Effects of Cluster Set Configuration on Mechanical Performance and Neuromuscular Activity

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Abstract

Ortega-Becerra, M, Sánchez-Moreno, M, and Pareja-Blanco, F. Effects of cluster set configuration on mechanical performance and neuromuscular activity. *J Strength Cond Res* XX(X): 000–000, 2020—The aim of this study was to compare the effects of different cluster set (CS) configurations on mechanical performance and electromyography (EMG) activity during the bench press (BP) exercise. Fourteen strength-trained men (age 23.0 ± 2.4 years; height 1.76 ± 0.08 m; body mass 78.3 ± 12.2 kg) performed 3 different protocols in the BP exercise consisting of 3 sets of 12 repetitions at 60% of 1 repetition maximum with interset rests of 2 minutes, differing in the set configuration: (a) traditional sets (TRDs), (b) cluster sets of 4 repetitions (CS4), and (c) cluster sets of 2 repetitions (CS2). Intraset rests of 30 seconds were interposed for CS protocols. The mean propulsive values of force, velocity, and power output were measured for every repetition by synchronizing a linear velocity transducer with a force platform. The root mean square (RMS) and median frequency (MDF) for pectoralis major (PM) and triceps brachii (TB) muscles were also recorded for every repetition. Force, velocity, and power values progressively increased as the number of intraset rests increased (TRD < CS4 < CS2). The CS2 protocol exhibited lower RMS-PM than CS4 and TRD for almost all sets. In addition, TRDs showed significantly lower MDF-TB than CS2 for all sets and lower MDF-TB than CS4 during the third set. In conclusion, more frequent intraset rests were beneficial for maintaining mechanical performance, which may be mediated, from a neuromuscular perspective, by lesser increases in EMG amplitude and attenuated reductions in EMG frequency.

Key Words: resistance training, intraset rest, fatigue, electromyography, amplitude, frequency

Introduction

Resistance training (RT) has traditionally been prescribed using set and repetition schemes with no rest between repetitions, and rest intervals provided after the completion of each set (traditional set; TRD) (5,24). During a TRD configuration, fatigue develops as the number of repetitions within the set increases, resulting in impairments in force, velocity, and power (20). In this regard, it has been shown that better maintenance of mechanical performance may be beneficial to induce positive neuromuscular adaptations and prevent fast-to-slow muscle phenotype shift during RT (33,34). However, higher impairments of performance within the set (i.e., reaching or approaching muscle failure) may create a greater hypertrophic stimulus (33,34). A strategy to minimize fatigue accumulation and maintain force, velocity, and power throughout the set is the introduction of brief intraset rest periods; this is defined as a cluster set (CS) (14).

Previously, researchers have shown that a CS acutely attenuates fatigue development and allows the maintenance of mechanical performance (24,39) along with creating lower metabolic and hormonal stress (7,11,26,29,30,41,43) compared with TRD configurations. However, most studies comparing mechanical performance between CS and TRD structures have used only one type of instrumentation or used solely kinetic or kinematic data (6,7,11,15,26,28,41,43), which may result in bias in the calculation of variables, especially power output (4). To date, only a few studies examining the effects of CS configuration have combined both kinetic and kinematic data (16,29,30,40), which seems to be superior when measuring force, velocity, and power (4). However, all these studies were conducted using lower-body exercises (i.e., power clean and back squat exercises). For instance, Tufano et al. (40) performed 3 × 12 repetitions at 60% of 1 repetition maximum (RM) in the back squat exercise comparing 3 set structures: TRDs, CSs of 4, and CSs of 2 repetitions. These authors (40) reported that CS configuration maintained velocity and power throughout repetitions, whereas a TRD structure did not. Therefore, whether these findings from CS studies can be extrapolated to the most commonly prescribed upper-body exercises in RT settings, such as the bench press (BP), deserves to be investigated.

Most literature has only focused on mechanical performance (i.e., kinematic and kinetic parameters), and examining the mechanisms behind these performances during different set configurations is less common (12,42). In this regard, monitoring the electromyography (EMG) activity attained in each repetition may provide better knowledge about the muscle excitation and neuromuscular fatigue accumulated throughout the training session (44). To the best of our knowledge, only one study has investigated the effect of CS configuration on EMG activity (27), by comparing 6 sets of 6 repetitions at 20% of 1RM in the loaded countermovement jump (CMJ) exercise, continuously or with a 30-second pause every 2 repetitions (27). These authors observed a greater root mean square (RMS) in the vastus lateralis and rectus femoris muscles, but not in the vastus medialis, during the TRD configuration compared with a CS, along with progressive decrements in median frequency (MDF) without differences between set configurations (27). Likewise, the

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CMJ exercise involves both eccentric and concentric muscle actions, whereas the CS approach is mainly used to maintain acute concentric exercise performance (39). Therefore, it would be reasonable to further examine the effects of CS configurations on concentric-only exercises, avoiding any extraneous effects of the stretch shortening cycle (42). Finally, although mechanisms underlying improved training quality during CS configurations may be mediated by neuromuscular activity, EMG activity during a CS in upper-body exercises remains to be investigated. To address the aforementioned gaps in the literature, the aim of this study was to compare the effects of one TRD and 2 different CS structures on strength, velocity, and power output, along with EMG activity, during a high-volume BP session in strength-trained men. We hypothesized that the more frequent the number of intraset rests, the greater the strength, velocity, and power values and the lower the neuromuscular markers of fatigue.

Methods

Experimental Approach to the Problem

A randomized cross-over research design was used to investigate mechanical performance and neuromuscular activity during 3 different resistance exercise protocols consisting of 3 sets of 12 repetitions with 60% of 1RM in the BP exercise. The protocols differed only in the set configuration: (a) TRDs, (b) CSs of 4 repetitions (CS4), and (c) CSs of 2 repetitions (CS2). Subjects performed 3 sessions, one per protocol in a random order, separated by a period of 4–7 days. Before these testing sessions, 2 preliminary sessions were devoted to familiarizing the subjects with the BP execution technique (i.e., stopping between eccentric and concentric phases and lifting the load at maximal intended velocity) and to recording the individual grip width (approximately 150% of the biacromial distance) and electrode position on the pectoralis major (PM) and triceps brachii (TB) muscles, which were replicated throughout the experiment. Subjects were asked to refrain from any strenuous physical activity for at least 2 days before each session. All sessions took place in a neuromuscular research laboratory under the direct supervision of a researcher, at the same time of the day for each subject and under similar environmental conditions (20° C and 60% humidity, approximately).

Subjects

Fourteen strength-trained men (age range: 20–30 years 23.0 ± 2.4 years; height 1.76 ± 0.08 m; body mass 78.3 ± 12.2 kg; mean ± *SD*) with at least 2 years of RT experience in the BP exercise (range 2–10 years; 1RM strength for the BP exercise: 77.4 ± 15.3 kg, and 0.99 ± 0.14 normalized per kg of body mass). Subjects were injury free and were fully informed about the procedures, potential risks, and benefits of the study, and they all signed a written informed consent form before the tests. Subjects reported themselves to be free from consumption of drugs, medications, or dietary supplements known to influence physical performance. This study was approved by the institutional review committee of the Pablo de Olavide University, in accordance with the Declaration of Helsinki.

Procedures

Experimental Session. Three different resistance exercise protocols were performed: (a) TRDs consisted of 3 × 12 repetitions at 60% of 1RM with interset rest intervals of 2 minutes, (b) CS4 used the same structure as TRDs (i.e., 3 × 12 repetitions at 60% of 1RM with interset rest of 2 minutes) with an additional 30 seconds intraset rest after the fourth and eighth repetition of each set, and (c) CS2 used the same structure as TRDs with an additional 30 seconds intraset rest after the 2nd, 4th, 6th, 8th, and 10th repetition of each set (Figure 1). The tests were performed on a Smith machine (Fitness Line; Peroga, Murcia, Spain) with the subjects placed in the supine position on top of a flat bench (Bench Fitness Line; Peroga), with their feet resting on the bench, and their hands placed on the bar in the positions individually recorded during the familiarization session. The position on the bench was carefully adjusted so that the vertical projection of the bar corresponded with each subject's intermammary line. Two telescopic bar holders with a precision scale were placed at the left and right sides of the Smith machine to: (a) precisely replicate the individual range of movement between trials, (b) impose a pause between the eccentric and concentric phases, and (c) prevent potential extraneous variables that could affect mechanical or neuromuscular data, such as breathing movements or countermovement at the beginning of the concentric phase. The bar holders were positioned so that the bar stopped ~1 cm above each subject's chest. The subjects were required to perform the eccentric phase at a controlled velocity (~0.30–0.50 $m \cdot s^{-1}$) and to maintain a static position for ~1 second at the end of this phase (i.e., ~1 cm above each subject's chest at the bar holders), and thereafter, they performed a purely concentric push at maximal intended velocity. This momentary pause between phases was imposed to minimize the contribution of the rebound effect and allow for more reproducible measurements (31). Each subject was carefully instructed to always perform the concentric phase of each repetition in an explosive manner but throwing the bar at the end of the concentric phase was

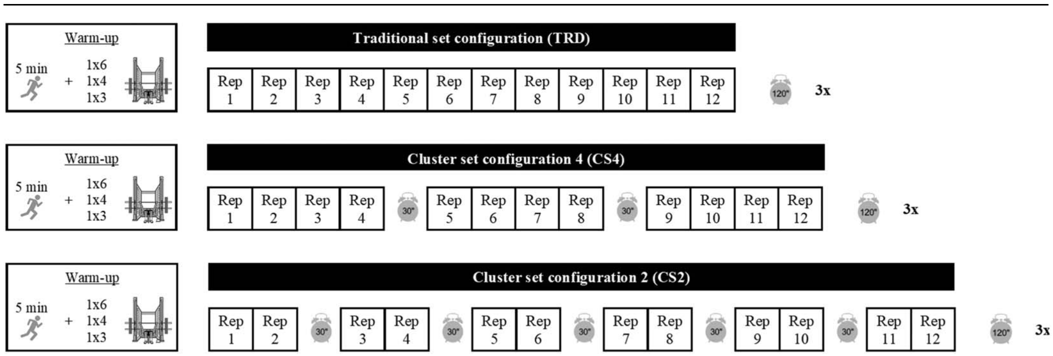

Figure 1. Schematic representation of the 3 different resistance exercise protocols analyzed, which consisted of 3 sets of 12 repetitions with 60% of 1RM in the bench press exercise differing in the set configuration: (a) traditional sets (TRDs), (b) cluster sets of 4 repetitions (CS4), and (c) cluster sets of 2 repetitions (CS2).

Table 1
Relative (ICC with 95% CIs) and absolute (coefficient of variation, CV) reproducibility of different variables analyzed.*†

	ICC (95% CI)	CV (%)
MPF	0.992 (0.977–0.997)	2.3
MPV	0.986 (0.958–0.996)	2.8
MPP	0.971 (0.911–0.990)	4.7
RMS-PM	0.990 (0.969–0.997)	7.1
RMS-TB	0.935 (0.803–0.979)	14.8
MDF-PM	0.947 (0.840–0.983)	7.5
MDF-TB	0.950 (0.851–0.984)	8.3

*ICC = intraclass correlation coefficient; CI = confidence interval; MPF = mean propulsive values of force; MPV = mean propulsive values of velocity; MPP = mean propulsive values of power; RMS = root mean square; MDF = median frequency; PM = pectoralis major muscle; TB = triceps brachii muscle.
†*N* = 14.

not allowed. A timer was used to monitor the duration of the intraset rest. A standardized warm-up was performed, consisting of 5 minutes of running at a self-selected easy pace, 5 minutes of joint mobilization exercises, followed by 3 sets of 6-4-3 repetitions (3-minute rest) with progressive absolute loads ranging from the weight of the bar (i.e., 20 kg) to 60% of 1RM. The absolute load corresponding to 60% of 1RM was adjusted through the lifting velocity, which has been previously established as 0.79 ± 0.05 $m \cdot s^{-1}$ (10).

Mechanical Variables Data Acquisition. A force plate (FP-500; Ergotech, Murcia, Spain) synchronized with a linear velocity transducer (T-Force System; Ergotech) was installed on the equipment to record force, velocity, and power data. The force plate was mounted under the bench the subjects lay on (specifically built to be used over a force plate), and the linear encoder was attached to the bar used during the exercise. The feet were positioned on the bench to record the force applied against the force platform. All data were acquired at 1,000 Hz and processed with specific software (T-Force System v.3.65.1; Ergotech). The mean propulsive values of force (MPF), mean propulsive values of velocity (MPV), and mean propulsive values of power output (MPP) were recorded for every repetition. The propulsive phase corresponds to the portion of the concentric action during which the measured acceleration is greater than the acceleration due to gravity ($-9.81\ m \cdot s^{-2}$) (37).

EMG Signal Acquisition. Electrodes were placed over the PM and TB muscles of the right side according to surface EMG recommendations for noninvasive muscle evaluation (22). Electrode positions were drawn with a permanent marker to replicate the electrode positions in the different protocols. Electromyographic signals were collected using a parallel bar, bipolar, surface electromyographic sensor from Trigno wireless EMG system (an interelectrode distance of 10 mm, common mode rejection ratio >80 dB, and bandwidth filter between 20 and 450 Hz ± 10%) (Delsys, Inc., Road Natick, MA). The baseline noise was <5 μV peak-to-peak and sampling rate was 2,000 Hz. The raw data from the EMG were stored in digital format using EMG works Acquisition software (Delsys, Inc.). The RMS and MDF values were calculated. The MDF was measured to determine the frequency at which the spectrum could be split into 2 parts of equal power (9). From each repetition the highest averaged (over sliding windows of 500 ms with an overlap of 499 ms) RMS and MDF values for each muscle were recorded (RMS-PM, RMS-TB, MDF-PM, and MDF-TB). The value of the signal from the first repetition of each resistance exercise protocol was used to normalize the EMG parameters.

Table 2
Descriptive characteristics of each resistance exercise protocol.*†

	TRD	CS4	CS2
Load (kg)	45.8 ± 9.3	45.7 ± 9.1	45.7 ± 9.1
MPV_{BEST} ($m \cdot s^{-1}$)	0.78 ± 0.02	0.79 ± 0.02	0.79 ± 0.02
VL (%)	42.9 ± $11.7^{CS4,CS2}$	26.2 ± 10.6^{CS2}	15.6 ± 5.0
MPV_{LAST} ($m \cdot s^{-1}$)	0.33 ± $0.14^{CS4, CS2}$	0.51 ± 0.18^{CS2}	0.65 ± 0.06

*TRD = traditional sets; CS4 = cluster sets of 4 repetitions; CS2 = cluster sets of 2 repetitions; Load = absolute load lifted in each protocol; MPV_{BEST} = velocity of the fastest (usually first) repetition in the set; MPV_{LAST} = mean velocity of the last repetition over the sets. VL = mean percent loss in velocity from the fastest to the last repetition over the sets. Statistically significant differences with a CS4 protocol = ^{CS4} $P < 0.05$. Statistically significant differences with a CS2 protocol = ^{CS2} $P < 0.05$.
†Data are mean ± *SD*, *n* = 14.

Statistical Analyses

Data are reported as mean ± *SD*. Sample size was calculated (using GPower version 3.1.9.4) introducing the following parameters: effect size (ES) 0.50 for between-protocols comparisons based on a previous research using a similar protocol (40) and α error probability (0.05) and power (0.95), which resulted in a sample size of 12 subjects. The normal distribution of the data was confirmed using the Shapiro-Wilk test ($P \geq 0.05$). Intrasession absolute reliability was measured by the standard error of measurement (*SEM*), which was expressed in relative terms through the coefficient of variation (CV). The *SEM* was calculated as the RMS of the intrasubject total mean square. Relative reliability was calculated with the intraclass correlation coefficient (ICC) using the 1-way random effects (1,k) model and its 95% confidence interval (CI). According to Stokes (38), CV values of ≤15% can be classified as "satisfactory." The ICC values were interpreted according to Koo and Li's guidelines (23) as an "excellent" (ICC >0.90), a "good" (0.75 < ICC <0.90), a "moderate" (0.50 < ICC <0.75), and a "poor" (ICC ≤0.50) reliability. Following Koo and Li's guidelines (23), this interpretation was based on the lower and the upper bound 95% CI. A 1-way repeated measures analysis of variance (ANOVA) with Bonferroni's post hoc comparisons was conducted to compare the average values attained during each protocol. A 3 × 3 (protocol × set) repeated measures ANOVA with Bonferroni's post hoc comparisons was performed to analyze differences between protocols in the different sets performed. A 3 × 36 (protocol × repetition) repeated measures ANOVA with Bonferroni's post hoc adjustments was also conducted to compare differences between protocols in the different repetitions completed. Significance was accepted at $P \leq 0.05$. In addition, ES values were calculated using Hedge's *g* on the pooled *SD* (17) using a purpose-built spreadsheet. The ES values were interpreted using the thresholds proposed by Hopkins et al. (18) as follows: ES < 0.2, trivial; 0.2 ≤ ES < 0.6, small; 0.6 ≤ ES < 1.2, moderate; 1.2 ≤ ES < 2.0, large; 2.0 ≤ ES < 4.0, very large; and ES ≥ 4.0, almost perfect. The rest of statistical analyses were performed using SPSS software version 20.0 (SPSS, Inc., Chicago, IL). Figures were designed using SigmaPlot 12.0 (Systat Software, Inc, San Jose, CA).

Results

Table 1 shows the reliability values (ICC and CV) of the different mechanical and neuromuscular parameters analyzed. All parameters analyzed showed from "good" to "excellent" ICC values. Moreover, CV was "satisfactory," with CV values lower than 10% for all variables under study except for RMS-TB (CV = 14.8%). Table 2

Table 3

Mechanical and neuromuscular characteristics of each resistance exercise protocol (average of 36 repetitions).*†

	Resistance exercise protocols			Effect size		
Mechanical and neuromuscular parameters	TRD	CS4	CS2	TRD vs. CS4	TRD vs. CS2	CS4 vs. CS2
MPF (N)‡	495.4 ± 89.4^{CS4,CS2}	514.9 ± 94.4	549.4 ± 113.4	−0.21	−0.51	−0.32
MPV (m·s^{-1})‡	0.58 ± 0.08^{CS4,CS2}	0.68 ± 0.06^{CS2}	0.73 ± 0.03	−1.37	−2.41	−1.02
MPP (w)‡	258.5 ± 43.2^{CS4,CS2}	304.6 ± 60.9^{CS2}	341.0 ± 62.6	−0.85	−1.49	−0.57
RMS-PM (%)‡	115.0 ± 21.0^{CS2}	107.0 ± 15.2^{CS2}	91.4 ± 14.4	0.42	1.27	1.02
RMS-TB (%)	98.7 ± 21.6	95.7 ± 11.0	83.3 ± 16.8	0.17	0.77	0.85
MDF-PM (%)	87.8 ± 20.5	88.0 ± 9.5	96.1 ± 11.5	−0.01	−0.48	−0.75
MDF-TB (%)‡	84.6 ± 10.3^{CS4,CS2}	94.6 ± 10.7	95.8 ± 10.7	−0.92	−1.04	−0.11

*TRD = traditional sets; CS4 = cluster sets of 4 repetitions; CS2 = cluster sets of 2 repetitions; MPF = mean propulsive values of force; MPV = mean propulsive values of velocity; MPP = mean propulsive values of power. RMS = root mean square; MDF = median frequency; PM = pectoralis major muscle; TB = triceps brachii muscle. Statistically significant differences with a CS4 protocol = ^{CS4} $P < 0.05$. Statistically significant differences with a CS2 protocol = ^{CS2} $P < 0.05$. Effect sizes were calculated to provide standardized differences between protocols.
†Data are mean ± *SD*, $n = 14$.
‡Significant "protocol" effect ($P < 0.05$).

shows the descriptive characteristics of each resistance exercise protocol. The absolute load used and the highest velocity at which this load was lifted (MPV_{BEST}) were very similar for all protocols. The mean velocity of the last repetition over the sets (MPV_{LAST}) and the mean percent loss in velocity from the fastest to the last repetition over the sets (VL) were significantly different between protocols.

Table 4

Mechanical and neuromuscular characteristics of each set during a resistance exercise protocol.*†‡

	TRD	CS4	CS2
MPF (N) #			
Set 1	511.4 ± 96.1^{CS4,CS2}	524.9 ± 98.2	538.6 ± 92.2
Set 2	494.3 ± 89.6^{CS4,CS2,***}	515.7 ± 94.8^{CS2,*}	538.4 ± 90.0
Set 3	481.6 ± 82.6^{CS4,CS2,***},§	504.2 ± 90.8 ^{CS2,**},§	534.7 ± 90.6
MPV (m·s^{-1}) #			
Set 1	0.66 ± 0.05^{CS4,CS2}	0.71 ± 0.04	0.73 ± 0.03
Set 2	0.58 ± 0.09^{CS4,CS2,**}	0.68 ± 0.06^{CS2,*}	0.73 ± 0.04
Set 3	0.51 ± 0.10^{CS4,CS2,***},§	0.65 ± 0.08 ^{CS2,**},§	0.72 ± 0.04
MPP (w) #			
Set 1	302.4 ± 55.2^{CS4,CS2}	325.6 ± 58.0^{CS2}	343.1 ± 64.9
Set 2	264.1 ± 45.9^{CS4,CS2,**}	311.0 ± 55.1^{CS2,**}	342.6 ± 63.8
Set 3	231.2 ± 40.0$^{CS4, CS2,***}$,§	297.5 ± 53.2^{CS2,**},§	337.3 ± 59.9
RMS-PM (%)			
Set 1	110.7 ± 16.4^{CS2}	104.8 ± 11.2	95.2 ± 11.9
Set 2	116.2 ± 21.9^{CS2}	104.5 ± 11.2^{CS2}	90.8 ± 16.8
Set 3	118.2 ± 29.6^{CS2}	111.8 ± 34.0^{CS2}	88.4 ± 16.2*
RMS-TB (%)			
Set 1	105.6 ± 25.5	102.0 ± 15.5	88.9 ± 14.5
Set 2	96.9 ± 20.7	92.6 ± 14.1	81.6 ± 19.3**
Set 3	93.6 ± 19.2^{CS2}	92.6 ± 14.4^{CS2}	79.4 ± 18.0**
MDF-PM (%) #			
Set 1	92.9 ± 19.7	90.1 ± 12.1	94.2 ± 8.3
Set 2	86.6 ± 21.5*	88.2 ± 10.3	97.4 ± 14.7
Set 3	84.1 ± 19.4 ^{CS2**}	85.7 ± 9.6^{CS2}	96.7 ± 14.6
MDF-TB (%)			
Set 1	86.6 ± 7.2^{CS2}	96.0 ± 11.7	97.3 ± 9.3
Set 2	83.6 ± 12.1^{CS2}	92.9 ± 11.3	94.7 ± 11.7
Set 3	81.6 ± 13.2^{CS4,CS2}	94.9 ± 11.5	95.3 ± 12.8

*TRD = traditional sets; CS4 = cluster sets of 4 repetitions; CS2 = cluster sets of 2 repetitions; MPF = mean propulsive values of force; MPV = mean propulsive values of velocity; MPP = mean propulsive values of power. RMS = root mean square; MDF = median frequency; PM = pectoralis major muscle; TB = triceps brachii muscle.
†Data are mean ± *SD*, $n = 14$.
‡Significant protocol × set interaction: #< 0.001. Statistically significant differences with a CS4 protocol: ^{CS4} $P < 0.05$. Statistically significant differences with a CS2 protocol: ^{CS2} $P < 0.05$. Statistically significant differences with set 1 at the corresponding protocol: *$P < 0.05$, **$P < 0.01$, ***$P < 0.001$.
§Statistically significant differences with Set 2 at the corresponding protocol: $P < 0.01$.

Table 3 shows the mechanical and neuromuscular characteristics of each entire resistance exercise protocol (averaged 36 repetitions), as well as the ES values for between-protocols comparisons. Significant differences between protocols were observed for all variables analyzed, except for RMS-TB and MDF-PM. The CS configurations (i.e., CS4 and CS2) showed higher MPF values during the entire session compared with TRDs. The MPV and MPP increased as the number of intraset rests increased (TRD < CS4 < CS2). The CS4 and TRD protocols exhibited significantly higher RMS-PM than CS2. Moreover, a TRD showed significantly lower MDF-TB values than the CS protocols.

Table 4 shows the mechanical and neuromuscular outcomes of each set during the different resistance exercise protocols. Significant "protocol × set" interactions ($P < 0.001$–0.05) were observed for all mechanical variables (i.e., MPF, MPV, and MPP) and MDF-PM. Protocols with a higher number of intraset rests (TRD < CS4 < CS2) showed higher MPF, MPV, and MPP values for almost all sets. In addition, the TRD and CS4 protocols showed significantly decreased MPF, MPV, and MPP values as the number of sets increased. However, the CS2 protocol maintained constant for MPF, MPV, and MPP values during the 3 sets. With regard to neuromuscular variables, a significant "protocol" effect was observed for RMS-PM ($P < 0.001$) and MDF-TB ($P = 0.03$). Cluster sets of 2 repetitions showed lower RMS-PM than TRD and CS4 for almost all sets. In addition, TRDs showed significantly lower MDF-TB than CS2 for all sets and lower MDF-TB than CS4 during the third set.

Figure 2 shows the evolution of mechanical parameters throughout the 36 repetitions for each resistance exercise protocol. Significant "protocol × repetitions" interactions ($P < 0.001$) were observed for all mechanical variables. Performance in these variables progressively decreased throughout the 36 repetitions for all protocols; however, performance in these parameters improved as the number of intraset rests increased (TRD < CS4 < CS2).

Figure 3 depicts the development of neuromuscular variables throughout the 36 repetitions for each resistance exercise protocol. Significant "protocol × repetitions" interactions were observed for RMS-PM ($P < 0.001$), MDF-PM ($P < 0.001$), and MDF-TB ($P = 0.005$). The RMS-PM value progressively increased within each set for TRDs, whereas it remained more stable for CS protocols. Conversely, MDF-PM and MDF-TB progressively decreased within each set for TRDs, remaining relatively stable for both CS configurations.

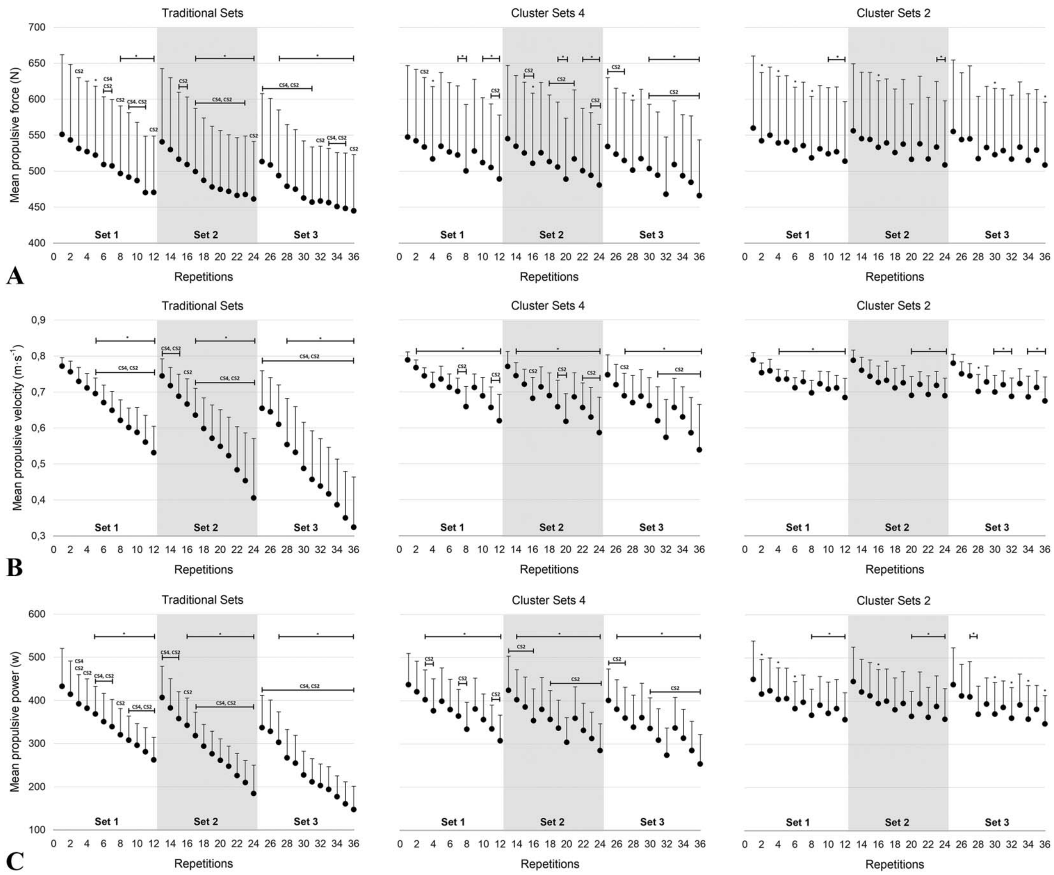

Figure 2. Evolution of mechanical parameters throughout the 36 repetitions for each resistance exercise protocol. A) Mean propulsive force; (B) mean propulsive velocity; and (C) mean propulsive power. Data are expressed as mean ± *SD* ($N = 14$). *Significant differences from the first repetition at the corresponding repetition ($P < 0.05$). Cluster sets of 4 repetitions (CS4) indicate significant differences with the CS4 protocol at the corresponding time point ($P < 0.05$). Cluster sets of 2 repetitions indicate significant differences with the CS2 protocol at the corresponding time point ($P < 0.05$).

Only in some repetitions during the third set did CS4 show significant lower values of MDF-PM than CS2.

Discussion

This is the first study to investigate neuromuscular activity in relation to CS configuration in an upper-body exercise. Our results clearly indicate that set structure affects mechanical and neuromuscular stimuli. Overall, the higher the number of intraset rests (TRD < CS4 < CS2), the greater the mechanical stimuli (i.e., higher force, velocity, and power) and the lower the neuromuscular markers of fatigue (i.e., lower RMS-PM and higher MDF-TB). Therefore, more frequent intraset rests induce lower levels of fatigue, allowing for a better maintenance of mechanical performance, which may be mediated, from a neuromuscular perspective, by a reduced increase in EMG amplitude along with a lower reduction in EMG frequency.

As expected, introducing short and frequent intraset rest periods was beneficial for minimizing the magnitude of velocity loss within the set and for better maintaining mechanical performance throughout the session. The CS2 protocol kept the force, velocity, and power values constant during the 3 sets. These findings are consistent across a variety of resistance exercises, including back squat (11,26,40,41), power clean (14,16), unloaded (28) and loaded jumps (1,15), and BP (1,7,8,25). By contrast, another study reported no differences in mean force during the BP exercise with 6RM load, comparing TRD and CS structures (6). The different loading conditions may explain the discrepancies between studies. However, a recent meta-analysis report revealed that CS structures are beneficial for optimizing acute mechanical performance for moderate (60–79% 1RM) and heavy loads (≥80% 1RM) (24). Moreover, previous CS studies using upper-body exercises did not combine kinetic and kinematic measurements (1,7,8,25). Therefore, the process for obtaining kinetic data required a double-differentiation process (i.e., differentiating kinetic data from kinematic data), which may have affected the accuracy of the kinetic data. By synchronizing a force platform with a linear velocity transducer, we were able to directly determine the 3 mechanical variables examined in this study. Decreases in force are primarily responsible for impairments in velocity and, as a consequence, in power output. When the number of repetitions in a row is shortened, by introducing intraset rests (i.e., CS structures) or splitting the total volume into more sets (i.e., set configuration), better maintenance of muscular phosphocreatine and adenosine triphosphate stores is possible, resulting in superior force, velocity, and power values throughout the entire training session (12). In this regard, previous studies have suggested that executing more than 5 repetitions is detrimental to power development (1,28). In contrast with this statement, our results showed that even a CS with 4 repetitions (CS4) was detrimental with regard to maximizing power output because it showed

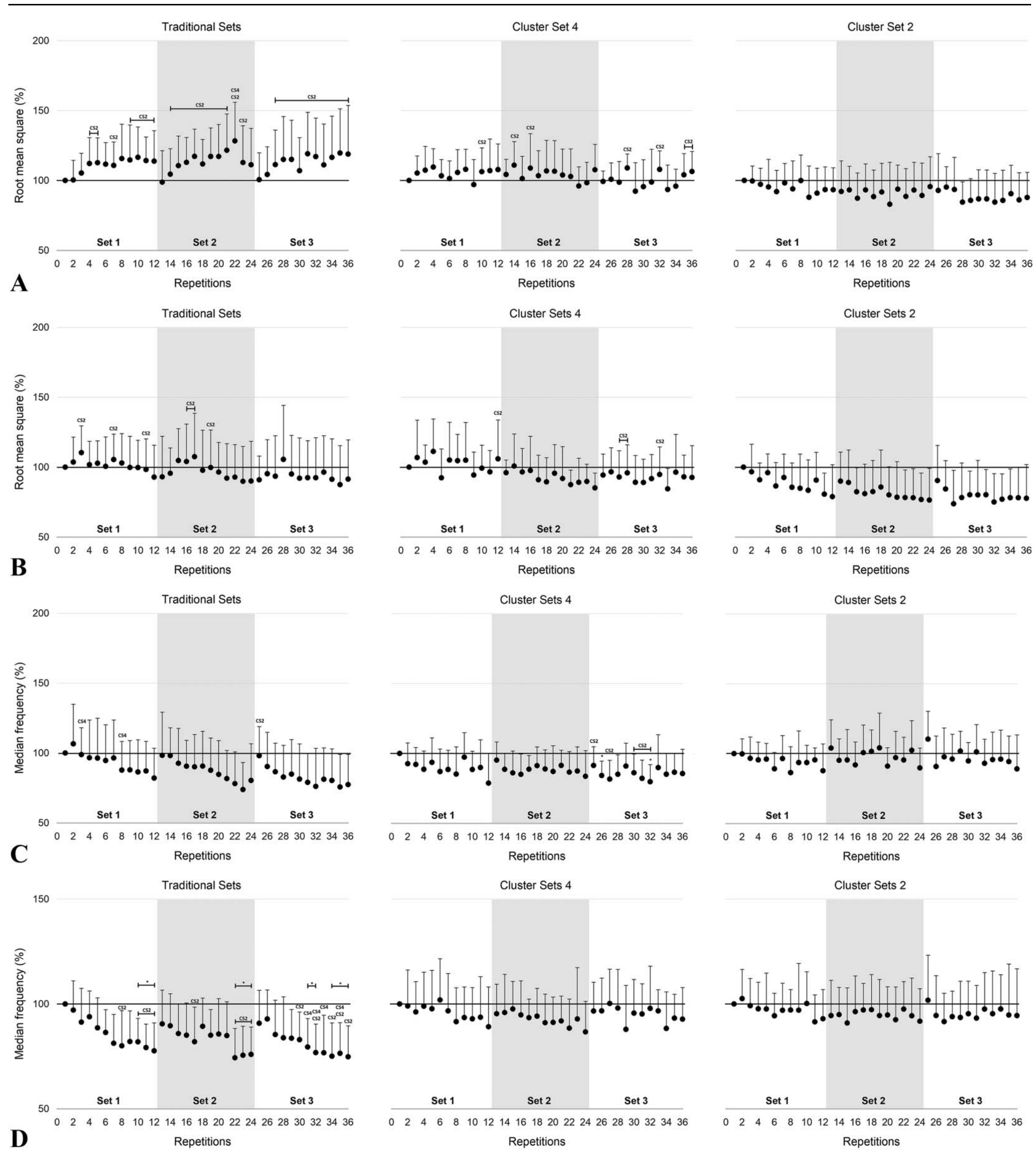

Figure 3. Evolution of neuromuscular parameters throughout the 36 repetitions for each resistance exercise protocol. A) Root mean square (RMS) for pectoralis major (PM) muscle; (B) RMS for triceps brachii (TB) muscle; (C) median frequency (MDF) for PM muscle; and (D) MPF for TB muscle. Data were normalized with respect to the first repetition of each resistance exercise protocol. Data are expressed as mean ± *SD* (*N* = 14). *Significant differences from the first repetition at the corresponding repetition ($P < 0.05$). Cluster sets of 4 repetitions (CS4) indicate significant differences with the CS4 protocol at the corresponding time point ($P < 0.05$). Cluster sets of 2 repetitions (CS2) indicate significant differences with the CS2 protocol at the corresponding time point ($P < 0.05$).

lower MPP values than a CS with 2 repetitions (CS2). Therefore, it is conceivable that the maximal number of repetitions allowed in a row for maintaining performance throughout the session will depend on the relative load (%1RM), total volume, intraset and interset rest time, type of exercise, and the athlete's characteristics.

By analyzing the RMS and the MDF of the EMG power spectrum of PM and TB muscles, our data suggest that neuromuscular fatigue decreased as the number of intraset rests increased (TRD < CS4 < CS2). Furthermore, these differences became greater during the latter repetitions because the TRD configuration progressively increased EMG amplitude and decreased EMG frequency as the number of repetitions completed increased, whereas CS2 remained relatively stable throughout the 36 repetitions (Figure 3). Based on the literature, an increase in EMG amplitude may be expected along with a decrease in EMG frequency during the repetitions and sets (13,35). To the best of our knowledge, only one study had previously investigated neuromuscular activity during CS configurations (27). These authors reported higher increments in RMS during 6 sets of 6 repetitions with 20% 1RM in the loaded CMJ exercise for TRD structures (continuously, $n = 9$) compared with CS (30-second pause every 2 repetitions, $n = 9$); however, both protocols induced similar decrements in MDF (27). The stretch shortening cycle involved in CMJ, along with the fact that a cross-over design was not conducted in the study, may have hampered the detection of potential differences in the EMG spectral parameters between protocols (27). The increase in EMG amplitude due to fatigue may be related to increased motor unit synchronization (45) along with increases in muscle activation (19). In addition, the fatigue-induced reduction in EMG frequency has been attributed to decreases in the firing rate of fatigued fast motor units (2) and impairments in action potential conduction velocity associated with metabolic byproduct accumulation and decline in intramuscular pH (3), as typically observed during TRD approaches (6,7,11,12,26). However, the EMG signal may also be affected by other factors, such as fiber membrane properties, which makes EMG interpretation limited (21).

Taken together, the present EMG findings suggest that introducing short intraset rests (i.e., 30 seconds) between every small cluster of repetitions (i.e., 2 or 4) are effective in minimizing neuromuscular fatigue, which may explain, at least partially, the greater mechanical performance typically observed during CS configurations. These findings may support the positive neuromuscular adaptations (i.e., greater RMS-PM) observed after an 8-week BP training program with low fatigue within the set (i.e., 15% of velocity loss) (32); however, higher levels of fatigue during the set (i.e., 50% of velocity loss), which induce higher metabolic and mechanical stress (36), showed higher hypertrophy in the PM muscle (32). Therefore, whether introducing frequent intraset rest periods aiming to alleviate training-induced fatigue may result in reduced structural adaptations should be further investigated.

Practical Applications

Strength and conditioning coaches should consider implementing more frequent intraset rest periods within RT sessions to acutely maximize force production, and as a consequence, movement velocity and power output, and to minimize neuromuscular fatigue development. Further research must examine the long-term structural and neuromuscular adaptations of such protocols within a chronic training environment.

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