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TITLE PAGE

Title:

Cluster vs. Traditional training programmes: changes in the force-velocity relationship.

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Cluster vs. Traditional training programmes: changes in the force-velocity relationship

ABSTRACT

This randomised controlled study examined the force-velocity relationship changes (force and velocity axis intercepts, slope and estimated maximum power) in response to 5-week training programmes differing in the set configuration. For each session, the traditional group performed 4 sets of 8 repetitions with 5 min of rest between sets and exercises, while the cluster group completed 16 sets of 2 repetitions with 1 min of rest between sets and 5 min between exercises. Both programmes were performed with the 10-repetition maximum load, including bench press, parallel squat, lat pull-down, and leg curl exercises. Individual force-velocity profiles were obtained for bench press and squat using a linear velocity transducer before and after the intervention, along with lactate and mechanical performance during the intervention. Results showed in bench press similar changes of the force-velocity profile after both protocols (no shift of the slope and higher force and velocity axis intercept values). For the squat, significant changes in the slope ($P = 0.001$) and the velocity intercept ($P = 0.002$) toward a velocity profile were observed after cluster but not after traditional training. These results suggest that set configuration may modulate changes of force-velocity relationship, especially for squat.

Keywords: strength, mechanical profile, set configuration, resistance training, fatigue.

Introduction

Muscles have different mechanical and functional properties that allow force, velocity and power production. As the force-velocity (F-V) relationship is inverse, greater concentric forces are possible at slower velocities and vice versa (Hill, 1938). In this regard, the interaction between force and velocity in multi-joint movements is a quality indicator of successful performance in explosive sport disciplines (Izquierdo, Häkkinen, Gonzalez-Badillo, Ibáñez, & Gorostiaga, 2002) and underpins a general mechanical profile of the muscular system (Samozino, Rejc, Di Prampero, Belli, & Morin, 2012).

The seminal studies (Fenn & Marsh, 1935; Hill, 1938; Wilkie, 1950) showed that the F-V relationship can be described by nonlinear, concave upward functions that can be expressed using either exponential (Fenn & Marsh, 1935) or hyperbolic equations (Hill, 1938; Wilkie, 1950). However, it has been suggested that when multi-joint exercises are considered, a linear model can be applied for the F-V relationship although this linearity could be a consequence of the relatively narrow range of forces usually evaluated in human studies (Alcazar et al., 2018). The linear F-V model, is expressed as follows:

$$F(V) = F_0 + S \cdot V$$

where F_0 corresponds to the ordinate axis intercept (i.e. theoretical maximum force at null velocity) and S is the slope of the linear regression. Furthermore, this approach provides other parameters such as the theoretical maximum values of velocity (V_0) and an estimation of the maximum power output (P_{max}) (García-Ramos, Jaric, Padial, & Feriche, 2016; Rahmani, Viale, Dalleau, & Lacour, 2001; Samozino et al., 2013; Yamauchi & Ishii, 2007). Additionally, the force and the velocity applied to a specific load, such as the force and velocity performed with the one-repetition maximum load (1RM), can be placed on the F-V spectrum as an interesting feature of neuromuscular

performance (Rivière, Rossi, Jimenez-Reyes, Morin, & Samozino, 2017). All these parameters have shown, in general, acceptable levels of reliability in multi-joint exercises (García-Ramos & Jaric, 2018; Iglesias-Soler et al., 2019).

This linear approach has been previously used to describe mechanical profiles in multi-joint exercises like jumping, cycling, running, or lifting in many populations (Allison, Brooke-Wavell, & Folland, 2013; Zivkovic, Djuric, Cuk, Suzovic, & Jaric, 2017). However, research about the changes in the linear F-V relationship in response to different resistance training protocols is scarce (Djuric et al., 2016; Iglesias-Soler et al., 2017; Jiménez-Reyes, Samozino, & Morin, 2019).

The adaptations to resistance training can be modulated by manipulating some variables such as volume, frequency, velocity, load, work-to-rest ratio, or set configuration. This study is focused on the set configuration which is defined by the repetitions performed in a set with regard to the maximum feasible number of repetitions (Iglesias-Soler et al., 2016; Mayo, Iglesias-Soler, & Fernández-Del-Olmo, 2014). In this sense, manipulating the number of repetitions contained in a set has been proven to be an effective way for inducing different types of neural and muscular adaptations (Iglesias-Soler et al., 2017; Morales-Artacho, Padial, García-Ramos, Pérez-Castilla, & Feriche, 2017; Tufano, Conlon, et al., 2017).

Traditionally, resistance training involves performing repetitions in a continuous manner. As a result, this type of traditional set configuration results in acute neuromuscular fatigue and the accumulation of metabolic products (Haff, Burgess, & Stone, 2008). One method of reducing fatigue during resistance training is to add short intra-set rest intervals, creating what is known as cluster sets (Haff et al., 2008; Hansen, Cronin, Pickering, & Newton, 2011; Lawton, Cronin, & Lindsell, 2006). In this regard,

69 different types of cluster subclass exist that have been identified and explained in a recent
70 review (Tufano, Brown, & Haff, 2017). It has been shown that cluster sets allow the
71 increase in the number of repetitions performed at optimal mechanical performance
72 (García-Ramos, Nebot, et al., 2016), eliciting greater velocity and power output in the last
73 repetitions and greater net total power output (Lawton et al., 2006; Oliver et al., 2016;
74 Tufano et al., 2016). Moreover, a lower demand of the glycolytic metabolism in
75 comparison with traditional sets is observed (García-Ramos et al., 2015; Gorostiaga et
76 al., 2012; Iglesias-Soler et al., 2012).

77 On the other hand, the velocity specificity principle of resistance training suggests
78 that strength and power increase most near the velocity of training, so greater
79 improvements in strength occur at or near this velocity, and therefore the power mainly
80 increases at that specific velocity (Behm & Sale, 1993b; Cormie, McGuigan, & Newton,
81 2010). Previous studies showed that the high velocity and high force portions of the F-V
82 relationship are mainly changed by using explosive type strength training with medium-
83 light loads and heavy loads, respectively (Cormie et al., 2010; Häkkinen & Komi, 1985).
84 Since these studies contrasted different loads, their findings cannot be exclusively
85 attributed to differences in training velocities. In other studies, training programmes of
86 maximum or sub-maximum intended velocity were contrasted (Munn, Herbert, Hancock,
87 & Gandevia, 2005) but since intended velocity is a key factor to maximise strength
88 adaptations (Behm & Sale, 1993a; Blazevich, Gill, & Newton, 2002) modulating velocity
89 voluntarily is a potential limitation. An alternative approach to contrast the effect of
90 velocity on the F-V relationship is by modulating the set configuration since it allows to
91 design interventions differing in the velocity whereas the load, volume, intensity, and
92 intended velocity remain equated between conditions (Iglesias-Soler et al., 2012). Thus,
93 on the basis of their differences regarding the velocity and power performance a different

adaptation in the F-V relationship can be expected between training programmes. To the best of our knowledge, few studies have explored the effects of different set structures on the F-V relationship (Iglesias-Soler et al., 2017; Morales-Artacho, Padial, García-Ramos, Pérez-Castilla, & Feriche, 2017). In the study of Iglesias-Soler et al. (2017), there were similar changes in the mechanical profile despite the higher training velocities maintained during the inter-repetition training protocols in comparison with a traditional set configuration during a unilateral knee extension exercise. Nevertheless, this study was conducted using a single joint exercise, reducing the practical application. Similarly, no differences were found in the F-V after performing cluster or traditional structures in the other study which focused on the countermovement jump exercise (Morales-Artacho et al., 2017).

Therefore, the main purpose of this study was to examine the changes in F-V relationship parameters (i.e., V_0, F_0, *S*, and P_{max}) of multi-joint upper and lower body exercises following cluster or traditional resistance training programmes. Secondly, the changes in the position of the force and velocity associated with the 1RM on F-V relationship were analysed as complementary features of the individual´s mechanical profile. We hypothesised that training protocol with a cluster set configuration will mitigate the velocity loss throughout the sessions allowing improving the high velocity portion of F-V relationship compared to a traditional training programme.

Methods

Experimental design

To address the purposes of this study, a randomised controlled trial design was conducted. All the participants completed two familiarisation sessions, two pretesting sessions (i.e., 1RM and 10RM testing session respectively), and one posttesting session (i.e.,1RM).

After the pre-testing, the participants assigned to the experimental groups performed 10 training sessions throughout 5 weeks performing a traditional training (TT) or cluster training (CT) differing on how the configuration of the set was tailored. The subclass of cluster training performed was rest-redistribution training, where the total rest time was equal between groups, but the frequency and duration of individual rest periods differed. Before and after the intervention, the F-V relationships were obtained for both the bench press (BP) and parallel squat (SQ) exercises. A schematic representation of the experimental design is shown in Figure 1.

Figure 1 about here

Participants

Eleven women and 28 men participated in this study (age 23 ± 4 years; body mass 72.9 ± 11.0 kg; height 1.77 ± 0.08 m; body mass index [BMI] 23.91 ± 2.98 kg m^{-2}). All of them were Sport Science students, physically active (i.e., their standard academic curriculum included 6 to 8 activity classes per week at low to moderate intensities), without injuries and with at least three months of experience in resistance training. The participants read and signed an informed consent before their participation. The study was approved by the ethical committee of the University of A Coruna and conducted according to the tenets of the Declaration of Helsinki.

Procedures

Familiarisation Sessions

Participants performed two familiarisation sessions with at least 48 hours between them. Individual marks were recorded to adjust the machines to each participant in order to standardise and allow a full range of motion for each exercise. All sessions (familiarisation, testing, and training) started with a standardised warm-up of 5 min of

142 cycling at 60-80 revolutions per min on a cycle ergometer (Monark 828E, Monark
143 Exercise AB, Vansbro, Sweeden). Then, the participants completed two sets of 10
144 repetitions with approximately 50% of perceived maximum load and 2 min of recovery
145 between sets in a Smith machine (Multipower Shock [Model SH004/0], Telju Fitness,
146 Toledo, Spain) for BP and SQ whereas LP (lat pull-down) and LC (leg curl) were
147 performed on their respective machines (Biotech Fitness Solutions, Brazil). In the second
148 familiarisation session, participants were instructed to perform the maximum number of
149 repetitions with approximately 75% of perceived maximum load in order to get more
150 experience reaching muscular failure.

151 *Anthropometric Measurement*

152 In third session, height was assessed to the nearest 0.1 cm by a stadiometer (Seca 202,
153 Seca Ltd., Hamburg, Germany), and body mass was assessed using a digital scale (Omron
154 BF-508, Omron Healthcare Co., Kyoto, Japan). BMI was calculated as body mass in
155 kilograms divided by height in meters squared ($kg \cdot m^{-2}$).

156 *1RM Test*

157 Although all the exercises were performed in the familiarisation and training sessions, the
158 1RM test was only conducted for the BP and SQ. The exercise sequence was randomised
159 for the pre-and post-testing sessions. The 1RM load was obtained using a protocol that
160 combines velocity decrement with increasing load. This protocol has shown a high
161 reliability in previous studies (Iglesias-Soler et al., 2019, 2016). It started with the
162 participants performing three repetitions of the exercise only with the load of the Smith
163 machine barbell (21.40 kg). After 1 min of recovery, a new trial (i.e., three reps) was
164 performed with an increment of 10-20 kg in SQ and 5-10 kg in BP. Trials were repeated
165 until a loss of at least 25% with respect to the first set regarding the mean velocity

166 recorded during the propulsive phase (i.e. mean propulsive velocity: MPV) was observed.
167 The propulsive phase is defined as the portion of the concentric phase during which the
168 measured acceleration was greater than acceleration due to gravity (i.e., bar acceleration
169 > -9.81 $m \cdot s^{-2}$) (Izquierdo et al., 2002). Then the participants performed sets of two
170 repetitions with 2 min of recovery with load increments of 2.5-7.5 kg in BP and 5-10 kg
171 in SQ. Finally, when a loss of 50% in MPV was recorded, the last stage of the test started
172 consisting in performing trials of one repetition with 3 min of recovery between them and
173 load increments of 1.25-5 kg in BP and 1.25-7.5 kg in SQ. This last procedure was
174 repeated until the participant was not able to overcome the load or complete the range of
175 movement. The number of loads used to obtain the 1RM load in the pretest was 7 ± 2 in
176 BP and 10 ± 2 in SQ, whereas in the posttest 8 ± 2 and 10 ± 2 were needed for BP and
177 SQ respectively.

178 Along with MPV, mean propulsive force (MPF), mean propulsive power (MPP),
179 and mechanical work (J) were obtained during the concentric phase of every repetition of
180 the test with a linear velocity transducer (T-Force System, Ergotech Consulting, Murcia,
181 Spain). This system consists of a linear velocity transducer interfaced to a personal
182 computer by means of a 14-bit resolution analogue to digital data acquisition board and
183 custom software (T-Force Dynamic Measurement System, Version 2.35). Instantaneous
184 velocity was sampled at a frequency of 1,000 Hz and subsequently smoothed with a
185 fourth-order low-pass Butterworth filter with a cut-off frequency of 10 Hz.

186 The BP was performed on a flat bench where participants started with the elbows
187 fully extended and then they moved the barbell in a controlled way to their chest, waiting
188 for 1 second in this position to avoid bouncing the barbell off the chest. Individual grip
189 was recorded during the familiarisation and maintained through the intervention. The

eccentric phase was controlled and the concentric one was performed at the maximum intended velocity without releasing the bar.

For the SQ, the participants used a self-selected squat stance. They started in a standing position with the barbell over their shoulders and descended until the upper thighs were parallel to the floor and then performed the concentric phase as fast as possible until the standing position (i.e., full knee extension with the feet maintaining contact with the ground). The range of movement of the SQ was controlled by placing an adjustable bench at the height required to achieve a parallel squat, after which participants performed touch-and-go squats (i.e., without pause, in a continuous manner). Similarly, to BP, the participants were asked to perform each concentric phase of SQ at the maximum intended velocity.

10RM Test

This test aimed to know the maximum load that a participant could lift no more than 10 times. Firstly, participants performed 10 repetitions of BP and SQ with the 50% 1RM. Then, after 5 min of recovery, they repeated the exercise with the 70% 1RM. If the participants completed 11 repetitions, the load was increased (i.e., 2.5-5 kg), whereas if they could not complete 10 repetitions, the load was decreased until the 10RM was obtained. A rest of at least 5 min between attempts was allowed. Participants were asked to perform each repetition as fast as they could. Muscle failure was identified when the participant was unable to overcome the load or when the full range of movement of the exercise was not completed. All the tests were recorded in 3 ± 1 attempts. The 10RM loads corresponded to an average of 80.88 ± 7.35% of the 1RM for the SQ and a 78.80 ± 3.90 % for BP. This recorded load was maintained and used by the experimental groups throughout the training intervention.

214 *Training Programmes*

215 The participants were assigned to a traditional training (TT), cluster training (CT), or a
216 control (CON) group following a randomised block design in order to warrant that the
217 groups were equated regarding the sex distribution and the baseline strength levels. The
218 composition of the groups was: 13 (3 female/10 male) in TT; 11 (4 female/7 male) in CT
219 and 15 (4 female/11 male) in CON.

220 Participants in the TT and CT groups trained twice per week during 5 weeks for a
221 total of 10 training sessions that were separated by least 48h. Both groups used a 10RM
222 load during the BP, SQ, LP, and LC for a total of 128 repetitions and 75 min of total rest
223 per session, being therefore the load, volume, and rest equated between experimental
224 groups. After the general warm up and before each exercise, all participants performed a
225 specific warm up including one set of 10 repetitions with the 50% of the 10RM load.
226 Participants in TT performed 4 sets of 8 repetitions with the 10-repetition maximum load
227 and 5 min of rest between sets and exercises, while in CT completed 16 sets of 2
228 repetitions with 1-minute rest between sets and 5 min between exercises. The participants
229 were instructed to perform each repetition as fast as possible, an all of them completed
230 the programmed volume throughout the intervention. In CON, participants were asked to
231 continue with their usual lifestyles during the 5-week study period. The training groups
232 did not perform other kind of strength training during the intervention. They were also
233 asked to avoid any work-out the day before of each session.

234 *Lactate Measurement*

235 For contrasting the glycolytic metabolism involvement between training protocols and
236 for monitoring its progression throughout the training period, capillary blood lactate
237 concentration was measured at baseline and 1 and 3 min after the sessions 1, 5, and 10 by

using a portable blood lactate analyser (Lactate Scout, SensLab GmbH, Germany). The higher value obtained after each training session (i.e., peak) was used for further analysis.

Data Analysis

Although all the exercises were performed in the training sessions, F-V relationship parameters were only obtained for BP and SQ, as representatives of multi-joint exercises for the upper and lower body, respectively. For each participant, the F-V relationship was calculated from MPV and MPF values recorded during the progressive 1RM test. For the loads at which more than one repetition was recorded, the one with the higher value of MPV was considered for analysis. For SQ, force was calculated considering the system mass (external load + participants body mass). Additionally, the load of the maximum mean propulsive power (MPP_{max}) was identified from the 1RM test and considered for further analysis.

The parameters obtained from the individual linear regressions were the *S*, V_0 (i.e. theoretical maximum velocity achieved when the force is null), F_0 (i.e. theoretical maximum force achieved when velocity is zero), and P_{max} (i.e. $P_{max} = (F_0 \cdot V_0)/4$). The coefficient of determination (R^2) and the standard error of estimation (SEE) of each individual regression were extracted in order to examine the goodness of fit of the F-V relationship by the linear model.

In order to evaluate the changes in the positions on the F-V relationship of the force and velocity associated to the 1RM (F_{1RM} and V_{1RM}, respectively), the ratios between MPF performed with the 1RM and F_0 (F_{1RM}/F_0) and between MPV recorded with the 1RM and V_0 (V_{1RM}/V_0) were calculated.

In order to contrast the mechanical performance between CT and TT, the average MPV of the 320 repetitions of both BP and SQ throughout the training program was

262 calculated. To analyse the velocity loss throughout each session of each training program,
263 the last to the first repetitions ratio was calculated. The average MPV of the last two
264 repetitions and the first two ones were considered to calculate it as follows: [(average
265 last two repetitions MPV/average first two repetitions MPV) - 1] × 100). Thus, the lower
266 this percentage was, the higher the magnitude of velocity loss has been, being positive
267 values interpreted as velocity gains. To analyse the overall maintenance of velocity, the
268 mean to maximum MPV ratio of each session was obtained and calculated in percentage
269 as follows: [(average MPV /maximum MPV)] × 100). Values near 100% imply less
270 velocity loss.

271 Finally, the accumulated work throughout the sessions was obtained for BP and SQ as
272 the sum of work performed during the concentric phase of each repetition (i.e., 320
273 repetitions).

274

275 ***Statistical Analysis***

276 Normality assumption for all the variables was verified by using a Shapiro-Wilk test.

277 It must be pointed that previously, a three-way ANOVA with sex as an inter-
278 participant factor (i.e., time x group x sex) was performed in order to ascertain if data
279 from men and women could be analysed together. In this regard, the data were pooled
280 between sexes because no significant interactions were detected between sex and the rest
281 of the factors.

282 Lactate concentration values were analysed by a three-way ANOVA with an inter-
283 participant factor (group: TT and CT) and two repeated measures factors: session (1, 5,
284 and 10) and time (baseline and peak after training).

285 The progression of the velocity loss variables (last to the first repetitions and
286 mean- to-maximum ratio) throughout the sessions was analysed by a two-way ANOVA
287 with an inter-participants factor corresponding to the experimental groups (TT and CT)
288 and a repeated measures factor corresponding to time (sessions 1 to 10). Furthermore, an
289 independent samples t-test was used for comparing the experimental groups (i.e., CT vs
290 TT) regarding the accumulated work throughout the sessions.

291 Changes in 1RM, MPP_{max}, F-V parameters (F_0, V_0, *S*, P_{max}), F_{1RM}/F_0 and V_{1RM}/V_0 were
292 analysed by 3 × 2 ANOVA with group (TT, CT, and CON) and time (pretest and posttest)
293 as factors.

294 When a significant interaction was detected, post-hoc *t*-tests were carried out with
295 the Bonferroni's adjustment. The effect size for each factor of ANOVA was reported
296 using the partial eta squared (pη2). Additionally, Hedge´s *G* and the corresponding 95%
297 confidence intervals (CI) were calculated for pairwise comparisons. In order to simplify,
298 we only report the effect size and the Hedge's *G* when the effect of the factor was
299 significant. The lower thresholds to consider an effect size as small, medium and large
300 were 0.0099, 0.0588 and 0.1379 for $p\eta^2$ (Richardson, 2011) and 0.2, 0.5 and 0.8 in the
301 case of the Hedge´s *G.* Data are reported as mean ± standard deviation or marginal mean
302 ± standard error for the main effects of analyses of variance (ANOVAs). All the analyses
303 were carried out by using the statistical package SPSS version 20.0 (SPSS, IBM, Armonk,
304 NY, USA). The level of statistical significance was set at 0.05. A post hoc power analysis
305 was calculated using the G Power software (version 3.1.9.2). Statistical power (1-b) for a
306 within-between interaction of an ANOVA with 3 groups and two measurements (i.e.,
307 pretest-posttest), for a sample size of 39, a correlation among repeated measures of 0.5
308 and a medium effect size (f = 0.25) is 0.92.

309

Results

The accumulated work throughout sessions in BP corresponded to an average of 32790.51 ± 15035.34 J in TT and 27839.58 ± 9001.61 J in CT. No differences between groups were detected after performing the t-test (P = 0.411). Regarding SQ, the total work throughout the training programme was of 88284.14 ± 23684.10 J in TT and 83554.85 ± 22534.86 J in CT. The t-test did not detect significant differences between groups (P = 0.951). Lactate concentration analysis showed a time × group interaction with higher peak values after TT compared to CT (Figure 2).

Figure 2 about here

Regarding the average MPV (Figure 3), nonsignificant differences between groups were detected in BP (P = 0.103; *G* = 0.673; 95 % CI: [-0.125, 1.472]). For SQ, this parameter was higher in CT in comparison with TT (P = 0.049; *G* = 0.823; 95% CI: [0.014, 1.632]). Besides, for the velocity loss variables (i.e. last to the first repetitions and mean to maximum ratio) only the group effect was significant, indicating lower velocity loss and higher velocity maintenance for CT in comparison with TT (Figure 4).

Figure 3 about here

Figure 4 about here

Descriptive and ANOVA results of 1RM are shown in Table 1.

Table 1 about here

Regarding MPP_{max} in BP, groups obtained the following mean values in pretest and posttest: TT (362.89 ± 165.29 W and 405.81 ± 157.15 W), CT (319.78 ± 133.64 W and 407.66 ± 158.94 W), and CON (330.34 ± 130.37 W and 338.04 ± 131.24 W). A significant effect of time was observed (P < 0.001; pη2 = 0.528). Additionally, a group ×

time interaction was detected ($P < 0.001$; $p\eta 2 = 0.356$). Post-hoc analysis showed higher values of MPP_{max} in the posttest compared to the pretest for TT ($P = 0.002$; $G = 0.286$; 95% CI: 0.148, 0.424) and CT ($P < 0.001$; $G = 0.418$; 95% CI: [0.277, 0.558]), but not for CON ($P = 0.528$). Lastly, no main effect of group was observed ($P = 0.666$).

Focusing on MPP_{max} in SQ, groups obtained the following mean values in pretest and posttest: TT (1297.63 ± 402.35 W and 1404.34 ± 362.13 W), CT (1164.22 ± 421.72 W and 1451.57 ± 406.21 W), and CON (1183.69 ± 302.67 W and 1215.39 ± 399.43 W). Both a significant time effect ($P < 0.001$; $p\eta 2 = 0.309$) and a group × time interaction ($P = 0.019$; $p\eta 2 = 0.197$) were detected. Post-hoc analysis showed that MPP_{max} improved after training in CT ($P < 0.001$; $G = 0.693$; 95 % CI: 0.248, 1.139) in comparison with pretest values, but not in TT ($P = 0.088$) or CON ($P = 0.579$). No main effect of group was observed ($P = 0.532$).

F-V relationship parameters for BP are shown in Table 2. Regarding BP, median values for R^2 were 0.972 (Range: 0.852 to 1.00) and 0.980 (Range: 0.900 to 0.998) at the pretest and posttest, respectively. Furthermore, the SEE values were 22.97 N in pretest and 20.66 N in posttest. The ***S*** analysis showed no effect of time ($P = 0.176$), group ($P = 0.495$) or group×time interaction ($P = 0.669$). Regarding F_0, a time effect ($P < 0.001$; $p\eta 2 = 0.410$) and an interaction between group and time ($P = 0.008$; $p\eta 2 = 0.243$) was observed. Post-hoc analysis detected higher values in posttest compared to pretest for TT ($P = 0.003$; $G = 0.113$; 95% CI: 0.062, 0.164) and CT ($P < 0.001$; $G = 0.242$; 95% CI: 0.109, 0.376), but not for CON ($P = 0.717$). The effect of the group factor was not significant ($P = 0.796$). With respect to V_0, significant effects of time ($P < 0.001$; $p\eta 2 = 0.354$), group ($P = 0.048$; $p\eta 2 = 0.160$) and group × time interaction ($P = 0.017$; $p\eta 2 = 0.207$) were detected. Post-hoc analysis showed higher values for TT ($P = 0.008$; $G = 0.595$; 95 % CI: 0.157, 1.033) and CT ($P < 0.001$; $G = 1.259$; 95 % CI: 0.574, 1.944) in

the posttest in comparison with the pretest, but this was not the case for CON (P = 0.767). Post-hoc analysis showed higher values of V_0 for TT (P =0.030; *G* = 0.970; 95 % CI: 0.205, 1.734) and CT (P = 0.001; *G* = 1.548; 95 % CI: 0.685, 2.411) compared with CON in the posttest. Regarding P_{max}, a significant effect of time (P < 0.001; pη2 = 0.359) and group × time interaction (P = 0.002; pη2 = 0.303) was observed. Post-hoc analysis revealed higher values of P_{max} in the posttest compared to the pretest for TT (P = 0.006; *G* = 0.266; 95 % CI: 0.155, 0.378) and CT (P < 0.001; *G* = 0.464; 95 % CI: 0.247, 0.680), but not for CON (P = 0.725). No main effect for group was observed (P = 0.451). Focusing on F_{1RM}/F_0, a significant effect of time (P = 0.040; pη2 = 0.115) was observed, with higher values at the posttest compared to pretest. No main effect of group (P = 0.768) or group × time interaction (P = 0.578) were detected. For the V_{1RM}/V_0 ratio, results showed a time effect (P = 0.002), with lower values after the training period in comparison with the pretest. Nevertheless, neither main effect of group (P = 0.388) or interaction (P = 0.696) were observed. No significant effects were obtained for V_{1RM}.

Table 2 about here

F-V relationship parameters for SQ are shown in Table 3. The medians of R^2 for SQ were 0.915 (Range: 0.725 to 0.984) and 0.901 (Range: 0.724 to 0.976) for the pretest and posttest, respectively. On the other hand, the SEE values were 79.99 N in pretest and 77.01 N in posttest. The analysis of the *S* reflected a time effect (P = 0.008; pη2 = 0.178), such that the *S* values were higher in the posttest compared to pretest (i.e., less steep). A group × time interaction was observed (P = 0.031; pη2 = 0.176). Post-hoc analysis detected that *S* values were higher after the training period for CT in comparison with the pretest (P = 0.001; *G* = 0.714; 95 % CI: 0.210, 1.217), but this was not observed not for TT (P = 0.682). No changes were observed in CON (P = 0.622). Also, no effect of group

was observed for the *S* (P = 0.686). Regarding F_0, a significant effect of time (P = 0.014; pη2 = 0.157) and an interaction between group and time (P = 0.013; pη2 = 0.215) was observed. Post-hoc analysis detected higher values at the posttest in comparison with the pretest for TT (P = 0.001; *G* = 0.248; 95 % CI: 0.137, 0.359) but neither for CT (P = 0.125) or CON (P = 0.441). The main effect of the group was non-significant (P = 0.559). The analysis of V_0 showed a time effect (P = 0.011; pη2 = 0.167). Additionally, a group × time interaction was observed (P = 0.049; pη2 = 0.154). Post-hoc analysis detected higher values at the posttest in comparison with the pretest for CT (P = 0.002; *G* = 0.917; 95 % CI: 0.297, 1.538]) but not for TT (P = 0.207) and CON (P = 0.892). No group effect was observed for V_0 (P = 0.976). Regarding P_{max}, a time effect was detected (P < 0.001; pη2 = 0.298), such that values were higher in the posttest in comparison with the pretest. Nevertheless, neither group effect (P = 0.960) or group × time interaction was observed (P = 0.091). Regarding F_{1RM}/F_0, a significant group × time interaction (P = 0.029; pη2 = 0.179) were observed. No main effect of time (P = 0.094) or group was detected (P = 0.069). In this regard, post-hoc analysis detected higher values at posttest compared to pretest for CT (P = 0.004; *G* = 0.850; 95 % CI: 0.074, 1.626) but neither for TT (P = 0.559) or CON (P = 0.801). The V_{1RM}/V_0 ratio analysis showed neither main effect or interaction. For V_{1RM}, a time effect was detected (P = 0.045; pη2 = 0.107), with higher values at the posttest in comparison with the pretest. Neither group effect (P = 0.554) nor group × time interaction was observed (P = 0.379). A representation of the changes in the mean F-V relationship for each group and exercise is shown in figure 5.

Table 3 about here

Figure 5 about here

Discussion and Implications

The main findings of the present study were: (i) TT entailed greater lactate production and velocity loss in comparison with CT; (ii) both training programmes produced similar gains in 1RM; (iii) for BP, changes in F-V were similar for TT and CT (i.e., no shift of the slope and higher force and velocity axis intercept values); (iv) for SQ, changes in F-V parameters were observed with CT towards a velocity profile, whereas these changes were not observed in TT; and (iv) no pre-post differences were observed between training conditions regarding the position of V_{1RM} on F-V of both exercises whereas the gain of F_{1RM}/F_0 was only significant in SQ for CT.

In agreement with other studies (García-Ramos et al., 2017; Gorostiaga et al., 2012), blood lactate concentration after training sessions were higher in TT in comparison with CT. This suggests that short sets, with recovery between a cluster of repetitions reduce the glycolytic involvement of the session (Haff et al., 2008). On the other hand, TT produced higher velocity losses during the sessions in comparison with CT. This suggests that cluster structures enhance the velocity maintenance during training session, what is consistent with previous studies (García-Ramos et al., 2015; Oliver et al., 2016). It is necessary to point out that differences in velocity loss were not the same for BP and SQ. For BP, the average values of the first to last repetition ratio during sessions were 39% for TT and 13% for CT, whereas for SQ, losses of 15% and 5% were observed in TT and CT, respectively. We found similar outcomes to those previously reported (Sánchez-Medina & González-Badillo, 2011), indicating higher values of velocity loss for BP in comparison with SQ, these differences being explained due to a greater movement control and higher V_0 improvements in SQ compared to BP. However, we hypothesised that these differences could be induced by the V_{1RM} increases that only occurred in SQ. As the comparisons between exercises are not calculated, this topic needs further investigation.

In agreement with other studies, strength gains related to 1RM were similar for TT and CT (Iglesias-Soler et al., 2017, 2016; Morales-Artacho et al., 2017). Despite the mechanical and metabolic differences between protocols, similar strength gains were observed when the rest of the loading variables were equated. For BP, MPP_{max} increased for both TT and CT, although the effect size was higher for CT (0.286 and 0.418 for TT and CT, respectively). Regarding SQ, MPP_{max} achieved higher values after training only in CT. Thus, in agreement with other long-term studies (Blazevich & Jenkins, 2002; Morales-Artacho et al., 2017), CT presented an advantage to increase maximal power output, especially in lower extremities exercises.

The analysis of F-V relationship showed goodness of fit values similar to others previously reported for multi-joint exercises (Cuk et al., 2014; Rahmani et al., 2001; Rivière et al., 2017; Samozino et al., 2012). In this regard, R^2 values higher than 0.800 were observed in most of the participants (i.e. 85% in SQ pretest; 90% in SQ posttest; 97.5% in BP pretest and 100% in BP posttest). Focusing on BP, changes in F-V parameters were similar for both training protocols. The improvements in F_0 and V_0, during both TT and CT could have contributed to the increase of maximal power after both training protocols whereas no changes in *S* occurred (i.e., F-V displacement to the right and parallel to the pretest one). Regarding SQ, F-V parameters changed in a different way while performing TT or CT protocols. CT produced alterations in the *S* and V_0, showing higher values after training. On the other hand, TT produced only changes in F_0. Since P_{max} (i.e., $[F_0 \times V_0) / 4]$) increased after both training protocols, our results suggest that improvements in the maximum estimated power were mainly based on force and velocity gains for TT and CT, respectively. Overall, the results suggest that CT was efficient modifying the F-V toward a velocity profile (Samozino et al., 2012). These outcomes indicate that the set configuration was not able to modulate the adaption in F-

458 V in the case of BP. Nevertheless, it must be pointed out that in this exercise the effect
459 size for the changes of V_0 were 0.595 and 1.944 for TT and CT, respectively. This
460 suggests an effect toward a higher velocity profile in CT. Since the appearance of an
461 effect may be a matter of time, further studies should implement longer training programs
462 in order to elucidate this possibility. It must be pointed out that some studies did not find
463 an increase or a change in V_0 after training. Discrepancies with these studies can be
464 caused by the difference in the exercise performed (Iglesias-Soler et al., 2017) or by
465 differences in the training intervention design (Morales-Artacho, Padial, García-Ramos,
466 Pérez-Castilla, Argüelles-Cienfuegos, et al., 2018). Furthermore, higher V_0 values were
467 reported after an intervention using attached rubber bands on the barbell (i.e., "inertia"
468 condition) (Djuric et al., 2016). The authors reported higher values of V_0 in the group
469 "inertia" compared with the other conditions (i.e., "weight" and "weigh plus inertia"). As
470 our training intervention corresponds to a "weight plus inertia" condition (i.e., the use of
471 barbell and plates), we suggest that the application of cluster protocols may result in an
472 easier way to increase V_0 compared with a more complex inertia design.

473 Considering the results from both exercises as a whole, it seems that exercises
474 which imply more mechanical and neural control (i.e., with a higher muscle mass, number
475 of joints and degrees of freedom involved such as occurs in SQ in comparison with BP)
476 do not experiment alterations in F-V relationship as a consequence of performing TT
477 protocols. Nevertheless, exercises that imply less muscle implication such as BP obtain
478 similar F-V parameters changes by performing TT or CT protocols. This is in agreement
479 with a previous study in which similar changes in F-V were observed after unilateral leg
480 extension exercise training programmes differing in the set configuration (Iglesias-Soler
481 et al., 2017). Another explanation to the different effects of set configuration depending
482 on the type of exercise could be found regarding the velocity loss variables. In BP, the

velocity loss was more pronounced through the sessions compared to SQ. This suggests that in the SQ, participants trained at higher relative velocities what could have contributed to improve the velocity portion of the F-V relationship.

Regarding the position of F_{1RM} on the F-V relationship, our results ranged from 84 to 94% in both exercises and are coincident with other data previously published (Rivière et al., 2017). In this regard, only the implementation of cluster structures caused increments of F_{1RM}/F_0 for SQ. Thus, our outcomes suggest that F_{1RM}/F_0 is affected by the set configuration in resistance training for SQ. On the other hand, concomitant changes of V_{1RM} and V_0 of SQ resulted in similar V_{1RM}/V_0 ratios before and after training. In contrast, increments of V_0 after both training programs entailed a decrease of this ratio for BP. These results for BP are consistent with previous studies suggesting the stability of V_{1RM} (Gonzalez-Badillo & Sanchez-Medina, 2010). However, this was not the case for SQ since both V_{1RM} and of V_0 were affected by training in a similar proportion as indicated by the lack of significant changes inV_{1RM}/V_0. Overall, the results suggest that set configuration did not differentially affect to V_{1RM}/V_0. However, conclusions derived from the V_{1RM} must be taken carefully because of its limited reliability (Iglesias-Soler et al., 2019).

One possible limitation of this study is that all the participants had a limited experience in resistance training (i.e. 3 months). This could affect the results, since cluster training is more recommended for more advanced athletes with higher strength levels (Haff & Nimphius, 2012). On the other hand, 4.52 % of the F-V relationships had an R^2 lower than 0.800. These lower coefficients can be a consequence of analysing the propulsive phase, which entail differences between loads regarding the analysed range of movement, or because some cases presented a more oriented curvilinear profile. However, we finally chose the linear approach since reliability of the F-V parameters for

our exercises is higher than other curvilinear models (Iglesias-Soler et al., 2019). Finally, the minimum load allowed by the Smith machine (i.e. 21,4kg) limited the collection of data corresponding to higher velocity portions of the F-V relationship, especially for women.

Conclusion

Our data show that both TT and CT training programs produce similar gains in strength and peak power, with a higher lactate production and velocity loss in TT in comparison with CT. Cluster structures were particularly effective for increasing the velocity profile in SQ, so this set configuration is recommended for obtaining this type of adaptation in the lower limbs. This study also suggests that if the main aim of the coach is to improve the quality of a session regarding velocity, cluster training could be a good option.

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Disclosure statement

The authors have no conflicts of interest to declare.

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693 **FIGURES LEGEND:**

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695 **Figure 1.** Schematic representation of the study. Figure 1A: Experimental design of the
696 15 sessions. F: Familiarisation session. 1RM: 1-repetition maximum test. 10RM: 10-
697 repetition maximum test. F-V: individual Force-Velocity profile testing. S: session. LT:
698 Measurement of the capillary blood lactate before and after the session. Figure 1B:
699 Experimental protocols performed. TT: Traditional training. CT: Cluster training.

700 **Figure 2.** Capillary lactate concentration (LT) obtained before (baseline) and after (peak)
701 sessions 1, 5, and 10. Points represent the estimated marginal means (pooled means for
702 sessions 1, 5, and 10) and the error bars the corresponding standard error. TT: Traditional
703 training group. CT: Cluster training group. *: Significant differences between groups for
704 the peak values after sessions ($P \leq 0.05$).

705 **Figure 3.** Average mean propulsive velocity (MPV) for the Bench Press (BP) and the
706 Parallel squat (SQ) exercise. Data are presented as mean ± SD. *: Significant differences
707 between groups ($P \leq 0.05$).

708 **Figure 4.** Velocity loss calculated as the last to the first repetition ratio (LFR) and velocity
709 maintenance calculated by the mean to the maximum ratio (MMR) during the 10
710 experimental sessions (S) of traditional (TT) or cluster (CT) training for the Bench Press
711 (BP) exercise (A and B) and the Parallel squat (SQ) exercise (C and D). Data are presented
712 as mean ± SD.

713 **Figure 5.** Mean force-velocity relationships of traditional (TT), cluster (CT) and Control
714 (CON) group before (solid line) and after training (dashed line). Figure 5A: Bench press
715 (BP). Figure 5B: Parallel squat (SQ).

716