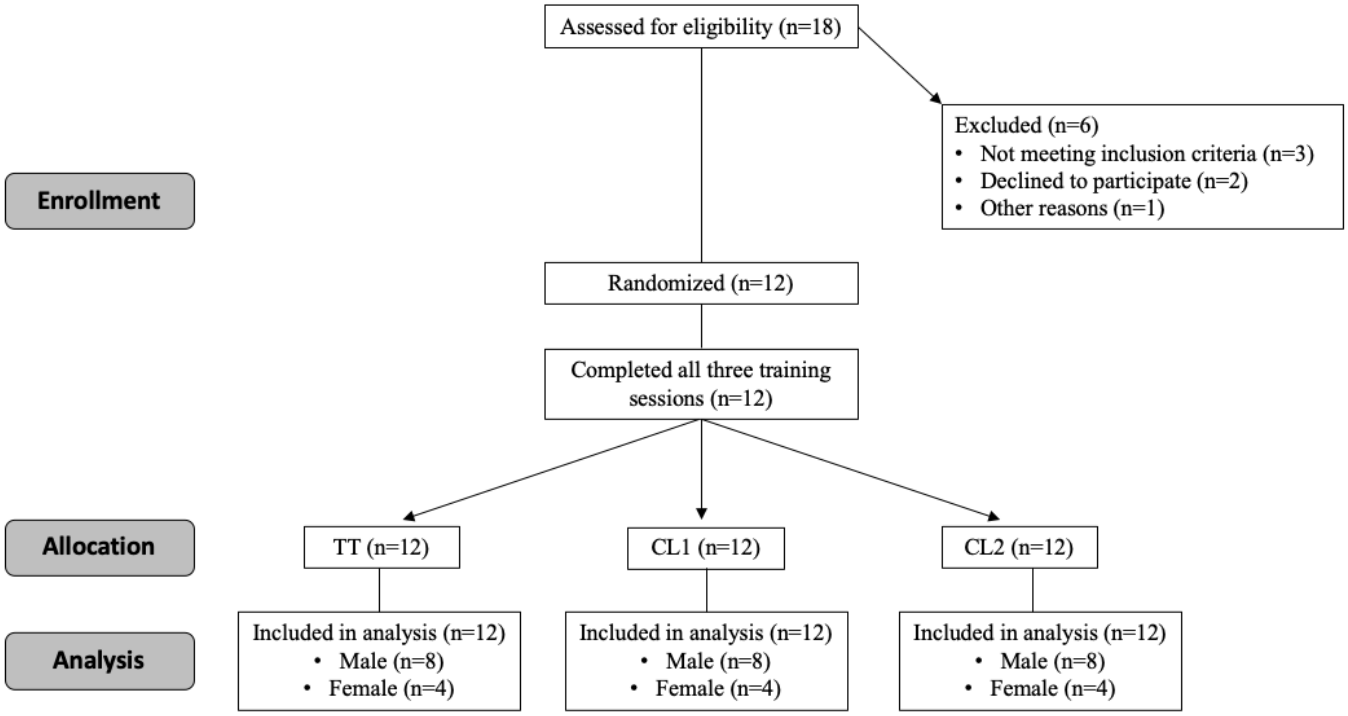

**FIG. 2.** CONSORT diagram.
Abbreviations: TT, traditional training; CL1, cluster training 1; CL2, cluster training 2.

to 810 nm) to measure the ratio of the oxyhaemoglobin concentration/total haemoglobin concentration ($SmO_2$) in the muscle according to the modified Beer–Lambert law. Light is emitted at 1-s intervals on the tissue at one location, and the light intensity is recorded by two detectors that receive spacings of 12.5 and 25 mm. The device was housed in the dark elastic bandage provided by the manufacturer to prevent contamination from ambient light. In addition, the average and lower $SmO_2$ values were obtained during the four sets of the barbell bench press. For this, the Seego program (Real Track Systems, Almería, Spain) monitored the $SmO_2$ data every 2 s, which, in addition to being able to be observed in real time, were recorded in the Moxy PC software (Fortiori Design LLC, Minneapolis, MN, USA), which allowed calculation of the average of the recorded values and the lowest point of the $SmO_2$ in each set of the barbell bench press.

### *Mechanical variables*

*One repetition maximum testing*. Prior to testing, subjects warmed up on a stationary bicycle for 5 min at 75 W. Afterwards, subjects performed dynamic upper-body movements and a warm-up session at the estimated intensity of 50% and 85% 1RM for 5–10 repetitions for all exercises. Then, the load was increased within 4–5 trials separated by at least 3 min until the 1RM was obtained (Haff & Triplett, 2015). The 1RM was stablished as the greatest weight that can be lifted once while maintaining acceptable exercise technique.

*Push-up and pull-up tests.* The push-up test was initiated with a subject in a standard push-up position, with the arms fully extended and feet together. Then, participants started the push-up by bending the elbows and lowering the body as a single unit until the upper arms were at least parallel to the ground (90° push-up) and then returning to the starting position by raising the entire body until full extension of the arm. Failure was defined when the subjects were not able to lower the whole body until the upper arms were at least parallel to the ground or to extend the arms completely. In the pull-up test the subject started in a standard pull-up position, with legs placed behind the body, ankles crossed, and knees flexed. Moreover, subjects were instructed to use an overhand grip with hands placed slightly wider than shoulder width and to extend the elbows fully in each repetition. Failure was defined when the subjects were not able to pass their chin over the pull-up bar. Between both tests, 5 minutes of rest were established.

*Movement velocity.* Mean and lower repetition values of velocity were calculated for each subject during the four sets of the barbell bench press, using a linear position transducer (EV Pro Isocontrol Dinámico 5.2. Quasar Control SL, Spain) that was fixed to the barbell. The concentric phase of each repetition was automatically identified by the linear position transducer. This system consists of a cable extension linear velocity transducer interfaced to a personal computer for digital data acquisition and custom software. Vertical instantaneous velocity was directly sampled by the device at a frequency of 1000 Hz.

### *Perceptual variables*

*Perception of effort and pain.* RPE was assessed by the OMNI-Resistance Exercise Scale [33], which is a validated RPE for resistance exercise. The OMNI-RES consisted of 10 reporting options between 1 (extremely easy) and 10 (extremely hard). The level of muscle pain was assessed after a single push-up exercise maintained for 5 s with a 90° elbow flexion using a VAS of 100 mm, with the furthest point on the left (0) representing no pain and the furthest point on the right (100) representing extreme pain.

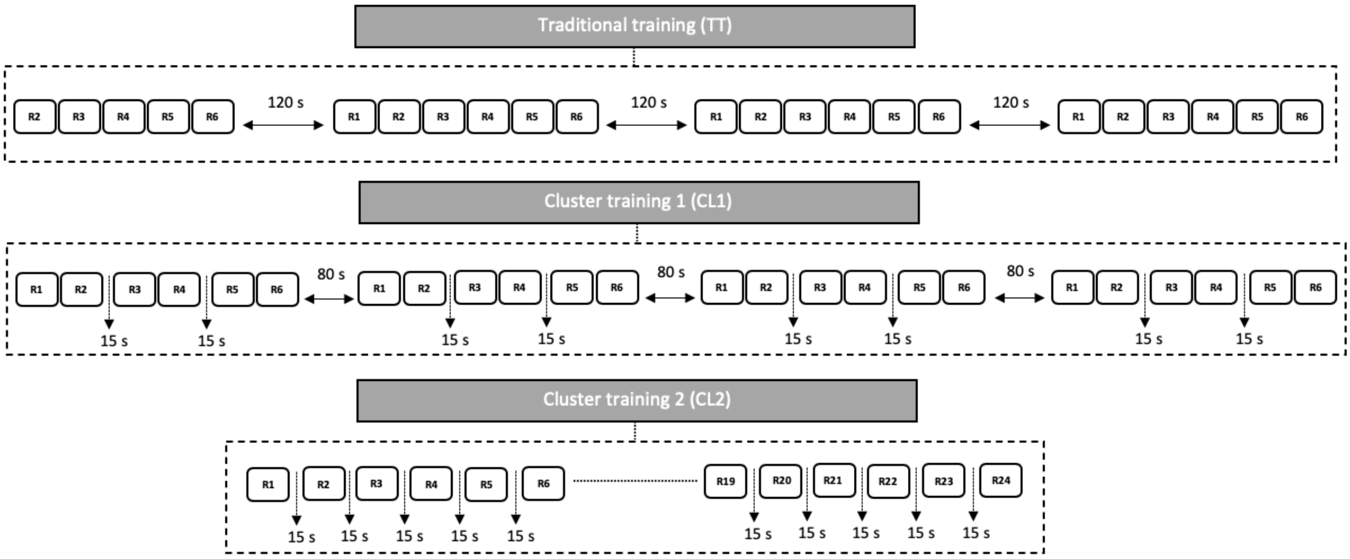

**FIG. 3.** Overview of the 3 set configurations used in the present study.

### *Training sessions*

In each session, the set configuration was randomized while the order of the exercises was the same: 1. Barbell bench press; 2. Chest-supported row machine; 3. Incline barbell bench press; 4. Lat pull-down machine; 5. Decline barbell bench press; 6. T-bar row. The total assigned rest time was equal between protocols (360 s), but its distributions were different (Figure 2). In the traditional training (TT), an inter-set rest of 120 s was established at the end of each set. In cluster 1 (CL1), sets were divided into three blocks of two repetitions with an intra-set rest of 15 s and an inter-set rest of 80 s. In cluster 2 (CL2), a single set of 24 repetitions was carried out with an inter-repetition rest of 15 s (Figure 3). Training always started with the barbell bench press for all participants, in which data of movement velocity and $SmO_2$ were collected. The intensity for all protocols was fixed at 85% of 1RM.

### *Statistical analysis*

The statistical analysis was carried out with SPSS 22.0 computer software for Windows. The Shapiro–Wilk test was applied in order to verify a normal distribution of data, and Levene's test was used to assess the homogeneity of variance. A two-way analysis of variance (ANOVA) with repeated measures was used to explore differences in $SmO_2$, movement velocity, push-up and pull-up tests, and arterial blood pressure variables in the three protocols (TT, CL1, CL2). If significant interaction was found, Bonferroni pairwise post-hoc analyses examined differences between training protocols and across test times. In addition, a one-way ANOVA was applied to analyse differences in HR, La, RPE, and VAS pain values. Moreover, for each ANOVA, partial omega-squared ($\omega_p^2$) was calculated and qualitatively interpreted using the following thresholds: $< 0.01$ trivial, $> 0.01$ small; $> 0.06$ medium, and $> 0.14$ large. The significance level was set at $p \le 0.05$, with a confidence level of 95%. Mean and standard deviations (SD) were used as descriptive statistics.

## RESULTS

Values of movement velocity and $SmO_2$ variables are shown in Table 1 for all groups. A main effect for time on mean velocity (F = 75.545; $p < 0.001$) was detected. This was observed with the decrease in mean velocity throughout the four sets. In addition, an interaction between time and protocol was found (F = 9.622; p = 0.001) in the last sets in the TT group compared to CL1 and CL2. Regarding the lower values of velocity, a main effect for time was observed (F = 70.280; $p < 0.001$). Moreover, similar to mean velocity, an interaction between time and protocol was found (F = 4.274; p = 0.022) in the last sets. According to mean and lower $SmO_2$ values, no significant changes were observed between groups or when comparing all sets.

For push-up and pull-up tests, a significant interaction (F = 71.052, $p < 0.001$; F = 31.108, $p < 0.001$) was found for time. The number of push-up repetitions performed was significantly lower ($p < 0.05$) after the training in all groups. However, the number of pull-up repetitions was significantly lower ($p < 0.05$) after the training only in TT and CL2. In addition, no main group or interaction effect was observed. Regarding SBP values, a main effect on time was observed in which the TT group showed significantly decreased values ($p < 0.05$). In contrast, a small interaction effect was observed

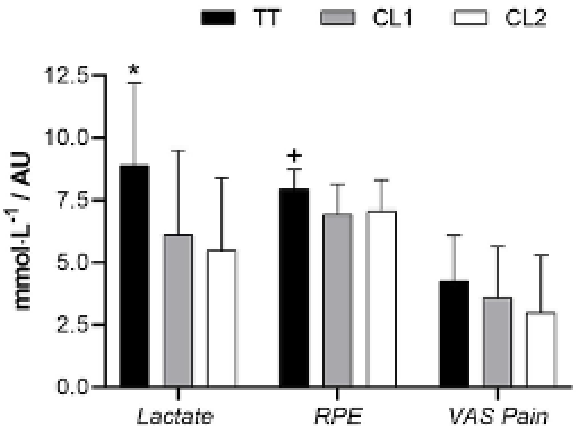

**FIG. 4.** Rating of blood lactate values, RPE and VAS pain.
Note: Data are mean ± SD. * Significantly different to CL1 and CL2; + Significantly different to CL1; A.U. Arbitrary units.

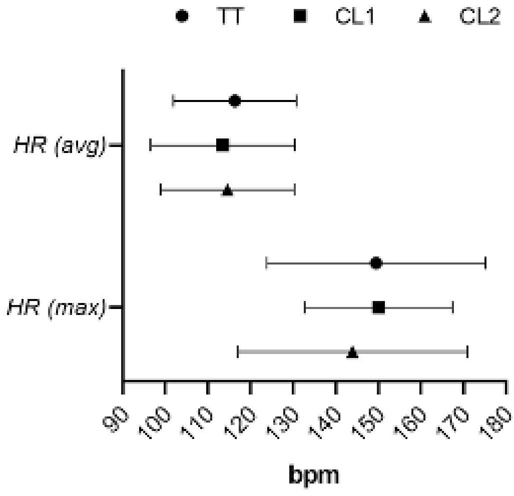

**FIG. 5.** Pooled data for maximum and average heart rate for both groups.
Note: Data are mean ± SD. No significant differences were found between protocols.

**TABLE 1.** Velocity and muscle oxygen saturation values for all set configurations (mean ± SD).

| | | SET 1 | SET 2 | | SET 3 | | SET 4 | |
|---|---|---|---|---|---|---|---|---|
| | | | | % | | $\Delta^2$% | | $\Delta^3$% |
| **Mean velocity** (m·s−1) | TT | 0.37 ± 0.06 | 0.33 ± 0.07$^{a}$ | -12.12 | 0.29 ± 0.07$^{ab*}$ | -13.79 | 0.22 ± 0.05$^{abc*}$ | -31.81 |
| | CL1 | 0.37 ± 0.07 | 0.34 ± 0.06 | -8.82 | 0.34 ± 0.07 | 0 | 0.32 ± 0.08$^{a}$ | -6.25 |
| | CL2 | 0.37 ± 0.07 | 0.33 ± 0.09$^{a}$ | -12.12 | 0.32 ± 0.10$^{a}$ | -3.12 | 0.30 ± 0.08$^{a}$ | -6.66 |
| | T (*p*) | | | | < 0.001 | | | |
| | $\omega_p2$ (rating) | | | | 0.68 (*Large*) | | | |
| | G (*p*) | | | | 0.357 | | | |
| | $\omega_p2$ (rating) | | | | 0.01 (*Small*) | | | |
| | T x G (*p*) | | | | 0.001 | | | |
| | $\omega_p2$ (rating) | | | | 0.32 (*Large*) | | | |
| **Lower velocity** (m·s−1) | TT | 0.28 ± 0.08 | 0.25 ± 0.07 | -12.00 | 0.19 ± 0.05$^{ab*}$ | -31.57 | 0.16 ± 0.04$^{abc*}$ | -18.75 |
| | CL1 | 0.31 ± 0.07 | 0.27 ± 0.08 | -14.81 | 0.25 ± 0.08$^{a}$ | -8 | 0.25 ± 0.09$^{a}$ | 0 |
| | CL2 | 0.32 ± 0.09 | 0.29 ± 0.10 | -10.34 | 0.27 ± 0.09$^{a}$ | -7.40 | 0.24 ± 0.12$^{ab}$ | -12.50 |
| | T (*p*) | | | | < 0.001 | | | |
| | $\omega_p2$ (rating) | | | | 0.66 (*Large*) | | | |
| | G (*p*) | | | | 0.164 | | | |
| | $\omega_p2$ (rating) | | | | 0.04 (*Small*) | | | |
| | T x G (*p*) | | | | 0.022 | | | |
| | $\omega_p2$ (rating) | | | | 0.15 (*Large*) | | | |
| **Mean SmO$_2$** (%) | TT | 50.75 ± 12.98 | 52.18 ± 15.01 | 2.74 | 53.00 ± 14.14 | 1.54 | 50.90 ± 19.79 | -4.12 |
| | CL1 | 52.14 ± 21.69 | 51.32 ± 18.65 | -1.59 | 52.64 ± 21.85 | 2.50 | 53.03 ± 19.67 | 0.73 |
| | CL2 | 45.19 ± 20.10 | 44.46 ± 24.74 | -1.64 | 46.87 ± 23.29 | 5.14 | 46.58 ± 24.56 | -0.62 |
| | T (*p*) | | | | 0.42 | | | |
| | $\omega_p2$ (rating) | | | | < 0.01 (*Trivial*) | | | |
| | G (*p*) | | | | 0.67 | | | |
| | $\omega_p2$ (rating) | | | | < 0.01 (*Trivial*) | | | |
| | T x G (*p*) | | | | 0.91 | | | |
| | $\omega_p2$ (rating) | | | | < 0.01 (*Trivial*) | | | |
| **Lower SmO$_2$** (%) | TT | 32.66 ± 23.70 | 34.66 ± 22.74 | 5.77 | 39.58 ± 20.66 | 12.43 | 39.5 ± 20.29 | -0.20 |
| | CL1 | 40.62 ± 28.31 | 37.33 ± 26.08 | -8.81 | 42.16 ± 26.94 | 11.45 | 38.58 ± 24.95 | -9.27 |
| | CL2 | 35.64 ± 29.81 | 36.41 ± 28.95 | 2.11 | 36.83 ± 27.41 | 1.14 | 36.08 ± 30.04 | -2.07 |
| | T (*p*) | | | | 0.22 | | | |
| | $\omega_p2$ (rating) | | | | 0.01 (*Small*) | | | |
| | G (*p*) | | | | 0.93 | | | |
| | $\omega_p2$ (rating) | | | | < 0.01 (*Trivial*) | | | |
| | T x G (*p*) | | | | 0.23 | | | |
| | $\omega_p2$ (rating) | | | | 0.02 (*Small*) | | | |

Note: a *Significant difference ($p < 0.05$) with respect to set 1*; b *Significant difference ($p < 0.05$) with respect to set 2*; c *Significant difference ($p < 0.05$) with respect to set 3*; $\Delta$% *percent change between sets 2 and 1*; $\Delta^2$ % *percent change between sets 3 and 2*; $\Delta^3$ % *percent change between sets 4 and 3.* * *Significant difference ($p < 0.05$) with respect to CL1 and CL2*; $\omega_p2$ = partial omega-squared; T, *main time effect*; G, *main group effect*; T x G, *interaction effect*.

**TABLE 2.** Values of functional tests and arterial blood pressure (SBP and DBP) for all set configurations (mean±SD).

| | | TT | | CL1 | | CL2 | |
|---|---|---|---|---|---|---|---|
| | | *Pre* | *Post* | *Pre* | *Post* | *Pre* | *Post* |
| **Push-up test** (reps) | mean ± SD | 30.42 ± 14.55 | 20.50 ± 12.43$^{\dagger}$ | 31.14 ± 14.19 | 23.36 ± 12.27$^{\dagger}$ | 31.42 ± 12.80 | 24.25 ± 12.07$^{\dagger}$ |
| | Δ% | -48.39 | | -33.30 | | -29.56 | |
| | T (*p*) | < 0.001 | | | | | |
| | $\omega_p2$ (rating) | 0.67 (*Large*) | | | | | |
| | G (*p*) | 0.89 | | | | | |
| | $\omega_p2$ (rating) | < 0.01 (*Trivial*) | | | | | |
| | T x G (*p*) | 0.486 | | | | | |
| | $\omega_p2$ (rating) | < 0.01 (*Trivial*) | | | | | |
| **Pull-up test** (reps) | mean ± SD | 8.00 ± 6.24 | 5.75 ± 5.43$^{\dagger}$ | 7.73 ± 5.90 | 6.91 ± 5.38 | 7.42 ± 5.62 | 6.25 ± 5.50$^{\dagger}$ |
| | Δ% | -39.13 | | -11.86 | | -18.72 | |
| | T (*p*) | < 0.001 | | | | | |
| | $\omega_p2$ (rating) | 0.46 (*Large*) | | | | | |
| | G (*p*) | 0.97 | | | | | |
| | $\omega_p2$ (rating) | < 0.01 (*Trivial*) | | | | | |
| | T x G (*p*) | 0.069 | | | | | |
| | $\omega_p2$ (rating) | 0.09 (*Medium*) | | | | | |
| **SBP** (mmHg) | mean ± SD | 10.85 ± 0.80 | 11.13 ± 0.68$^{\dagger}$ | 10.86 ± 0.45 | 11.06 ± 0.62 | 11.00 ± 0.56 | 10.96 ± 0.14 |
| | Δ% | 2.51 | | 1.80 | | -0.36 | |
| | T (*p*) | 0.049 | | | | | |
| | $\omega_p2$ (rating) | 0.07 (*Medium*) | | | | | |
| | G (*p*) | 0.99 | | | | | |
| | $\omega_p2$ (rating) | < 0.01 (*Trivial*) | | | | | |
| | T x G (*p*) | 0.196 | | | | | |
| | $\omega_p2$ (rating) | 0.03 (*Small*) | | | | | |
| **DBP** (mmHg) | mean ± SD | 6.71 ± 0.45 | 6.73 ± 0.42 | 6.82 ± 0.46 | 6.78 ± 0.47 | 6.50 ± 0.45 | 6.81 ± 0.45$^{\dagger}$ |
| | Δ% | 0.29 | | -0.58 | | 4.55 | |
| | T (*p*) | 0.118 | | | | | |
| | $\omega_p2$ (rating) | 0.04 (*Small*) | | | | | |
| | G (*p*) | 0.83 | | | | | |
| | $\omega_p2$ (rating) | < 0.01 (*Trivial*) | | | | | |
| | T x G (*p*) | 0.050 | | | | | |
| | $\omega_p2$ (rating) | 0.11 (*Medium*) | | | | | |

Note: $^{\dagger}$ *Significant difference (p < 0.05) with respect to pre*; Δ% *percent change between post and pre*; $\omega_p2$ = partial omega-squared; T, *main time effect*; G, *main group effect*; T x G, *interaction effect*.

as DBP decreased significantly ($p < 0.05$) in CL2 after the training (Table 2). Nevertheless, no significant changes were observed between groups in arterial blood pressure values.

The maximum and mean HR values were similar in all training groups (Figure 4). However, blood lactate values were significantly higher ($p < 0.05$) in the TT group after the training compared to the CL1 and CL2 groups (8.90 vs. 6.13 and 5.48 mmol·l-1, respectively). Consequently, the reported RPE values were higher in the TT group as well. However, they were only significant ($p < 0.05$) with respect to the CL1 group (7.95 vs. 6.91 a.u., respectively). No differences were observed in VAS pain between protocols.

## DISCUSSION

The main purpose of the present study was to compare the effects of three different set configurations (TT, CL1 and CL2) on perceptual responses, physiological indicators and mechanical parameters during resistance training sessions conducted with upper-body exercises. Our main findings are: a) the CL1 and CL2 set configurations were able to maintain greater mean velocities during all sets of the bench press; b) while TT was the set configurations that produced lower movement velocities throughout the sets, the three set configurations presented similar $SmO_2$ values; c) more frequent repetitions (TT) were associated with higher lactate concentrations and RPE values.

In relation to movement velocity during strength exercises, previous research has shown that this parameter decreased as neuromuscular fatigue increased [34]. Our results show a greater loss of mean velocity in the last sets (3rd and 4th) in the TT compared to both CLs, suggesting greater neuromuscular fatigue. These results are in agreement with previous studies that have shown a greater loss of performance in protocols with rest at the end of each set [19, 35–37]. This progressive loss of movement velocity during the sets could generate an undesired effect on neuromuscular adaptations [15], which can be partially attenuated by the use of cluster training configurations. All training groups performed each protocol reaching or near muscle failure in the last repetition. In addition, lower velocity values were obtained during the TT during the last sets. This indicates that this group made a greater effort at the end of each set, so the phosphocreatine (PCr) deposits could be completely depleted without recovering to maintain performance [38]. Therefore, the use of a cluster configuration could provide sufficient time for partial replacement of PCr [39] and attenuate the velocity loss.

Similarly, the intramuscular mechanical pressure during the strength training caused a decrease in the $SmO_2$ (21). Previous research has shown changes in oxygen saturation values after performing four sets of eight reps at 80% of 1RM [40] and three sets of eight reps at 80% of 1RM [27] with a normal set configuration (i.e., rest between sets). In our protocol, all training groups performed fewer repetitions per set than in the aforementioned studies, which could have prevented $SmO_2$ values from being lower at the end of each set. In addition, no significant differences in $SmO_2$ (both mean and lower values) were observed between TT and CLs. However, Tufano et al. [31] observed higher values of tHB and $SmO_2$ in the rest-redistribution protocol compared with the traditional protocol. The authors concluded that the frequent concentric muscle actions that occur during this protocol increased the mechanical pumping to facilitate venous return and replenish PCr stores. Nevertheless, muscle oxygenation changes depend on exercise mode and muscle actions [26], so it is possible that the muscle evaluated in the present study (pectoral muscle) could have a different response to training in terms of oxygen saturation compared to other, larger muscles (vastus lateralis) previously evaluated. In addition, this lack of differences between protocols could be explained by the high level of training of the evaluated subjects, who are accustomed to training until muscle failure and have a highly developed anaerobic metabolism, which could have attenuated the decrease in $SmO_2$ in the TT [41].

In connection with the performance during the functional tests (push-up and pull-up), a significant decrease was observed after every protocol. Intense exercise causes a reduction in neuromuscular performance due to the development of central and peripheral fatigue [42]. However, although the primary effect of cluster set configurations is the reduction of fatigue by introducing intermittent rest within a set [23], no differences between groups were found in the push-up and pull-up tests.

Consistent with our results, a recent review concluded that although cluster training could have a positive effect in attenuating loss of movement velocity and power output, it is not clear that it has a positive effect on performance in all exercises [43], specifically when training with such high loads (+85% of 1RM). Moreover, it is also difficult to extrapolate conclusions of the benefits obtained with the lower body cluster training over the upper body, since the little existing scientific evidence suggests that the development of fatigue and performance differs between the upper and lower limbs [44]. According to arterial blood pressure, no differences between groups were found. Although the sympathetic vasoconstrictor tone may also be elevated after an acute bout of resistance exercise due to an increase of plasma norepinephrine levels [45], only an increment in the SBP and DBP was observed in the TT.

In relation to La accumulation, TT showed higher values in this parameter after training with respect to cluster configurations. This is in agreement with previous studies that examined the effect of different set configurations on metabolic responses [17, 19, 23, 39]. It has been reported that decreases in power output and movement velocity during strength exercises could decrease ATP/PCr availability, increasing La accumulation [46]. Moreover, it is possible that the recovery between the repetitions in cluster protocols decreases metabolite accumulation, resulting in lower La values compared to TT [7]. As observed in previous studies [20, 23], La values were associated with an increase in perceived fatigue in TT. In addition, decreases in power output have been associated with decreases in PCr levels [46]. Although PCr was not measured in this investigation, TT could have increased PCr depletion, leading to higher RPE values [47]. Moreover, reported muscle pain was also higher in the group that obtained higher La levels, although without reaching statistical significance. Thus, both scales (RPE and VAS pain) could serve as an effective tool to quickly control the training load without applying more expensive methods in time and resources [48]. Finally, the mean and maximum HR values were similar in all training groups. This may be logical, since the intensity was high (80% of 1RM) in all sessions.

## CONCLUSIONS

In conclusion, the data presented herein indicate that during an acute high-load resistance training session, the application of cluster set configuration could attenuate the movement velocity loss, at least in the bench press exercise, as well as the metabolic and perceptual responses in the overall session.

### Practical applications

In practical terms, coaches and physical fitness professionals should be cautious when recommending cluster configurations to their athletes, as the organization of the different variables (intensity, volume, and rest distribution) that compose them could cause different responses in performance and muscle fatigue.

### Limitations

Several limitations of this study need to be noted. The first is the impossibility of using NIRS for measuring changes in muscle oxygen saturation during exercise. Others are the limited sample size and the inclusion of both genders, which should be considered when interpreting the results.

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