ORIGINAL ARTICLE

Acute effects of different set configurations during a strength-oriented resistance training session on barbell velocity and the force–velocity relationship in resistance-trained males and females

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Abstract

Purpose This study explored the acute effects of strength-oriented resistance training sessions performed using three different set configurations on barbell velocity and the force–velocity (F–v) relationship of upper-body muscles in men and women.
Method Thirteen men (age: 23.8 ± 2.5 years; 6-repetition maximum [6RM] load: 73.4 ± 15.6 kg) and 13 women (age: 21.5 ± 1.4 years; 6RM load: 32.8 ± 5.2 kg) performed 24 repetitions with a 6RM load during the bench press exercise using traditional (TR: 6 sets of 4 repetitions with 3 min of rest between sets), cluster (CL: 6 sets of 4 repetitions with 15 s of intra-set rest every two repetitions and 2 min and 45 s of rest between sets) and inter-repetition rest (IRR: 1 set of 24 repetitions with 39 s of rest between repetitions) set configurations. The F–v relationship parameters [maximum force (F_0), maximum velocity (v_0) and maximum power (P_{max})] were determined before and after each training session.
Results The average training velocity did not differ between the three set configurations ($p = 0.234$), but the IRR set configuration generally provided higher velocities during the last repetition of each set. Significant decreases in F_0 ($p = 0.001$) and P_{max} ($p = 0.024$) but not in v_0 ($p = 0.669$) were observed after the training sessions. Comparable velocity loss was observed for men and women (-12.1% vs. -11.3%; $p = 0.699$).
Conclusions The administration of very short intra-set rest periods does not allow for the attainment of higher velocities than traditional set configurations during strength-oriented resistance training sessions conducted with the bench press exercise when the work-to-rest ratio is equated.

Keywords Strength training · Cluster set · Inter-repetition rest · Velocity loss

Abbreviations

TR	Traditional set configuration
CL	Cluster set configuration
IRR	Inter-repetition rest set configuration
1 RM	One repetition maximum
F–v	Force–velocity
F_0	Maximal theoretical force
v_0	Maximal theoretical velocity
P_{max}	Maximal theoretical power
ES	Effect size
SD	Standard deviation

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Introduction

Strength training plays an important role in the physical preparation of many sports (McGuigan et al. 2012; Suchomel et al. 2016). Resistance training sessions typically encompass several sets of different exercises (Marshall et al. 2011). Sets have been commonly performed without any rest between repetitions and introducing rest periods between successive sets (traditional set configuration; TR). More recently, a set configurations known as cluster (CL) has been proposed (Haff et al. 2008; Tufano et al. 2017a).

The CL set configuration typically introduces brief rest periods ($\approx$ 6–30 s) between groups of repetitions and a longer rest period is introduced between successive sets. A type of CL set configuration known as inter-repetition rest (IRR) consists of performing all repetitions in a single set but introducing a rest period after each repetition (Iglesias-Soler et al. 2012; González-Hernández et al. 2017; Tufano et al. 2017b; García-Ramos et al. 2017). It is important to note that the training session duration could be the same for the TR, CL and IRR set configurations (i.e., equated work-to-rest ratio), differing only in the distribution of the rest within the training session (Tufano et al. 2017c). The CL and IRR set configurations have proven to be effective for altering mechanical, metabolic and perceptual variables when compared to TR set configurations (Iglesias-Soler et al. 2012, 2014; Girman et al. 2014; Moreno et al. 2014; Oliver et al. 2015, 2016, García-Ramos et al. 2015, 2017; Tufano et al. 2016, 2017b; González-Hernández et al. 2017).

It is generally accepted that performing resistance training at the maximum possible velocity induces greater strength gains than training deliberately at a lower velocity (González-Badillo et al. 2014; Pareja-Blanco et al. 2014). Similarly, reducing the magnitude of velocity loss during resistance training has also been recommended to enhance athletic performance (Pareja-Blanco et al. 2017). In this regard, CL and IRR set configurations may be effective at maintaining higher velocities and power outputs during resistance training sessions (Iglesias-Soler et al. 2012, 2014; Girman et al. 2014; Moreno et al. 2014; Oliver et al. 2015, 2016, García-Ramos et al. 2015, 2017; Tufano et al. 2016, 2017b, c; González-Hernández et al. 2017). It should be noted that the vast majority of studies that have analysed the effects of CL and IRR set configurations on barbell velocity have used loads lower than the typically used during strength-oriented resistance training sessions (> 85% of the 1-repetition maximum; 1RM) (Tufano et al. 2017a). Haff et al. (2003) also reported that introducing 30-s rest periods between successive repetitions allow for the maintenance of higher velocities during the clean pull exercise performed at 90% and 120% of power clean 1RM compared to a TR set configuration. However, to the authors' knowledge no research has examined if the CL and IRR set configurations could also allow for higher movement velocities when heavy loads ($\geq$ 85%1RM) are used during upper-body exercises (e.g., bench press). In addition, although many studies have explored the acute effect of CL and IRR set configurations in male subjects (Iglesias-Soler et al. 2012, 2014; Girman et al. 2014; Moreno et al. 2014; Oliver et al. 2015, 2016; García-Ramos et al. 2015, 2017; Tufano et al. 2016, 2017b, c; González-Hernández et al. 2017), only two studies have explored their effects on women (Koefoed et al. 2018; Korak et al. 2018). Korak et al. (2018) found in trained females that the total volume lifted during the back squat exercise was

higher following a IRR set configuration (4 s of rest between each repetition) compared to a traditional set configuration. However, no study has compared the acute effects of different set configurations (TR, CL and IRR) on mechanical variables between men and women. It is plausible that the changes in mechanical variables would not significantly differ between males and females since previous studies have revealed that they can perform a similar number of repetitions before reaching muscular failure when exercising against the same relative load (Clark et al. 2003; Pincivero et al. 2004). However, this is not evident since previous studies have also shown sex differences in the temporal recovery of neuromuscular function following resistance training (more pronounced loss and prolonged recovery in women compared to men) (Davies et al. 2018).

The lower fatigue induced by CL and IRR set configurations is evidenced by the higher mechanical outputs (i.e., force, velocity and power outputs) commonly reported during these set configurations compared to the TR set configuration (García-Ramos et al. 2015; Tufano et al. 2016, 2017b). However, it has been suggested that CL and IRR set configurations could be more effective at maintaining velocity than force outputs (Hansen et al. 2011). In this regard, it is important to remember that the values of force and velocity collected under individual loads are inter-dependent and, therefore, they cannot be used to elucidate whether CL and IRR set configurations exert a greater effect on force or velocity capacities. The force–velocity (F–v) relationship, which requires the assessment of force and velocity outputs against at least two different loading conditions, is ideally suited for determining the selective impact on force and velocity capacities (García-Ramos and Jaric 2018). The F–v relationship has recently been shown to be an effective tool for evaluating the selective changes in the muscles maximal capacity to produce force (F_0; force-intercept) and velocity (v_0; velocity-intercept) after executing different resistance training sets (García-Ramos et al. 2018a). Therefore, modelling the F–v relationship before and after a training session would not only allow for the determination of the residual fatigue effects of a training session through the recording of maximal power capacity (P_{max}), but it can also help to discriminate if the changes in P_{max} are caused by changes in F_0, v_0, or both.

To fill the aforementioned gaps in the literature, in the present study a group of physically active men and women performed strength-oriented resistance training sessions using three different set configurations: TR (repetitions distributed into several sets without intra-set rest), CL (repetitions distributed in several sets with brief rest periods after every two repetitions), and IRR (all repetitions performed within a single set introducing rest periods after each repetition). Specifically, the aims of the present study were (I) to compare movement velocity between the three different set

configurations during bench press strength-oriented resistance training sessions, (II) to explore the fatigue induced by the different resistance training sessions through the magnitude of the F–v relationship parameters (F_0, v_0, F–v slope, and P_{max}), and (III) to examine the between-sex differences in the aforementioned variables. We hypothesised that (I) the CL and IRR set configurations would allow for higher movement velocities when compared to the TR set configuration, (II) all set configurations would induce a significant decrease in P_{max}, being the decrease in F_0 more pronounced than in v_0 due to the use of heavy loads (high-force and low-velocity) during training, and (III) the velocity loss and the changes in the F–v relationship parameters would not significantly differ between men and women.

Methods

Subjects

Based on the results obtained by Tufano et al. (2017b) who compared movement velocity between traditional and cluster set configurations, we conducted an a priori power analysis using the GPower 3.1 software to calculate the minimum sample size required for a repeated-measures ANOVA using classical frequentist analysis. We considered the effect sizes obtained for movement velocity of the aforementioned study and assumed an alpha of 0.05 and power of 0.80. Our analysis projected a minimum sample size of 12 subjects per group. Therefore, we conservatively recruited 13 men (age = 23.8 ± 2.5 years; body mass = 73.4 ± 8.9 kg; body height = 1.77 ± 0.07 m; 6RM load = 73.4 ± 15.6 kg) and 13 women (age = 21.5 ± 1.4 years; body mass = 62.2 ± 8.7 kg; body height = 1.69 ± 0.06 m; 6RM load = 32.8 ± 5.2 kg) to participate in this study. At the beginning of the study, the males (6.2 ± 2.0 years) had a greater training experience with the bench press than the females (1.2 ± 1.5 years). Subjects were instructed to avoid any strenuous exercise two days before each testing session. All subjects were informed of the study procedures and signed a written informed consent form prior to initiating the study. The study protocol adhered to the tenets of the Declaration of Helsinki and was approved by the University of Granada Institutional Review Board.

Study design

A two-group repeated-measures design was used to examine the acute effect of three different set configurations (TR, CL and IRR) on barbell velocity and the F–v relationship during strength-oriented resistance training sessions conducted with the bench press exercise. Prior to the three main testing sessions, all subjects were involved in a 4-week training program (twice a week, with 48–72 h of rest between sessions)

with the objectives of increasing maximal strength and ensuring proper technique during the bench press exercise. In each training session, subjects performed five sets of the bench press exercise in a Smith machine (Technogym, Barcelona, Spain) as well as several complementary exercises such as the seated military press, lat pulldown, or leg press. The intensity in the bench press exercise was progressively increased from ≈ 70%1RM during the first week of training to ≈ 85%1RM during the last week of training. A linear velocity transducer was used to measure barbell velocity during all training sessions. The relative load (%1RM) was estimated from the mean velocity of the barbell (Pestaña-Melero et al. 2017) and the subjects were told to stop the set when the mean velocity dropped below 0.30 m s⁻¹ in men and 0.35 m s⁻¹ in women (approximately 2–3 repetitions in reserve) (García-Ramos et al. 2018b). Different stopping velocities were used to leave a similar number of repetitions in reserve since the velocity of the 1RM seems to be higher for women than men in the bench press exercise (Torrejon et al. 2018).

The three main experimental sessions consisted of a strength-oriented resistance training session using different set configurations: traditional set configuration (TR; 6 sets of 4 repetitions with 3 min of rest between sets), cluster set configuration (CL; 6 sets of 4 repetitions with 15 s of intra-set rest every two repetitions and 2 min and 45 s of rest between sets), and inter-repetition rest set configuration (IRR; 1 set of 24 repetitions with 39 s of rest between repetitions) (Fig. 1). The order of the different set configurations was randomised and they were separated by 4–7 days. The F–v relationship was determined on two occasions during each session: 5 min after the warm-up (pre-session) and 10 min after the last set of the training session (post-session). All subjects were evaluated in the afternoon (between 16:00 and 20:00 h) and under similar environmental conditions (~ 22 °C and ~ 60% humidity).

Procedures

Subjects performed 4 testing sessions after the 4-week resistance training period. The first session was used to determine the 6RM load in the bench press exercise, which was then used as the testing load during the 3 remaining testing sessions (i.e., TR, CL and IRR set configurations). All testing sessions began with a standardised warm-up that included 5 min of jogging and dynamic stretching, followed by 3 sets of 10, 5, and 2 repetitions in the bench press exercise against the 40%6RM, 70%6RM, and 100%6RM load, respectively. Subjects rested for 2 min between the warm-up sets and 5 min between the last set of the warm-up and the start of the testing protocol.

The testing protocol started with the determination of the F–v relationship during the bench press throw exercise. The
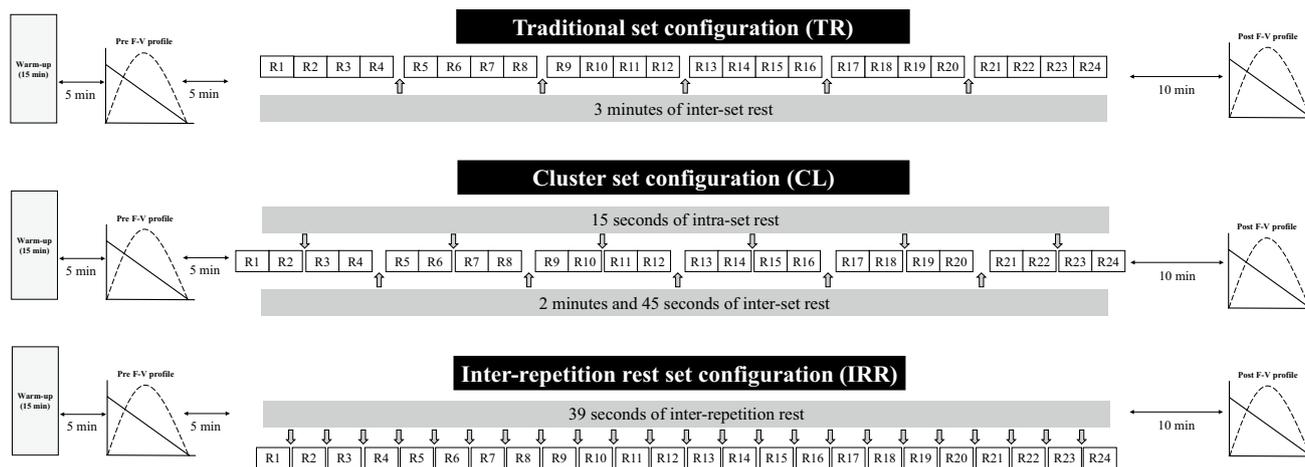
Fig. 1 Traditional (TR; 6 sets of 4 repetitions with 3 min of rest between sets), cluster (CL; 6 sets of 4 repetitions with 15 s of intra-set rest every two repetitions and 2 min and 45 s of rest between sets), and inter-repetition rest (IRR; 1 set of 24 repetitions with 39 s of rest between repetitions) set configurations analysed in the present study.

Note that the time needed to complete the training session was the same for the three set configurations (≈ 17 min). The force–velocity (F–v) relationship during the bench press throw exercise was measured before and after the resistance training session. R, repetition

mean propulsive values of force and velocity were computed with a linear velocity transducer (T-Force System; Ergotech, Murcia, Spain; sampling frequency 1000 Hz) against a light (17 kg; mass of the unloaded Smith machine barbell) and a heavy load (individual 6RM load). Two repetitions were performed with each load separated by at least 30 s. Force was calculated as the product of the mass lifted and the total acceleration (gravity + acceleration of the barbell). The mass of the arms (10% of body mass according to Winter's table) (Winter 1990) and the friction force of the Smith machine (11 N) were considered for all force computations (Rahmani et al. 2018). The F–v relationship parameters were determined at the beginning and at the end of the testing session following identical procedures. Namely, the force and velocity data collected under the two different loads were modelled through a linear regression: $[F(V) = F_0 - aV]$, where F_0 represents the force-intercept, a is the slope of the F–v relationship (F–v slope = F_0/v_0), and v_0 is the velocity-intercept (García-Ramos and Jaric 2018). Maximum power output (P_{max}) was not directly measured but was calculated as $P_{max} = (F_0 \cdot v_0)/4$ (Jaric 2015).

After determining the pre-session F–v relationship, subjects completed 1 of the 3 testing sessions (see Fig. 1 for details). The bench press exercise was performed in a Smith machine using the standard five-point body contact position technique (head, upper back, and buttocks firmly on the bench with both feet flat on the floor). Subjects self-selected the grip width, which was measured and kept constant on every lift. Subjects initiated the task holding the barbell with their elbows fully extended. From this position, they were instructed to perform the downward phase until contacting their chest at the lower portion of the sternum, and

immediately after contact they performed the upward phase of the lift as fast as possible. The upward phase ended when the subjects' elbows reached full extension. The maximum velocity of the barbell achieved during the lifting phase was collected with a linear velocity transducer to compare movement velocity between the three set configurations. Subjects were instructed to perform all repetitions at the maximum intended velocity and they remained seated on the bench during each recovery period. A manual timer was used to monitor the length of the recovery period and a countdown from 5 was used to prepare the subjects for a new repetition.

Statistical analyses

Data are presented as mean ± standard deviation. The normal distribution of the data (Shapiro–Wilk test) and the homogeneity of the variances (Levene's test) were confirmed ($p > 0.05$). Two-way mixed ANOVAs (within-subjects factor: set configuration [TR, CL and IRR]; between-subjects factor: sex [men and women]) were conducted on the maximum velocity achieved at the first repetition of each training session as well as on the averaged velocity value of the training session (i.e., averaged maximum velocity of the 24 repetitions). A one-way repeated measures ANOVA was applied to compare movement velocity between the 3 set configurations during each of the 24 repetitions performed. The velocity loss (%) of each set of 4 repetitions with respect to the first repetition of the training session was calculated and a three-way mixed ANOVA (within-subjects factors: set configuration [TR, CL and IRR] and number of sets [1, 2, 3, 4, 5 and 6]; between-subjects factor: sex [men and women]) was applied. Finally, a three-way mixed ANOVA

(within-subjects factor: time [pre-session and post-session] and set configuration [TR, CL and IRR]; between-subjects factor: sex [men and women]) was applied on the magnitude of the F–v relationship parameters (F_0, v_0, F–v slope, P_{max}). Bonferroni post hoc corrections were used for pairwise comparisons. Hedge's g effect size (ES) was also calculated and its magnitude was interpreted according to the following scale: trivial (< 0.2), small (0.2–0.59), moderate (0.60–1.19), large (1.2–2.0) and very large (> 2.0) (Hopkins et al. 2009). Partial eta squared (η_p^2) was used during multiple comparisons. Statistical tests were performed using the software package SPSS (version 22.0; SPSS, Inc., Chicago, IL, USA). Significance level was set at $p \leq 0.05$.

Results

The ANOVAs conducted on the velocity values attained at the first repetition of each session as well as on the averaged velocity value of the training session did not reveal a significant main effect for "set configuration" ($p = 0.786$ [$\eta_p^2 = 0.010$] and 0.159 [$\eta_p^2 = 0.074$], respectively), "sex" ($p = 0.153$ [$\eta_p^2 = 0.083$] and 0.102 [$\eta_p^2 = 0.107$], respectively), or "set configuration" × "sex" interaction ($p = 0.867$ [$\eta_p^2 = 0.006$] and 0.677 [$\eta_p^2 = 0.016$], respectively) (Table 1). The one-way ANOVA conducted on the individual repetitions revealed significant differences in velocity values under some individual repetitions with the IRR set configuration providing higher velocity values than the TR and CL set configurations at repetitions 4 ($p < 0.001$, $\eta_p^2 = 0.294$), 16 ($p = 0.003$, $\eta_p^2 = 0.215$), 20 ($p < 0.001$, $\eta_p^2 = 0.288$) and 24 ($p < 0.001$, $\eta_p^2 = 0.380$) (Fig. 2).

Table 1 Comparison of the maximum velocity achieved at the first repetition of each training session and the averaged maximum velocity of the 24 repetitions between the set configurations in men and women

Sex	Set configuration	First repetition velocity (m s^{-1})	Mean training velocity (m s^{-1})
Men	TR	0.710 ± 0.182	0.611 ± 0.139
	CL	0.695 ± 0.188	0.594 ± 0.154
	IRR	0.703 ± 0.188	0.630 ± 0.175
Women	TR	0.791 ± 0.088	0.677 ± 0.082
	CL	0.783 ± 0.104	0.687 ± 0.107
	IRR	0.769 ± 0.106	0.706 ± 0.059

Mean ± standard deviation

TR, traditional set configuration (6 sets of 4 repetitions with 3 min of rest between sets); CL, cluster set configuration (6 sets of 4 repetitions with 15 s of intra-set rest every two repetitions and 2 min and 45 s of rest between sets); IRR, inter-repetition rest set configuration (1 set of 24 repetitions with 39 s of rest between repetitions)

No significant differences were observed between the set configurations nor between men and women ($p > 0.05$)

The descriptive values of the percent of velocity loss and the pairwise comparisons are shown in Table 2. The ANOVA conducted on the percent of velocity loss (Table 2) only revealed a significant main effect for the "number of sets" ($p < 0.001$, $\eta_p^2 = 0.418$). The "set configuration" ($p = 0.103$, $\eta_p^2 = 0.091$), "sex" ($p = 0.699$, $\eta_p^2 = 0.006$) and the interactions "set configuration" × "sex" ($p = 0.705$, $\eta_p^2 = 0.014$), "set configuration" × "number of sets" ($p = 0.990$, $\eta_p^2 = 0.011$), "sex" × "number of sets" ($p = 0.852$, $\eta_p^2 = 0.016$) and "set configuration" × "sex" × "number of sets" ($p = 0.591$, $\eta_p^2 = 0.034$) did not reach statistical significance. The analysis of the main effect revealed a larger decrease in velocity as the number of sets increased (set 1: -6.9%; set 2: -9.7%; set 3: -11.7%; set 4: -12.5%; set 5: -14.0%; and set 6: -15.2%). Although no significant differences were reached, the velocity loss was generally lower following the IRR set configuration (-8.6%) compared to the CL (-12.9%) and TR (-13.6%) set configurations. Finally, the decrement in velocity was comparable for men (-12.1%) and women (-11.3%).

A significant main effect of "sex" was observed for all F–v relationship parameters (F_0: $p < 0.001$, $\eta_p^2 = 0.706$; v_0: $p < 0.001$, $\eta_p^2 = 0.650$ F–v slope: $p = 0.050$, $\eta_p^2 = 0.147$; P_{max}: $p < 0.001$, $\eta_p^2 = 0.812$). The main effect of "time" was significant for F_0 ($p = 0.001$, $\eta_p^2 = 0.369$) and P_{max} ($p = 0.024$, $\eta_p^2 = 0.195$) but not for v_0 ($p = 0.669$, $\eta_p^2 = 0.008$) or the F–v slope ($p = 0.515$, $\eta_p^2 = 0.018$). Neither the main effect of "set configuration" nor the interactions reached statistical significance for any of the F–v relationship parameters. Post hoc comparisons revealed (I) larger values of F_0, v_0 and P_{max} for men compared to women, and (II) a significant decrease in F_0 and P_{max} after the training sessions (Fig. 3).

Discussion

This study was designed to explore the effect of strength-oriented resistance training sessions performed using three different sets configurations (TR, CL and IRR) on barbell velocity and the F–v relationship of upper-body muscles in men and women. The main finding of the present study was that neither the average training velocity nor the changes in the F–v relationship parameters after the training session were meaningfully affected by the set configuration. However, we did find that the IRR set configuration tended to provide higher velocities than the TR and CL set configurations during the last repetitions of the sets of 4 repetitions. The strength-oriented resistance training sessions induced significant decreases in F_0 and P_{max} but not in v_0. Finally, it should be noted that the velocity loss was comparable for men and women.

Numerous studies have reported higher mechanical outputs (e.g., velocity and power) for the CL and IRR set

Fig. 2 Comparison of the maximum velocity of the barbell between the three different set configurations in men (upper-panel) and women (lower-panel). TR, traditional set configuration (6 sets of 4 repetitions with 3 min of rest between sets); CL, cluster set configuration (6 sets of 4 repetitions with 15 s of intra-set rest every two repetitions and 2 min and 45 s of rest between sets); IRR, inter-repetition rest set configuration (1 set of 24 repetitions with 39 s of rest between repetitions); >, significantly higher velocity value ($p < 0.05$ using Bonferroni post hoc correction)
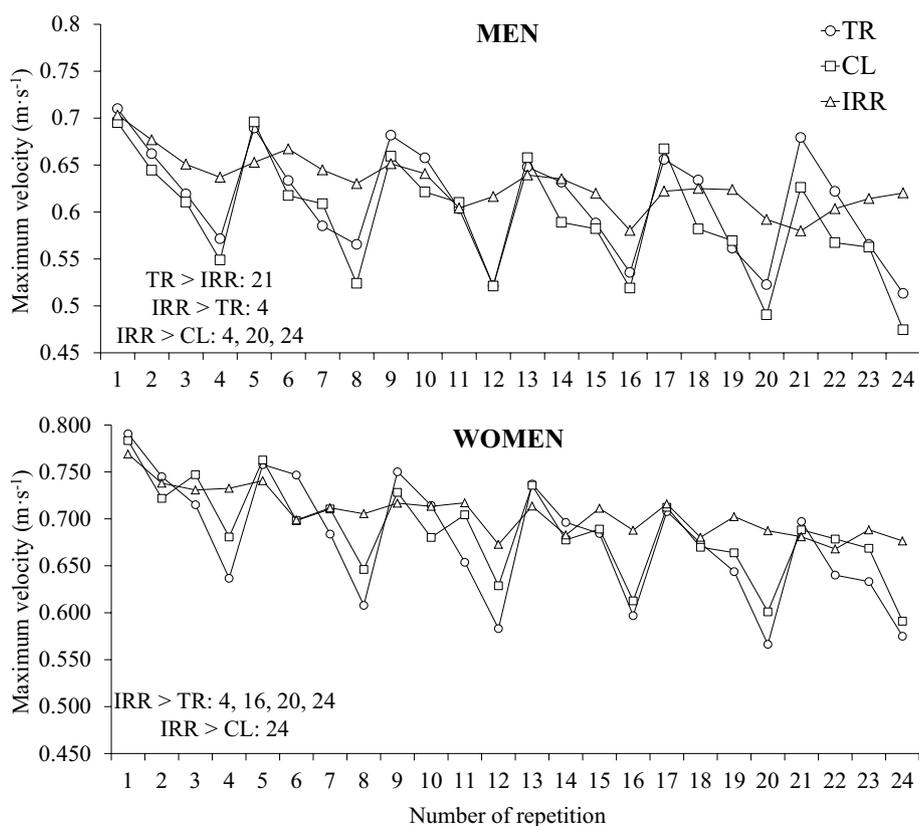
Table 2 Percent of velocity loss with respect to the first repetition of the training session in men and women

Sex	Set configuration	Set 1 (%)	Set 2 (%)	Set 3 (%)	Set 4 (%)	Set 5 (%)	Set 6 (%)
Men	TR	− 9.5 ± 5.4	− 12.3 ± 6.6	− 12.4 ± 11.4	− 13.7 ± 14.0	− 14.9 ± 13.2	− 14.6 ± 13.7
	CL	− 10.0 ± 7.4	− 11.1 ± 14.1	− 12.7 ± 12.4	− 14.3 ± 13.8	− 15.0 ± 14.8	− 17.8 ± 15.1
	IRR	− 4.4 ± 6.0	− 7.3 ± 10.0	− 10.6 ± 10.0	− 12.1 ± 9.6	− 12.6 ± 11.9	− 12.7 ± 14.4
Women	TR	− 8.6 ± 4.2	− 11.4 ± 6.1	− 14.6 ± 9.2	− 13.9 ± 8.0	− 17.8 ± 9.5[a]	− 19.3 ± 10.0[a,b]
	CL	− 6.4 ± 4.1	− 10.1 ± 5.4	− 12.7 ± 7.1[a]	− 13.3 ± 6.7[a]	− 15.5 ± 9.4[a]	− 16.2 ± 8.8[a,b]
	IRR	− 2.7 ± 7.9	− 6.2 ± 12.2	− 7.5 ± 10.0	− 8.0 ± 10.6	− 8.1 ± 12.5	− 10.5 ± 12.7

Mean ± standard deviation

TR, traditional set configuration (6 sets of 4 repetitions with 3 min of rest between sets); CL, cluster set configuration (6 sets of 4 repetitions with 15 s of intra-set rest every two repetitions and 2 min and 45 s of rest between sets); IRR, inter-repetition rest set configuration (1 set of 24 repetitions with 39 s of rest between repetitions)

Statistical significance was defined as $p < 0.05$ using Bonferroni post hoc correction

[a]Significantly different than set 1

[b]Significantly different than set 2. No significant differences were observed between men and women neither between the set configurations at any set

configurations compared to the TR set configuration (Iglesias-Soler et al. 2012, 2014; Girman et al. 2014; Moreno et al. 2014; Oliver et al. 2015, 2016; García-Ramos et al. 2015, 2017; Tufano et al. 2016, 2017b, c; González-Hernández et al. 2017). The main novelty of the present study was the application of a heavy load commonly used during strength-oriented resistance training session

(6RM; ≈ 85%1RM) during a traditional upper-body exercise. Contrary to our first hypothesis, the set configuration did not meaningfully affect the average velocity of a strength-oriented resistance training session conducted with the bench press exercise. Only the IRR set configuration provided a higher velocity under some individual repetitions and it presented a slightly lower velocity loss compared to the TR
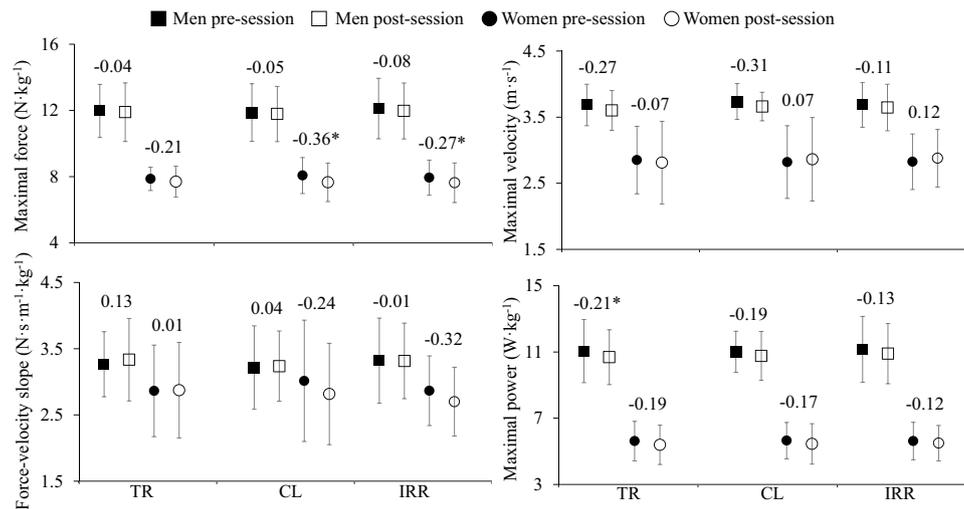
Fig. 3 Comparison of the maximum force (upper-left panel), maximum velocity (upper-right panel), force–velocity slope (lower-left panel; absolute values are presented) and maximum power (lower-right panel) values obtained before (filled) and after (empty) the strength-oriented resistance training session using traditional (TR: 6 sets of 4 repetitions with 3 min of rest between sets), cluster (CL: 6 sets of 4 repetitions with 15 s of intra-set rest every two repetitions and 2 min and 45 s of rest between sets) and inter-repetition rest (IRR 1 set of 24 repetitions with 39 s of rest between repetitions) set configurations. The numbers represent the Hedge's g effect size. *, $p < 0.05$. Data are presented as mean values and standard deviations

and CL set configurations. The magnitude of velocity loss progressively increased with the number of sets suggesting that the inter-set rest period during the TR and CL set configurations did not allow for a complete recovery. Therefore, longer intra- and inter-set rest periods seem necessary to maintain high velocity outputs during strength-oriented resistance training session conducted with the bench press exercise.

The findings of the present study differ from the higher velocities reported by Haff et al. (2003) following a CL set configuration during a strength-oriented resistance training session. The differences between studies in the total rest period (same work-to-rest ratio *vs.* same inter-set rest period) or subject population (sports science students *vs.* track and field and weightlifters) could have contributed to the discrepancy in results. The shorter inter-set rest period used in the present study for the CL set configurations compared to the TR set configuration should have reduced the differences between the two conditions as a result of the longer inter-set rest period allowing for higher muscle performance (Filho et al. 2013). It has also been shown that physical fitness and maximal strength levels are positively associated with a reduction in the time needed to recover from a physical effort (Chiu et al. 2003; Seitz et al. 2014) and, consequently, the optimal rest period should be determined considering the participant's training status (longer rest periods for individuals with a lower training status). However, we believe that the main factor explaining these contradictory findings is the lower duration of the intra-set rest periods in our study (15 s every 2 repetitions *vs.* 30 s after each

repetition). The longer inter-repetition rest periods used by Haff et al. (2003) should have allowed the partial resynthesis of phosphocreatine (PCr) and adenosine triphosphate (ATP) which allow for a maintenance of force production capacity (Bogdanis et al. 1998). Therefore, we recommend the use of longer intra-set rest periods than the ones used in the present study to effectively maintain high velocity outputs during a strength-oriented resistance training sessions conducted with the bench press exercise.

The F–v relationship was used to explore the effect of the different resistance training sessions on the maximal capacities of upper-body muscles to produce force (F_0), velocity (v_0) and power (P_{max}) (García-Ramos et al. 2018a). The decrement in the maximal mechanical capacities was low and comparable for the three different set configurations. Therefore, it can be concluded that the residual fatigue effect of the resistance training session was not meaningful. However, of even more importance could be that F_0 was significantly decreased after the training sessions (significant main effect of "time" was detected by the ANOVA), while no significant changes were observed for v_0. These results support the use of the F–v relationship to assess the selective changes in the maximal capacities of the muscles to produce force and velocity. Note that a decrement in F_0 and not in v_0 was expected because the load used during training was closer to F_0. Finally, note that due to the high linearity of the F–v relationship reported in non-fatigued (Jaric 2015) and fatigued (García-Ramos et al. 2018a) conditions, the F–v relationship can be accurately determined from the force and velocity data

collected under only two different loading conditions (i.e., two-point method) (García-Ramos and Jaric 2018). However, the lack of a passive control condition should be considered as a limitation of the present study since it did not allow us to control for the effect of time in the magnitude of the F–v relationship parameters.

Although previous studies have explored the effect of both CL and IRR set configurations on mechanical variables in women (Koefoed et al. 2018; Korak et al. 2018), to the authors' knowledge this is the first study that has explicitly compared the effect of different set configurations between men and women. The present study suggests that there is a comparable velocity loss for men and women during the three set configurations assessed in the present study. This result is in line with previous studies suggesting that men and women do not significantly differ in the number of repetitions that can be performed before reaching muscular failure when exercising with the same relative load (%1RM) (Clark et al. 2003; Pincivero et al. 2004). Although not reaching statistical significance, the IRR set configuration showed the lowest velocity loss for both sexes, suggesting that the IRR set configuration may be considered when focusing on maintaining high-velocity outputs during strength-oriented resistance training sessions. However, the progressive decrease in velocity during the IRR set configuration suggests that it may be more beneficial to introduce longer inter-set rest periods after 4–6 repetitions instead of performing a single set of 24 repetitions.

Conclusions

The average training velocity did not significantly differ between the three set configurations. The only systematic difference between the set configurations was observed during the last repetitions of the sets, in which the IRR set configuration generally provided higher velocity outputs. The mechanical fatigue induced by the strength-oriented resistance training sessions, assessed through the magnitude of the F–v relationship parameters, was low and comparable for the three different set configurations. However, a larger decrement in the capacity to produce maximal force (F_0) than maximal velocity (v_0) was observed after the training session. The velocity loss and the changes in the F–v relationship parameters after training were comparable for men and women. Therefore, since both the CL and IRR set configurations implemented in the present study were mostly ineffective to maintain higher velocity outputs than a TR set configuration, we recommend the use of longer intra-set rest periods than the ones used in the present study to maintain high-velocity outputs during strength-oriented resistance training sessions conducted with the bench press exercise.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

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