Force-velocity profile changes and cardiovascular parameters adaptations at rest after resistance training programmes differing in set configuration

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produced by the candidate

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in the University of A Coruna.

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Place and date Supervisor Eliseo Iglesias Soler

A mamá y a papá
Y a mi abuela Lola por ser mi inspiración de vitalidad.

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"The mechanical efficiency of a submaximal effort is always less than that of a maximal effort occupying the same time, and in general the stronger effort is the more efficient" Hill 1922

Entre la impaciencia y la tranquilidad. JRV

ABSTRACT

During training, the combination of the force and the velocity exerted by muscles determines the individual mechanical profile, that reveals the muscles strengths and weakness. In order to modify this profile, set configuration was manipulated. This thesis aims to identify resistance exercise structures that effectively combine the optimization of mechanical performance with positive hemodynamic and cardiovascular adaptations. A randomised controlled study examined the force-velocity profile changes and the cardiovascular adaptations at rest in response to 5-week training programmes differing in set configuration. 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. The load performed corresponded to the 10-repetition maximum. Similar changes toward a power-oriented profile were observed in bench press after both regimes while in parallel squat only cluster structures produced any alteration toward a velocity-oriented profile. Traditional sets entailed greater velocity loss, lactate production and heart rate peak during intervention compared to cluster sets. Both protocols did not alter the cardiovascular parameters at rest after training intervention.

Keywords: force-velocity profile, cardiovascular adaptation, set configuration, resistance training, fatigue.

RESUMEN

Durante el entrenamiento, los músculos producen combinaciones de velocidad y fuerza que determinan un perfil mecánico, revelando las fortalezas y debilidades musculares. Para modificar este perfil, la configuración de la serie fue manipulada. Esta tesis busca determinar estructuras de entrenamiento de fuerza que combinen la optimización del rendimiento mecánico con adaptaciones hemodinámicas y cardiovasculares positivas. Un estudio aleatorizado controlado examinó los cambios en el perfil de fuerza-velocidad y las adaptaciones cardiovasculares en reposo tras dos programas de entrenamiento de 5 semanas con configuraciones de la serie diferentes. El grupo tradicional realizó 4 series de 8 repeticiones con 5 minutos de descanso entre series y ejercicios mientras el cluster completó 16 series de 2 repeticiones con 1 minuto de descanso entre series y 5 entre ejercicios. La carga utilizada fue 10RM. Se observaron cambios similares en *press* de banca hacia un perfil orientado a la potencia, mientras que en sentadilla paralela solo el entrenamiento cluster produjo alteraciones hacia un perfil orientado a la velocidad. Las series tradicionales implicaron una mayor pérdida de velocidad, producción de lactato y frecuencia cardíaca pico durante la intervención en comparación con las series cluster. Ambos protocolos no alteraron los parámetros cardiovasculares en reposo tras el entrenamiento.

Palabras clave: perfil fuerza-velocidad, adaptaciones cardiovasculares, configuración de la serie, entrenamiento de fuerza, fatiga.

RESUMO

Durante o adestramento, os músculos producen combinacións de velocidade e forza que determinan un perfil mecánico, revelando as fortalezas e debilidades musculares. Para modificar este perfil, manipulouse a configuración da serie. Esta tese busca determinar estruturas de adestramento de forza que combinan eficazmente a optimización do rendemento mecánico con adaptacións hemodinámicas e cardiovasculares positivas. Un estudo aleatorizado controlado examinou os cambios no perfil de forza-velocidade e nas adaptacións cardiovasculares en repouso despois de dous programas de adestramento de cinco semanas con diferentes configuracións de serie. O grupo tradicional realizou 4 series de 8 repeticións con 5 minutos de descanso entre conxuntos e exercicios mentres o grupo cluster completou 16 series de 2 repeticións con 1 minuto de descanso entre series e 5 entre exercicios. A carga utilizada foi a do 10RM. Observáronse cambios similares en *press* de banca cara un perfil orientado á potencia, mentres que en sentadilla paralela só o adestramento clúster produciu alteracións cara un perfil orientado á velocidade. A series tradicionais implicaron unha maior perda de velocidade, produción de lactato e pico de frecuencia cardíaca durante a intervención en comparación coas serie cluster. Ambos protocolos non alteraron os parámetros cardiovasculares en repouso despois do adestramento.

Palabras clave: perfil forza-velocidade, adaptacións cardiovasculares, configuración da serie, adestramento de forza, fatiga.

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ABBREVIATIONS

1RM	One repetition maximum
ApEn	Approximate entropy
ATP	Adenosine triphosphate
BEI	Baroreflex effectiveness index
BMI	Body mass index
BP	Bench Press
BRS	Baroreflex sensitivity
CMJ	Countermovement jump
CT	Cluster training
DBP	Diastolic blood pressure
F_0	Maximum theoretical force
F_{1RM}	Force associated to the 1RM
F-V	Force-Velocity
HF	Power of high frequency
HRV	Heart rate variability
LC	Leg curl
LF	Power of low frequency
LF/HF	Ratio between the power of low and high frequency
LFR	Last to the first repetitions ratio
LMaxR	Last to the maximum repetition ratio
LMR	Last to the mean ratio
LP	Lat pull-down
LT	Capillary blood lactate concentration
MAP	Mean arterial pressure

MinMaxR	Minimum to maximum ratio
MMR	Mean to the maximum repetition ratio
MPF	Mean propulsive force
MPP	Mean propulsive power
MPP_{max}	Maximum mean propulsive power
MPV	Mean propulsive velocity
PCr	Phosphocreatine
P_{max}	Estimated maximum power
P-V	Power-Velocity
RMSSD	Squared root of the standard deviation of RR interval
RPE	Rate of Perceived Exertion
S	Slope of the linear regression
SampEn	Sample entropy
SBP	Systolic blood pressure
SDNN	Standard deviation of the RR interval
SEE	Standard error of estimation
SQ	Parallel Squat
TT	Traditional training
V_0	Maximum theoretical velocity
V_{1RM}	Velocity associated to the 1RM

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1 General introduction

Resistance training has progressively become a subject of study in sports science. It has been investigated from a sport performance point of view as well as from a preventive and a therapeutic perspective (1). Resistance training is recognised as a good method that provides mechanical, hormonal, metabolic, cardiovascular and healthy benefits (2). However, to be as helpful as possible, this kind of training should be adjusted to the target population. In this sense, identifying the training parameters that modulate the different effects, become a priority objective in order to provide safe and effective guidelines. Additionally, differences in environment, age, sex or genetics may influence the training program.

When a resistance training intervention is performed, the individual muscle mechanical properties allow the production of force, velocity and therefore power. Different combinations of these parameters are dependent of multiple factors, as for example biological markers. The relationship between force and velocity draw the individual mechanical profile that has been investigated since 1922 (3–5). Currently it is represented by linear approaches when multi-joint exercises are selected (6–8). In this regard, the force-velocity (F-V) mechanical profile refers to the slope of the linear regression (9). This profile and its different associated parameters provide valuable and practical information that reveals the muscles mechanical strengths and weaknesses. Therefore, it could be helpful to guide the training process toward the specific qualities to develop (10).

Taken into account the F-V profile, the resistance training variables (e.g., volume, load, rest, frequency, set configuration…) can be manipulated in order to modulate the responses regarding the objective desired. Although the use of F-V profiles seems an interesting tool to observe the changes in the individual mechanical properties (11), there are limited studies including them.

On the other hand, it is noted that the mechanical improvements after a resistance intervention occurs in line with metabolic and cardiovascular adaptations (12–15). Firstly, during consecutive muscle contractions, the metabolic system regulates the appearance of fatigue caused by the accumulation of lactic acid and the depletion of phosphocreatine (PCr) and adenosine triphosphate (ATP). Specific resistance training protocols can regulate the metabolic function to finally improve performance (16). In this regard, some training variables are manipulated in order to retard the appearance of fatigue. One of them is the set configuration that traditionally is performed in a continuous manner. There is the possibility to break the training sets in small clusters or groups in order to reduce the accumulated fatigue by the addition of rest intervals between them. This kind of set configuration is called cluster training and became a trend and novel method used by athletes (17). Beyond metabolic benefits (18,19), cluster structures enhance the mechanical work eliciting greater velocity and net total power output (20–22). Despite this has been evidenced, few studies have explored how the muscle mechanical properties changed after this kind of structures (23,24). This is the chance to examine the responses regarding the F-V individual mechanical profile.

Additionally, cluster training has not been enough explored, especially its cardiovascular effects. This is because the cardiovascular response has been described traditionally after aerobic exercise. Moreover, most studies in this line, reported acute effects that recommend cluster training as a strategy where the response of blood pressure and heart rate is lower in comparison with traditionally resistance protocols (25,26). Thus, it is important to investigate how a resistance program performing cluster sets will induce adaptations in the autonomic control and in the cardiac baroreflex control.

In this sense, the main aim of this thesis is to evaluate the mechanical, metabolic and cardiovascular effects as well as the neuromuscular performance after two resistance training programs differing in set configuration.

This thesis may help to identify resistance exercise structures that effectively combine the optimization of mechanical performance with positive hemodynamic and cardiovascular adaptations.

It is hypothesized that shorter set configurations will enhance the high velocity portion of the F-V relationship and will improve the power output in higher magnitude than longer sets. Additionally, shorter structures will produce less stress in the metabolic system and more favourable adaptations in the autonomic control and in cardiac baroreflex control in comparison with traditional configurations.

2 Theoretical framework

2.1 Force-velocity relationship

2.1.1 Concept

The inverse relationship between the force and the velocity produced in muscles is well-known in the literature, hence greater concentric forces are possible at slower velocities and vice versa (3). The behaviour of these parameters has been studied since the beginning of the XX century. The F-V relationship was firstly explored by Hill (5) in 1922 using a tachometer for the evaluation of the in vivo mechanical work of muscles. From this experiment, Fenn & Marsh (4) tried to explore this conception in 1935, that was later clearly described by Hill in 1938 (3). They carried out experiments on isolated frog and cat single muscles by isotonic contractions under different loads, to finally find different conclusions about the stretch–shortening cycle.

Experimental results from Fenn & Marsh (4) about the F-V relationship were well fitted by a simple exponential equation (Eq.1) where a is the coefficient of tension loss and k is the coefficient of viscosity. F_0 corresponded to the theoretical maximum force when velocity is cero. They concluded that the muscle cannot be treated as a simple mechanical system (due to its elastic properties) and that the exponential model was the appropriate to fit the F-V relationship.

$$\textbf{Eq. 1.}\ \ \mathrm{F(V) = F_0\ e^{-av} - kv}$$

In 1938, Hill (3) performed thermodynamic experiments with frog muscles and suggested that the mechanics of contraction are associated to the muscles energy metabolism. He derived an equation (Eq. 2) introducing a constant of shortening heat (a) and a constant defining the absolute rate of energy liberation (b). (Figure 1)

$$\textbf{Eq. 2.}\ \ (\mathrm{F} + a)(\mathrm{V} + b) = (\mathrm{F_0} +\ a)b = \mathrm{const.}$$

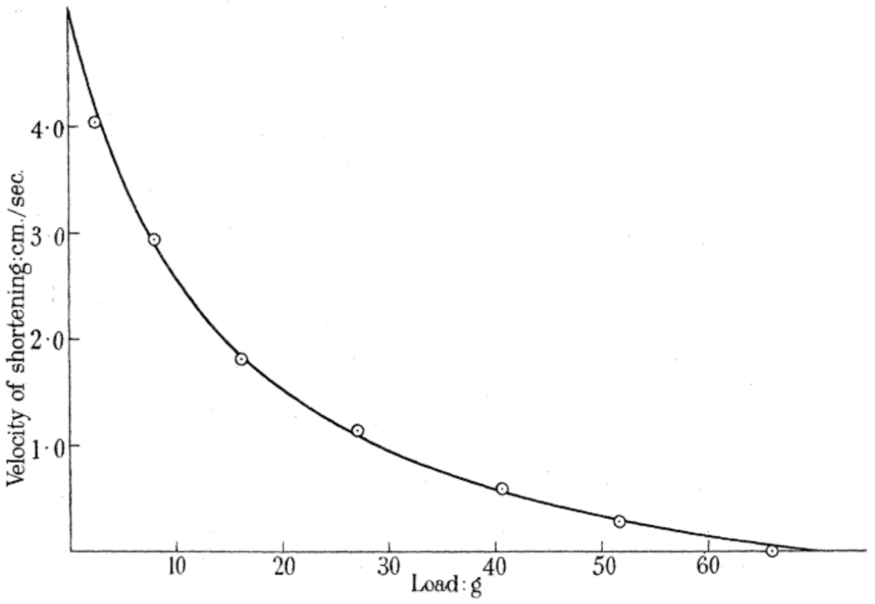


Figure 1. Representation of the hyperbolic force-velocity relationship reported by Hill in 1938 from frog isolated sartorius muscle. From Hill (3).

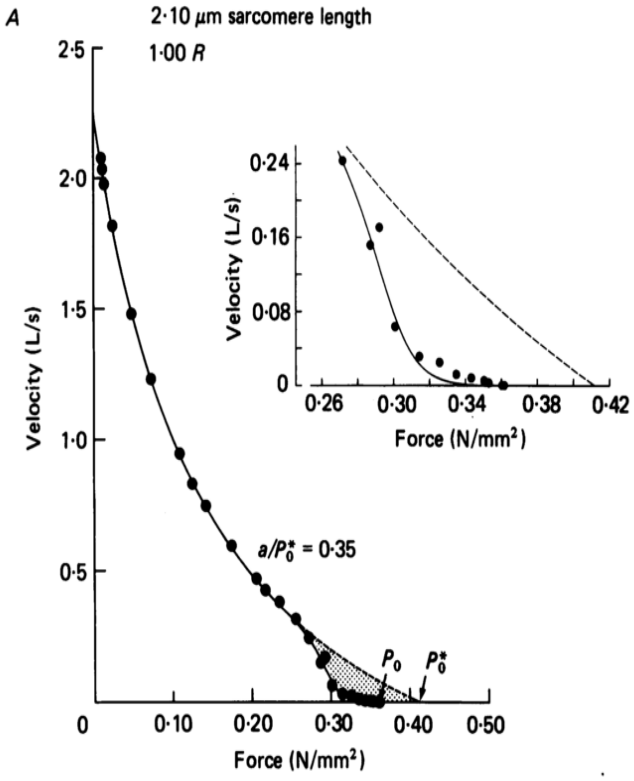
Later in 1947, Dern et al. (27) tried to explain that relationship for first time in humans muscles, performing maximal voluntary flexions of the forearm. The results were fitted by a curvilinear function. Also Wilkie (28) experimented with maximal isotonic elbow flexions and could finally fit the obtained results using the equation presented by Hill. The cross-bridge model formulated by Huxley (29) in 1957 also confirmed the predicted hyperbolic approach.

Nevertheless, thirty years later, Wickiewicz et al. (30) found that for the quadriceps muscle group, the in vivo F-V relationship curve, falls off from the expected by Hill. The hyperbolic equation did not predict correctly the forces at low velocities. Other authors also detected no fitting in animals muscles (31–33). It was demonstrated that some Hill's theories were incorrect. The constant α do not represent the heat of shortening, since it corresponded to the degree of muscle shortening (34). Also, the parameter that represents the curvature of the hyperbola (i.e., a/F_0) was proved not to be constant, as it could change depending, for example, the temperature or the type and length of muscles. Also, Hill recognised that the F-V data fall off from the proposed hyperbola in the high force region (35). In this regard, it was necessary to explore what happens in that high force section of the F-V relationship, but unfortunately the published studies in that time did not evaluate values above the 80 % of the maximal isometric force.

In this line, were Edman and collaborators (36) in 1976 who examined in frogs muscles the high force region of the F-V relationship (i.e., above the 75 % of the maximal isometric force). They observed that the departures from the hyperbolic curve at low velocities seemed a reversal curvature at the 78 % of the maximal isometric force and at the 10 % of the maximal velocity. He suggested that during and isometric response a few percentages of cross-bridges do not make proper contact and nor interaction with thin filaments as happens in an isotonic contraction. This could be one of the possible reasons why the F-V relationship seems different above the 80% of the maximal isometric force.

He introduced the concept of the double-hyperbolic shape and tried to find the best way to represent it mathematically. In 1988 Edman (31) introduced in Hill's equation a correction term that reduces the velocity in the high force range. Consequently, two different hyperbolas were needed to characterize the F-V relationship (Figure 2).

This author also tried to explain this relationship when the load exceeds the isometric force. His study explained that when this occurs, the F-V relationship formed a smooth sigmoidal function with inflexion at F_0. Between the 90 % and the 120 % of maximal isometric force, the F-V curve remains nearly flat. Beyond the 160 %, the velocity of elongation increases progressively (31). This was later explained by Hahn (37), reporting that in eccentric contractions the force production is increased by 1.2 to 1.8 times the isometric force. This high generation of force corresponds with negative velocities that became more negative as force increases.



B

$$V = \frac{(F_0 - F)}{F + a}\,(1 - \frac{1}{1 + e^{-k1(F - k2\,F_0)}})$$

Figure 2 . A: Representation of the Force-Velocity curve in frog muscles. The shaded area shows the difference between the hyperbolic function and the new equation adding the correct term. B: Equation with the correct term From Edman (31).

Since the double-hyperbolic conclusions were obtained after animal experiments and in simple muscles, more investigation was needed to understand the F-V relationship behaviour. In 1984, Wickiewicz et al. (30) examined the muscle architecture to finally analyse the F-V relationship in humans. They tested different movements involving knee extensors, knee flexors, ankle plantar-flexors and ankle dorsiflexors to finally explain that the maximum torque-velocity relationship at higher speeds seemed linear for all muscle's groups. Those dissimilarities were attributed to neural inhibition or data collection technique. However, other studies proposed that differences from Hill's hyperbola had its origin in the interaction between myosin cross-bridges and the actin filaments (38).

2.1.2 Linear approach

Going further, F-V relationship has been studied during the years in more functional exercises that not only include single-joint rotations. The evaluation of the dynamics in multi-joint movements is considered more important than mono-articular movements as they are more transferable to daily living (39). In this regard, many studies found that the F-V relationship was quasi-linear when multi-joint exercises were considered (6).

Equation 3 corresponds to the linear model, where F_0 represents the maximal force when velocity is zero (i.e., force axis intercept), and *S* is the slope of the linear regression [i.e., *S* = - (V_0/F_0)]. The theoretical value of the maximum velocity (V_0) is obtained when force equals zero (i.e. velocity axis intercept). Finally, the theoretical value of maximum power (P_{max}) is estimated as the product of $F_0/2$ and $V_0/2$ [i.e., $P_{max} = (F_0 \cdot V_0)/4$]. The power-velocity (P-V) relationship can be expressed by a second-degree polynomial curve. Following this approach, maximum values of power are reached against resistance around 50 % of the theoretical maximal value of force and velocity. Both F-V and PV relationships are represented in Figure 3.

$$\textbf{Eq. 3.}\ \mathrm{F(V)} = \mathrm{F_0} - \mathrm{SV}$$

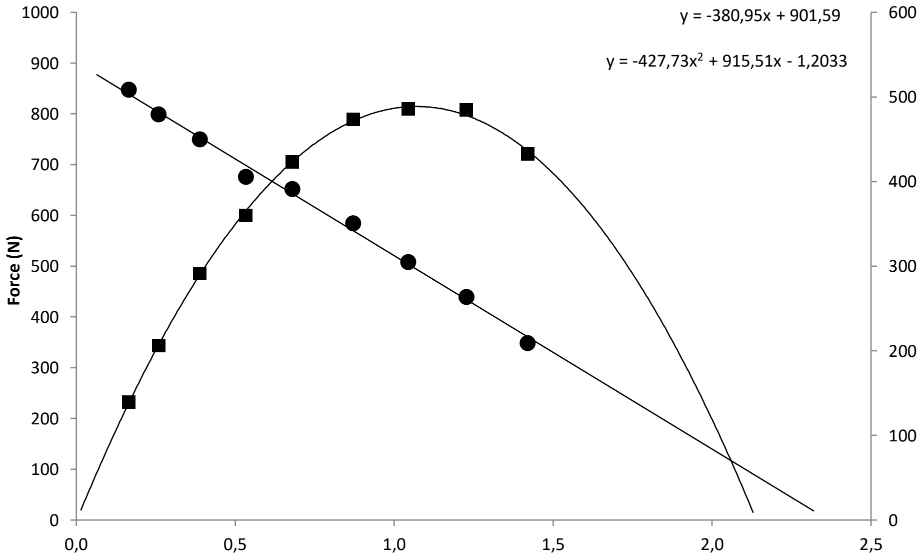


Figure 3. Representation of the Force-velocity and Power-velocity individual profile in bench press performed in this study. The regression equation of both linear (F-V) and polynomic (P-V) model are included.

Additionally, the force and the velocity applied to a specific load, such as the force and the velocity performed with the one repetition maximum (1RM) load, can be placed on the F-V spectrum as an interesting feature of neuromuscular performance (40) (i.e., F_{1RM} and V_{1RM} respectively). 1RM represents the maximal dynamic muscular strength and it is useful to indicate the training load and to determine strength improvements. In this regard, V_{1RM} was demonstrated useful in order to measure the training loading intensity since it was suggested to be stable for the bench press exercise (41). Both V_{1RM} and F_{1RM} parameters were previously explored in multi-joint exercises as squat jump (40).

2.1.2.1 Describing and comparing F-V linear profiles

First studies detecting that linear appearance in complex exercises were those related to cycling. In 1981, Sargeant et al. (42) carried out an experiment where participants performed series of 20 seconds of maximum efforts in bicycle ergometer at different crank velocities. They concluded that peak force was inversely and linearly related to crank velocity. Few years later, Vandewalle et al. (43,44) confirmed that behaviour in arm and leg cycling reporting that pedalling activities imply the participation of numerous agonist and antagonist muscles groups acting as motors or fixators of a joint. Also, the level of activation is not constant as happening in the isolated muscle experiments.

This relationship was also evaluated in resistance exercises like bilateral or unilateral knee-hip extension (45,46), leg extension (23,47), squat (48) or bench press (8,49) determining the great goodness of fit of the linear regression. Soon this approach appeared in many studies describing mechanical profiles in jumping, starting with Bosco in 1995 using a novel dynamometer for squat jump (50). Nowadays the works of Samozino et al. (9,51–53) deepened into the topic until finding the optimal linear profile for jumping performance reporting a theoretical approach (53,54).

Regarding sprints, two different models allow the description of the individual F-V profiles and both results provide a strong inverse linear F-V relationship (55,56). The multiple trial method consists in repeated sprints increasing progressively the external resistance (i.e., using different resisted materials or devices) and the single method is based on an inverse dynamic approach applied to the body centre of mass using anthropometric and spatiotemporal data (57). A recent study showed a great reliability of the single method to assess children and adolescents F-V and P-V profiles in sprinting (58).

This F-V linear profile was described in different sport population. A recent cross-sectional study of elite Norwegian athletes from 23 sport disciplines was performed by Haugen et al. (59) with the aim of describe and compare their F-V profiles. The F-V data were obtained by a 40 meters run test using the method proposed by Samozino (57). Results from this study placed bobsleigh athletes at the top of the score regarding F_0 and sprinters concerning V_0. In contrast, the lower achievements in F_0 and V_0 were obtained by speed skating and fencing athletes respectively. They also reported the differences between men and women. In general, these differences were represented by 9.3 % in F_0, 11.9 % in V_0 and 21.9 % in P_{max}, being higher in men.

On the other hand, Giovani et al. (60) described the F-V parameters in boxers and Nikolaidis (61) in swimmers using cycle ergometers. Both studies were focused on the differences in F-V characteristics between upper and lower limbs. Both investigations found a “strong” profile in legs muscles and a “velocity” profile in arms. In this regard, P_{max}, F_0 and V_0 were greater in legs while the slope was higher in arms (i.e., less steep).

The study of Stavridis et al. (62) sought to compare the differences in the horizontal and vertical F-V profile between female sprinters and hurdlers. In order to obtain their profiles, 40m sprints and loaded jumps were completed. Large higher values of F_0, V_0 and P_{max} were observed in sprinters compared to hurdlers. This indicates that sprinters applied higher oriented forces onto the ground during acceleration that means higher power outputs. These differences are normal being in consideration the nature of the discipline performed. However, since hurdle events are considered sprints, hurdlers should perform as similar as possible to a sprinter. This information is useful for coaches in order to reduce the race time.

Last studies explained above, found a strong linear appearance in their recorded F-V data. The reason of this linear fitting was not exactly described. While Yamauchi et al. (45) suggested that some neural mechanisms are responsible, Bobbert (63) proposed that the explanation could be found in the "*segmental dynamics*" because a complex movement involves rotations of body segments and the angular acceleration of that segments influence the final movement. Hence, in a multi joint movement the participation of many muscles are needed at the same time making the difference with respect to single rotations (46). Also, other study suggest that this linearity could be a consequence of the relatively narrow range of forces usually evaluated in human studies (64). This topic needs further investigations.

The opportunity to use the linear model to describe multi-joint exercises allows an easily calculation of the individual F-V parameters and helps researchers to characterize different populations and complex exercises. In this sense, deficit parameters could be detected in order to improve performance and find the optimum F-V slope for different tasks.

2.1.2.2 The reliability of the linear F-V profile

Some studies tried to verify that the linear model could fit the F-V data of different exercises and populations. In addition, it is necessary to examine if the parameters obtained from this approach are reliable and valid. In this regard, Iglesias-Soler et al. (65) have explored the goodness of fit of three regression models (i.e., linear, polynomial and exponential) and the reliability of their parameters on the F-V relationship for bench press and squat. They observed higher values of the adjusted coefficient of determination (i.e., over 0.919) for the polynomial and the linear model compared with the exponential one. However, the reliability of the linear regression parameters was higher than the obtained by the other approaches (i.e., lower intra-class correlation coefficient, coefficient of variation and standard error of measurement). The authors concluded that the linear model is a good option to describe the individual profile for bench press and squat (65).

Other authors confirmed this linear approach reliability in multi-joint exercises like deadlift high pull (66), bench press throws (67) and sprints (58). Specifically, the study of García-Ramos & Jaric (67) explored the reliability of a multiple load method and a two point method. They revealed that the distance between experimental points is more important for getting a reproducible F-V relationship than the number of points. In contrast, Cuevas-Aburto et al. (68) used a wider range of loads to increase the reliability of the F-V relationship in bench press by the addition of very light loads into the routine testing (i.e., completing low force region).

Hence, knowing that F-V profiles are reliable, they can be useful to identify any change, either naturally or produced by a training intervention. The possible alterations in F-V profiles are going to be described in the next section.

2.1.3 Changes in F-V relationship

The individual F-V profile is not a fixed parameter. It could be altered by different reasons as a specific training program, fatigue, an injury or disease and clearly with aging. While many acute studies analyse this topic, chronic or middle-long term studies are less common.

In this section some seminal and recent studies that try to find the F-V profile modifications under different training conditions are summarized.

2.1.3.1 Acute Fatigue

Assessing the mechanical behaviour of the muscles with the appearance of fatigue is advisable to control training procedures. Animal experiments in 1989 reported that fatigue is a crucial factor that results in alterations in the F-V relationship, related to a decrease in maximum velocity of shortening and a large loss of power (69). First studies in humans revealed that when fatigue is generated by a high intensity voluntary contraction, power is substantially reduced at higher velocities in comparison with lower ones (70,71).

Jones et al. (72) following similar procedures than De Ruiter et al. (71) experimented with an electrical stimulation on the human adductor pollicis muscle at 37 degrees. This muscle was stimulated during 9 sets and authors reported the F-V relationship for the initial fresh state, for the fatigued state (i.e., after 9 sets) and for the 6 minutes recovery state. They found that the decrease in power was more related with the loss of force (contributed a 40 %) than the descend of the maximal velocity of shortening (about 20 %). Moreover, an increase in the curvature of the F-V relationship fitted by the hyperbolic model (i.e., α/F_0 decrease from 0.22 to 0.11) was observed, caused by the large decreases in power. Moreover, force was recovered by a 96% after 80 seconds and peak power and maximum velocity returned to 90 % and 92 % after 6 minutes respectively.

In agreement with the previous studies, the review of Jones (73) confirmed that the short decrements in force and velocity (i.e., about 20-30%) resulted in an important loss in power output production (i.e. a reduction about 33% of the fresh value). Also, this review suggested that the appearance of the F-V relationship become more concave under fatigue conditions (i.e., lower value of α/F_0), revealing that an increase in the concave shape resulted in less force production at intermediate velocities of shortening (Figure 4). Additionally, he explained that a fatigued muscle lead to greater force production in the eccentric phase of the movement in comparison with a fresh muscle. This occurs because fatigued muscles become more resistant to stretch.

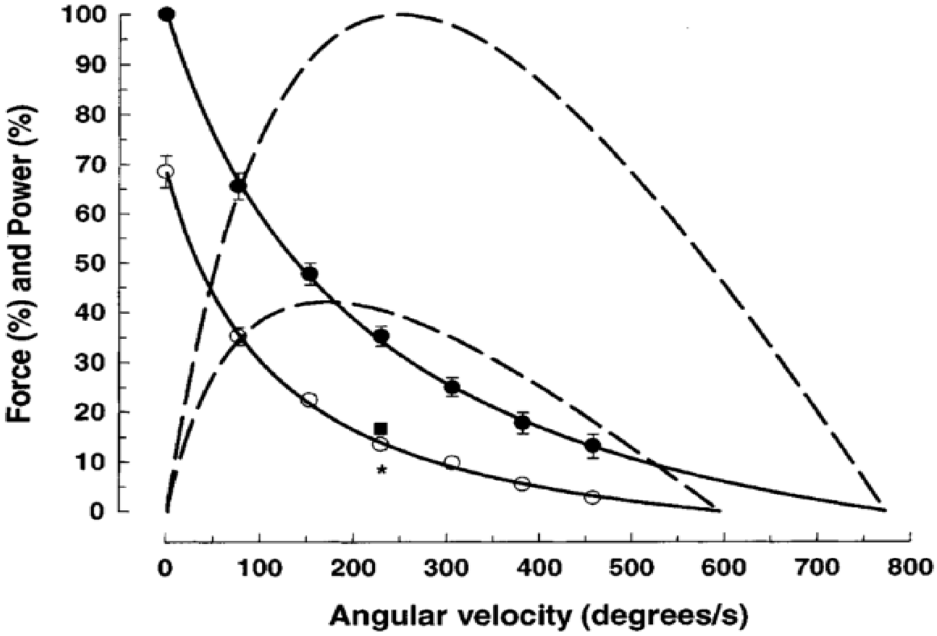


Figure 4. F-V and PV relationship of fresh (filled circles) and fatigued muscles (open circles). From De Ruiter (71)

Moreover, an interesting study compared the F-V relationship shape after performing an isometric or an isotonic fatiguing contraction in rats (74). Data were fitted by Hill's equation. They revealed a significant difference between these two sorts of fatigue protocols regarding the maximal shortening velocity. This parameter decreased more during the intermittent isotonic contractions (i.e., 33 % of pre-fatigue) than during isometric contractions (i.e., 19 % of pre-fatigue). Observing the figures of this investigation, a linear appearance of the F-V relationship was observed, so it is possible that a linear approach could fit that experimental results. After 45 min of recovery, all the F-V parameters were nearly recuperated except the maximal shortening velocity that remained depressed after the isometric contractions.

Recent researches that explore multi-joint exercises, use the linear model to fit their F-V results. This is the case of the study presented by García-Ramos et al. (75), where different fatigue protocols of upper body muscles were performed. F-V data were strongly fitted by linear approaches (i.e., $R^2 = 0.997$). In this work, five different fatiguing protocols were carried out. The first one was considered the "*non-fatigued*" and the following were progressively more fatiguing. They observed that in high fatigue protocols (i.e., light loads at high velocities to failure) the decrease in maximum power after training was caused by a reduction in V_0. However, when the fatigue is at the lowest level (i.e., heavy loads at lower speeds and not to failure) the P_{max} decrement was produced by a minimization of F_0. However, authors did not find significant differences in the F-V slope between the five protocols (75).

In short, the F-V profile changes immediately after exercise, that especially affects the intermediate velocity and force region resulting in a large decrement in power. The intensity of the protocol may determine if the power reduction is more affected by velocity or force decrements. Finally, this profile returns to the individual baseline levels after 45 minutes of isotonic fatigue contractions. However, this relationship needs more time to restore after performing isometric exercises.

2.1.3.2 Maturation and aging process

Maturation is considered the natural development of growth and aging (76). Since childhood to old age, humans experiment many mechanical and biological alterations. In sport, it is interesting to assess those changes in order to adjust and apply the different training strategies.

During six years, a longitudinal study was conducted by Schleichardt et al. (76) in order to observe and compare the F-V profiles of elite throwers over the maturing process. Individual profiles of both women and men (ranged from 12 to 35 years of age) were obtained from leg press exercise. Three age categories were distinguished: under 18 years old, over 17 and less than 20 years and finally over 20 years. They observed differences between genre and the track-event performed. Female and male showed a different F-V profile development during their maturation process (Figure 5).

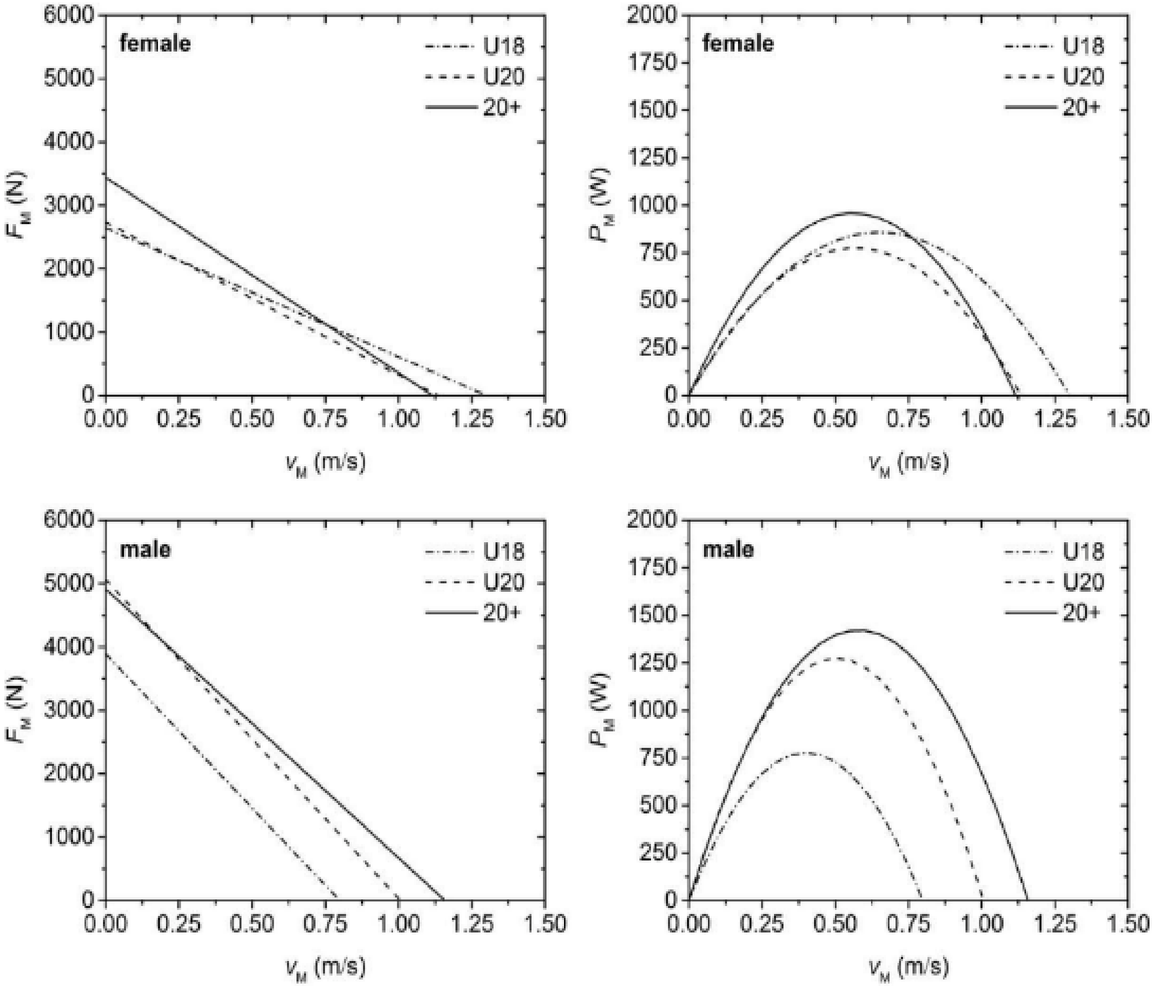


Figure 5. Calculated F-V and P-V profiles of mean representatives for the female and male groups during maturation. From Schleichardt et al. (76).

Women experimented an improvement in F_0 and P_{max} (i.e., 30 % and 12 % respectively) throughout all the maturation process. These enhancements were more remarkable over 20 years old. Nevertheless, the maximum velocity of contraction was slightly reduced (i.e., – 15 %) which means less ability to generate forces at high velocities. Male athletes experimented big improvements in F_0 and P_{max} (i.e., 26 % and 83 %) but the gains were more pronounced until 20 years of age than after. Also, the maximum velocity of contraction was incremented throughout the maturing period (i.e., 45 %), therefore, their development was more speed-oriented than female athletes.

Going further, it is well-known that aging is associated with a deterioration of muscle mechanical properties. In this sense, the relationship between the force and the velocity produced by muscles is altered. Using the linear approach, it is possible to assess the F-V profile recording a few experimental points as it is recommended for this population. A systematic procedure reported by Alcazar et al. (77) was accepted as a valid, reliable and safe method to assess F-V relationship in these older adults. They used between 5 and 7 experimental point to obtain the F-V profile in the leg press exercise. The review study of Raj et al. (78) revealed lower production of force through a given range of velocities and a reduction in maximum velocity (i.e., about 20 -40% in both parameters) in older adults compared to young (Figure 6). The decrement in maximum power ranged between a 30% and an 80%.

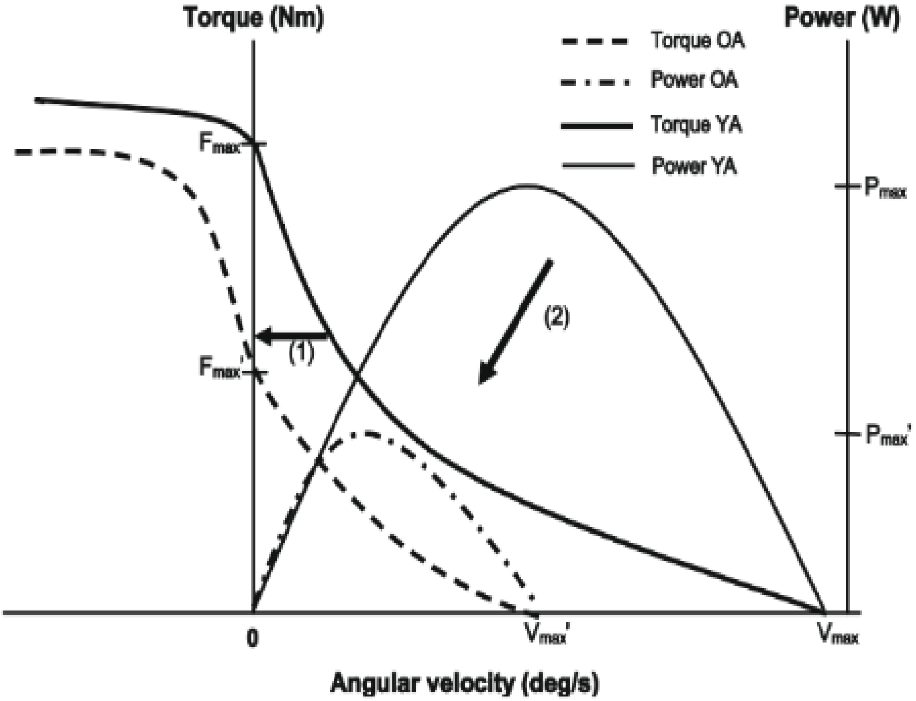


Figure 6. Differences in Force Velocity relationship between older (OA) and young adults (YA). From Raj et al. (78).

Unilateral leg press exercise was evaluated in the study of Allison et al. (79). Both F-V and P-V relationship were lower in older men compared with young, mainly because of the low values achieved in isometric strength (i.e., 19% lower) that contribute more to the differences in maximum power (i.e., 28% lower in older adults). Also Yamauchi et al. (46) explored the possible alterations in elderly women performing unilateral and bilateral knee-hip extension. Results showed significantly lower values of maximum force and power in older women compared to young regarding both exercises, but no differences in maximum velocity were detected. A decrease of 75% in force and power was observed in elderly women compared to young. Authors pointed out that maximum velocity in aging also depends on the type of muscle fibres and genders.

Additionally, in the study of Alcazar et al. (80) the influence of different F-V profiles on physical function, cognitive function, frailty and health-related quality of life was evaluated.

Older people with force or velocity deficit exhibit lower levels of physical function and quality of life. Moreover, the group with force deficit also demonstrated an impairment of cognitive function.

Those alterations could be incremented if a certain disease is presented. For example, lower concentric maximal power values in lower limbs were observed in older adults with chronic obstructive pulmonary disease COPD compared to healthy older adults (81). Focus on the regions of the F-V spectrum, the differences were distributed toward the beginning of the movement (i.e., at greater speeds).

The main cause of the reduction in isometric and concentric strength in older adults is the loss of muscle mass. Other factors as the decline in specific tension of the muscle fibres or the reduction in fibre pennation angle, contribute to this force reduction (82). On the other hand the decrement in maximum velocity of contraction is given by many factors as the muscle fascicle length, the physical activity level and the decline in the intrinsic speed of the myosin molecule (78).

In summary, men and women experience a different F-V profile development during maturation, being it more speed-oriented in men. At a larger stage, during aging, the loss of muscle mass and other specific factors contribute to a downward and leftward shift of the F-V profile, caused by a lower velocity and force production that entails a large decrement in power (i.e., until 80 %). To counterbalance this natural process, different training protocols including resistance exercises are in development.

2.1.3.3 Chronic adaptations: Training strategies and detraining

In order to improve performance in sport, coaches elaborate different programs and training methods with specific goals. Knowing the mechanical profiles of athletes, it is possible to describe their changes when a given training method is conducted. There are different experiments that attempted to see that modifications.

In 1985 Häkkinen & Komi (83) tried to determine the changes in electrical and mechanical behaviour of leg extensors muscles performing heavy resistance strength training. The study lasted 36 weeks where the strength training consisted mainly in full squat exercise with loads from 70 % to 100 % of 1RM. They fitted the data by Hill's equation. Results showed a great shifting of the high-force portion on the F-V curve after training. The improvements were smaller in the higher-velocity portion of the curve. They concluded that combine high intensity concentric and eccentric movement contractions is useful to develop maximal force (83). Another study carried out by Häkkinen & Komi (84) analysed the effect of explosive type strength training (i.e., jumping exercises without weight or with light weights) on electromyographic and force production after 25 weeks of intervention. An increase in explosive force production was in line with significant improvements in the neural activation of the leg extensors muscles. Great improvements in the high velocity portion of the F-V relationship were observed for both squat jump and countermovement jump (CMJ). Therefore, they recommended light weight training in order to enhance the velocity zone of the F-V curve.

The study of Kaneko et al. (85) explored the effect of different intensities on the F-V relationship performing elbow flexions. The training load was different for each of 4 groups (i.e., without load, 30% of F_0, 60% of F_0 and isometric training with 100 % of F_0). After 12 weeks of intervention, authors revealed that training by maximum contractions without weight was most effective to enhance the maximum velocity. On the other hand, the isometric exercise improved the isometric force. The group that trained at 30% of F_0 produced a similar enhancement across the entire F-V spectrum. Similarly, the group that performed at 60% of F_0 produced a rightward shift of the F-V curve but greater improvements were observed in the force region than in the velocity zone. They concluded that training with different training loads caused specific modifications of the F-V relationship.

In the study of Djuric et al. (86) an 8 weeks intervention program was carried out including bench press throws under three different training conditions. Participants performed bench throws against a bar loaded by an external force (i.e., protocol “weight”), weight plates (i.e., protocol “weight plus inertia”) or using attached rubber bands (i.e., protocol “inertia”). They pointed out that the “inertia” training load is more effective than “weight” in order to increase power output. However, all groups improved their power values. Greater V_0 values were reported after the inertia condition compared with the others. This suggests that the use of rubber bands which contribute to the concentric contraction, is beneficial for the enhancement of the velocity portion in the F-V profile.

Nowadays is common the interest of improving key activities that are presented in many sports, like sprinting and jumping. In this sense, different methodologies are in continuous development to enhance them. For example, resisted training is a useful method to improve sprint performance (87). Recently studies tried to describe the F-V relationship under resisted conditions using a weighted sled or motorize devices (88–90). Beyond description, other authors explored the alterations in F-V profile after performing a resisted sprint program. The application of different combination of loads expected to produce different modifications in F-V relationship. Cross et al. (91) analysed the outcomes performing sprints with a load that decrease a 10 % the maximal velocity and an “optimal” load (i.e., heavier) to finally concluded that the responses in F-V profile after training were similar. However, performing very heavy sled training (i.e. 80 % of body mass) resulted in specific improvements in F_0 with no effect on V_0. This strategy suggested to be efficient for athletes with force deficit regarding their individual

F-V sprint profile (87). Another study used a heavier sled resistance training where two soccer players groups performed resisted sprints during 11 weeks with loads corresponding to 120 % and 90 % of their body mass (92). Results showed that both groups improved sprint performance after training and in agreement with previous studies, the use of very heavy loads improves the early acceleration in sprint performance (87). One recent study wanted to explore the common changes in the F-V sprint acceleration profile of elite soccer players during 1 year (93). No specific intervention was carried out, athletes followed they usual soccer training regimen. Results showed that F_0 and P_{max} reached their maximum values during the middle of the competitive period, being lower at the beginning and at the end of the competitive period. The increase of these variables until the middle of the season suggests that the specific soccer training and the competitions contributed to enhance the short acceleration performance. However, the important decrement of force at the end of the season could have other risks as a hamstring injury (which is common in this sport). No differences in V_0 were detected. This suggests that no specific sprint training was carried out. Authors recommended the inclusion of this training as players require to run at high velocities during the match.

Being in consideration the optimal profile described in jumping (9,94), other studies tried to modify F-V relationship in lower limbs to optimized the individual characteristics. Jimenez-Reyes et al. (95) reported the effectiveness of an individualized training based on the weaknesses areas of the F-V profile. In this regard, training was conducted to enhance force, velocity or both using different exercises. Finally results showed that all participants increased significantly their jumping performance. Another study used the optimal jump profile in order to enhance the F-V imbalance in female ballet dancers (96). After 9 weeks of a training plan based on their F-V profile, the experimental groups presented higher CMJ height, F_0 and V_0 values compared with control. Authors concluded that knowing the F-V imbalance is easier to improve the CMJ jump height.

On the other hand, during an entire season training program there are some periods of rest or injury phases. In this regard it is interesting to know how these periods could affect the individual F-V relationship. These changes were analysed by the study of Andersen et al. (97). The response to a resistance training and subsequent detraining were explored in lower limb muscles. The intervention program was conducted during three months (i.e., 38 sessions) followed by three months of detraining period. Subjects were untrained men. Resistance leg exercises were performed in a traditional manner and load were progressively increased throughout months. The torque increased at slow to medium velocities after training and decreased to baseline levels after detraining. Nevertheless, both force and velocity during unloaded limb movement increased after detraining. They concluded that untrained men had changed their intrinsic contractile properties (i.e., faster contraction) and that they had increased the expression of fast muscle myosin heavy chain isoforms.

The above-mentioned studies showed that F-V profile could be manipulated in order to improve the individual mechanical deficits. In summary, literature showed that the high velocity and high force portions of the F-V relationship are mainly changed by using explosive type strength training with medium-light loads and heavy loads, respectively. However, these studies contrasted different loads, but their outcomes cannot be exclusively attributed to differences in training velocities. Knowing that velocity is a key factor to maximize strength adaptations (98,99), modulating velocity voluntarily is a potential limitation. An alternative approach to contrast the effect of velocity on the F-V relationship is by modulating the set configuration since it allows to design interventions differing in velocity whereas load, volume and intensity remain equated between conditions (100).

2.2 Set configuration

Coaches control and adjust the different variables and factors in order to achieve the training program goals. Frequency, recovery, number of repetitions, load or velocity of execution are common parameters that determine the volume and the intensity of a resistance training session. Other parameter is capable enough to affect the overall training purpose: set configuration. Nowadays, this variable is popular in many studies, becoming a point of interest in resistance training. In this regard, set configuration is defined as the number of repetitions performed in each set with respect to the maximum possible number of repetitions (101).

The manipulation of set configuration provides new and different stimuli that enhance physiological adaptations that will derive in a performance improvement, particularly in well training or elite athletes (17,102). Traditionally, during a resistance training program, set configuration is performed in a continued fashion with a given time of rest between each set. Fatigue appears in a fast manner as successive repetitions are performed. This is caused by the decrease in PCr and ATP stores, as well as the accumulation of metabolic bioproducts (i.e., lactate). This method is known as traditional set configuration and is the most usual protocol used in strength training as resulted in muscle hypertrophy enhancement (103,104).

Different attempts to bypass fatigue and produce better and faster results originate the development of diverse original methods. In this regard, the possibility to break the common sets of repetitions in small clusters or groups may be a good option to reduce the cumulate fatigue by the addition of rest intervals between them. This kind of set configuration is called cluster training.

2.2.1 Cluster training

Becoming a novel strategy in strength training, cluster protocol is simply a set structure in which rest periods are more frequent than traditional ones (103). Cluster training encloses different methodologies of application depending on the target population, sport disciplines or goals. That strategies (i.e. basic cluster, inter-set rest redistribution, equal work-to-rest ratio or rest pause method) are collected in the review study of Tufano et al. (103). In this context, is necessary to be most accurately with the description of the cluster configuration performed.

But, what can this method provide in contrast to traditional protocols? The following paragraphs contain the acute and chronic effects of both resistance training configurations.

2.2.1.1 Acute responses

2.2.1.1.1 Mechanical performance

Force, velocity and power values achieved during training are a feature point that lead the final performance improvement. Different studies tried to examine how these parameters could be maintained or even incremented during the entire training session. In this regard, the novel cluster training was tested in many studies. Specifically, velocity and power are the most common variables that were analysed in literature (105).

The study of Sánchez-Medina & González-Badillo (106) was the first that aimed to analyse the acute response after different set configurations. The mean propulsive velocity was measured during sets and the ratio between the fastest and the lowest repetition value was used to examine the velocity loss. Results revealed greater losses of velocity when the number of repetitions performed in a set were closer to the maximum possible number of repetitions. They pointed the velocity loss as an indicator of neuromuscular fatigue in resistance training and confirmed that can be altered by the manipulation of the set configuration. In line with this observation, Tufano et al. (22) compared the effect of traditional and two different basic cluster set structures during back squats [i.e., 3 sets of 12 repetitions, 3 sets of 3 groups of 4 repetitions and 3 sets of 6 groups of 2 repetitions, respectively]. Recovery between sets were 120 seconds. The inclusion of 30 seconds of intra-set rest intervals in cluster protocols allow the maintenance of velocity and power over the sets and reduced fatigue. Authors suggested that intraset rest intervals of 30 seconds placed after every 2 repetitions is an effective technique for maintaining velocity and power. In the same line, the study of Torrejón et al. (107) revealed that during exercise the inter-repetition rest protocol or the basic cluster regime (i.e., pauses two repetitions) allow for a better maintenance of velocity in the last repetition of each set in comparison with a traditional one. They also pointed out that there was a comparable velocity loss for men and women (i.e., -12.1 % and -11.3 % respectively).

One study, focused on bench press, grouped the repetitions in singles (6 sets of 1 repetition), doubles (3 sets of 2 repetitions) and triples (2 sets of 3 repetitions) with 20, 50 and 100 seconds of recovery, respectively (20). Contrary to what they were hypothesized, no significantly differences were found between cluster protocols regarding power output. However, power production was greater (i.e., 21-25%) compared with continuous protocols. Despite no significantly differences were found between cluster groups regarding power, a greater increase in this variable was noted in the triples group (20). In this sense, it has been suggested that breaking sets into groups of 3 repetitions will enhance power output. On the other hand, García-Ramos et al. (108) recommended the bench press throws exercise in order to maximize the power improvements after cluster training.

A recent study compared twelve resistance training protocols (i.e., 8 of them corresponded to inter-repetition rest intervals protocols and 4 were continuous methods) using different load intensities (i.e., 60 %, 70 %,75 %, 80% 1RM) in full squat exercise (109). The set configuration and the load were combined to design all the protocols. Inter-repetitions rest intervals methods used a recovery time of 10 or 20 seconds. Velocity loss during exercise was assessed by the ratio between the fastest and the lowest mean propulsive velocity value of each set. As expected, the continuous regimes presented greater velocity loss compared to the inter-repetition configurations in a large range of loading intensities (since 60 % to 80 % of 1RM). Although no significant differences were observed between the cluster protocols, authors recommended 10 seconds of inter-repetition rest because it requires low work-to-rest ratio.

The study of Davies et al. (110) that lasted 8 weeks, examined the acute velocity maintenance across a full training session and across each set at the midpoint of the training program. They contrasted the average of every repetition with the first repetition recorded. Cluster structures presented greater maintenance of mean velocity during 3 of the 4 sets performed. However, no differences in peak velocity were observed. Across the entire training session, the cluster training group also presented better maintenance of the mean velocity values in comparison with the traditional regimen.

Another examples of cluster structures are those which equal the work-to-rest ratio. Also in back squat, this strategy was performed in the study of Iglesias-Soler et al. (100) where the distribution of rest between every repetition resulted in higher mean propulsive velocity values (i.e., + 19%) compared with continuous protocols. In this line, the study of Mayo et al. (25) experimented with three set configurations with the same volume, rest time and intensity. The protocols were 5 sets of 8 repetitions with 3 minutes of rest, 10 sets of 4 repetitions with 80 seconds of recovery and 40 sets of 1 repetition with 18.5 seconds of rest between each repetition. In agreement with previous studies, analysis revealed significant lower mean velocity values for the longer set configuration (i.e., 5 sets x 8 repetitions) in comparison with the other two.

Some of the studies explained above are included in the recent review of Latella et al. (105). The authors have investigated the acute neuromuscular performance (i.e., strength, velocity and power) that were explained in the literature after using cluster sets in resistance training. They corroborated that velocity, power and peak force are beneficiated when a cluster structure is performed (i.e., significant benefit for both inter-repetition rest and intra-set rest). Contrary, mean force results revealed that there are not differences between using cluster or traditional strategies. Finally, the use of moderate to heavy loads were recommended to warrant these benefits.

Apart from typical resistance exercises, plyometric training is a useful method to enhance power development. Some studies sought to compare the impact of cluster training in different plyometric exercises. For example, Moreno et al. (111) compared a traditional protocol with two cluster structures (i.e., rest redistribution method) and observed greater maintenance of power performing unloaded plyometric squat jump during cluster structures. They observed a noticeable decrease in power after the third repetition of the set in the traditional protocol. Authors concluded that it is recommended to execute more than 2 and less than 5 squat jumps in each set (with 27-45 seconds of rest) to allow power maintenance, improve take of velocity and jump height. These results are in agreement with other studies that performed CMJ vertical jump and standing long jump (19). Other study that combined plyometric training with loads sought to analyse the mechanical performance of leg muscles during loaded countermovement jumps, following cluster or traditional structures (112). Authors observed greater decrements in power output after the fourth repetition during traditional sets without meaningful changes during cluster. They finally suggested that the inclusion of 30 seconds of recovery between clusters of 2 repetitions will minimize the muscle fatigue development. Hence, velocity (and resulting power) maintenance is one of the benefits that cluster training could provide.

In addition to force, velocity and power individual capacities, technique is one of the most important aspects that led sport success. Training programs try to optimize the required sport movements to perform them correctly in competition. Some studies examined the effect of different set configurations in sport disciplines. For example, in order to improve performance in weightlifting, Haff et al. (113) sought to compare the differences between performing cluster and traditional sets in clean pull. Barbell velocity and displacement were recorded during the tests to conclude that there was a decrease of these parameters during traditional set. They reported that thirty seconds of rest between repetitions allowed the velocity maintenance and the displacement through the entire set. Related to the power clean exercise, other study found that cluster configurations allow the maintenance of technique despite the level of fatigue (114). A decrease of 7.3 % in peak vertical displacement were observed when the repetitions were performed with a traditional configuration while no significant differences were observed during two cluster configurations (114). Additionally, they observed greater losses in peak power output during traditional (15.7 %) in comparison with the addition of 20 seconds of pause (5.5 %) and 40 seconds (3.3 %) between repetitions. Another exercise that is used in weightlifting training is deadlift. Moir et al. (115) tried to compared the mechanical differences between traditional and two basic cluster configurations (i.e., 4 continuous repetitions; 2 sets x 2 repetitions and 4 sets x 1 repetition, respectively). Results showed that cluster sets increased the impulse as a consequence of greater time taken to perform the concentric phase of the movement (i.e., more time under tension). As the ability to generate high barbell velocities in weightlifting is related to success in competition, cluster training could be a good method to enhance the fast stimuli.

In short, cluster sets contribute to the maintenance of velocity and power during resistance (25,100,109,116) and plyometric exercises (111,112). In this sense, greater velocity loss percentages are related to longer set configurations both in upper (107,108) and lower limbs (100). Moreover, exercise technique, that is normally conditioned by fatigue, was demonstrated to be controlled (i.e., maintained) using cluster structures (114). Finally, the use of moderate to heavy loads were recommended to warrant these benefits (105).

2.2.1.1.2 Acute Fatigue

In the recent study of Torrejón et al. (107) three different set configurations were performed in order to observe the acute changes in the F-V spectrum of men and women. F-V profile was recorded pre and 10 minutes post exercise. Traditional training group performed 6 sets of 4 repetitions with 3 min of rest between sets. The classic cluster training group carried out 6 sets of 4 repetitions with 15 seconds of intraset rest every two repetitions. The load used corresponded to the 6RM. Finally, the other cluster structure was an inter-repetition rest protocol were participants completed 1 set of 24 repetitions with 39 seconds of rest between repetitions. All the regimes produced significant decreases in F_0 and P_{max} after the training session but no differences in V_0 were observed. Additionally, the changes in F-V parameters after training were similar for men and women. Authors concluded that the decrement in the maximal mechanical capacities was low and comparable between protocols. In this case, the traditional structure consisted in only 4 repetitions with a high recovery time that allows an energy restoration. In this sense is comprehensible that all structures produced similar low acute changes in the F-V profile.

In the study of Mora-Custodio et al. (109) muscle fatigue was assessed regarding the loss of CMJ height post exercise. Intervention consisted in twelve resistance training protocols (i.e., 8 of them corresponded to inter-repetition rest intervals protocols and 4 were continuous methods) using different load intensities (i.e., 60 %, 70 %,75 %, 80% 1RM) in full squat exercise (109). The set configuration and the load were combined to design all the protocols. Inter-repetitions rest intervals methods used a recovery time of 10 or 20 seconds. The continuous protocols presented greater loss of CMJ height compared to inter-repetition protocols when the intensity corresponded to the 60% of 1RM. No significant differences were observed between the inter-repetition protocols. Results suggest that the addition of at least 10 seconds results in lower loss in CMJ height after exercise and therefore lower fatigue is generated. Similar results were obtained in the study of Girman et al. (19) where cluster sets protocols resulted in better sustainability of the jump performance.

In the study of Río-Rodríguez et al. (117) all participants carried out two training sessions of isometric knee extension differing in set configuration. Traditional protocol consisted in 4 sets of 50 % of maximum voluntary contractions (the duration of the set was and average of 4 seconds) with 180 seconds of rest. Intra-set rest configuration consisted of 16 sets (the duration of the set was about 1 second) with 36 seconds of recovery. Before and after exercise, maximum voluntary contraction of knee extension was recorded. Intra-set rest configuration produced a loss of 18 % in maximum voluntary contraction after exercise while traditional sets resulted in a 32 %. Authors concluded that cluster structures induce lower central and peripheral fatigue and that set configuration is a key factor for its regulation.

In general, cluster protocols lead less fatigue after exercise in comparison with traditional structures. In this regard, better isometric and dynamic performance was observed after cluster in comparison with traditional regimes (19,100,109,117). Therefore, introducing cluster sets is a good method that contributes to the quality of the entire session (i.e., maintenance of performance).

2.2.1.1.3 Metabolic and hormonal responses

The acute metabolic and hormonal responses to resistance training are markers that may determine the following adaptations. During continuous maximal voluntary contractions, the stores of PCr and ATP suffer a decrement (118). Additionally, the increase of metabolic products, as blood lactate, stop the regeneration of those stores. The lactate accumulation in working muscle causes inhibition of contractile processes that results in a performance loss. In this sense, an inverse relationship between lactate concentration and PCr was reported (119).

On the other hand, the hormonal acute responses after resistance training are related to an increase of total testosterone concentrations, growth hormone and cortisol (104,120). The magnitude of the elevation depends, for example, on the exercise performed, the intensity, the volume or the training experience (104).

Cluster training is suggested that allow the partially replenishment of ATP and PCr storages due to the additional rest periods (17). Therefore, the accumulation of blood lactate is reduced, being better for power and velocity maintenance (17). This was confirmed in the study of Sánchez-Medina et al. (106) where they observed that peak post-exercise lactate concentration increased linearly as the number of repetitions in a set approached the maximum predicted. The lactate concentration showed a high correlation ($r = 0.93-0.97$) with the losses in mean propulsive velocity. Previous studies pointed out that these metabolic impact are responsible in part of the hormonal responses (121).

The following paragraphs contain the different metabolic and hormonal acute responses that some studies reported after comparing traditional and cluster protocols.

The study of Girman et al. (19) contrasted the effects of traditional and cluster structures in heavy resistance training. Both protocols completed 4 sets of 6 repetitions. Cluster group separated those repetitions in doubles with 15 seconds of recovery between them. No differences between groups were detected in both growth hormone and cortisol values. Blood lactate values were significantly lower after cluster sets in comparison with traditional sets regarding the middle of the session (i.e., 7.69 mmol. L^{-1} and 12.78 mmol. L^{-1} respectively).

In Oliver et al. (122) subjects performed traditional (i.e., 4 sets x 10 repetitions) or cluster intra-set rest redistribution (i.e., 4 groups x 2 sets x 5 repetitions). No differences between protocols were reported for the values of lactate after the first set. However, blood lactate concentrations were higher for traditional in comparison with cluster immediately, 15 and 30 min after exercise. In agreement with previous studies, no differences between groups were observed for growth hormone and testosterone values (19,123). Finally, cortisol values were significantly lower 30 min after exercise in cluster group compared to traditional.

Goto et al. (124) included in their investigation the impact of metabolic stress on hormonal responses and muscular adaptations. Authors compared the long-term effects of a regimen consisted in 3-5 sets of 10 repetitions with 1 minute of rest and a protocol including 30 seconds of recovery at the midpoint of each set (both with the 10RM load). After 12 weeks of training results revealed that the continuous protocol presented higher lactate, growth hormone, epinephrine and norepinephrine responses compared with the other regime. In agreement with previous studies, no differences in testosterone hormone were observed.

Iglesias-Soler et al. (100) sought to compare a resistance exercise protocol leading to muscular failure with other configuration that distributed the rest time between each repetition. The exercise performed was parallel back squat. They observed higher blood lactate concentrations (i.e., immediately and 6 minutes after training) for the protocol leading to failure compared with the other configuration. Other study focused on upper body muscles, conducted by García-Ramos et al. (18), detected significant higher values of lactate after traditional sets compared with three different cluster structures.

Finally, Tufano et al. (123) aimed to compare different cluster sets regarding the metabolic and endocrine responses in back squat. They performed classic cluster (i.e., 3 x 3 sets x 4 repetitions) and two intra-set rest redistribution (i.e., 9 sets x 4 repetitions and 36 sets x 1 repetition). All protocols produced an elevation in total testosterone, growth hormone, sex hormone-binding globulin. No significant differences were observed between protocols. The samples of blood lactate were recorded during (i.e., repetition 12, 24, 36) and after exercise (i.e., 5, 15 and 30 min). As well, no differences were observed between configurations at any moment of measurement.

In this sense, cluster structures imply a lower demand of the glycolytic metabolism in comparison with traditional sets, with a reduction in the levels of blood lactate production as well with similar hormonal responses during and after training. These acute responses may be responsible for chronic adaptations.

2.2.1.1.4 Protein synthesis

The mechanisms under the stimulation of protein synthesis after training have been attribute to the activation of some signalling molecules in the mTOR (mammalian target of rapamycin) pathway. In line with this affirmation, the recent study of Salvador et al. (125) aimed to explore if there is any mechanistic difference between perform cluster or traditional protocols regarding muscle anabolism. Participants performed cluster (4 sets of 2 groups of 5 repetitions with 30 and 90 seconds of rest) or traditional protocols (4 sets of 10 repetitions with 120 seconds of recovery). Back squat was the exercise performed at 70 % of 1RM. Blood and muscle biopsy samples were measured at rest and after exercise (immediately, 2 and 5 hours after). Results showed that traditional sets tended to increase the myofibrillar protein synthesis response in the early phase of recovery compared to cluster condition. However, no differences between protocols were observed 5 hours post exercise. They concluded that cluster configurations are as valid as traditional training regarding the protein stimulation.

2.2.1.1.5 Rating of Perceived Exertion

Rating of perceived exertion (RPE) scales are useful to prescribe resistance training because they give a subjective measure of the intensity of the effort and fatigue (126,127). As set configuration is associated with the intensity and metabolic effects produced in resistance training, it may influence as well the RPE response. Hardee et al. (128) compared the effect of two inter-repetition rest protocols with respect to a continuous structure (i.e., 3 sets x 6 repetitions). Inter-repetition rest programs added 20 and 40 seconds of recovery between every repetition. Lower RPE was observed for the protocol with 40 seconds of recovery. Also, higher average peak power was obtained for inter-repetition rest protocols in comparison with the continuous.

Session ratings of perceived exertion responses were measure in the study of Kraft et al. (129). Recreationally strength trained men completed 3 rounds of 6 upper body exercises with a load that represented the 60 % 1RM. The aim was to explore the influence of work rate and recording time on RPE. Participants performed the training session following three different protocols: 3 sets x 8 repetitions with 1.5 minutes of rest; 3 sets of 8 repetitions with 3 minutes of recovery and 2 sets of 12 repetitions with 3 minutes of rest. Both RPE for 3 x 8 x 1.5 min (5.3 ± 1.8) and 2 x 12 x 3 min (6.2 ± 1.7) protocols was higher than the 3 x 8 x 3 minutes regimen (4.2 ± 1.8). Results revealed that rest intervals might be modulators of the perceived exertion, being higher with shorter rests. Finally, they concluded that lower work ratio produced lower values of perceived exertion.

Mayo et al. (130) compared the RPE in squat and bench press performing different set configurations equating the work to rest ratio. In agreement with previous studies, higher values of RPE were observed for the traditional set configuration in comparison with cluster sets. Additionally, Mayo et al. (131) reported that the perceived response was affected by submaximal set configurations, achieving lower ratings of perceived exertion the shorter sets in comparison with longer ones.

A recent study of Vasconcelos et al. (132) sought to evaluate the RPE in trained man comparing a cluster set configuration and a traditional one. The RPE were evaluated and compared before and between the sets and after 15 and 30 min of training. No significant differences were observed between configurations regarding RPE. Authors suggested that man with experience in strength training did not exhibit differences performing different configurations. Additionally, no differences in RPE values were observed in the study of Tufano et al. (123) comparing different subclasses of cluster structures (i.e., basic cluster sets and rest-redistributions sets) in trained men.

In summary, RPE can be modulated by different resistance training parameters as intensity, volume, rest periods and set configuration. Longer rest periods (129), shorter sets (131) and lower work to rest ratio (129) lead to lower values of RPE. Additionally, RPE was found to be similar comparing different subclasses of cluster protocols (123). Finally, experience athletes reported similar RPE values regardless of the set configuration performed (132).

2.2.1.1.6 Cardiovascular responses

The most common cardiovascular variables reported in literature are heart rate and blood pressure. It is also necessary to consider the variability of these parameters and understand the processes involved. The heart rhythm is modulated by the cardiovascular centre in the medulla oblongata. This centre regulates heart rate by the activity or the inhibition of the parasympathetic and sympathetic nervous system. The activation of the parasympathetic or vagal activity produces a decrease in heart rate, while the sympathetic stimulation causes an increase. Heart rate variability (i.e., the oscillation in the interval between consecutive heart beats) reflects the autonomic nervous system activity over cardiac function. It has been used as a non-invasive method that allows the measurement of the changes in the cardiac autonomic activity (133). A heart rate variability reduction, increases the probability of a cardiovascular disease (134). On the other side, blood pressure variability determines the fluctuations of the blood pressure, and it is an indicator of the sympathetic vasomotor tone and baroreceptors activity. Greater blood pressure variability is associated with cardiac, vascular and renal damage, as well with a higher risk of having a cardiovascular event (135). The measurement of these parameters provides useful information before, during and after exercise and helps the early prediction of cardiovascular diseases.

The baroreflex mechanism contribute in the modulation of the possible changes in blood pressure in order to maintain the homeostasis. In this process, alert signals (higher blood pressure values) cause an activation of the reflex baroreceptors that produce cardiac adjustments in order to decrease heart rate. In this sense, heart rate diminution contributes to a cardiac output reduction towards normal blood pressure values. In other words, the baroreceptors cause a reflex inhibition of the cardiac and vasomotor sympathetic efferent activity, that finally restore the basal blood pressure. Moreover, this mechanism could produce the reverse effect increasing blood pressure in response to a physiological variation by the deactivation of the baroreceptors. The sensitivity of the baroreflex determines the capability of activation of this mechanism (136).

In short, it is well known that the increases in blood pressure is the result of an increase in heart rate as well as a reflex vasoconstriction in the vessels of non-exercising muscles (137). The modulation of these parameters is affected by the different resistance training variables. In this regard, the following studies showed the acute cardiovascular impact when diverse set configurations are performed.

Mayo et al. (25) reported that in the case that volume and work-to-rest ratio are equated in training, set configuration will affect the cardiovascular response. In this sense, longer set configurations produced greater reduction of the vagal cardiac autonomic control and baroreflex sensitivity compared with shorter sets. They suggested that those differences were caused by the different glycolytic involvement between sessions, knowing that vagal activity is inversely related with lactate production. Baum et al. (138) reported that short muscle relaxations (i.e., 3 seconds) are needed for blood pressure and metabolic recovery during dynamic contractions. Additionally, they reported that the slopes of the increases in blood pressure induced by the different regimens performed (i.e., continuous vs. intermittent mode) were similar in elderly and young men.

In the study of Río-Rodríguez et al. (117) all participants carried out two separated training sessions of isometric knee extension with different set configurations. Traditional structures consisted in 4 sets of 50 % of maximum voluntary contractions (the duration of the set was and average of 4 seconds) with 180 seconds of rest, while intra-set rest configuration consisted of 16 sets (the duration of the set was about 1 second) with 36 seconds of recovery. Heart rate analysis showed that traditional structures lead to higher heart rate mean values during and after exercise compared to cluster sets. Maximum values of mean arterial pressure, mean systolic blood pressure and mean diastolic blood pressure were higher for the traditional protocol compared to cluster during exercise.

Previous studies pointed out that the pressure response in resistance training is more affected by the time under tension during a set (i.e., the length of the set) than the intensity of the load (139). In the last example, the duration of the traditional protocol was four times greater than the duration of the cluster program. This may explain the greater hemodynamic response in traditional set configuration.

In order to compare the acute pressure response between cluster and traditional protocols, Mayo et al. (26) selected a study design where healthy participants performed two different experimental sessions. In the first one, they carried out 40 repetitions with 18.5 seconds of rest between reps with a load that represented the 10RM. The other session consisted in 5 sets of 8 repetitions with 180 seconds between sets with the same load (i.e., 10RM). Contrary to their hypothesis, the inter-repetitions rest design produced higher systolic blood pressure peaks in comparison with the traditional protocol. As was explained by MacDougall et al. (137), the performance of a Valsalva maneuver (i.e., voluntary pressurization of the intra-abdominal cavity) exaggerates the increase in blood pressure during heavy resistance exercise. Knowing that the individual repetition produces an excessive intrathoracic pressure in comparison with consecutive repetitions, Mayo et al. (26) pointed out that this could be the explanation why the systolic blood pressure was greater in cluster compared to traditional sets. Other studies supported these findings (140). In the study of Massaferri et al. (140) the addition of 5 or 10 seconds in the middle of sets induced higher blood pressure responses than continuous structures but lower heart rate during discontinuous. A similar study proposed by Polito et al. (141) also observed a maximization of the hemodynamic responses with discontinuous protocols.

The study of Iglesias-Soler et al. (142) contains a complete analysis of the effect of set configuration on hemodynamic and cardiac autonomic modulation. Participants performed two high-intensity training differing in set configuration. Traditional training consisted in 3 sets of parallel squats until failure with 3 minutes of recovery with the 4RM load. During cluster training subjects lifted the same load, with recovery periods between each repetition in a manner that volume, intensity and work-to rest ratio were equated. The objective of this study was to examine the cardiovascular responses regarding systolic blood pressure, heart rate, rate pressure product (i.e., the product of heart rate and systolic blood pressure), heart rate variability and heart rate complexity (i.e., quantify the complexity of the R-R interval time event series). Results indicated that systolic blood pressure and heart rate were higher during exercise in traditional sets compared to cluster sets. Additionally, both set configurations produced acute decreases in heart rate variability and complexity after training.

In summary, when isometric training is performed under different set configurations, traditional sets produced higher heart rate mean values during and after exercise in comparison with cluster sets (117). Also, mean blood pressure values were higher during traditional training compared to cluster. On the other hand, training to failure produce a higher cardiovascular stress compared to cluster training. Finally, cluster structures should contain more than 1 repetition in order to mitigate the high peaks of blood pressure produced at the beginning of the set (26,140,141). Knowing the acute cardiovascular response after the cluster and traditional sessions, it is interesting to know the middle-long term adaptations, since investigations about this topic are limited.

2.2.1.2 Chronic adaptations

The above-mentioned acute differences in mechanical performance, metabolic, hormonal and cardiovascular responses after traditional or cluster sessions may cause different adaptations when middle-long-term programs are conducted. However, while acute effect studies in this topic are typical, few studies have chronically implemented cluster protocols in training. In this sense, the following sections will summarize the adaptations regarding mechanical performance, muscle hypertrophy and neural mechanisms.

It was not possible to include a cardiovascular, metabolic or a hormonal section because of the few studies reporting specific adaptations after resistance training protocols differing in set configuration. However, the cardiovascular (12,143–147) metabolic (13,14,145) and hormonal (148) responses have been investigated after common resistance training programs. Overall, studies showed chronic reduction on resting blood pressure values for the hypertension population (144) and greater heart rate variability (143). On the other hand, it was demonstrated that this kind of training positively affect metabolic parameters in youth (i.e., mitigation of the metabolic dysfunction) (14). Regarding cardiovascular adaptations, HRV was analysed in the study of de Sousa et al. (147) where healthy participants followed 5 weeks of bench press and leg press training. Both cluster and traditional protocols produced similar increases in HRV, however the effect size was low. Focusing on hormonal adaptations, only the study of Arazi et al. (148) evaluated these adaptations after resistance training interventions differing in set configuration. After 8 weeks of training intervention both cluster and traditional groups presented higher testosterone and insulin-like growth factor levels compared with control group. Regarding cortisol responses, both traditional and cluster groups demonstrated significant decreases post-training while a small significant increase was observed in control group. The total increase in testosterone levels corresponded to a 14.6 % for traditional group and a 10.6 % for cluster group. In the case of insulin-like growth factor measurements, greater increases were observed after cluster (16.6 %) compared to traditional protocols (15.5 %).

In the following sections the mechanical, neural and muscle adaptations induced by different set configurations are going to be presented.

2.2.1.2.1 Mechanical performance adaptations

2.2.1.2.1.1 Maximal strength and power

One of the first studies that sought to compare the chronic effects produced by different set configurations was carried out for 6 weeks and involved the upper body muscles. Lawton et al. (149) compared traditional and rest-redistribution protocols and equalized the work-to-rest ratio between groups. Authors observed both increases in power and strength, but greater strength improvements after traditional training (9.7 % vs. 4.9 %) (149). Regarding lower body muscles, Hansen et al. (150) carried out an experiment with rugby players during preseason. They found that after 8 weeks of training intervention performing cluster and traditional structures, greater strength results were obtained after traditional. Nevertheless, the magnitude-based inferences showed a greater effect of cluster training for peak power and peak velocity in jumping squat compared to traditional.

Additionally, other study compared both configurations in upper and lower body muscles after 12 weeks of hypertrophy training intervention (151). Authors explored if hypertrophic training with intraset rest intervals produced greater grains in power compared to traditional hypertrophy training. The results showed greater power output in bench press and vertical jump after cluster training but in contrast with previous studies (149,150), higher maximum strength responses were found after cluster protocols.

On the other hand, the study of Folland et al. (152) compare two protocols differing in set configuration and in the level of fatigue. One group carried out 4 sets of 10 repetitions with 30 seconds of pause between sets and the other performed 40 single repetitions with 30 seconds of inter repetition rest. The load used corresponded to the 73 % of the 1RM for knee extension. After 9 weeks, both groups reached similar strength improvements. Authors concluded that fatigue and the metabolic involvement were not decisive for strength gain. Izquierdo et al. (153) also found similar strength improvements after two training interventions leading or not to failure. One group performed 3 sets of 10 repetitions (i.e., with the 10 RM load) and the other entailed 6 sets of 5 repetitions. Results revealed that training to failure did not result in greater gains in strength in resistance trained men.

In the same line, Iglesias-Soler et al. (23) observed after 5 weeks of unilateral knee extension, that both traditional and cluster configurations resulted in similar improvements of strength (isometric strength and dynamic 1RM) and power production. Participants performed an equalized work-to-rest ratio with the 10RM training load.

Two high-volume set configuration were performed by recreationally trained men in the study of Karsten et al. (154). Experimental groups carried out two different set configurations for 6 weeks equalizing the volume, intensity and frequency. One group performed 4 sets of 10 repetitions to failure per exercise with 2 minutes of recovery and the other performed 8 sets of 5 repetitions with 1 minute of rest. All of them trained with loads that represented the 75% of the 1RM of each exercise (upper and lower body routine). Finally, bench press and parallel squat were the exercises evaluated. Both groups improved the bench press and parallel squat 1RM after intervention. Specifically, traditional sets showed larger increases in bench press and cluster sets presented greater increases in squat. Additionally, the shorter configuration increased the upper-body power. Authors finally recommended the use of cluster sets, as it could provide novel stimulus that benefit the mechanical power output.

In the study of Arazi et al. (148) thirty female volleyball players were evaluated after 8 weeks of resistance training intervention comprised a nonlinear undulating, multi-exercise program performing different set configurations. Traditional training group performed the repetitions in a continuous manner (e.g., 1 set of 10 repetitions) but the number of repetitions varied through the training intervention. On the other hand, the cluster protocol entailed groups of repetitions with recovery between them (e.g., 2 sets of 5 repetitions with 30 seconds of rest). The set structures also were different throughout the training program. In order to evaluate the strength gains, 1RM of back squat, bench press, military press and deadlift were tested before and after training. Results revealed that both traditional and cluster groups obtained large significant improvements in all strength exercises (i.e., gains between 5.5 % and 8.7 %). No differences between groups were observed.

The study of Nicholson et al. (155) explored the effect of a 6 weeks back squat training intervention regarding strength, hypertrophy and two cluster type structures. Trained males were assigned to 4 different training groups. Strength training consisted in 4 sets of 6 repetitions (85 % 1RM) with 5 minutes of rest between sets and hypertrophy training entailed 5 sets of 10 repetitions (70 % 1RM) with 90 seconds of rest. On the other hand, cluster structures corresponded to 4 sets of 6 groups of 1 repetition with 25 seconds of inter-repetition rest and 5 minutes of recovery between sets. Cluster protocol only differed in the load used, one was performed with the 85 % of 1RM load and the other with the 90 %. Results revealed that all training groups obtained significant 1RM improvements after training ranging between 8 % and 13 %. Moreover, the strength protocol and the higher volume load cluster training demonstrated a larger effect size compared to the hypertrophy regimen. Authors indicated that the smaller improvements in strength of the hypertrophy group and the lower volume load cluster group, underlines that metabolic stress and repetition velocity are secondary in order to the development of maximal strength.

Finally, the recent study of Davies et al. (110) tried to examine the changes in bench press velocity and power after 8 weeks of high load training differing in set configuration. Traditional training consisted in 4 sets of five repetitions with five minutes of recovery and cluster regime added 30 seconds between each repetition and 3 minutes after each set. Participants used a load that corresponded to the 85 % of 1RM. The intervention period consisted in a full-body resistance program, identical for all subjects except for the bench press exercise that differed in the set structure. Both groups increased absolute and relative muscular strength in a similar percentage. Significant enhancements in peak and mean power were observed in the range of loads from 45 to 75% of 1RM but no differences between groups. Also, significant decreases were found at 55 and 65% of 1RM for peak and mean velocity. No differences between groups were observed for these variables. Authors concluded that both configurations lead to similar effects in movement velocity and muscular power after high load resistance training.

Differences in studies designs and protocols could explain the previous contradictory adaptations. Similar increases in power and strength are frequently related to the studies where training volume, training load and total rest time between protocols were equated (110). However, most studies showed better improvements in strength after traditional protocols (149,150,155) being cluster more beneficial for the power output development (150,151). Specifically, comparisons between chronic studies are reported in the systematic review of Tufano et al. (103).

2.2.1.2.1.2 F-V relationship

In this section the studies that sought to compare the effect of different set configurations on the F-V relationship are going to be presented.

The first study was carried out by Iglesias-Soler et al. (23) performing unilateral knee extension. For 5 weeks, a total of 10 sessions were carried out where each participant completed in every session two different training protocols (i.e., one with each leg) differing in set configuration. Traditional training consisted in 4 sets of 8 repetitions with 3 minutes of rest between sets while inter-repetition rest training consisted in 32 individual repetitions with 17.4 seconds of rest between each repetition. The load used during training intervention corresponded to approximately 75 % of 1RM (i.e., 10RM load). Results revealed that mean velocity was greater in the inter-repetition rest training during all the sessions. However, similar changes in the slope, V_0, F_0 and P_{max} were obtained after both protocols. Effect sizes for those changes were medium to large regarding all the parameters with the exception of V_0 that were small. In this regard, a steeper slope after both configurations were observed which indicated that F-V profiles progressed toward higher force capabilities. However, it is possible that the higher mean velocity observed in the cluster protocol compared to traditional lead to differences in the F-V profile in a longer program.

In the study of Goto et al. (124) the changes in F-V relationship were explored as a complementary analysis. This relationship was represented by the normalize unilateral knee extension torque (in percentage) and the angular velocity. No regression model was applied to the data hence, authors presented the pre and post experimental points (mean ± standard error values). Participants were assigned to a continuous (3-5 sets of 10 repetitions with 1 minute of rest), intermittent (including 30 second of rest at the midpoint of each set) or a control group in order to perform 12 weeks of resistance training. Training intervention consisted in a circuit of lat pulldown, shoulder press and bilateral knee extension. The load used represented the 75 %

of the 1RM load. The F-V relationship was revealed for the unilateral knee extension, where the continuous regime group increases the isometric and isokinetic force at almost all velocities examined. The changes were greater in the high force region compared to velocity section. No differences were observed for the other two groups (Figure 7). Continuous group presented a greater increase in isometric strength (19.1 ± 3.1 %) compared to intermittent (7.2 ± 3.2 %) and control (1.5 ± 1.0 %). In this study, work to rest ratio was not equated, as intermittent group had 30 extra seconds in the middle of each set. Differences in the intervention length (i.e., 23 sessions) and in the exercises performed during training could explain why both groups did not produce the same changes in the F-V profile, as was previously reported by Iglesias-Soler et al. (23).

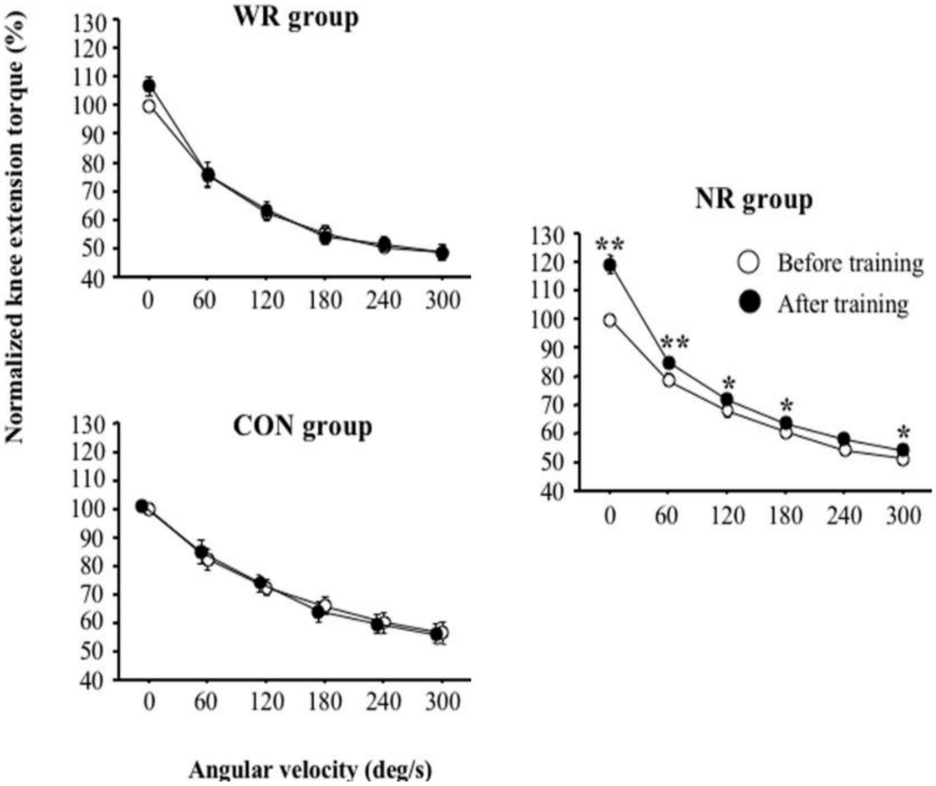


Figure 7. Changes in F-V relationship after the training intervention. Values corresponded to a knee extension exercise. WR: intermittent set configuration; NR: continuous set configuration. From Goto et al. (124)

A short term intervention was carried out by Morales-Artacho et al. (156) based on lower body force, velocity and power output. Participants completed 3 weeks of resistance training divided in two groups that performed cluster or traditional protocols. Cluster training consisted in 6 sets of 3 groups of 2 repetitions (30 seconds of rest every 2 repetitions and 270 seconds between sets) and traditional structures were performed in 6 sets of 6 continuous repetitions (5 minutes of rest between sets). F-V profile were obtained after loaded countermovement jump. Results showed greater improvements in peak power and velocity output after cluster sets compared to traditional. However, no clear differences were observed in the resulting F-V profile because the lack of significant changes in V_0, F_0 and Slope. As happened in the first study, a longer intervention is needed in order to observed other changes.

The study of Carneiro et al. (24) was the first investigation that examined the F-V relationship after different set configuration programmes in older adults. Postmenopausal women trained twice a week for 8 weeks performing unilateral leg extension. Each leg was randomly assigned into traditional or cluster group. Traditional training consisted in 3 sets of 4 repetitions with 90 seconds of rest between sets and cluster protocol included 30 seconds of inter-repetition rest. The load used corresponded to 90 % of 1RM. Results showed similar improvements of P_{max} and peak power at higher external resistance after both protocols. However, cluster structures were superior to traditional for the enhancement of peak power at lower external resistance. Additionally, cluster produced greater improvements in V_0 while traditional enhance more F_0. These outcomes lead to different changes in the F-V profile (Figure 8). This study confirms that for the leg extension exercise, long training interventions produce different changes in the F-V relationship when cluster and traditional set configurations are performed. Cluster training lead to a more oriented velocity profile while traditional training elicited a stronger profile. This also confirms that the manipulation of set configuration was useful in order to enhance force and velocity capabilities in elderly people.

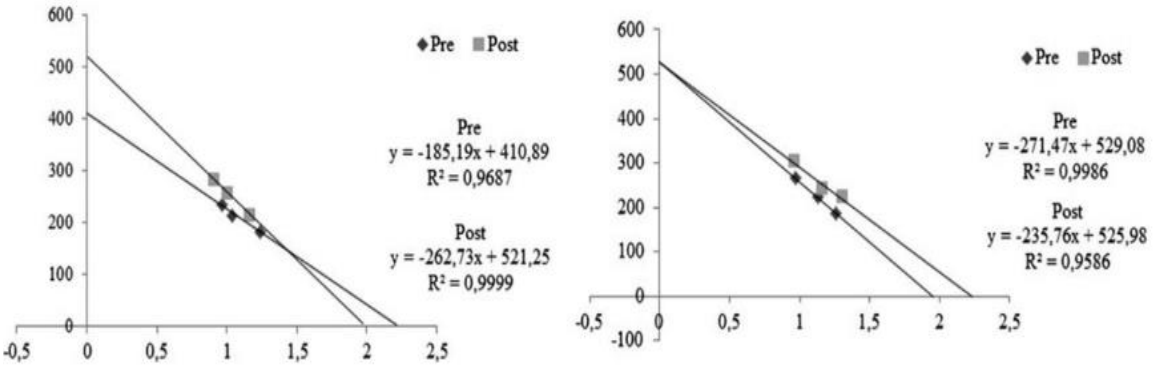


Figure 8. F-V relationship after traditional (left figure) and cluster (right figure) protocols. From Carneiro et al. (24)

The studies of both Iglesias-Soler et al. (23) and Carneiro et al. (24) have some similarities regarding their limitations. Firstly, the selection of a unilateral simple exercise where the cross education phenomenon could alter the results (longer set configurations produced greater cross education effect than shorter sets (157)) and secondly the lack of a control group. However, they were conducted with different population, had different work-to-rest ratio and a different intervention length. This could explain the dissimilarities in the obtained results. Additionally the study of Morales-Artacho et al. (156) did not include a control group and its limited length of intervention is a potential limitation for conclusive results.

In this regard, more investigation is needed in order to complete these outcomes and conclusions. For example, the addition of a control group is necessary to finally contrast the obtained results. Moreover, it is also important to explore the adaptations when upper-body exercises are performed. To the best of our knowledge, no previous study had explored the F-V profile changes in these kind of exercises as a consequence of training programmes differing in set configuration. Moreover, the addition of other multi-joint tasks is required because they could be more transferable to a normal resistance training routine. In this regard, it is interesting to choose exercises that could be commonly used by athletes of many sports and for people who exercise regularly or beginners.

2.2.1.2.2 Muscle hypertrophy

Theoretically, the acute hormonal response after resistance training may produce increases in muscle thickness. In the study of Oliver et al. (151) no differences were reported comparing cluster and traditional structures regarding gains in lean mass. Also similar increases in thigh circumference (corrected by skinfold thickness) were reported by Iglesias-Soler et al. (101) and Arazi et al. (148) comparing cluster and traditional structures. However, in the study of Goto et al. (124) traditional protocols showed a clear increase in quadriceps femoris cross-sectional area whereas cluster and control group did not. On the other hand, no differences in muscle thickness were observed after 5 weeks of unilateral biceps curl training performing cluster or traditional sets (157). Authors concluded that the intervention length and the session time was not enough to induce any changes. The recent review of Totó et al. (158) tried to explore the current literature regarding the effect of different set configurations on muscle hypertrophy. They concluded that cluster methods contribute to increase muscle mass nevertheless when total volume conditions are equated, traditional regimes could be better.

Finally, one of the benefits of cluster training is that is it possible to complete more training volume if additional recovery periods are included (16). Considering volume as the most important parameter for muscle hypertrophy (159) , we could speculate that cluster structures with extra recovery would contribute to muscle growth. However, with the current literature, there is no consensus and further studies are needed in this topic.

2.2.1.2.3 Neural adaptations

Iglesias-Soler et al. (101) compared the functional and neural effects of two training interventions differing in set configuration. For 5 weeks, participants completed 10 sessions of unilateral leg extensions where each leg performed a traditional (4 sets of 8 repetitions with 3 minutes of rest) or an inter-repetition rest configuration (32 repetitions with 17.4 seconds of pause between each repetition) with the 10RM load. Before and after intervention a neurophysiological measurement was conducted. Central neural adaptations were represented by the voluntary activation. Analysis revealed no significant factor effect, but a tendency towards lower values of voluntary activation for the inter-repetition rest training (from 96.5 ± 3.3% to 91.4 ± 4.4%). Authors explained that voluntary activation is not the responsible for the strength improvements achieved. Regarding peripheral changes, maximum M wave was reported. Post-hoc analysis showed higher values after training for traditional training in comparison with inter-repetition training. Authors suggested that traditional training improved the membrane excitability, but this did not affect the muscular performance that was similar for both configurations. Cortical adaptations were explored recording the following variables: resting motor evoked potentials, short interval intracortical inhibition and intracortical facilitation. However, ANOVA did not reveal any significant changes for these parameters. They concluded that both configurations did not produce changes in the corticospinal volley and in the intracortical facilitation and inhibition. Authors reported that if resistance training produces cortical adaptations, they would be achieved in longer training interventions. Additionally, a complementary experiment was conducted in order to analyse the effect of the cross-education phenomenon. Twelve participants were assigned to the presented groups. Each participant only trained one leg with one sort of set configuration. Results revealed an enhancement of the dynamic and isometric performance for both groups in the trained limb. Maximum voluntary contraction and maximum mean propulsive power were higher after training for the non-trained leg, what suggests a cross education effect. No differences in the magnitude of the cross education were found. Authors concluded that more simple size was needed in order to explore this phenomenon.

Later, the study of Fariñas et al. (157) explored again if set configuration could modulate the cross education phenomenon and its magnitude. Participants were randomly assigned to traditional, cluster or control group where experimental groups trained for 5 weeks performing unilateral biceps curl exercise (with the dominant limb). Subjects trained with their individual 10RM load. Cluster training consisted in 30 individual repetitions with 18.5 seconds of inter-repetition rest and traditional protocol entailed 5 sets of 6 repetitions with 135 seconds of recovery between sets. Results showed that the nontrained limb improve by 7.3 % the pretest 1RM load after traditional training but no changes after cluster intervention were observed. It is noteworthy that trained limb increased by 9.1 % the pretest 1RM load after traditional sets. In this regard, the gains in nontrained limb represent the 80.8 % of the improvements in trained limb. On the other hand, muscular endurance outcomes were only greater in posttest for the trained limb after traditional sets. Authors hypothesized that both protocols promoted different recruitment patterns that lead to different adaptations. Moreover, no differences in muscle thickness were detected in posttest. They finally revealed that greater cross education effect is produce when longer and more fatiguing training protocols are performed.

Although cluster training contributes in many mechanical and metabolic benefits, it is not recommended when the main goal is to transfer the strength gains from the trained to the nontrained limb. It is also important to take into account this phenomenon when unilateral exercises are performed. As was previously noted, two studies included unilateral leg extension in order to contrast the strength gains after cluster or traditional training (23,24). Since it was suggested that set configuration modulates the magnitude of the cross-education phenomenon, it is possible that strength improvements achieved by the leg trained with a traditional protocol were partially transferred to the cluster trained leg. In this regard, as cluster training was demonstrated to increase force in similar or less magnitude than traditional protocols, the traditional regimen could contribute to increase cluster strength gains. This may explain why authors did not find strength differences between protocols.

In conclusion, it seems that the central neural adaptations represented by the voluntary activation and peripheral adaptations (M wave) are not responsible for the strength improvements after training. Additionally, the strength gains occurred without cortical adaptations. In this sense, neural changes did not correlate with the performance improvement at least in a period of 5 weeks. Finally, traditional training is recommended to transfer the strength improvements from the trained to the nontrained limb because it produces a higher cross-education magnitude in comparison with cluster training.

3 Approach to the problem

Several studies have confirmed the reliability of the linear regression model to describe the individual F-V profile of different multi-joint tasks (65–67). Additionally, it was verified that this profile could be modified after exercise and after a specific training program (73,95). Acute fatigue affects the intermediate velocity and force region that entails a large power decrease (72). This downward and leftward shift of the F-V profile is also experienced during aging (78,79). Moreover, it is possible to produce different alterations of this profile regarding the manipulation of the resistance training parameters. In this sense, the high force and velocity region or the intermediate zone of the F-V profile could be specifically altered. The velocity specificity principle of resistance training suggests that strength and power increase most near the velocity of training (160,161). In this sense, previous studies showed that the high velocity and high force portions of the F-V relationship are mainly changed by using explosive type strength training with medium-light loads and heavy loads, respectively (84,160,162). Since these studies contrasted different loads, their findings cannot be exclusively attributed to differences in training velocities. In other studies, training programmes of maximum or sub-maximum intended velocity were contrasted (163) but since intended velocity is a key factor to maximise strength adaptations (98,99) modulating velocity voluntarily is a potential limitation.

An alternative approach to contrast the effect of velocity on the F-V relationship is by modulating the set configuration since it allows to design interventions differing in the velocity whereas the load, volume, intensity, and intended velocity remain equated between conditions (100). Cluster structures allows greater velocity ad power maintenance during exercise, with lower glycolytic demand and therefore less fatigue after training in comparison with traditional sets (20,100). Although similar strength adaptations were observed, cluster structures are more beneficial for power output development (151,156). Thus, based on 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 (23,24,156). Additionally, these studies present different limitations as for example the lack of a control group and the use of single joint exercises, reducing the practical applications. Moreover, cardiovascular and metabolic adaptations have only been completely analyzed after traditional training (13,14,145). In this sense, cluster structures need to be examined in order to explore their impact in these body systems. This could help to identify resistance training structures that effectively combine the optimization of mechanical performance with positive hemodynamic and cardiovascular adaptations.

In this regard, this thesis is going to explore the mechanical, neuromuscular, metabolic and cardiovascular adaptations caused by two resistance training programs differing in set configuration.

4 Hypothesis and purposes

4.1 Hypothesis

- Training protocols with a cluster set configuration mitigate the velocity loss throughout the sessions allowing the improvement of the high velocity portion of F-V relationship compared to a traditional training program.
- Cluster training contributes to lower heart rate response during training sessions in comparison with traditional training, resulting in positive effects in the cardiovascular variables at rest after intervention.
- Cluster training protocols, due to more frequent rest periods, derive in less lactate production after sessions in comparison with traditional training.
- Both training protocols produce similar improvements regarding maximal strength and endurance while cluster training enhances in a greater magnitude the maximum power output and the CMJ performance.

4.2 Purposes:

4.2.1 Main purposes:

- To examine the changes in the F-V relationship parameters (i.e., V_0, F_0, slope, and P_{max}) of two multi-joint exercises like bench press and parallel squat caused by two resistance training programmes differing in set configuration.
- To assess the cardiovascular adaptations in a basal state (heart rate, heart rate variability, blood pressure, blood pressure variability and baroreflex sensitivity) after two resistance training programmes differing in set configuration.

4.2.2 Secondary purposes:

- To analyse the blood lactate concentration in order to contrast the glycolytic involvement of two resistance training programmes differing in set configuration.
- To analyse and compare the velocity loss throughout two resistance training programmes differing in set configuration.
- To analyse the changes in the position of the force and velocity associated with the 1RM on the F-V relationship as complementary features of the individual mechanical profile caused by two resistance training programmes differing in set configuration.
- To assess the changes in maximum strength, muscular endurance, maximum power and jump performance after two resistance training programmes differing in set configuration.
- To describe the heart rate response during two resistance training programmes differing in set configuration.

5 Experimental study

5.1 Material and methodology

5.1.1 Experimental design

A randomised controlled trial design was conducted. All the participants completed two familiarisation sessions, two pretesting sessions and two posttesting sessions. Testing sessions consisted in 1RM [where F-V relationships for both bench press (BP) and parallel squat (SQ) were obtained], 10RM, CMJ, and a cardiovascular evaluation recorded at baseline. After the pre-testing, the participants assigned to the experimental groups completed 10 training sessions throughout 5 weeks performing a traditional training (TT) or a 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. A schematic representation of the experimental design is shown in Figure 9.

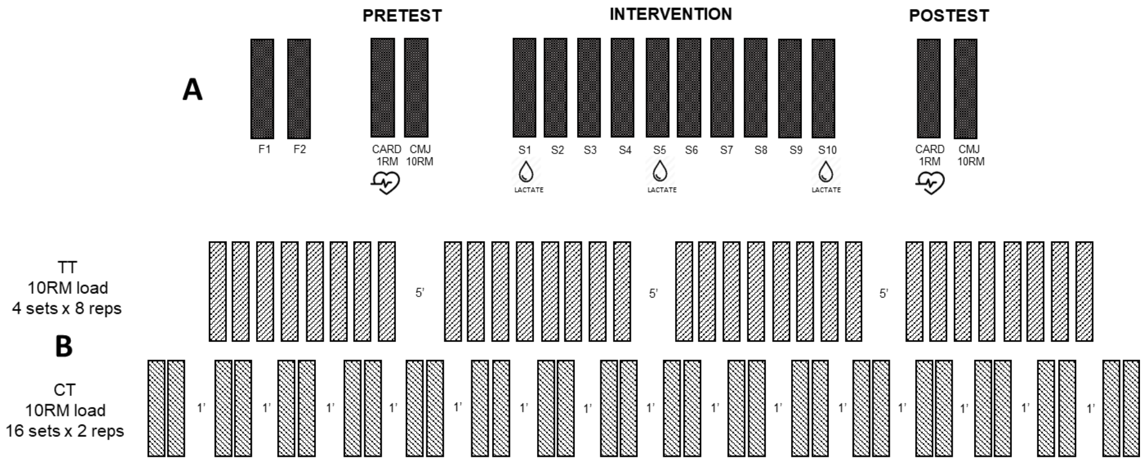


Figure 9. Schematic representation of the study. A: Experimental design of the 16 sessions. F: Familiarization session. 1RM: 1-repetition maximum test. 10RM: 10-repetition maximum test. FV: individual Force-Velocity profile testing. S: session. LT: Measurement of the capillary blood lactate before and after the session. B: Experimental protocols performed. TT: Traditional training. CT: Cluster training.

5.1.2 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 (Appendix B). The study was approved by the ethical committee of the University of A Coruna (Appendix C) and conducting according to the tenets of the Declaration of Helsinki.

5.1.3 Procedures

5.1.3.1 Familiarisation sessions

Participants performed two familiarisation sessions with at least 48 hours between them. Individual marks were recorded to adjust the machines to each subject 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 cycling at 60-80 revolutions per min on a cycle ergometer (Monark 828E, Monark Exercise AB, Vansbro, Sweeden). Then, the participants completed two sets of 10 repetitions with approximately 50% of perceived maximum load and 2 min of recovery between sets in a Smith machine (Multipower Shock [Model SH004/0], Telju Fitness, Toledo, Spain) for BP and SQ whereas lateral pull-down (LP) and leg curl (LC) were performed on their respective machines (Biotech Fitness Solutions, Brazil). In the second familiarisation session, participants were instructed to perform the maximum number of repetitions with approximately 75% of perceived maximum load in order to get more experience reaching muscular failure.

5.1.3.2 Exercises execution

The BP was performed on a flat bench where participants started with the elbows fully extended and then they moved the barbell in a controlled way to their chest, waiting for 1 second in this position to avoid bouncing the barbell off the chest. Individual grip 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 (Figure 10).

Figure 10. Bench press execution.

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 subjects performed touch-and-go squats (i.e., without pause, in a continuous manner) (Figure 11). Similarly, to BP the participants were asked to perform each concentric phase of SQ at the maximum intended velocity.

LP was performed using a seated LP machine (Biotech Fitness Solutions, Brazil). The LP bar was marked in order to standardise subjects grip. Also, the seat was adjusted to allow full arm extension during the eccentric phase. Subjects started grabbing the bar with extended arms. They had to pull the bar as fast as possible to the chest in diagonal direction. Eccentric phase was performed in a control manner (Figure 12).

Figure 11. Parallel Squat execution.

Regarding LC, subjects started in a prone position with heels in contact with the padding placed in the lever. Both shinbones were situated in a parallel way respect the floor and the hands were griping the handles. Leg position was standardized in familiarisation sessions. They were instructed to flex knees to bring the padding to touch their gluteus. Concentric phase was explosive and the eccentric one was performed in a control manner (Figure 13).

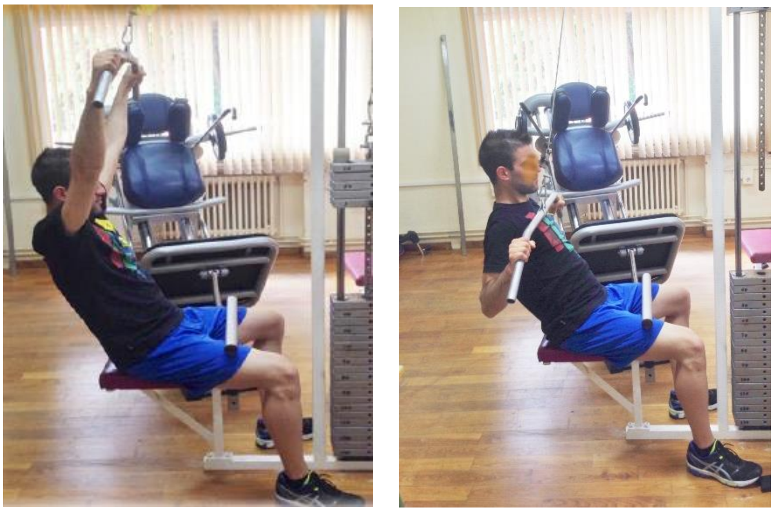


Figure 12. Lat pulldown execution.

Figure 13. Leg curl execution.

5.1.3.3 Anthropometric measurement

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

5.1.3.4 Cardiovascular evaluation

After anthropometric measurements a cardiovascular evaluation of each subject was conducted. Continuous monitoring of the heart rate and blood pressure was recorded by a Task Force Monitor (CNSystems Medizintechnik, Graz, Austria). Three-lead electrocardiogram recorded hear rate at a rate of 1000 Hz. Beat-by-beat blood pressure were registered by photoplesthysmography. After a calibration process, subjects were lying on a stretcher in a supine position (Figure 14). Two pneumatic cuffs were placed on the proximal phalange of the index and the middle fingers of the left hand for continuous blood pressure measurement with a sampling frequency of 100 Hz. An additional oscillometer were placed on the right arm. Data were collected during the last 10 minutes of a 20 minutes period. In this last 10 minutes a metronome was used in order to establish a breathing pattern with a respiratory frequency of 0.2 Hz (i.e., 12 inspirations per minute) (146). All subjects repeated this procedure after the training intervention period (i.e., included control group).

Figure 14. Cardiovascular evaluation at rest.

5.1.3.5 1RM test

Although all the exercises were performed in the familiarisation and training sessions, the 1RM test was only conducted for the BP and SQ. The exercise sequence was randomised for the pre-and post-testing sessions. The 1RM load was obtained using a protocol that combines velocity decrement with increasing load. This protocol has been previously used in some studies (100,101). It started with the participants performing three repetitions of the exercise only with the load of the Smith machine barbell (21.40 kg). After 1 min of recovery, a new trial (i.e., three reps) was performed with an increment of 10-20 kg in SQ and 5-10 kg in BP. Trials were repeated until a loss of at least 25% with respect to the first set regarding the mean velocity recorded during the propulsive phase (i.e. mean propulsive velocity: MPV) was observed. The propulsive phase is defined as the portion of the concentric phase during which the measured acceleration was greater than acceleration due to gravity (i.e., bar acceleration > $-9.81\ \mathrm{m\cdot s^{-2}}$) (164). Then the participants performed sets of two repetitions with 2 min of recovery with load increments of 2.5-7.5 kg in BP and 5-10 kg in SQ. Finally, when a loss of 50% in MPV was recorded, the last stage of the test started consisting in performing trials of one repetition with 3 min of recovery between them and load increments of 1.25-5 kg in BP and 1.25-7.5 kg in SQ. This last procedure was repeated until the participant was not able to overcome the load or complete the range of movement. The number of loads used to obtain the 1RM load in the pretest was 7 ± 2 in BP and 10 ± 2 in SQ, whereas in the posttest 8 ± 2 and 10 ± 2 were needed for BP and SQ respectively.

Along with MPV, mean propulsive force (MPF) and mean propulsive power (MPP) were obtained during the concentric phase of every repetition of the test with a linear velocity transducer (T-Force System, Ergotech Consulting, Murcia, Spain). This system consists of a linear velocity transducer interfaced to a personal computer by means of a 14-bit resolution analogue to digital data acquisition board and custom software (T-Force Dynamic Measurement System, Version 2.35). Instantaneous velocity was sampled at a frequency of 1.000 Hz and subsequently smoothed with a fourth-order low-pass Butterworth filter with a cut-off frequency of 10Hz.

5.1.3.6 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.

After intervention, participants executed another test where they have to perform as repetitions as possible with the 10RM pretest load. This was carried out for BP and SQ exercises in order to examine the muscular endurance of upper and lower body muscles.

5.1.3.7 CMJ

Subjects performed three CMJ with 1 min of recovery between them, using a force platform Kistler Quattro Jump (Quattro-Jump, Kistler Instrument, Switzerland). They were instructed to perform maximum vertical jumps. Subjects started in a standing position on the centre of the force plate with their hands on the hips. They performed a downward movement until 90 degrees of knee angle to finally jump as high as possible. Maximum force and power data from the best trial (i.e., regarding height) were recorded over push off phase (Figure 15).

Figure 15. Countermovement jump execution.

5.1.3.8 Training programmes

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

Participants in the TT and CT groups trained twice per week during 5 weeks for a total of 10 training sessions that were separated by at least 48 hours. Both groups used a 10RM load during the BP, SQ, LP, and LC for a total of 128 repetitions and 75 min of total rest per session, being therefore the load, volume, and rest equated between experimental groups. After the general warm up and before each exercise, all participants performed a specific warm up including one set of 10 repetitions with the 50% of the 10RM load. Participants in TT performed 4 sets of 8 repetitions with the 10 RM load and 5 min of rest between sets and exercises, while in CT completed 16 sets of 2 repetitions with 1 minute rest between sets and 5 min between exercises. The participants were instructed to perform each repetition as fast as possible, an all of them completed the programmed volume throughout the intervention. In order to monitor the heart rate during training intervention, subjects wore a band (Polar H10, Kempele, Finland).

In CON, participants were asked to continue with their usual lifestyles during the 5-week study period. The training groups did not perform other kind of strength training during the intervention. They were also asked to avoid any work-out the day before of each session.

5.1.3.9 Lactate measurement

For contrasting the glycolytic metabolism involvement between training protocols and for monitoring its progression throughout the training period, capillary blood lactate concentration (LT) 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.

5.2 Data analysis

5.2.1 Lactacidaemia

To examine the glycolytic involvement, the peak value of blood lactate of session 1, 5 and 10 was considered for analysis.

5.2.2 Mechanical Parameters

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 calculated. The accumulated work across the sessions was obtained for BP and SQ as the average of the sum of work performed during the concentric phase of each repetition.

To analyse the velocity loss throughout each session of each training program, different variables were calculated. Firstly, the last to the first repetitions ratio (LFR) where the average MPV of the last two repetitions and the first two ones were considered to calculate it as follows: ([(average last two repetitions MPV/average first two repetitions MPV) - 1] × 100). Thus, the lower this percentage was, the higher the magnitude of velocity loss has been, being positive values interpreted as velocity gains. The next variable corresponded to the relationship between the last repetition MPV value and mean MVP of the entire session (LMR). It represents how low or high is the value of the last repetition respect the mean of the session. Lower values imply a greater velocity loss. It is calculated as follows: ([(last repetition MPV/ average MPV) -1] × 100). Other variable also registered the MPV value of the last repetition in relationship with the maximum achieved MPV value. The last repetition to the maximum MPV value ratio (LMaxR) was calculated as follows: ([(last repetition MPV/maximum repetition MPV) -1] × 100). The lower this percentage the higher the magnitude of the velocity loss has been. The last variable reported the relationship between the minimum and the maximum MPV value (MinMaxR) and it was calculated as follows: ([(minimum MPV /maximum MPV) -1] × 100). Greater values imply less velocity loss.

To analyse the overall maintenance of velocity, the mean to maximum MPV ratio (MMR) of each session was obtained and calculated in percentage as follows: [(average MPV /maximum MPV)] × 100). Values near 100% imply great maintenance of velocity.

5.2.3 Goodness of fit

The coefficient of determination (R^2) and the standard error of estimation (SEE) of each individual regression were extracted to examine the goodness of fit of the F-V relationship by the linear model. These parameters were calculated by using Microsoft Office Excel 2007 (Microsoft Corporation, Washington, USA).

5.2.4 F-V parameters

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 + body mass).

The parameters obtained from the individual linear regressions were the Slope, V_0, F_0 and P_{max}. 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.

5.2.5 Neuromuscular performance

In order to measure maximal strength, the 1RM loads at both pretest and posttest of BP and SQ were collected. Additionally, the load of the maximum mean propulsive power (MPP_{max}) was identified and considered for further analysis. In order to evaluate muscular endurance, the number of repetitions performed with the 10RM pretest load were recorded after intervention. Finally, from the CMJ test, height, force and power were considered for the analysis.

5.2.6 Cardiovascular parameters

From cardiovascular evaluation at rest before and after intervention, the following parameters were obtained. Time domain, frequency domain and nonlinear measures of heart rate variability (HRV) were calculated to estimate cardiac autonomic modulation. Time domain parameters obtained were the standard deviation of the RR interval (SDNN) and the squared root of the standard deviation of RR interval (RMSSD). Regarding frequency domain, fast Fourier transformation method was used for spectral analyses of HRV. Power of high (HF: 0.15-0.4 Hz) and low frequency (LF: 0.04-0.15 Hz) bands were calculated in both absolute and normalized units (nu). HF is a cardiovagal control marker and LF is modulated by the sympathetic and parasympathetic activities (133). As an indicator of sympatho-vagal balance, the ratio between LF and HF power was calculated (LF/HF). The nonlinear measures obtained were the sample entropy (SampEn) and approximate entropy (ApEn). SampEn is an indicator of complexity and determines the probability of finding specific patterns in a range from 0 to 2, being fewer complex values close to 0. ApEn is a measure of regularity of the RR-interval series where high values resulting in more irregularity.

Calculations were performed after applying an automatic artefact correction (i.e., medium correction threshold level) using Kubios HRV software 3.3.1 (The Biomedical Signal and

Medical Imaging Analysis Group, Department of Applied Physics, University of Kuopio, Finland). Artefact correction never exceed the 10% of the signal.

Regarding blood pressure and its variability, some variables were recorded. In this sense, systolic blood pressure (SBP), diastolic blood pressure (DBP) and mean arterial pressure (MAP) were recorded-. Additionally, the variability of the blood pressure was evaluated using a spectral component of the SBP (in a lower frequency range), reporting the LF power of SBP (i.e., indicator of the sympathetic vasomotor tone).

Additionally, throughout all the training sessions, heart rate was recorded by a polar band (Polar H10, Kempele, Finland) using the mobile application Elite HRV and subsequentially analysed with Kubios (HRV software 3.3.1). After artefact correction previously mentioned, the maximum heart rate values were considered and averaged throughout the ten training sessions.

Finally, the baroreflex sensitivity (BRS) data was quantified by the sequence method in order to estimate the effect of the intervention on the cardiac baroreflex control. This method consists in identifying the sequences of three or more consecutive beats where SBP and the pulse interval increase or falls progressively in a linear fashion. BRS analysis included the ratio between the number of SBP ramps followed by the respective reflex pulse interval ramps and the total number of SBP ramps observed in a given time window, known as the baroreflex effectiveness index (BEI) (165). This parameter corresponds to the number of times the baroreflex is active in controlling the heart rate in response to blood pressure oscillations. BEI provides information on the baroreflex function that is complementary to BRS. In this sense, a reduction in BEI directly related to the level of baroreflex dysfunction, is expected in pathological conditions.

5.3 Statistical analysis

Normality assumption for all the variables was verified by using a Shapiro-Wilk test. If normality could not be assumed, nonparametric tests were used.

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

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

The progression of the velocity loss variables (e.g., LFR) and heart rate throughout the sessions was analysed by a two-way ANOVA with an inter-participants factor corresponding to the experimental groups (TT and CT) and a repeated measures factor corresponding to time (sessions 1 to 10).

Furthermore, an independent samples t-test was used for comparing the experimental groups (i.e., CT vs TT) regarding the accumulated work throughout the sessions.

Changes in 1RM, MPP_{max}, F-V parameters (F_0, V_0, Slope, P_{max}), F_{1RM}/F_0 and V_{1RM}/V_0, CMJ variables (height, force and power) and some cardiovascular variables (MAP, SDNN, RMSSD, BRS, ApEn and SampEn) were analysed by two-way ANOVA with group (TT, CT, and CON) and time (pretest and posttest) as factors. Additionally, this kind of analysis was used in order to evaluate the number of repetitions performed with the 10RM of the pretest before and after the intervention.

When a significant interaction was detected, post-hoc *t*-tests were carried out with the Bonferroni's adjustment. The effect size for each factor of ANOVA was reported using the partial eta squared (η^2). Additionally, Hedge´s *G* and the corresponding 95% confidence intervals (CI) were calculated for pairwise comparisons using the Comprehensive Meta-Analysis program (Version 2.2, USA). In order to simplify, we only report the effect size and the Hedge's *G* when the effect of the factor was significant. The lower thresholds to consider an effect size as small, medium and large were 0.2, 0.5 and 0.8 in the case of Hedge´s *G* and 0.01, 0.06 and 0.14 for η^2 (166). Data are reported as mean ± standard deviation or marginal mean ± standard error for the main effects of analyses of variance (ANOVAs). Parametric analyses were carried out by using the statistical package SPSS version 20.0 (SPSS, IBM, Armonk, NY, USA). The level of statistical significance was set at 0.05. Finally, a post hoc power analysis was calculated using the G Power software (version 3.1.9.2). Statistical power (1-b) for a within-between interaction of an ANOVA with 3 groups and two measurements (i.e., pretest-posttest), for a sample size of 39, a correlation among repeated measures of 0.7 and a medium effect size (f = 0.25) is 0.94.
In addition, as some cardiovascular variables (BEI, LF/HF, DBP, SBP, LF power of SBP, LF power and HF power) violated the assumption of normality, a two-way nonparametric ANOVA test was performed by using the nparLD R software package (version 3.5.2) in order to evaluate the main effects of the factor time (pretest and posttest) and group (TT, CT and CON).

5.4 Results

5.4.1 Main results

5.4.1.1 Lactacidaemia

The three-way (session time × group) ANOVA for LT showed a time × group interaction with higher peak values after TT compared to CT (Figure 16). Post-hoc analyses revealed higher values after the training session both in TT ($P < 0.001$; $\eta^2 = 0.852$; mean difference: 5.67 mmol. L^{-1}; CI= [4.46, 6.88]) and CT ($P = 0.020$; $\eta^2 = 0.280$; mean difference= 1.73 mmol. L^{-1}; CI= [0.31, 3.15]). Finally, LT was higher after the training session for TT in comparison with CT ($P < 0.001$; mean differences: 3.69 mmol. L^{-1}; $\eta^2 = 0.541$; CI of differences= [1.95, 5.43]).

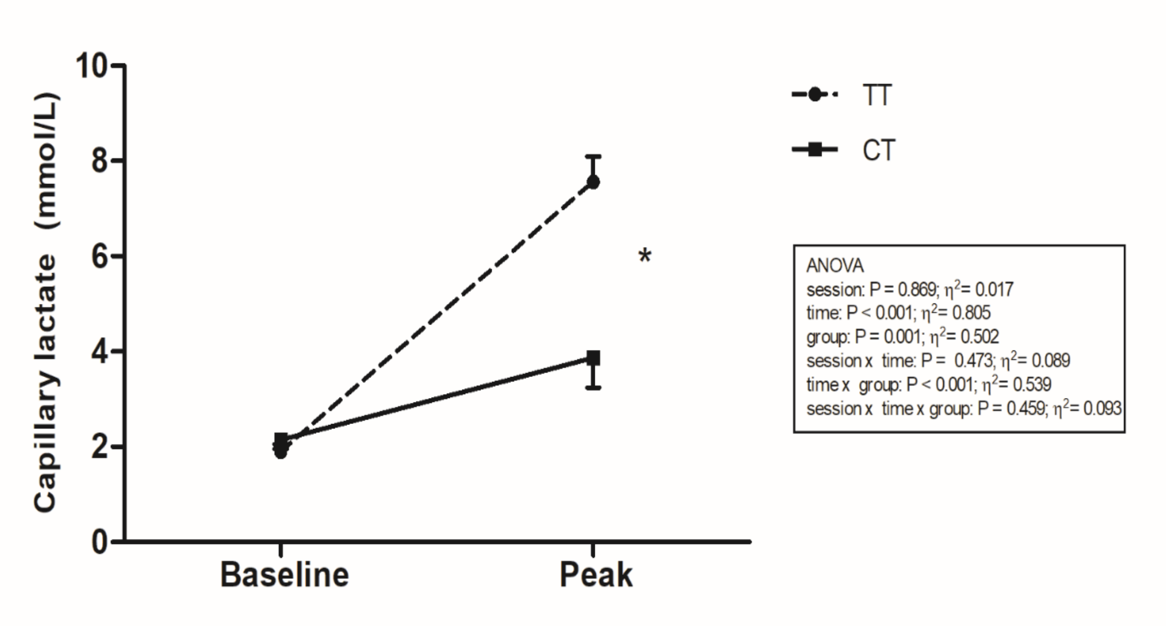


*Figure 16. Capillary lactate concentration (LT) obtained before (baseline) and after (peak) sessions 1, 5, and 10. Points represent the estimated marginal means (pooled means for sessions 1, 5, and 10) and the error bars the corresponding standard error. TT: Traditional training group. CT: Cluster training group. *: Significant differences between groups for the peak values after sessions ($P \leq 0.05$).*

5.4.1.2 Mechanical parameters

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 program 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).

Regarding the average MPV (Figure 17), non-significant 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]).

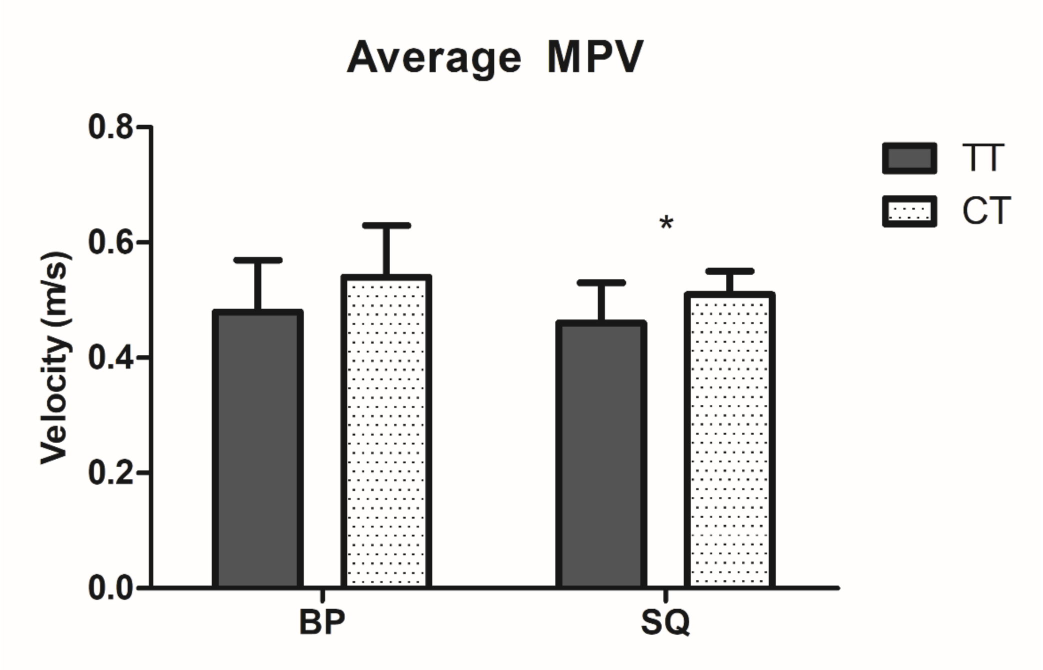


*Figure 17. Average mean propulsive velocity (MPV) for the Bench Press (BP) and the Parallel squat (SQ) exercise. Data are presented as mean ± SD. *: Significant differences between groups (P ≤ 0.05).*

Besides, for two of the velocity loss and maintenance variables (i.e., LFR and MMR) the group effect was significant, indicating lower velocity loss and higher velocity maintenance for

CT in comparison with TT (The graphical representation of these variables is included in figure 18). The results of the other velocity loss parameters are described as follows:

Regarding BP, LMR results revealed a group effect ($P < 0.001$; $\eta^2 = 0.484$). CT obtained higher mean values (- 12.96 %) than TT (- 37.79 %). No session ($P = 0.216$; $\eta^2 = 0.063$) nor group × session interaction was detected ($P = 0.094$; $\eta^2 = 0.085$).

For SQ, significant effects of both session ($P = 0.046$; $\eta^2 = 0.106$) and group ($P = 0.004$; $\eta^2 = 0.333$) were observed regarding LMR. CT obtained higher mean values (- 4.82 %) than TT (- 13.04 %) and both augmented during training program. The group x session interaction was not significant ($P = 0.218$; $\eta^2 = 0.065$).

Regarding BP, LMaxR showed significant effects of session ($P < 0.001$; $\eta^2 = 0.176$) and group ($P = 0.003$; $\eta^2 = 0.345$). CT presented higher LMaxR than TT (- 24 % and - 48 % respectively). LMaxR was increasing throughout the training period. No group × time interaction was detected ($P = 0.478$; $\eta^2 = 0.044$).

For SQ, significant effects of session ($P = 0.033$; $\eta^2 = 0.115$) and group ($P < 0.001$; $\eta^2 = 0.507$) were observed. CT obtained lower velocity loss than TT (- 16 % and - 25 % respectively). Values increased throughout sessions. A group × session interaction was not observed ($P = 0.175$; $\eta^2 = 0.070$).

In the case of MinMaxR in BP, results revealed a session ($P = 0.009$; $\eta^2 = 0.154$) and group effect ($P < 0.001$; $\eta^2 = 0.487$). CT obtained higher mean values (- 30.43 %) than TT (- 52.64 %).

No group × session interaction was detected ($P = 0.506$; $\eta^2 = 0.035$).

For SQ, significant effects of both session ($P = 0.030$; $\eta^2 = 0.685$) and group ($P = 0.004$; $\eta^2 = 0.337$) were observed regarding MinMaxR. CT obtained higher mean values (- 24.22 %) than TT (- 31.29 %) and both incremented during training program. The group x session interaction was not significant ($P = 0.215$; $\eta^2 = 0.525$)

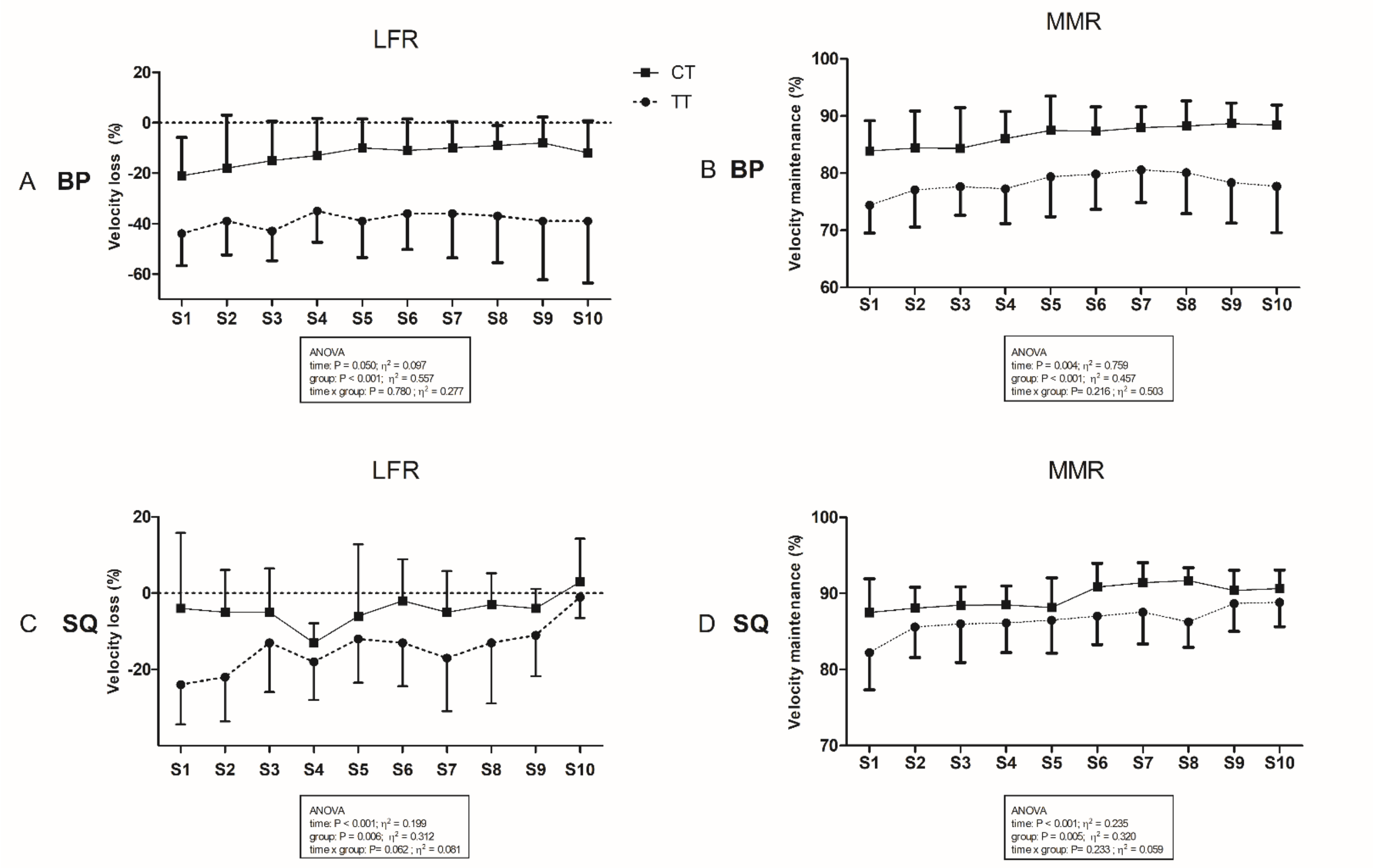


Figure 18. Velocity loss calculated as the last to the first repetition ratio (LFR) and velocity maintenance calculated by the mean to the maximum ratio (MMR) during the 10 experimental sessions (S) of traditional (TT) or cluster (CT) training for the Bench Press (BP) exercise (A and B) and the Parallel squat (SQ) exercise (C and D). Data are presented as mean ± SD.

5.4.1.3 Goodness of fit

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 average values were 22.97 ± 17.99 N in pretest and 20.66 ± 14.44 N in posttest.

For SQ, the medians of R^2 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 ± 39.06 N in pretest and 77.01 ± 40.37 N in posttest.

5.4.1.4 F-V parameters

F-V relationship parameters for BP are shown in table 1. The slope 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 ($P < 0.001$; $\eta^2 = 0.410$) and an interaction between group and time ($P = 0.008$; $\eta^2 = 0.243$) were 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 ($P < 0.001$; $\eta^2 = 0.354$), group ($P = 0.048$; $\eta^2 = 0.160$) and group × time interaction ($P = 0.017$; $\eta^2 = 0.207$) 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 ($P < 0.001$; $\eta^2 = 0.359$) and group × time interaction ($P = 0.002$; $\eta^2 = 0.303$) 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 ($P = 0.040$;

$\eta^2 = 0.115$) 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 1. F-V parameters obtained for bench press (BP) and parallel squat (SQ) before (pretest) and after (posttest) 5 weeks of traditional (TT) and cluster (CT) training or a control (CON).

	Parameters	**Group**	**Pretest**	**Posttest**
BP	Slope (Ns/m)	TT	-363.63 ± 157.01	-339.46 ± 136.50
		CT	-315.24 ± 89.50	-295.05 ± 101.22
		CON	-361.99 ± 126.90	-360.14 ± 125.91
	F_0 (N)	TT	729.70 ± 265.17	773.78 ± 289.00*
		CT	653.50 ± 208.70	723.81 ± 243.47*
		CON	699.55 ± 233.30	704.41 ± 225.60
	V_0 (m/s)	TT	2.06 ± 0.41	2.30 ± 0.28*
		CT	2.08 ± 0.31	2.48 ± 0.26*
		CON	1.97 ± 0.37	1.99 ± 0.33$^{\#}$
	P_{max} (W)	TT	397.23 ± 174.64	446.82 ± 167.56*
		CT	344.75 ± 136.79	434.29 ± 171.01*
		CON	320.29 ± 136.86	344.44 ± 143.88
	V_{1RM} (m/s)	TT	0.19 ± 0.05	0.16 ± 0.07
		CT	0.20 ± 0.08	0.19 ± 0.06
		CON	0.20 ± 0.06	0.18 ± 0.06
	V_{1RM}/V_0 (%)	TT	9.61 ± 3.20	7.18 ± 3.28
		CT	10.04 ± 4.41	7.58 ± 2.63
		CON	10.98 ± 6.50	9.63 ± 3.59
	F_{1RM}/F_0 (%)	TT	91.19 ± 5.81	94.50 ± 3.42
		CT	90.14 ± 5.01	92.28 ± 1.97
		CON	90.78 ± 8.40	91.32 ± 5.18

F_0: force axis intercept; V_0: velocity axis intercept; P_{max}: maximum estimated power; V_{1RM}: velocity associated to the 1RM; V_{1RM}/V_0: ratio between maximum propulsive velocity performed with the 1RM and V_0; F_{1RM}/F_0: ratio between maximum propulsive force performed with the 1RM and F_0; *: Significantly differences within group for pretest- posttest contrasts ($P < 0.05$); #: Significantly different from TT and CT ($P < 0.05$).

F-V relationship parameters for SQ are shown in Table 2. The analysis of the slopes reflected a time effect ($P = 0.008$; $\eta^2 = 0.178$), such that the slope values were higher in the posttest compared to pretest (i.e., less steep). A group × time interaction was observed ($P = 0.031$; $\eta^2 = 0.176$). Post-hoc analysis detected that slope 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 slopes (P = 0.686). Regarding F_0, a significant effect of time (P = 0.014; $\eta^2 = 0.157$) and an interaction between group and time (P = 0.013; $\eta^2 = 0.215$) 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; $\eta^2 = 0.167$). Additionally, a group × time interaction was observed (P = 0.049; $\eta^2 = 0.154$). 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; $\eta^2 = 0.298$), 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; $\eta^2 = 0.179$) was 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 nor interaction. For V_{1RM}, a time effect was detected (P = 0.045; $\eta^2 = 0.107$), 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 19.

Table 2. F-V parameters obtained for parallel squat (SQ) before (pretest) and after (posttest) 5 weeks of traditional (TT) and cluster (CT) training or a control (CON).

	Parameters	Group	Pretest	Posttest
SQ	Slope (Ns/m)	TT	-864.32 ± 333.84	-832.74 ± 355.74
		CT	-1046.52 ± 431.43	-741.36 ± 302.00*
		CON	-807.90 ± 289.52	-772.57 ± 291.26
	F_0 (N)	TT	2125.50 ± 568.70	2276.05 ± 543.76*
		CT	2136.21 ± 453.28	2208.80 ± 538.18
		CON	2031.23 ± 434.47	2000.35 ± 406.89
	V_0 (m/s)	TT	2.61 ± 0.60	2.94 ± 0.73
		CT	2.31 ± 0.99	3.21 ± 0.75*
		CON	2.84 ± 1.25	2.81 ± 0.86
	P_{max} (W)	TT	1304.96 ± 356.44	1662.12 ± 491.93
		CT	1239.08 ± 644.41	1673.67 ± 522.57
		CON	1399.63 ± 467.86	1461.26 ± 704.11
	V_{1RM} (m/s)	TT	0.27 ± 0.05	0.29 ± 0.07
		CT	0.28 ± 0.06	0.33 ± 0.05
		CON	0.28 ± 0.06	0.28 ± 0.08
	V_{1RM}/V_0 (%)	TT	10.64 ± 2.71	10.66 ± 3.92
		CT	13.28 ± 4.95	10.74 ± 3.32
		CON	10.39 ± 3.96	10.64 ± 3.98
	F_{1RM}/F_0 (%)	TT	91.38 ± 5.54	90.48 ± 5.58
		CT	84.10 ± 5.42	89.21 ± 5.67*
		CON	89.55 ± 4.40	89.91 ± 5.17

F_0: force axis intercept; V_0: velocity axis intercept; P_{max}: maximum estimated power; V_{1RM}: velocity associated to the 1RM; V_{1RM}/V_0: ratio between maximum propulsive velocity performed with the 1RM and V_0; F_{1RM}/F_0: ratio between maximum propulsive force performed with the 1RM and F_0; *: Significantly differences within group for pretest- posttest contrasts ($P < 0.05$).

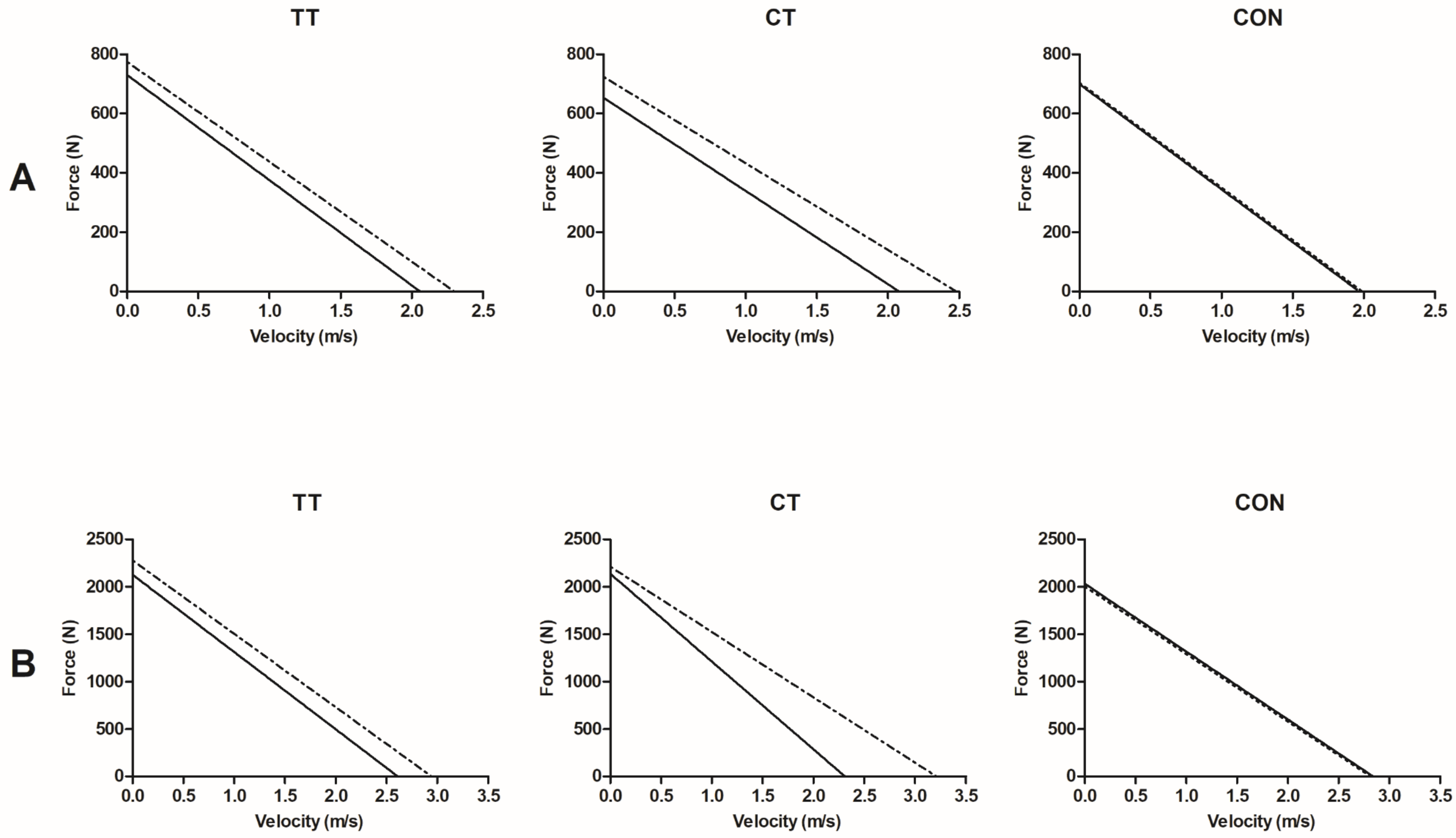


Figure 19. Mean force-velocity relationships of traditional (TT), cluster (CT) and Control (CON) group before (solid line) and after training (dashed line). Figure 5A: Bench press (BP). Figure 5B: Parallel squat (SQ).

5.4.1.5 *Neuromuscular performance*

5.4.1.5.1 Maximal Strength: 1RM

Descriptive and ANOVA results of 1RM are shown in table 3.

Table 3. One repetition maximum (1RM) values before (pretest) and after (posttest) 5 weeks of training using traditional or cluster configurations. Effect size for post-to pretest change is represented by Hedges' G with 95% CI.

	Group	**Pretest** (Mean ± SD) (Kg)	**Posttest** (Mean ± SD) (Kg)	**Hedge's *G*** (95% CI)	**P-value** **(η^2)**		
					time	**group**	**T x G**
BP	TT	68.90 ± 28.56	74.67 ± 30.31*	0.164 (0.103-0.225)	<0.001 (0.531)	0.730 (0.018)	0.001 (0.346)
	CT	60.49 ± 21.04	68.22 ± 23.42*	0.293 (0.160-0.425)			
	CON	64.40 ± 22.34	65.86 ± 21.89	0.015 (-0.068-0.098)			
SQ	TT	197.41 ± 51.53	210.00 ± 50.52*	0.230 (0.124-0.336)	<0.001 (0.481)	0.498 (0.038)	<0.001 (0.425)
	CT	182.92 ± 38.52	199.42 ± 43.40*	0.262 (0.196-0.328)			
	CON	185.16 ± 38.80	183.30 ± 37.40	-0.046 (-0.178-0.086)			

BP: bench press; SQ: parallel squat. TT: traditional training group; CT: cluster training group; CON; control group; T × G: time × group interaction. *: Significantly differences within group for pretest- posttest contrasts (P < 0.05).

5.4.1.5.2 Muscular endurance: 10RM repetitions

Descriptive results are shown in table 4. Respect to the number of repetitions completed with the 10RM load, a significant effect of time (P < 0.001; η^2 = 0.644), group (P = 0.002; η^2 = 0.334) and group × time interaction (P = 0.002; η^2 = 0.334) were detected for BP. Higher number of repetitions were performed after the training period by TT (P < 0.001; η^2 = 0.545) and CT (P < 0.001; η^2 = 0.510). Post-hoc analysis showed that TT carried out 4 repetitions more than CON (P = 0.002). CT also performed 4 repetitions more compared to CON (P = 0.002) in posttest. TT and CT performed similar repetitions in posttest (i.e., 15), therefore, no differences between experimental groups were observed (P = 0.803).

Regarding SQ, a significant effect of time ($P < 0.001$; $\eta^2 = 0.721$), group ($P < 0.001$; $\eta^2 = 0.438$) and group × time interaction was revealed ($P < 0.001$; $\eta^2 = 0.438$). Higher number of repetitions were performed after the training period by TT ($P < 0.001$; $\eta^2 = 0.707$) and CT ($P < 0.001$; $\eta^2 = 0.516$). Post-hoc analysis detected that TT performed 13 repetitions more than CON ($P < 0.001$). In the same line, CT performed 9 repetitions more than CON ($P = 0.003$) in posttest. TT performed and average of 3 repetitions more than CT after training, however this difference did not reach significance ($P = 0.179$).

Table 4. Number of repetitions performed with the 10RM load before (pretest) and after (posttest) 5 weeks of training using traditional or cluster configurations.

	Bench Press		**Parallel Squat**	
Group	**Pretest**	**Posttest**	**Pretest**	**Posttest**
TT	10 ± 0	15 ± 3*	10 ± 0	25 ± 7*
CT	10 ± 1	15 ± 2*	10 ± 0	22 ± 6*
CON	10 ± 1	10 ± 3#	10 ± 1	13 ± 6#

TT: traditional training group; CT: cluster training group; CON; control group; *: Significantly differences within group for pretest- posttest contrasts ($P < 0.05$); #: Significantly different from TT and CT ($P < 0.05$).

5.4.1.5.3 Maximal power output

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 ($P < 0.001$; $\eta^2 = 0.528$). Additionally, a group × time interaction was detected ($P < 0.001$; $\eta^2 = 0.356$). 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 ($P < 0.001$; $\eta^2 = 0.309$) and a group × time interaction ($P = 0.019$; $\eta^2 = 0.197$) 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 ($P = 0.532$).

5.4.1.5.4 CMJ performance

Focus on CMJ performance (Table 5), two-way repeated measures ANOVA showed a main effect of time ($P < 0.001$; $\eta^2 = 0.324$) with greater values in posttest regarding height. No group ($P = 0.830$) nor interaction effect was observed ($P = 0.586$). Respect to the value of the maximum power output, a time effect was detected ($P = 0.001$; $\eta^2 = 0.261$) with higher values in posttest. No group ($P = 0.876$) nor interaction was observed ($P = 0.269$). Regarding force, analysis revealed no effect of time ($P = 0.240$), group ($P = 0.879$), nor interaction between them ($P = 0.998$).

Table 5. Countermovement jump results pre and post intervention performed by all the study groups.

Group		**Pretest**	
	Height (cm)	P_{max}(W)	Force (N)
TT	42.02 ± 8.10	3597.76 ± 903.97	1750 ± 334.52
CT	43.45 ± 5.85	3544.64 ± 936.83	1681.60 ± 374.11
CON	43.06 ± 6.05	3448,51 ± 966.25	1713.79 ± 328.26
		Posttest	
TT	44.12 ± 8.29	4051.92 ± 1224.49	1785.62 ± 308.70
CT	46.26 ± 7.23	3722.86 ± 1007.06	1713.40 ± 318.80
CON	44.53 ± 6.72	3782.85 ± 852.45	1749.79 ± 378.09

CMJ: Countermovement jump; P_{max}: maximum power output during push-off phase; TT: traditional group; CT: cluster group; CON: control group.

5.4.2 Cardiovascular results

5.4.2.1 Heart rate response during intervention

The analysis of the average of maximum heart rate revealed no session effect (P = 0.460) nor interaction (P = 0.216). A group effect (P < 0.001; η^2= 0.506) was detected with higher values of heart rate in TT (166.104 ± 3.87 bpm) compared to CT (140.146 ± 4.24 bpm).

5.4.2.2 Heart rate variability

Regarding time domain parameters, no time (P = 0.551), group (P = 0.355) nor interaction (P = 0.558) were detected for SDNN. Mean values for this variable were 68.28 ± 6.60 ms for TT, 78.09 ± 7.17 ms for CT and 64.51 ± 6.14 for CON. Also, for RMSSD no time (P = 0.534), group (P = 0.647) nor interaction (P = 0.570) were observed. Mean values for this variable corresponded to 78.59 ± 9.27 ms for TT, 90.50 ± 10.07 ms for CT and 80.17 ± 8.63 ms for CON. Results are presented in figure 20.

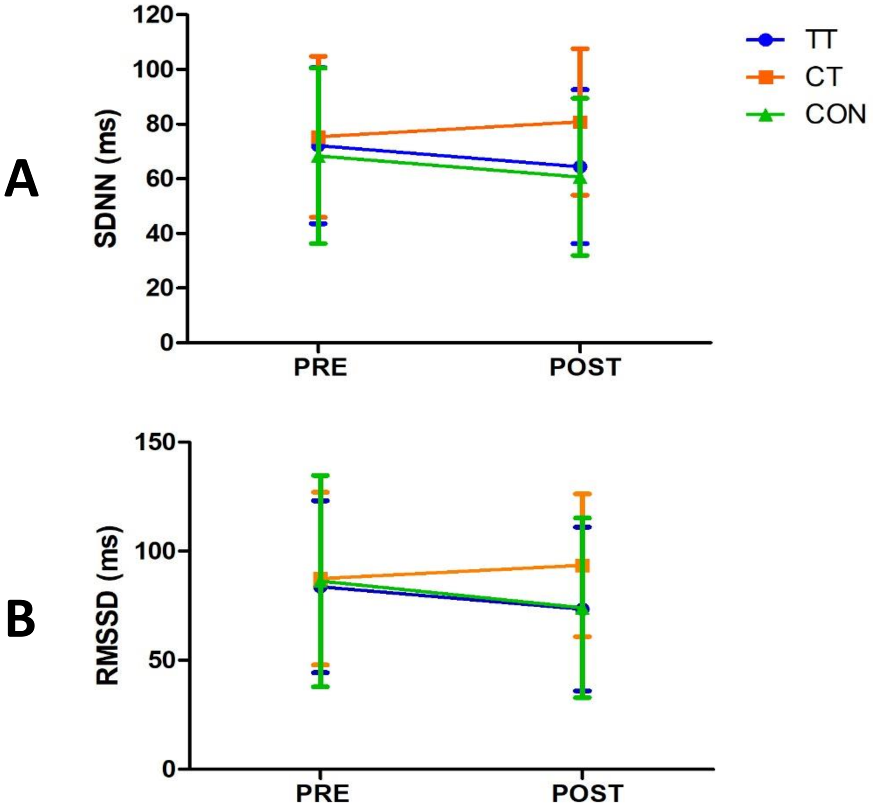


Figure 20. SDNN (A) and RMSSD (B) obtained before (pre) and after training intervention (post) for traditional (TT), cluster (CT) and Control (CON) group. Data are presented as mean ± SD.

For power of HF, non-parametric ANOVA test reflected no time (P = 0.437), group (P = 0.742) nor interaction (P = 0.226). Also, for power of HF with normalized units no time (P = 0.161), group (P = 0.629) nor interaction (P = 0.556) effect were observed.

Regarding power of the LF, no time (P = 0.168), group (P = 0.711) nor interaction (P = 0.634) were revealed. Also, for power of LF with normalized units no time (P = 0.197), group (P = 0.622) nor interaction (P = 0.602) effect were observed. Focus on LF/HF, no time (P = 0.175), group (P = 0.620) nor interaction (P = 0.581) were detected. Results are presented in figure 21.

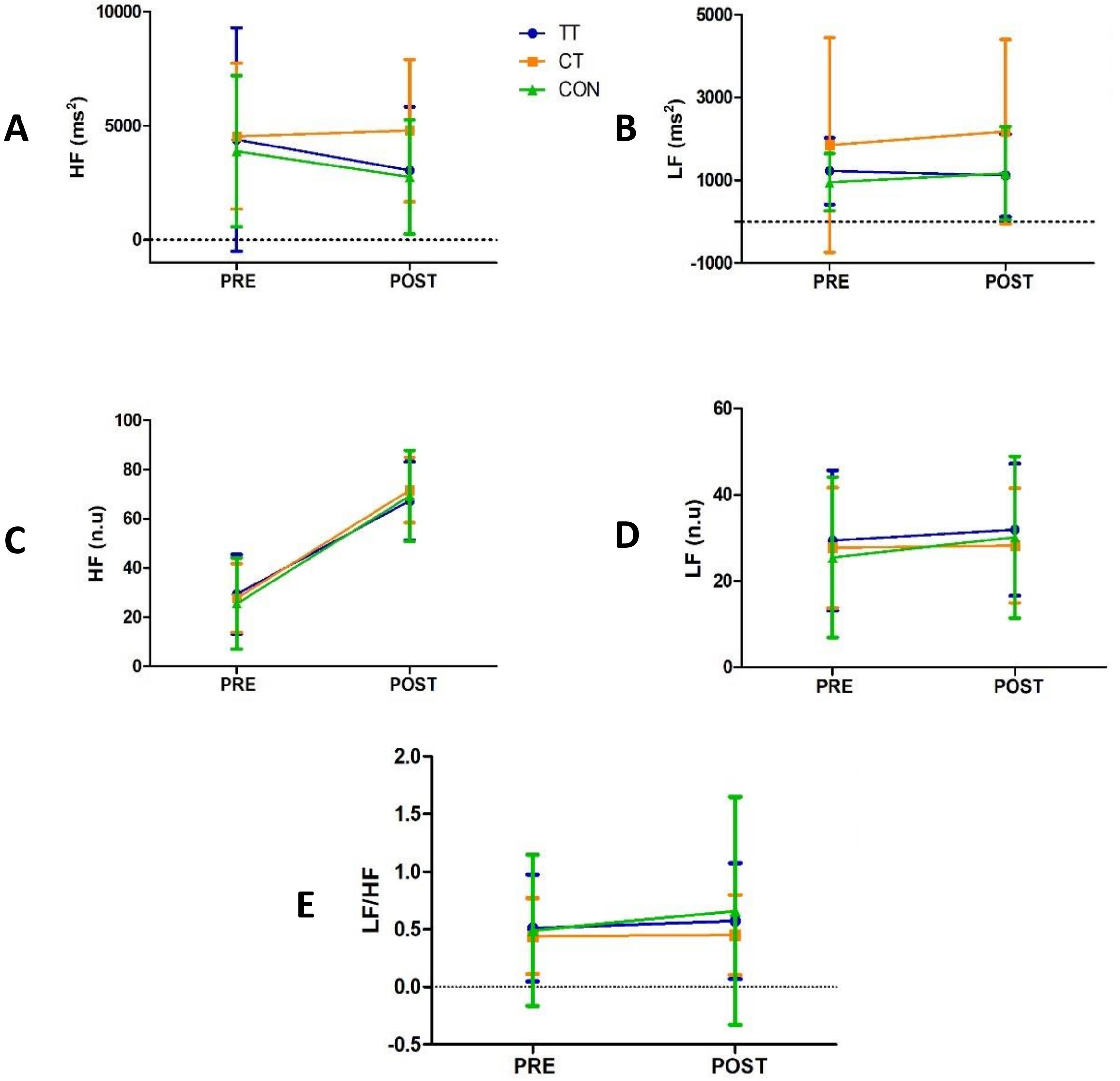


Figure 21. High frequency (HF) and low frequency (LF) in absolute (A-B) and normalized units (n.u) (C-D) and the ratio between the power of low and high frequency (LF/HF) (E) obtained before (pre) and after training intervention (post) for traditional (TT), cluster (CT) and Control (CON) group. Data are presented as mean ± SD.

For ApEn, results showed no time (P = 0.376), group (P = 0.702) nor interaction effect (P =0.514). Regarding SampEn, results revealed no group (P = 0.677) and nor interaction (P =0.872) effect but a tendency in time (P = 0.063) was detected. Results are presented in figure 22.

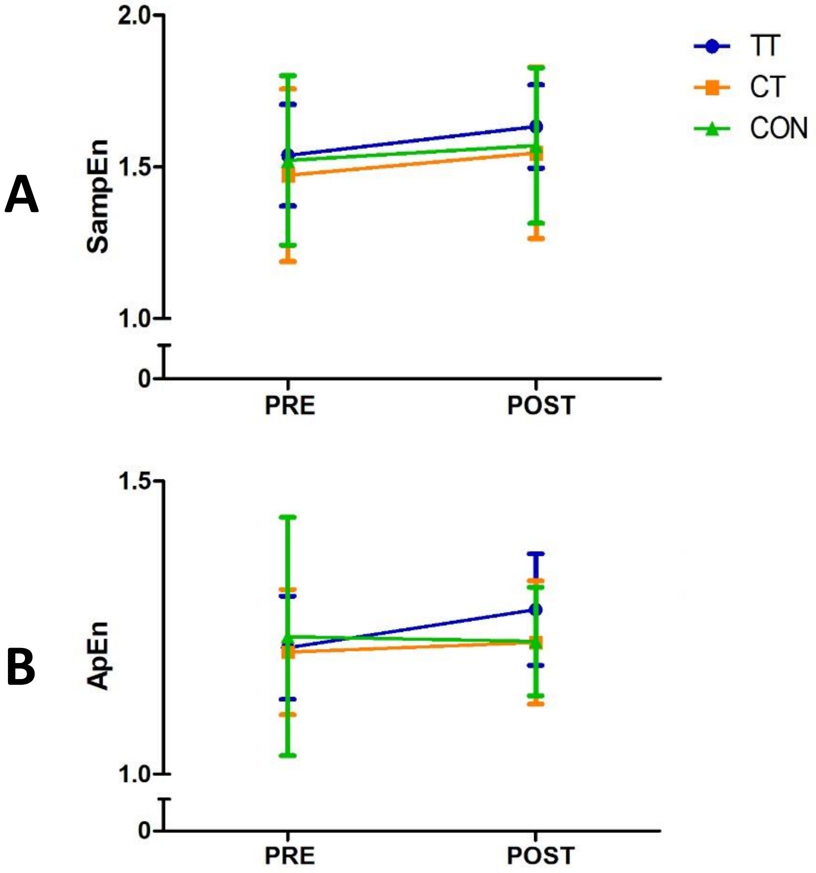


Figure 22. Sample entropy (SampEn) (A) and approximate entropy (ApEn) (B) obtained before (pre) and after training intervention (post) for traditional (TT), cluster (CT) and Control (CON) group. Data are presented as mean ± SD.

5.4.2.3 Blood pressure variability

For SBP, results showed no time (P = 0.789), group (P = 0.760) nor interaction effect (P =0.723). Regarding DBP, results showed no time (P = 0.079), group (P = 0.503) nor interaction effect (P =0.810). For MAP, results showed no time (P = 0.320), group (P = 0.577) nor interaction effect (P =0.466). Finally, for the LF power of SBP no time (P = 0.730), group (P = 0.748) nor interaction effect (P =0.530) were revealed. Results are presented in figure 23.

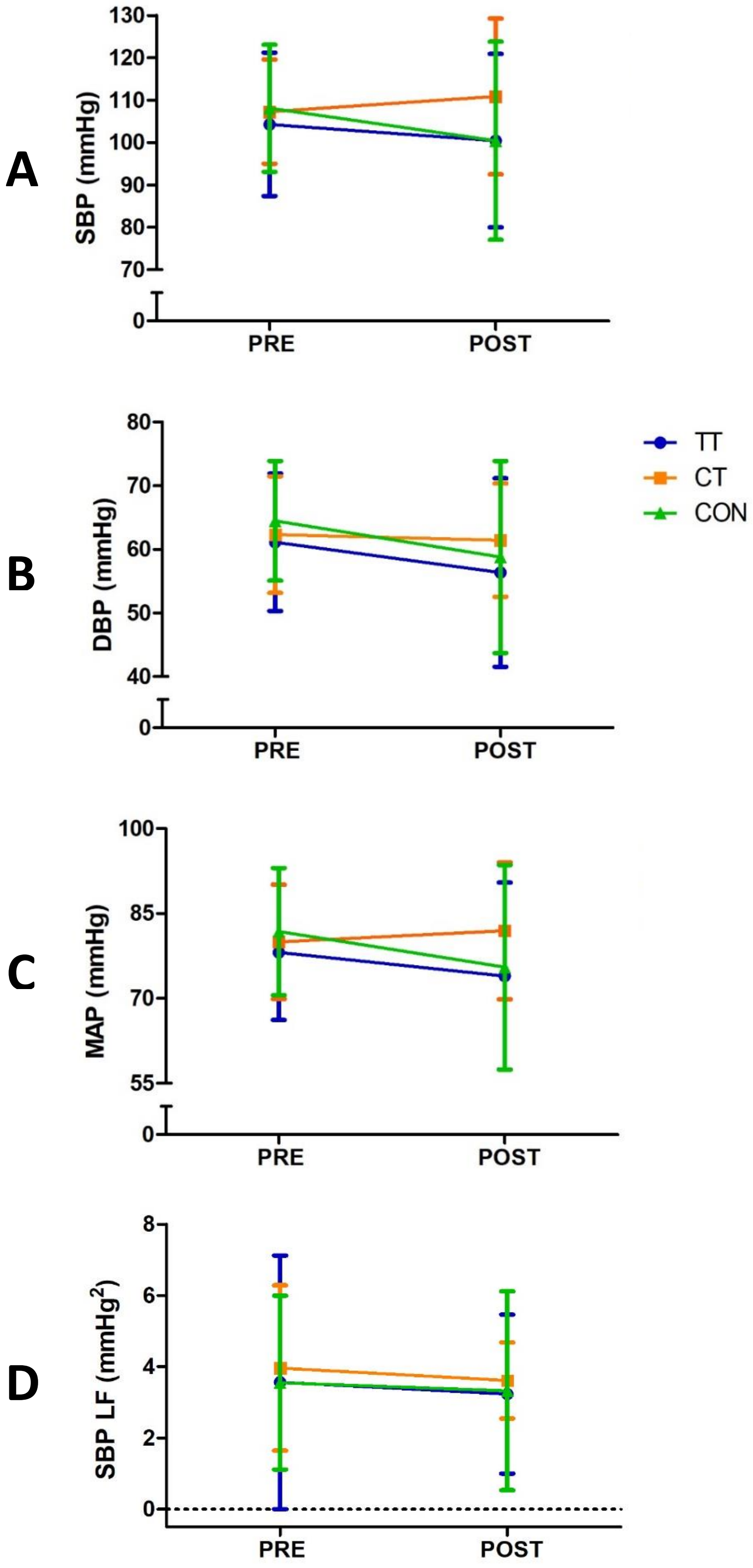


Figure 23. Systolic blood pressure (SBP) (A), diastolic blood pressure (DBP) (B) mean arterial pressure (MAP) (C) and lower frequency of SBP (D) obtained before (pre) after training intervention (post) for traditional (TT), cluster (CT) and Control (CON) group. Data are presented as mean ± SD.

5.

For BRS no time (P = 0.436), group (P = 0.252) nor interaction effect (P =0.212) were revealed. Results are presented. Regarding BEI, no group (P = 0.653) or time (P = 0.091) effect was detected. Finally, a group × time interaction effect (P =0.037) was revealed. Higher values in pretest was observed for TT in comparison with CT and CON (Figure 24).

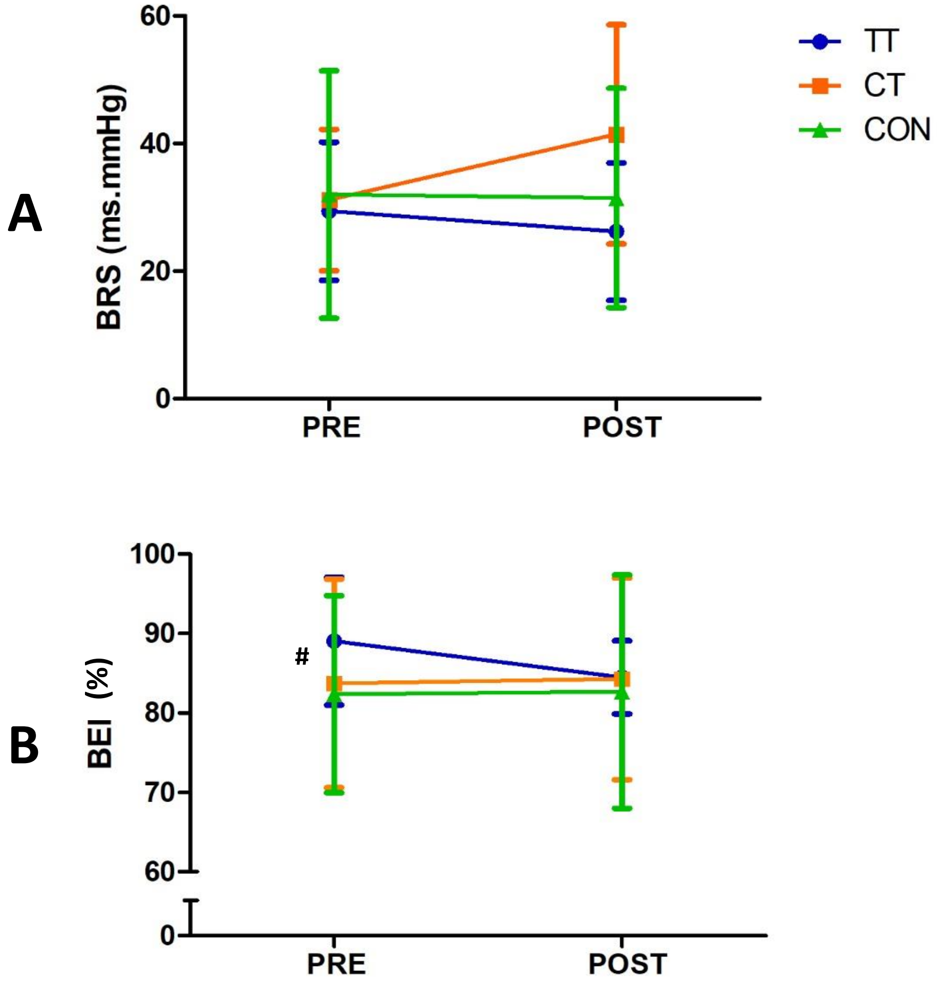


Figure 24. Baroreflex sensitivity (BRS) (A) and Baroreflex effectiveness index (BEI) (B) obtained before (pre) and after training intervention (post) for traditional (TT), cluster (CT) and Control (CON) group. Data are presented as mean ± SD. #: Significant differences between groups in pretest (P ≤ 0.05).

5.5 Discussion

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, muscular endurance and jump performance; (iii) MPP_{max} was greater for BP after both protocols while for SQ only improvements were found after CT; (iv) 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); (v) for SQ, changes in F-V parameters were observed with CT towards a velocity profile, whereas these changes were not observed in TT; (vi) 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; and (vii) no alterations in the autonomic control and in the cardiac baroreflex control were observed after intervention, however CT resulted in lower heart rate response during sessions compared to TT.

5.5.1 Lactacidaemia

In agreement with other studies, blood lactate concentration after training sessions was higher in TT in comparison with CT (19,122,124). In this study, the mean differences between the experimental groups were 3.69 mmol. L^{-1}, being an average of 7.56 ± 0.54 mmol. L^{-1} and 3.87 ± 0.63 mmol. L^{-1} for TT and CT respectively. TT produced almost twice the value of lactate concentration in comparison with CT. This is in line with other studies were TT presented practically the double of the CT lactate measurement (i.e., 12.78 ± 1.90 vs. 7.69 ± 3.73) (19). On the other hand, one study reported that the highest peak lactate values were obtained after performing 8-12 repetitions per set, as happened in this study (106). Literature have revealed that after a fatiguing maximum voluntary contraction (i.e., with a duration of about 1 minute) PCr needs 2 minutes in order to recover 67 % of its stores (118). In this study, TT entailed sets of 8 repetitions that lasted approximately 4 times more the duration of each set of 2 repetitions performed by CT. In this sense, it could be deduced that PCr consumption was higher for TT in comparison with CT during a set. Therefore, the anaerobic metabolism contributed in a higher magnitude in TT in order to produce energy. Literature revealed that the major PCr depletion occurred in the first half of a 10 repetition set, while muscle lactate accumulation was more related with the second half (167). This suggests that it was reasonable that TT entailed more lactate production with a greater PCr depletion than CT. In this line, the relationship between lactate production and PCr concentration was confirmed to be inverse (119,167). Therefore, as lactate accumulation was lower in CT, we can suggest that the redistribution of the pause allowed the partial replenishment of PCr stores. This reveals that cluster sets, reduced the glycolytic involvement of the training session (17). In this sense, our hypothesis (related to the lower lactate production cause by cluster protocols) could be accepted.

5.5.2 Mechanical parameters

The average MVP values of the training intervention were similar for both experimental protocols in the case of the BP exercise, while greater values were observed for CT regarding SQ. This could derive in different F-V relationship adaptations for BP and SQ. In the following paragraphs these questions are going to be explained.

Primarily, the velocity loss and the velocity maintenance parameters were examined regarding six different variables throughout the training intervention. Greater velocity maintenance and lower velocity loss were observed for CT throughout all the training program. In this line, acute studies reported greater velocity loss during longer sets for many resistance exercises (21,25,106,109,116). The studies of Davies et al. (110) and Tufano et al. (22) included the maintenance of velocity within each set and across a full training session. They took into account every repetition performed (i.e., average of the session and sets) and the value of the first repetition recorded. Results revealed greater maintenance of velocity for CT in comparison with TT for most of the sets performed. Additionally, the ability to maintain mean velocity throughout the session was greater for CT. In the same line as the current study, Fariñas et al. (157) analysed the velocity loss throughout all the training program regarding the velocity values of the first and the last repetition of each session. They found greater velocity loss percentages for TT (- 34 %) in comparison with CT (- 5 %) for the unilateral biceps curl exercise. In the current study we found similar percentages in the evaluated variables for the upper body muscles. For example, regarding LFR, TT presented velocity losses of 39 % and CT exhibited a 13 % for the BP exercise. This is due in part, because during muscle contractions, the increases in inorganic phosphate by the breakdown of PCr are related to a reduction in the velocity of shortening (168). Additionally, the myosin heavy chain IIX (i.e., the fastest isoform), is reduced during consecutive contractions, which also contributes to a velocity decline (97,169). The current study supports the idea that cluster structures are effective to attenuate velocity reduction during training by the diminution of the glycolytic involvement, due to the redistribution of the recovery periods.

Moreover, it is necessary to point out that differences in velocity loss were not the same for BP and SQ. Regarding BP, the velocity loss values across sessions represented, for example, by LMaxR (i.e., last repetition/maximum repetition value) 48 % for TT and 24 % for CT, whereas for SQ, losses of 25 % and 16 % were observed in TT and CT, respectively. We found similar outcomes to those previously reported, indicating higher values of velocity loss for BP in comparison with SQ (106,170). Authors revealed that differences could be due because the 1RM velocity reached in BP tend to be lower in comparison with SQ as happened in this thesis (average of 0.19 m/s and 0.29 m/s for BP and SQ respectively). The inferior velocity recorded in BP is reasonable because of the lower muscle groups involved and the lower coordination needed, that entailed more localized fatigue in comparison with SQ (106,170). In this sense, as the average of the MPV achieved during training was similar for both exercises (0.48 m/s and 0.50 m/s in SQ and BP respectively) BP seems to has a higher velocity range until its V_{1RM} value in comparison with SQ. Additionally, the average of the maximum MPV values reached during intervention corresponded to 0.54 m/s for SQ and 0.60 m/s for BP, strengthening the idea that a large velocity range is experienced during the BP exercise. As the comparisons between exercises were not calculated, this topic needs further investigation.

5.5.3 Goodness of fit

The analysis of the F-V relationship data showed a great goodness of fit of the linear model. This outcomes are similar to others previously reported for BP (8,49) and SQ (7,40). 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). This confirms that the linear model is appropriate in order to describe the F-V relationship for many multi-joint exercises, at least in the range of loads usually evaluated in human studies (64). Nevertheless, this topic needs further investigation. Other approaches also reported a great goodness of fit. For example, values over 0.900 of R^2 were reported for the polynomial model (64,171). However, the reliability of the polynomial parameters (for example, the coefficient that represents the concavity of the curve), was lower in comparison with the reliability of the linear parameters (65). A recent study reported the comparison between the linear, hyperbolic and double-hyperbolic approaches in order to describe the F-V data of the leg press and BP exercises (171). Authors revealed that hyperbolic equations overestimated F_0 values (13 ± 11 % and 6 ± 6 % in leg press and BP respectively) and that the linear model is valid to evaluate the F-V parameters in a range between the 25 and the 100% of F_0. They observed that the double-hyperbolic approach presented the greater goodness of fit. However, more studies are needed in order to confirm these results. In short, the linear model is considered valid in order to describe the F-V relationship of multi-joint exercises and it is recommended because its simplicity.

5.5.4 F-V relationship

Focusing on BP, changes in F-V parameters were similar for both training protocols. In this sense, there were no differences in the improvements in F_0 after TT (6.86 %) and CT (10.75 %). The enhancement of V_0 was also similar for both configurations (11.65 % and 19.23 % for TT and CT respectively). However, the effect size was greater for CT regarding both parameters (F_0: 0.242 vs. 0.113; V_0: 1.259 vs. 0.595) with specially differences in V_0.

The improvements in F_0 and V_0, could have contributed to the similar increment of P_{max} after both training protocols. There was a displacement of the F-V profile to the right, with no changes in the slope (i.e., the linear regression stayed nearly parallel to the pretest one). However, the displacement was more pronounced in the CT group. Despite no differences between groups were found in the P_{max}, this displacement should be considered similar. The results showed that both training regimes produced similar changes in the entire F-V spectrum for BP.

One possible reason, that could explain these results, are the velocity values at which the training intervention was carried out. Although CT was found to be better for velocity maintenance, there were no major differences between protocols regarding the average MPV of the entire intervention for BP. This suggests that despite greater velocity loss was observed for TT, a high number of repetitions should have been performed at a medium-high velocity. The study of Izquierdo et al. (170) revealed that during continuous repetitions at 75 % of 1RM, significant reduction in average velocity occurred at one third of the set (i.e., 34 %) in the case of BP. This suggests that at least 3 repetitions (of the 8 executed) in the TT group were performed at a great velocity. We hypothesised that the rest of the repetitions were carried out at a medium-low velocity, at least in the initial part of the investigation. It was remarkable that the values of velocity loss were progressively better during intervention (i.e., there were less velocity loss percentages in the last training sessions). This indicates that in the last part of the study a greater number of repetitions were performed at a high velocity for TT.

On the other hand, the effect of the training sessions produced a progressively adaptation to the load used. In this sense, we hypothesised that if the training load was adjusted to the individual improvements (in order to always represent the 10RM), the differences in velocity loss between configurations would always be large throughout sessions. In this regard, it was possible that TT did not reach a significant improvement regarding V_0 while the more frequent recovery periods in the CT regimen would maintain the enhancement of this variable.

To the best of our knowledge, this is the first study that analysed the changes in the F-V relationship for the upper-body muscles. Contrary to our hypothesis, we can conclude that CT did not produce a greater shift in the high-velocity portion of the F-V spectrum compared to TT. Both training protocols produced the same change in the F-V relationship toward a more power-oriented profile. This means that F-V profile experimented a rightward shift due to the concomitant improvements in V_0 and F_0 to finally result in a large power enhancement. Nevertheless, it must be pointed out that in this exercise the effect size for the changes of V_0 was higher for CT. This suggests an effect toward a higher velocity profile in CT. Since the appearance of an effect may be a matter of time, further studies should implement longer training programmes in order to elucidate this possibility.

Regarding SQ, F-V parameters changed in a different manner while performing TT or CT protocols. Firstly, CT produced alterations in the slope and V_0. Slope values were higher after training, representing an increase of 29.2 %. In this sense, a flatter linear regression was observed after intervention. This is due because of the large V_0 improvements (i.e., 39 %) while F_0 remained without changes. On the other hand, TT produced only changes in F_0 while V_0 and the slope achieved similar values in pretest and posttest. F_0 results were higher after training and improvements were represented by 7.1 %. P_{max} (i.e., $[F_0 \times V_0) /4]$) increased after both training configurations without group differences. In this sense, our outcomes suggest that improvements in the maximum estimated power were mainly caused by force gains in the case of TT and by velocity gains in the CT group.

Despite both groups trained in the same part of the F-V relationship, velocity tend to get further from the V_0 as the repetitions occur in a traditional set. This phenomenon does not happen in the cluster training, where the pauses between sets allow the maintenance of velocity around the same point of the F-V relationship. We suggest that the accumulation of repetitions in the “lowest part” of the training F-V portion (that was experimented by TT) was the reason why protocols had a different impact on V_0.

In short, we found that CT produced a large improvement in the high-velocity region of the F-V profile while TT does not. Other study that examined lower body exercises, found that CT led to a great improvement in the high-velocity region of the F-V relationship (24). In line with our results, large V_0 improvements were observed after training (i.e., 32%) causing flattened slopes (i.e., 22.42 %). Additionally, the F_0 increased only after TT, while P_{max} improvements occurred without differences between configurations. However, the work-to-rest ratio was not equated as happened in our study. Participants in CT had 30 extra seconds of recovery between each repetition, that could contribute to enhance the differences between protocols regarding V_0. On the other hand, contrary to our results, the study of Iglesias-Soler et al. (23) found similar changes in the F-V profile after both CT and TT following 5 weeks of unilateral leg extension training. Their outcomes showed higher values of F_0 and P_{max} after intervention with steeper slopes due to the lack of improvements in V_0. Therefore, they revealed that both configurations produced similar adaptations of the F-V profile toward higher force capabilities. Similar conclusions were reported by Goto et al. (124) also performing unilateral leg extension. They found that TT protocol produced greater increases in F_0 compared to CT (19.1 % vs 7.2 %) while no differences in V_0 were observed. However, this study did not report the values of all F-V parameters, because they did not adjust the data to a regression model. Despite this, results suggest that steeper slopes would appear after training for TT, towards a force-oriented profile. Other study revealed similar F-V profile changes after 3 weeks of plyometric training (i.e., loaded CMJ) (156). Although this investigation included a lower body exercise, the load used during training was velocity-oriented (i.e., 20 % 1RM) and this difficulted the comparison with our results. In this sense, it is reasonable that authors did not find any changes in F_0 after CT or TT as higher loads are needed to caused that effect (83,172). In this sense, both training protocols produced similar increases in velocity and power in the intermediate zone of the F-V profile without changes in slope.

These contradictory conclusions may be due to several factors. Firstly, the use of unilateral exercises where the cross education phenomenon could alter the results (longer set configurations produced greater cross education effect than shorter sets (157)). In this regard, literature revealed that it was observed bilateral activation in different brain areas related with the motor planning and force production during unilateral exercises, resulting in adaptations that may be accessible by both brain hemispheres (173). Therefore, three previous studies analysed unilateral leg extension but only one of them was in agreement with our study (24). In the investigation of Carneiro et al. (24), the effect of the cross-education phenomenon could be minimal because of the few number of repetitions (i.e., 4) performed in TT (due to the high load used). However, in the study of Iglesias-Soler et al. (23) there was a probability that the cross-education phenomenon could alter the outcomes, due to the longer set configuration performed by TT (i.e., 8 repetitions) in comparison with CT (sets of 1 repetition). In this sense, it was possible that force improvements achieved by the TT leg were partially transferred to the leg that followed CT, deriving in similar changes in the F-V profile toward force capabilities. Nevertheless, the authors of this study, affirmed in a past complementary investigation, that there were no differences in the cross education magnitude (between CT and TT) for this kind of intervention (101). A recent evidence observed that TT produced a higher cross education effect in upper-body and lower body muscles (157,174), so these confounding conclusions need to be clarified in further studies. Finally, the third study that reported the F-V profile for unilateral leg extension followed a different intervention protocol, that did not include this exercise. In this sense, no cross-education phenomenon could occur. Beyond the cross-education limitation, differences in the load used, work-to rest ratio, intervention length and evaluated population may be the principal factors for contradictory results. In short, our outcomes confirm that CT enhanced the higher velocity portion of the F-V spectrum for SQ. In this sense, the lower velocity loss experienced by the CT protocol finally derive in a velocity-oriented profile in SQ. Our hypothesis could be accepted for the SQ exercise.

Considering the results from both exercises as a whole, it seems that exercises which imply more mechanical and neural control (i.e., with a higher muscle mass, number of joints and degrees of freedom involved such as occurs in SQ in comparison with BP) do not experiment notable alterations in F-V relationship as a consequence of performing TT protocols. This also occurred in the study of Morales-Artacho et al. (156), were no changes in slope were observed performing squat jumps following TT protocols.

In this regard, our results suggest that exercises that imply less muscle implication such as BP obtain similar F-V parameters changes by performing TT or CT protocols at least in short-middle periods. This is in agreement with a previous study in which similar changes in F-V relationship were observed after 5 weeks of unilateral leg extension (considering leg extension as an exercise that needs lower coordination and postural control) (23). However, different changes performing CT or TT were revealed in the study of Carneiro et al. (24) after 8 weeks of also unilateral leg extension. This means that simpler exercises need more time to be beneficiated by a CT intervention. As was previously mentioned the effect size for the changes of V_0 were greater for CT than TT in the case of BP (1.548 vs 0.970). This suggests that a later effect toward a higher velocity profile will occur in CT proposing that the appearance of a significant effect may be a matter of time.

Another explanation to the different effects of set configuration depending on the exercise performed, could be found regarding the velocity loss variables. As was previously mentioned, the velocity loss was more pronounced through the sessions in BP 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.

In brief, upper and lower-body limb exercises improve the F-V profile in a different manner after both training programmes. Only a velocity-oriented profile was observed after CT for SQ while BP progressed toward a power-oriented profile after both configurations.

On the other hand, it must be pointed out that it is difficult to found studies were a training protocol produced significant increases or changes in V_0. Firstly, the lack of changes in this parameter in the studies related to set configuration, could be cause by the differences in the exercise or in the training intervention design (i.e., specially the load used and the intervention length). In this sense, only our study and the investigation of Carneiro et al. (24) found significant V_0 improvements using higher loads (i.e., > 80 % 1RM).

In general, other studies that tried to increase V_0 toward a more velocity-oriented F-V profile used plyometric training or resistance training exercises with light loads (i.e.,< 50 % of body mass) (84,86,95,96). For example, in the study of Jiménez-Reyes et al. (95) the F-V relationship was measured for CMJ. Training programmes were design in order to reduce the F-V imbalance from the optimal profile (51). After 9 weeks of power-speed oriented exercises, V_0 values increased 17 % in the velocity-deficit group. Another study reported higher V_0 values after an intervention using attached rubber bands on the barbell (i.e., calling it an “inertia” condition) (86). The authors reported higher values of V_0 in the group “inertia” compared with the other conditions (i.e., “weight” and “weigh plus inertia”). As our training intervention corresponds to a “weight plus inertia” condition (i.e., the use of barbell and plates), we suggest that the application of cluster protocols may result in an easier way to increase V_0 compared with a more complex inertia design. In this sense, this thesis confirms that it is possible to increase V_0 with a training intervention that used high load and volume.

Finally, as complementary features of the individual mechanical profile, the position of the force and the velocity associated with the 1RM were evaluated. 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 (40). In this regard, only the implementation of cluster structures caused increments in F_{1RM}/F_0 for SQ, while TT and CT increased this ratio for BP in a similar manner. Thus, our outcomes suggest that F_{1RM}/F_0 is affected by the set configuration in resistance training for SQ. This indicates that despite no significant increments were observed in F_0, the value of the maximal strength was greater and therefore the ratio increased. In this sense, the value of the F_{1RM} was closer to the F_0 value (that did not change) after training. This suggests that although no changes were observed in the high-force region of the CT group in SQ, CT participants were stronger after training. In line with this observation, in the study of Goto et al. (124) participants from the CT group did not reach significant improvements in lower limbs isometric force but they gain muscular strength after the training period. On the other hand, concomitant changes of V_{1RM} and V_0 in SQ resulted in similar V_{1RM}/V_0 ratios before and after training. In contrast, V_0 increments after both training programmes entailed a decrease of this ratio for BP. These results for BP are consistent with previous studies suggesting the stability of V_{1RM} (41). However, this was not the case for SQ since both V_{1RM} and V_0 were affected by training in a similar proportion as indicated by the lack of significant changes in V_{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 (65).

5.5.5 Neuromuscular performance

5.5.5.1 Strength 1RM

In agreement with other studies, strength gains related to 1RM were similar for TT and CT regarding both BP and SQ (101,148,155). However, the effect size was higher in CT for the BP exercise (0.293 vs. 0.164). Although different F-V profile changes occurred, CT group also enhanced maximal strength in SQ (despite it was altered toward a velocity-oriented profile). In this case, the F_{1RM} improvements were significant but not as high to finally cause an enhancement in F_0.

This confirms that rest-redistribution protocols with the same volume, load, total rest and intended velocity produced similar improvements in strength than a traditional regimen after a period of at least 5 weeks (101,103). This study is in contrast with others that reported higher strength gains after TT (149,150,157) or CT configurations (175). Differences in studies designs and protocols could explain these conflicting adaptations.

In this study, the strength improvement ranged between a percentage of 6.4 % and 12.8 % being consistent with other investigation with similar intervention length (between 8 % and 13 %) (155). Both traditional and cluster sets were suggest to improve maximal strength after a middle-term study without cortical specific adaptations (101). Additionally, this enhancement was produced despite the large differences in glycolytic involvement (i.e., blood lactate concentration) and in mechanical performance (i.e., velocity loss) observed in this thesis. Another study confirmed this affirmation reporting that metabolic stress and repetition velocity were secondary for the development of maximal strength (155). This idea was previously explained in the study of Folland et al. (152) where two protocols differing in set configuration and in the level of fatigue (i.e., TT: 4 sets x 10 repetitions with 30 seconds of rest; CT: 40 repetitions with 30 seconds of recovery) presented similar strength gains after 9 weeks. They reported that TT participants experienced severe muscle soreness (i.e., indicative of muscle damage) that CT did not exhibit. Despite these differences, both groups incremented their 1RM load for the leg extension exercise after intervention. This reaffirms that including more frequent recovery periods in order to minimise fatigue is a valid alternative in order to improve strength. In this regard, both training protocols increased (without differences) their maximal strength as we had hypothesised.

5.5.5.2 Muscular endurance (10RM repetitions)

Results from this study showed that both training programmes led to similar improvements in muscular endurance for BP and SQ. These outcomes are in agreement with others reported by Izquierdo et al. (153) regarding SQ. However, these authors found greater muscular endurance after TT to failure in the case of BP. They suggest that training to failure could provide and advantage for the upper body muscles. However, in the present study, cluster structures provided a novel stimulus that enhanced upper body muscular endurance without reaching the muscular failure. The study of Fariñas et al. (157) also revealed only greater improvements in muscular endurance after TT regarding unilateral biceps curl. They hypothesised that TT and CT structures promoted different recruitment patterns that finally produce different changes in the number of repetitions performed with the pretest 10RM load. Discrepancies between experiments could be due because the unilateral biceps curl involve lower muscle mass than BP, that could faster reach fatigue (more localized fatigue) (106). In this sense, BP fatigue could be distributed among a greater amount of muscle mass and therefore it does not represent the only critical parameter for the muscular endurance development. Additionally, volume could play an important role in this context being higher in our study (i.e., 6 repetitions more during each session and therefore more intervention time).

This study reaffirms the idea that it is not necessary to reach muscular failure in order to improve muscular endurance and that CT provides novel and different stimulus that finally benefit this parameter. In this sense, our hypothesis that both training protocols improve (without differences) the muscular endurance could be accepted.

5.5.5.3 Mean Maximal Power Output (MPP_{max})

Focusing on BP, both TT and CT increased their MPP_{max} values after training, however the effect size was higher for CT (0.418 vs. 0.286). This enhancement is reasonable as similar increases in the P_{max} were observed after both protocols, resulting in a more power-oriented profile. Results are in agreement with a similar length term study (i.e., 6 weeks), that found higher mean power output after CT and TT for upper body muscles (149). However, a longer term study (i.e., 12 weeks) found higher maximum mean power output in BP only performing CT (151). In this regard, as we found higher effect size after CT for BP, we hypothesised that a longer intervention could beneficiate in higher magnitude the power output production in the CT group.

Regarding SQ, MPP_{max} achieved higher values after training only in CT. Many studies revealed the advantage to increase maximal power output after CT in lower extremities exercises (153,156,176) while others revealed similar outcomes for both CT and TT (101,151). Differences in studies designs and intervention length could explain these dissimilarities. In the study of Izquierdo et al. (153), the superiority of CT for lower limb power development was found after the 16th week. In this sense, some interventions could need more time to observed significant differences between configurations. On the other hand, despite the increments in P_{max} were similar for both training protocols, the higher values observed in MPP_{max} after CT suggest that cluster structures are optimal to develop lower body power capabilities. As the distribution of the number of repetitions and the recovery time showed to be important in order to improve power output (22), this study provide a practical example to enhance this parameter. Finally, our hypothesis has to be partially accepted, because MMP_{max} values were only greater after CT for the SQ exercise while no differences between protocols were observed in BP.

5.5.5.4 Countermovement jump (CMJ)

In order to examine lower body strength and power development, CMJ test was performed before and after training. Results showed no statistical differences between training protocols regarding force, maximum power and height. Other studies are in agreement with these results reporting similar height (177) force and power output (150) after CT or TT. However, they also reported greater effect size for peak power (150,178) and height (177) after CT. These differences could be due because of the training intervention (i.e., exercises performed and load used) and the study length. For example, in the study of Oliver et al. (175) the maximum power produced during CMJ were measured after 4, 8 and 12 weeks. Significant differences in power between protocols were only observed after 12 weeks. On the other hand, studies that reported greater jump performance after CT also included in their intervention plyometric training (177,178). The combination of strength and power exercises has shown to be beneficial for the improvement of maximum jump height and maximum power output (95,179). In this sense, it is reasonable that greater results were observed after interventions that include the exercises that are going to be tested. This also had influence in the jump technique, because participants that performed jumps during all the intervention will be better familiarised with a correct execution. Additionally, the design of the training intervention regarding load selection may also affect the power adaptation (150). Resistance between 30 and 45 % of the 1RM were found to be optimal for the development of the maximum mechanical power (180). In this sense, it can be hypothesised that studies that used loads closer to the optimal power range could be more beneficiated by a cluster structure (that it was shown to result in a higher velocity of movement). In the present study, the loads performed during training intervention ranged between 78 % and 81 % of 1RM that are above the power threshold. However, increases in maximal strength are also necessary to enhance power (181). In this study, both TT and CT improved their maximum strength in a similar manner and that could be one of the reasons for the enhancement in jump performance. Additionally, both training groups improve in a similar manner their P_{max} regarding the SQ exercise. However, greater MPP_{max} values were only observed after CT.

In agreement with other studies, we can conclude that in order to optimize the power development for CMJ, it is recommended a combination of both traditional and cluster training for the correct development of force and velocity capabilities (150).

5.5.6 Cardiovascular responses and adaptations.

Results from this study revealed that maximum heart rate average was greater in TT compared to CT throughout the training intervention. Acute studies also reported higher mean and maximum heart rate values during one training session performing TT (117,140,142). However no differences between protocols were observed in the study of Polito et al. (141) performing knee extension. They reported that heart rate depends on the amount of muscle mass involved, exercise duration and intensity. In our study, 4 exercises were performed by session, involving upper and lower body muscles for 1 hour and 30 minutes. In this sense, it was reasonable that heart rate increases and that the redistribution of the rest in CT contributed to the partial recovery of this parameter. In line with our hypothesis, we can conclude that CT sessions resulted in lower hear rate peak response than TT.

To the best of our knowledge, middle-long term studies reporting cardiovascular adaptations after resistance training differing in set configuration are almost non-existent. Only one study has evaluated some of these parameters, focusing on HRV (147). Therefore, no previous middle-term study presented information about the blood pressure variability or the baroreflex mechanism after performing resistance training programmes with different set configuration. In this sense, in order to explain the obtained results and do the proper comparisons with literature, some acute studies that manipulated set configuration are going to be presented with the aim to discuss the possible middle-term adaptations that they suggest.

Regarding the basal cardiovascular measurements performed pre and post intervention, no significant changes were observed for all the evaluated parameters. Each variable is going to be discuss carefully considering the lack of studies in this topic.

Firstly, no differences were observed for any of the HRV parameters. Acute studies reported lower values of SDNN, RMSSD, LF power and HF power after high intensity squat exercise with no differences between set configuration (142). However, other acute study reported that set configuration affects the pattern of recovery of the vagal autonomic control of the heart (182). A failure session produced higher loss of the cardiac vagal control compared with an interrepetition rest session (where cardiac vagal control was scarcely affected). In this sense, lower cardiac autonomic modulation is observed after resistance exercise and a higher cardiovascular stress is produced by a traditional configuration in comparison with a cluster one (117,182). These conclusions were obtained immediately after exercise and the outcomes suggest that if these sessions were repeated during a period of time, TT protocols will produce a higher accumulate cardiovascular stress in comparison with CT regimes.

In general, middle-long term studies that have analysed HRV after a resistance training intervention found, in line with the current study, no changes in these parameters in healthy man following a traditional configuration (183,184). Moreover, no differences in these variables were detected in pre-hypertension men also after a TT intervention (12). Contrary to our results, the study of de Sousa et al. (147) observed higher RMSSD after 8 weeks of intervention in healthy males without differences between CT or TT. However, the effect size reported was low and the intervention length is longer than in our study. This suggests that more time is needed in order to detect an adaptation in the RMSSD, but more long term studies are necessary to support that. On the other hand, other study also revealed increases in RMSSD and HF power with no significant changes in the LF/HF ratio after a resistance program performed by women with fibromyalgia (143). In this case, the improvement was reasonable as HRV is reduced in this population.

Results suggest that TT induces a higher loss of the cardiac vagal control after exercise, that do not derive in any HRV impact in middle-long term studies carried out by healthy population. However, under pathological conditions positive effects in HRV function were observed after 16 weeks (143). In short, our outcomes suggest that resistance training may not affect resting HRV in healthy, young and active adults. This is due because they present a normal cardiac autonomic function. Additionally, the intervention length of this study is insufficient (5 weeks) in order to defect any change for this population.

On the other hand, heart rate complexity values remained unchanged after training intervention. Acute investigations reported lower values of the nonlinear measurements regarding SampEn during resistance exercise, suggesting that a higher sympathetic activation and a vagal withdrawal occurred (142,185). In this sense, authors revealed that during recovery the prolongation of depolarisation and repolarisation of the ventricles contributed to a cardiac irregularity reduction (142,185). However, values returned to baseline after 8 minutes of recovery (142). Contrary to our results, one study reported higher values of SampEn after 6 weeks of resistance training intervention (184). Nevertheless, SampEn values were restored to the pre-training measurement 2 weeks later. On the other hand, studies regarding ApEn are scarce, because most investigations in this topic calculated SampEn. In pathological subjects lower values of ApEn were observed immediately after exercise in a supine position (186). In this regard, literature revealed that heart rate complexity experiments an acute reduction (184) without a permanent adaptation as happened in our study.

On the other side, no changes in the blood pressure parameters and its variability were detected. In this sense, SBP, DBP, MAP and LF power of SBP remained unaltered in posttest.

Acute studies revealed that TT elicited higher SBP (117,142,182) and higher maximum values of DBP and MAP (117) than CT when intensity, volume and work-to-rest ratio were equated. However, higher values of SBP were detected in CT protocols with short pauses between clusters (≤ 10 seconds), or in inter-repetition rest protocols (26). These discrepancies were due because when the repetitions are carried out in small clusters, the performance of the Valsalva maneuver exaggerates the blood pressure response. These conclusions suggest that cluster sets (with an “optimal” number of repetitions per set) might produce a lower blood pressure response in comparison with traditional sets. Considering these findings, the question is to verify if a traditional middle-long-term protocol increases in a higher magnitude the blood pressure parameters after training in comparison with a cluster regimen.

Literature revealed that after resistance training intervention (following a traditional regimen) no changes in the SBP or DBP values were observed in women with fibromyalgia (143). However, a significant reduction in these parameters were reported when the participants were hypertensive (12,144,187). This confirms the benefits of resistance training in hypertensive population. Regarding the blood pressure variability, the analysis of the LF power of SBP showed no alterations after training. In this sense, no modifications in the sympathetic vasomotor tone were observed. To the best of our knowledge, this is the first study that has analysed the variability of the blood pressure after resistance training programmes. Previous studies e reported the blood pressure variability obtaining the LF power of SBP before and after 6 weeks of hybrid-functional electrical stimulation rowing intervention in spinal cord injury patients. Non changes in blood pressure variability were observed after training despite improvements in the maximum oxygen uptake (189). Considering these studies, it was difficult to compare these outcomes with ours, because of the multiple differences between studies designs (population, training protocol and intervention length). In the study of this thesis, all the participants were young, physical active and healthy (pretest SBP corresponded to an average of 107 mmHg), and this could be the reason why no significant changes were observed for all these parameters. Additionally, as was previously mentioned, a longer intervention is needed.

Finally, regarding the baroreflex mechanism, no differences were observed in posttest for BRS or BEI. Acute studies found higher decreases in BRS after exercise for TT than CT configurations (25,117). Additionally, lower values of BEI were revealed after 10 minutes of a traditional session in comparison with a cluster one (190). This suggests that the baroreflex function is reduced in a higher magnitude after a TT session. In this sense, acute outcomes put forward that it is possible that the baroreflex mechanism could be negatively affected by a traditional session. However, it is not clear if this impact could derive in a negative effect in middle-long interventions. In this sense, in agreement with the current results, some chronic studies reported no changes in BRS after resistance training in healthy men (183) and in women with fibromyalgia (143). Nevertheless, other study found that after 4 weeks of resistance intervention, hypertensive men decreased the BRS values by a reduction in sensitivity due to a decrease in blood pressure (12). As novelty, this thesis reported information about the baroreflex effectiveness measured as BEI, observing no alterations after training intervention. BRS and BEI provide information about the baroreflex function and we can conclude that this mechanism is not affected by 5 weeks of resistance training intervention performed by healthy, young and active subjects.

In summary, our results showed that no alterations in HRV, blood pressure parameters and baroreflex mechanism after a resistance training intervention performed by young normotensive participants with a normal cardiac autonomic function. In this sense, no differences were detected between set configurations, suggesting that middle-term resistance training programmes with the same load, volume, work-to-rest ratio and intended velocity did not produce any adaptations in the cardiovascular system of this population. Our data pointed out that the kind of intervention performed in this study did not produce an adaptation in the cardiac autonomic control, sympathetic vasomotor tone and the cardiac baroreflex control. In this regard, the greater heart rate response observed in TT compared to CT did not affect the cardiovascular parameters at rest. Therefore, our hypothesis should be partially accepted. TT contributed to a greater heart rate response during sessions, but this did not derive in a negative effect in the evaluated cardiovascular parameters at rest.

6 Conclusions

- Cluster structures are efficient in order to modify the F-V relationship toward a velocity-oriented profile in complex lower body exercises. Regarding simpler exercises like bench press, cluster training and traditional training produce the similar changes of the entire F-V spectrum toward a more power-oriented profile.
- A middle-short resistance training intervention produces no alterations in the autonomic control and in the cardiac baroreflex control. Programmes with the same load, volume, work-to-rest ratio and intended velocity performed by healthy, young and active adults produce no adaptations despite the set configuration performed.
- A resistance training program with a cluster set configuration entails less lactate production in comparison with a traditional set, due to the partial replenishment of the ATP and PCr stores during more frequent recovery periods.
- Traditional resistance training protocols produce greater velocity loss during training intervention for both upper and lower body exercises. Additionally, a greater velocity loss was observed in upper body exercises compared with lower body exercises.
- Both cluster and traditional set configurations are valid in order to improve maximal strength and muscular endurance for upper and lower body exercises. Cluster structures produce and increase in the maximum power output for lower body exercises while traditional training does not. Both cluster and traditional sets improve the maximum power output for upper body exercises.

  Cluster and traditional training programmes are valid in order to improve jump performance.

- Cluster set configuration improves the F_{1RM}/F_0 ratio for lower limbs and upper limbs exercises while traditional protocols produce and improvement of this ratio regarding upper limbs. Set configuration does not differentially affect the V_{1RM}/V_0 ratio, with no alterations after a resistance training intervention.
- Cluster sessions result in a lower peak heart rate response in comparison with the traditional sessions.

7 Limitations of the study

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 (172). 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 (65). On the other side, 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. Finally, the fact that subjects were healthy, young and active limited the possible cardiovascular adaptations following an intervention of 5 weeks.

8 Future lines of research

Taken together the mechanical, metabolic and cardiovascular adaptations observed, it is possible to have a vision of the processes that are affected by set configuration. Thus, it is of great interest to explore and expand this topic in multiple directions.

High performance athletes

Future studies need to include experienced athletes in order to exploit the multiple benefits that cluster training can provide. The exploration of the F-V profile of the specific multi-joint exercises that an athlete usually repeats during the season program (directly transferable to competition) could be beneficial helping the final performance. In this regard, any positive change in the F-V profile of these specific exercises could derive in a great performance enhancement. Additionally, longer training interventions need to be carried out in order to observed with more detail all the possible changes. In this sense, follow an entire season program of a group of athletes would be interesting to follow the F-V profile changes during all the training process in order detect weakness and do the proper corrections or variations in the daily intervention.

F-V sprint profile adaptations

Sprint performance is a key activity in many sports. Knowing that resistance training contributes to the enhancement of sprint performance by the improvement of the mechanical muscle properties, it is interesting to explore if cluster protocols (with a tendency toward a velocity-oriented profile) could beneficiate in a greater magnitude this key activity. In this sense, it is possible that a change in a F-V exercise relationship derive in a positive or a negative shift of other F-V action relationship.

F-V sprint profile in youth population

To describe the F-V sprint profile in youth populations of different sports in order to observe the differences regarding the sports nature. Additionally, the comparison with the F-V profile and the competition results (in the case for example of athletics) could be a good indicator of success. Moreover, this line could be interesting also for the detection of new talents.

Pathological population

In order to explore the cardiovascular adaptations that could be derived from different resistance training programmes differing in set configuration, it is interesting to expand this line to pathological population. In this sense, the aim will be the detection of any alteration in the cardiovascular parameters during and after the intervention at basal state.

Unilateral exercises – Cross education phenomenon

The analysis of the changes in the F-V profile regarding the trained and the non-trained limb of a unilateral intervention (employing different set configurations). One possibility is to explore if the cross-education phenomenon contributes to a positive F-V profile shift in the non-trained limb.

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APPENDIX A

Abstract of at least 3000 words in an official language

MARCO TEÓRICO

El entrenamiento de fuerza se ha convertido progresivamente en una materia de estudio en el campo de ciencias del deporte. Se ha investigado principalmente desde una perspectiva que busca mejorar el rendimiento deportivo, pero también desde un enfoque preventivo y terapéutico, en busca de fines saludables. Para diseñar un entrenamiento de fuerza, es necesario que los parámetros que lo constituyen estén ajustados a la población objetivo. En este sentido es importante conocer cómo se pueden modular las variables del entrenamiento para producir el efecto deseado. Esto se ha convertido en un objetivo prioritario para poder desarrollar guías de entrenamiento lo más efectivas posibles.

Al realizar un entrenamiento, en este caso de fuerza, las propiedades mecánicas del músculo permiten la producción de fuerza, velocidad y, por consiguiente, potencia. Al combinar estos parámetros obtenemos el llamado perfil mecánico individual, que ha sido investigado desde 1922 (3–5). Varios investigadores han intentado aplicar a lo largo de los años modelos de regresión que pudieran ajustar de la mejor manera posible la relación inversa entre la fuerza y la velocidad (F-V) muscular. Modelos exponenciales (4), hiperbólicos (3) y doble hiperbólicos (31) han logrado describir la relación F-V en músculos aislados de animales. Sin embargo, a partir de 1980, se empezó a explorar esta relación en ejercicios poliarticulares y complejos, con más transferencia a las actividades de la vida cotidiana. Los primeros fueron llevados a cabo por Sargeant et al. (42) y Vandewalle et al. (43,44) utilizando cicloergómetros. Observaron que el comportamiento muscular seguía un patrón distinto al descrito anteriormente.

El modelo matemático que adaptó los resultados de sus estudios fue la regresión lineal (i.e., $F(V) = F_0 – SV$). Este modelo permite averiguar el valor de la fuerza teórica máxima cuando la velocidad es cero (F_0), la velocidad teórica máxima cuando la fuerza es nula (V_0) y la pendiente de la recta ($S= - (F_0/V_0)$). Actualmente este modelo se ha utilizado para describir la relación F-V en numerosos ejercicios de fuerza bilaterales y unilaterales como extensión de cuádriceps

(23,47), sentadilla (48) o *press* de banca (8,49). Además, se ha aplicado también para describir el perfil mecánico del salto, llegando al punto de obtenerse un perfil idóneo para conseguir el máximo rendimiento en salto en contramovimiento (53,54). El sprint también ha sido representado con este enfoque lineal (55,56). La fiabilidad y replicabilidad de este modelo se ha estudiado para confirmar su aplicación (58,65–67). Este perfil proporciona información práctica que revela las debilidades y fortalezas individuales. En este sentido, su utilización puede ser óptima para guiar el entrenamiento hacia las cualidades específicas a desarrollar (10).

Para mejorar el perfil individual, es necesario modular las variables del entrenamiento (i.e., volumen, carga, descanso, frecuencia, configuración de la serie…) en dirección al objetivo deseado. A pesar de que la manipulación de este perfil puede resultar beneficioso para el rendimiento deportivo, escasos estudios han reportado entrenamientos que alteren el perfil F-V (83,84,86,95,97). Estudios previos revelaron que las regiones de alta velocidad y fuerza de esta relación se ven afectadas principalmente por el entrenamiento de fuerza explosivo con cargas ligeras y por la utilización de cargas pesadas, respectivamente. Sin embargo, estas investigaciones solo contrastaron diferentes cargas, por lo que sus resultados no pueden atribuirse exclusivamente a las diferencias en las velocidades de entrenamiento. Sabiendo que la velocidad es un factor clave para maximizar las adaptaciones de fuerza (98,99), la modulación voluntaria de la velocidad es una limitación. Un enfoque alternativo para contrastar el efecto de la velocidad en la relación F-V es manipulando la configuración de la serie establecida, ya que permite diseñar intervenciones que difieren en velocidad mientras que la carga, el volumen y la intensidad permanecen igualados entre las condiciones (100). En este sentido la configuración de la serie es un parámetro del entrenamiento que hace referencia a la distribución de las repeticiones y los descansos durante un entrenamiento de fuerza. La configuración clásica es la llamada configuración tradicional, que consiste en realizar series de repeticiones continuas. La configuración alternativa que se ha convertido recientemente en objeto de estudio, es la llamada configuración cluster (17). La respuesta aguda a la realización de series tipo cluster ha sido ampliamente estudiada. Sin embargo, los estudios de adaptaciones crónicas son menos frecuentes.

Las investigaciones revelan que de forma aguda, la configuración cluster contribuye a un mantenimiento de la velocidad y la potencia durante ejercicios con carga externa y ejercicios pliométricos (25,100,109,111,112,116). Por tanto, las pérdidas de velocidad son menores que al realizar configuraciones tradicionales (100,107,108). También se ha observado que la configuración cluster necesita una demanda metabólica menor que las series tradicionales (19,100,123,124). La fatiga que se acumula al completar repeticiones de manera continuada hace que los depósitos de PCr y ATP desciendan a la vez que se van acumulando productos metabólicos como el ácido láctico que inhiben los procesos contráctiles del músculo. En este sentido, menores concentraciones de lactato tras el ejercicio se han visto al completar un entrenamiento tipo cluster (19,100,123,124). A su vez, la percepción del esfuerzo es menor. Se ha demostrado que cuanto más largos sean los periodos de descanso, más cortas sean las series y más bajo sea el ratio trabajo-descanso, menor es la percepción del esfuerzo percibido (123,129,131). Por último, los estudios han revelado que algunas respuestas cardiovasculares se ven mitigadas al realizar entrenamiento cluster. En este sentido, se han reportado valores más bajos de frecuencia cardíaca y de tensión arterial durante el entrenamiento al seguir una configuración tipo cluster comparado con un protocolo tradicional (117,140,142,182). Además, se ha observado que la configuración tradicional produce un descenso mayor de la sensibilidad barorrefleja cardíaca que la configuración cluster, tras una sesión de entrenamiento (25,117).

De manera crónica la configuración cluster es capaz de incrementar la fuerza máxima al igual que una configuración tradicional, sin embargo se le atribuye mayor efecto para el desarrollo de la potencia (151,156). Por lo tanto, teniendo en cuenta el beneficio que presenta el cluster con respecto a la velocidad y la potencia, se puede esperar una adaptación diferente en la relación F-V al emplear distintas configuraciones de la serie. Hasta donde sabemos, pocos estudios han explorado los efectos de diferentes configuraciones de la serie sobre la relación F-V (23,24,156). Además, estos estudios presentan diferentes limitaciones como, por ejemplo, la falta de un grupo de control y el uso de ejercicios monoarticulares, lo que reduce las aplicaciones prácticas. Por otro lado, este estudio podría ser una oportunidad para mejorar el conocimiento sobre los efectos crónicos al aplicar distintas configuraciones de la serie. Por tanto, se propone examinar, además de adaptaciones mecánicas, las adaptaciones cardiovasculares y metabólicas que solo se habían analizado después del entrenamiento tradicional (13,14,145). Esto podría ayudar a identificar estructuras de entrenamiento de resistencia que combinen efectivamente la optimización del rendimiento mecánico con adaptaciones hemodinámicas y cardiovasculares positivas.

OBJETIVOS E HIPÓTESIS

En definitiva, esta tesis examinará las adaptaciones mecánicas, metabólicas y cardiovasculares, así como el rendimiento neuromuscular al contrastar dos programas de entrenamiento de resistencia que difieren en la configuración de la serie.

Se hipotetiza que las configuraciones cluster producirán una pérdida menor de velocidad que conllevará al desarrollo de la región de alta velocidad de la relación F-V e incrementarán la potencia máxima en mayor magnitud que las series tradicionales. Además, las estructuras cluster producirán menos estrés en el sistema metabólico y adaptaciones más favorables en el control autónomo y en el control barorreflejo cardíaco en comparación con las configuraciones tradicionales.

MÉTODO

Se llevó a cabo un único estudio con un diseño de prueba aleatorizada controlada con 39 participantes (28 hombres y 11 mujeres) jóvenes, sanos y físicamente activos. Tras la realización de tests previos que determinaron el perfil fuerza-velocidad (F-V) de cada sujeto (Test 1RM), la capacidad de salto (Test CMJ) y las variables cardiovasculares en reposo, se distribuyó a los participantes en grupo tradicional (TT), grupo cluster (CT) y grupo control (CON). Los grupos experimentales completaron 5 semanas de entrenamiento (2 sesiones a la semana) realizando un circuito de 4 ejercicios (*press* de banca, sentadilla paralela, jalón al pecho y curl de bíceps) que duraba 1h y 30 min aproximadamente. TT realizó 4 series de 8 repeticiones de cada ejercicio con 5 min de recuperación mientras que CT completaba 16 series de 2 repeticiones con 1 minuto de pausa. Entre ejercicios ambos recuperaban 5 minutos. El volumen, el descanso y la intención de superar la carga a máxima velocidad se equiparó para ambos grupos. La frecuencia cardíaca estuvo monitorizada durante todas las sesiones y la concentración capilar de lactato se midió tras terminar la sesión 1, 5 y 10. Finalmente todos los test iniciales se repitieron para analizar las posibles adaptaciones. Cabe destacar que los perfiles F-V individuales solo se calcularon para el ejercicio de *press* de banca y para la sentadilla paralela.

RESULTADOS Y DISCUSIÓN

Los principales hallazgos de este estudio fueron: (i) TT produjo mayor concentración de lactato y pérdida de velocidad en comparación a CT; (ii) ambos programas de entrenamiento produjeron ganancias similares en fuerza máxima, resistencia muscular y rendimiento de salto; (iii) el valor de la máxima potencia medida fue superior para *press* de banca tras ambos protocolos, mientras que para la sentadilla paralela solo se encontraron mejoras después de CT; (iv) los cambios en F-V fueron similares para TT y CT (es decir, sin desplazamiento de la pendiente y valores más altos de fuerza y velocidad máxima teórica) para *press* de banca; (v) para la sentadilla paralela, se observaron cambios en los parámetros F-V con CT hacia un perfil de velocidad, mientras que estos cambios no se observaron en TT; (vi) no se detectaron diferencias entre pre y posttest entre protocolos con respecto a la posición de la velocidad asociada al 1RM en F-V para ambos ejercicios, mientras que la ganancia del ratio de fuerza (F_{1RM}/F_0) solo fue significativa en la sentadilla paralela en CT; y (vii) no se observaron alteraciones en el control autónomo y en el control barorreflejo cardíaco después de la intervención, sin embargo, la CT resultó en una respuesta de frecuencia cardíaca más baja durante las sesiones en comparación con TT.

Lactacidaemia y parámetros mecánicos

Los resultados de estudios previos también observaron una mayor implicación glucolítica tras la realización de un entrenamiento con una configuración de la serie tradicional (19,122,124). La concentración de lactato dificulta la contracción muscular y se ha visto que tiene una relación inversa con los niveles de fosfocreatina (119,167). Por tanto, esto sugiere, que el protocolo cluster permite reponer los depósitos de energía durante los periodos de descanso más frecuentes. Esto a su vez contribuye a un mantenimiento del rendimiento durante la sesión, lo que implica una menor pérdida de velocidad, también reportado por estudios previos (22,157). En esta línea se ha observado que los ejercicios que implican un menor número de grupos musculares y articulaciones y por tanto más sencillos en su ejecución tienen una pérdida de velocidad más pronunciada debido a la fatiga localizada (como ha sucedido en este estudio al observar pérdidas de velocidad más llamativas en *press* de banca que en sentadilla paralela). Esto también se justifica con el mayor rango de pérdida de velocidad observado para el ejercicio de *press* de banca en comparación a la sentadilla paralela. Los valores de V_{1RM} corresponden a 0.19 m/s en *press* de banca y 0.29 m/s en sentadilla paralela siendo los valores medios de velocidad máxima alcanzada durante la intervención de 0.60 m/s para *press* de banca y 0.54 m/s en el caso de la sentadilla paralela.

Bondad de ajuste

Por otro lado, la literatura apuntaba al modelo lineal como válido para la representación de la relación F-V para ejercicios poliarticulares (7,8,40,49). Esta afirmación se ha confirmado en este estudio, con coeficientes de determinación mayores a 0.800 y errores estándar de estimación bajos.

Adaptaciones en el perfil Fuerza-Velocidad

Al observar los perfiles F-V para el ejercicio de pres de banca antes y después del entrenamiento se ha comprobado que ambas configuraciones de la serie han tenido el mismo efecto. De esta manera, ambos grupos han incrementado en magnitud similar su potencia máxima, fuerza y velocidad máximas teóricas. Esto produjo un desplazamiento del perfil F-V hacia la derecha casi paralelo al perfil obtenido en el pretest. Se observó por tanto un perfil mejorado orientado hacia la potencia. Se sugiere que este resultado pudo ser debido a que no hubo diferencias de velocidad media propulsiva entre los grupos durante todas las sesiones de entrenamiento. Sin embargo, se observaron tamaños del efecto más grandes en la velocidad teórica máxima en CT. Por ello se sugiere que, en una intervención de mayor duración, CT podría producir una mejoría destacable en la región de alta velocidad del perfil F-V. Cabe destacar que este es el primer estudio que analiza los cambios en el perfil F-V para ejercicios del tren superior. Por otro lado, los cambios producidos en el perfil F-V para la sentadilla paralela han sido diferentes teniendo en cuenta la configuración realizada. El grupo CT ha mejorado la velocidad teórica máxima y la potencia teórica máxima a la vez que las pendientes se han aplanado. Por su parte el grupo TT ha mejorado la fuerza teórica máxima y la potencia teórica máxima. En este caso ambos grupos han mejorado la potencia sin diferencias, siendo el cambio producido por las ganancias en velocidad (grupo CT) o por las ganancias en fuerza (grupo TT). Por tanto, se observó como CT mejoró considerablemente la región de alta velocidad del perfil F-V mientras que TT desarrolló la de alta fuerza. Esta disparidad se debe en parte a que CT entrenó a una mayor velocidad media propulsiva durante toda la intervención comparado con TT. Por ello, a pesar de que ambos grupos entrenaron en la misma parte de la relación F-V, la velocidad tiende a alejarse de la velocidad teórica máxima a medida que realizamos repeticiones sin descanso, como ocurrió en TT. Este fenómeno no ocurrió en CT, donde las pausas entre series permitieron el mantenimiento de la velocidad alrededor del mismo punto de la relación F-V. Presumimos que la acumulación de repeticiones en la "parte más baja" de la región F-V estimulada por el entrenamiento (que fue experimentada por TT) fue la razón por la cual los protocolos tuvieron un impacto diferente en la región de alta velocidad. Un estudio reciente encontró adaptaciones similares en el perfil F-V tras realizar 8 semanas de extensión de cuádriceps unilateral (24). Sin embargo otros estudios no encontraron diferencias (23,156). Estas conclusiones contradictorias pueden deberse a varios factores como por ejemplo la duración de la intervención, la carga usada, el ratio trabajo-pausa, la población evaluada y el fenómeno de “cross education”.

Teniendo en cuenta los resultados de ambos ejercicios en conjunto, parece que los ejercicios que implican un mayor control mecánico y neuronal (es decir, con una mayor masa muscular, número de articulaciones y grados de libertad involucrados, como ocurre en la sentadilla paralela en comparación con el *press* de banca) no experimentan alteraciones notables en la relación F-V como consecuencia de la realización de protocolos TT. Esto también se ha podido observar en el estudio de Morales-Artacho et al. (156), donde no se observaron cambios en la pendiente tras realizar media sentadilla con salto siguiendo un protocolo tradicional. En este sentido, nuestros resultados sugieren que los ejercicios que implican menor masa muscular (como el *press* de banca) obtienen cambios similares en los parámetros F-V al realizar protocolos TT o CT, al menos en períodos cortos-medios de intervención. Esto está concordancia con un estudio previo en el que se observaron cambios similares en la relación F-V después de 5 semanas de extensión de cuádriceps unilateral (considerando la extensión de la pierna como un ejercicio que necesita una menor coordinación y control postural) (23). Sin embargo, se revelaron diferentes cambios tras la realización de CT o TT en el estudio de Carneiro et al. (24) después de 8 semanas también de extensión de cuádriceps unilateral. Esto significa que los ejercicios más simples necesitan más tiempo para beneficiarse de una intervención tipo cluster. Por tanto, como se mencionó anteriormente, el tamaño del efecto en la mejoría de la velocidad teórica máxima fue mayor para CT en el caso del ejercicio de *press* de banca. Esto sugiere que se producirá un efecto posterior hacia un perfil orientado a la velocidad en el grupo CT, proponiendo que la aparición de un efecto significativo podría ser solo cuestión de tiempo.

Tras estos cambios de perfil F-V en los grupos, cabe esperar el resultado de los distintos test atendiendo a fuerza máxima, resistencia a la fuerza, potencia máxima o rendimiento en salto en CMJ.

Rendimiento neuromuscular

En primer lugar, ambos grupos mejoraron de forma similar la fuerza máxima para *press* de banca y sentadilla paralela. Esto está en acuerdo con otros estudios previos (101,148,155). A pesar de que ocurrieron diferentes cambios en el perfil F-V, el grupo CT también mejoró la fuerza máxima en sentadilla paralela (aunque el perfil se orientó a la velocidad). Esto confirma que protocolos de redistribución de la pausa con el mismo volumen, carga, descanso total e intención de levantar a máxima velocidad, produjeron mejoras similares en la fuerza que un régimen tradicional después de un período de al menos 5 semanas (101,103). Asimismo, los resultados indicaron que la resistencia muscular mejoró sin diferencias entre grupos tras el entrenamiento. Este estudio sugiere que no es necesario alcanzar el fallo muscular para mejorar este parámetro y que el entrenamiento cluster es igual de válido que otros protocolos al proporcionar nuevos estímulos. Por otro lado, la potencia máxima mejoró de la misma manera para ambos grupos para el ejercicio de *press* de banca. Esto puede ser razonable ya que el perfil para este ejercicio se orientó a la potencia tras el entrenamiento. Sin embargo, para el ejercicio de sentadilla paralela solo se encontraron incrementos de potencia tras CT. Otros estudios también señalan el entrenamiento cluster como beneficioso para mejorar la potencia en ejercicios de extremidades inferiores (153,156,176). A pesar de que ambos entrenamientos mejoraron de manera similar la potencia máxima teórica (P_{max}) en el perfil F-V, los resultados de la potencia máxima medida son superiores para CT. Esto revela la superioridad del entrenamiento cluster para el desarrollo de la potencia en miembros inferiores. El último test fue el rendimiento en salto en CMJ. Sorprendentemente y en contra de nuestra hipótesis, ambos grupos mejoraron su rendimiento para las variables de potencia máxima y altura del salto. No hubo diferencia entre grupos. Otros estudios reportaron del mismo modo incrementos similares de altura (177), fuerza y potencia (150). En el estudio de Oliver et al. (175) la potencia máxima del salto fue medida después de la 4º, 8º y 12º semana. Diferencias significativas entre los protocolos se reportaron después de la semana 12. De acuerdo con otros estudios, podemos concluir que para optimizar el rendimiento en salto en CMJ, se recomienda una combinación de entrenamiento tanto tradicional como en grupo para el desarrollo correcto de las capacidades de fuerza y velocidad (150).

Respuesta y adaptación cardiovascular

Finalmente, la frecuencia cardíaca pico recogida durante las sesiones fue mayor en la sesión tradicional en comparación a la cluster. A pesar de esta apreciación, el análisis cardiovascular en reposo concluyó que no se produjeron alteraciones en la variabilidad de la frecuencia cardíaca, tensión arterial y su variabilidad y barorreflejo cardíaco tras el entrenamiento. Es la primera vez que un estudio recoge un análisis completo de las variables cardiovasculares en reposo tras entrenamientos que difieren en la configuración de la serie. Al tratarse de sujetos jóvenes, normotensos y con una función cardíaca normal se sugiere que a medio-corto plazo esta población no experimentará adaptaciones cardiovasculares. Al no encontrarse ningún cambio entre evaluaciones, los resultados sugieren que los programas de entrenamiento de resistencia con la misma carga, volumen y relación trabajo-descanso no producen alteraciones en el control autónomo, tono simpático vasomotor y control barorreflejo cardíaco de sujetos jóvenes sanos y físicamente activos.

CONCLUSIONES

Las principales conclusiones de esta tesis son:

- Las estructuras cluster son eficientes para modificar la relación F-V hacia un perfil orientado a la velocidad en ejercicios complejos del miembro inferior. Con respecto a ejercicios más simples como el *press* de banca, el entrenamiento cluster y el entrenamiento tradicional producen cambios similares de todo el espectro F-V hacia un perfil más orientado a la potencia.
- Una intervención de entrenamiento de fuerza de medio-corto plazo no produce alteraciones en el control autónomo y en el control barorreflejo cardíaco. Los programas con la misma carga, volumen, relación trabajo-descanso y velocidad intencionada realizados por adultos sanos, jóvenes y activos no producen adaptaciones independientemente de la configuración establecida.
- Un programa de entrenamiento de resistencia con una configuración cluster implica una menor producción de lactato en comparación con una configuración tradicional, debido a la reposición parcial de los depósitos de ATP y PCr durante períodos de recuperación más frecuentes.
- El entrenamiento de fuerza con series tradicionales produce una mayor pérdida de velocidad durante la intervención de entrenamiento para los ejercicios del miembro inferior y superior. Además, se observó una mayor pérdida de velocidad en los ejercicios de tren superior en comparación con los ejercicios de miembro inferior.
- Tanto las configuraciones cluster como las tradicionales son válidas para mejorar la fuerza máxima y la resistencia muscular para los ejercicios de miembro inferior y superior. Las estructuras cluster producen y aumentan la potencia máxima para los ejercicios de miembro inferior, mientras que el entrenamiento tradicional no. Tanto

las series clúster como las tradicionales mejoran la potencia máxima para los ejercicios de miembro superior.

- La configuración cluster mejora el ratio F_{1RM} / F_0 para los ejercicios de las extremidades inferiores y las extremidades superiores, mientras que los protocolos tradicionales solo aumentan esta proporción para las extremidades superiores.
- La configuración establecida no afecta al ratio V_{1RM} / V_0, ya que este permanece sin alteraciones después de una intervención de entrenamiento de fuerza.
- Los programas de entrenamiento cluster y tradicional son válidos para mejorar el rendimiento del salto en contramovimiento.
- Las sesiones tradicionales producen una respuesta de la frecuencia cardíaca pico más elevada en comparación con las sesiones cluster.

LIMITACIONES

Una posible limitación de este estudio es que todos los participantes tenían una experiencia limitada en el entrenamiento de resistencia (3 meses). Esto podría afectar los resultados, ya que el entrenamiento cluster es recomendado para atletas avanzados con niveles de fuerza más altos (172). Por otro lado, 4.52% de las relaciones F-V tenían un R^2 inferior a 0.800. Estos coeficientes más bajos pueden ser una consecuencia del análisis de la fase propulsiva, que conlleva diferencias entre las cargas con respecto al rango de movimiento analizado, o porque algunos casos presentan un perfil curvilíneo. Sin embargo, finalmente elegimos el enfoque lineal ya que la confiabilidad de los parámetros F-V para nuestros ejercicios es mayor que otros modelos curvilíneos (65). Por otro lado, la carga mínima permitida por la máquina Smith (es decir, 21.4 kg) limitó la recopilación de datos correspondientes a porciones de mayor velocidad de la relación F-V, especialmente para las mujeres. Finalmente, el hecho de que los sujetos fueran sanos, jóvenes y físicamente activos limitó las posibles adaptaciones cardiovasculares en este estudio de medio plazo (5 semanas).

APPENDIX B

Informed consent

Hoja de consentimiento informado

DOCUMENTO DE CONSENTIMIENTO PARA LA PARTICIPACIÓN EN UN ESTUDIO DE INVESTIGACIÓN

TÍTULO. Efectos sobre los perfiles de fuerza-velocidad y parámetros cardiovasculares en reposo de programas de entrenamiento de fuerza diferenciados por la configuración de la serie

Yo,

- He leído la hoja de información al participante del estudio arriba mencionado que se me entregó, he podido hablar con ***Investigador principal*** y hacerle todas las preguntas sobre el estudio necesarias para comprender sus condiciones y considero que he recibido suficiente información sobre el estudio. ☐
- Comprendo que mi participación es voluntaria, y que puedo retirarme del estudio cuando quiera, sin tener que dar explicaciones. ☐
- Accedo a que se utilicen mis datos en las condiciones detalladas en la hoja de información al participante. ☐
- Presto libremente mi conformidad para participar en el estudio. ☐

Respeto a la conservación y utilización futura de los datos y/o muestras detallada en la hoja de información al participante,

☐ NO accedo a que mis datos sean conservados una vez terminado el presente estudio

☐ Accedo a que mis datos se conserven una vez terminado el estudio, siempre y cuando sea imposible, incluso para los investigadores, identificarlos por ningún medio

☐ Accedo a que los datos y/o muestras se conserven para usos posteriores en líneas de investigación relacionadas con la presente, y en las condiciones mencionadas. En particular, accedo a que los resultados puedan ser expuestos en publicaciones científicas o presentados en congresos os reuniones científicas de cualquier tipo.

En cuanto a los resultados de las pruebas realizadas,

☐ DESEO conocer los resultados de mis pruebas

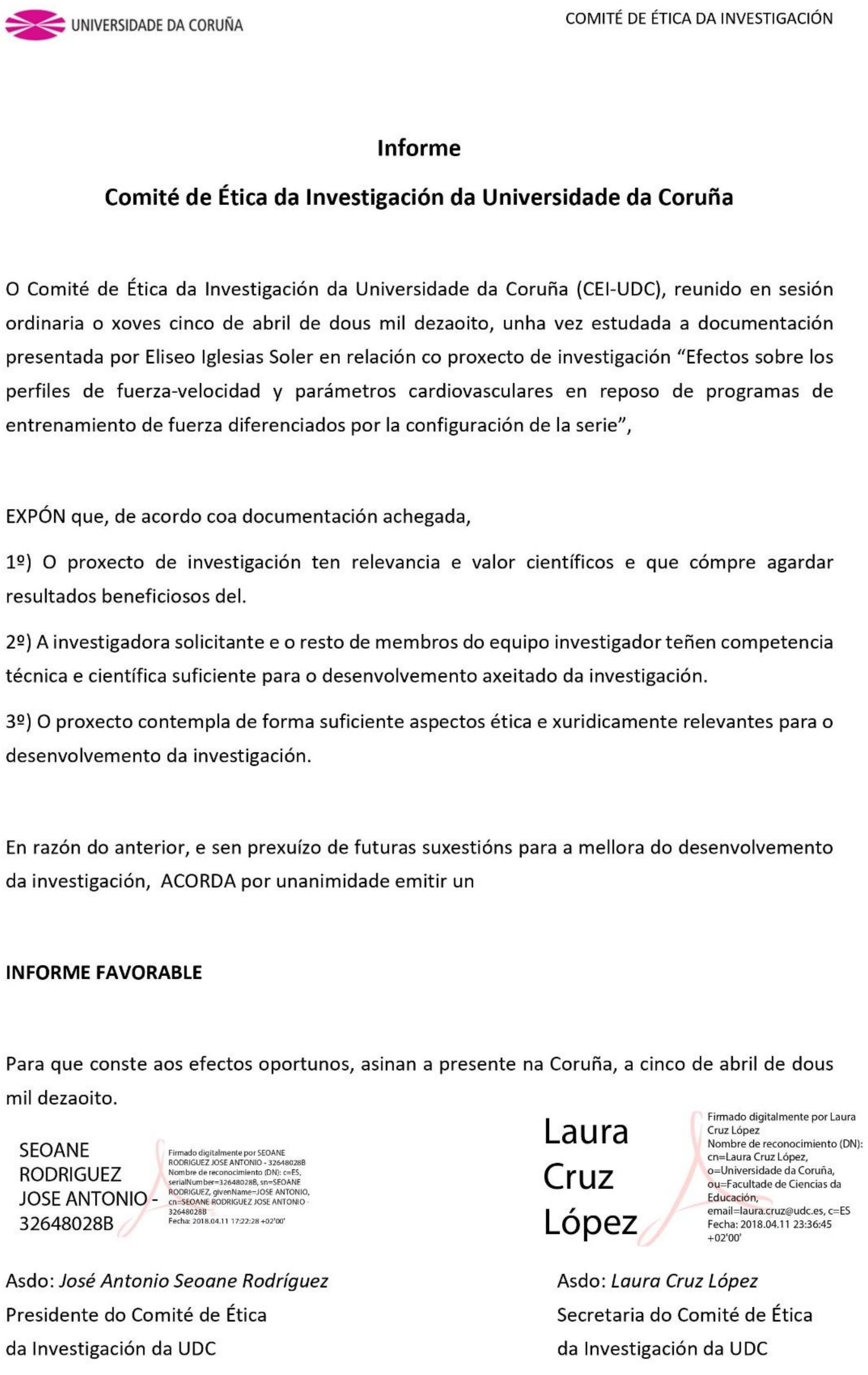
☐ NO DESEO conocer los resultados de mis pruebas

El/la participante,
Fdo.:
Fecha:

El/la investigador/a,
Fdo.: ***investigador principal***
Fecha:

APPENDIX C

Ethical committee approval



UNIVERSIDADE DA CORUÑA

COMITÉ DE ÉTICA DA INVESTIGACIÓN

Informe

Comité de Ética da Investigación da Universidade da Coruña

O Comité de Ética da Investigación da Universidade da Coruña (CEI-UDC), reunido en sesión ordinaria o xoves cinco de abril de dous mil dezaoito, unha vez estudada a documentación presentada por Eliseo Iglesias Soler en relación co proxecto de investigación “Efectos sobre los perfiles de fuerza-velocidad y parámetros cardiovasculares en reposo de programas de entrenamiento de fuerza diferenciados por la configuración de la serie”,

EXPÓN que, de acordo coa documentación achegada,

1º) O proxecto de investigación ten relevancia e valor científicos e que cómpre agardar resultados beneficiosos del.

2º) A investigadora solicitante e o resto de membros do equipo investigador teñen competencia técnica e científica suficiente para o desenvolvemento axeitado da investigación.

3º) O proxecto contempla de forma suficiente aspectos ética e xuridicamente relevantes para o desenvolvemento da investigación.

En razón do anterior, e sen prexuízo de futuras suxestións para a mellora do desenvolvemento da investigación, ACORDA por unanimidade emitir un

INFORME FAVORABLE

Para que conste aos efectos oportunos, asinan a presente na Coruña, a cinco de abril de dous mil dezaoito.

SEOANE
RODRIGUEZ
JOSE ANTONIO -
32648028B

Firmado digitalmente por SEOANE RODRIGUEZ JOSE ANTONIO - 32648028B
Nombre de reconocimiento (DN): c=ES, serialNumber=32648028B, sn=SEOANE RODRIGUEZ, givenName=JOSE ANTONIO, cn=SEOANE RODRIGUEZ JOSE ANTONIO - 32648028B
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Laura
Cruz
López

Firmado digitalmente por Laura Cruz López
Nombre de reconocimiento (DN): cn=Laura Cruz López, o=Universidade da Coruña, ou=Facultade de Ciencias da Educación, email=laura.cruz@udc.es, c=ES
Fecha: 2018.04.11 23:36:45 +02'00'

Asdo: *José Antonio Seoane Rodríguez*
Presidente do Comité de Ética
da Investigación da UDC

Asdo: *Laura Cruz López*
Secretaria do Comité de Ética
da Investigación da UDC

APPENDIX D

Papers published, congress contributions and international stay during de doctoral period

Papers published

- **Rial-Vázquez, J**; Mayo, X; Tufano, J; Fariñas, J; Rúa-Alonso, M; Iglesias-Soler, E. (2020) Cluster vs. Traditional training programmes: changes in the force-velocity relationship. Sports Biomechanics.1-19
- Iglesias-Soler, E; Mayo, X; **Rial-Vázquez, J**; Haff, G. (2018) Inter-individual variability in the load-velocity relationship is detected by multi-level mixed regression models. Sports Biomechanics.
- Fariñas, J; Mayo, X; Giráldez-Garxcía, M.A; Carballeira, E; Fernandez-del-Olmo, M**; Rial-Vázquez, J**; Derek Kingsely, J; Iglesias-Soler, E. (2019) Set configuration in strength training programs modulates the cross-education phenomenon. Journal of strength and conditioning research 12: 1-7.
- Iglesias-Soler, E. Mayo, X. **Rial-Vázquez, J**. Morín-Jiménez, A. Aracama, A. Guerrero-Moreno, JM. Jaric, S. (2019) Reliability of force-velocity parameters obtained from linear and curvilinear regressions for the bench press and squat exercises. Journal of sports sciences. 1-8

Congress publications

- **Rial-Vázquez, J**., Iglesias-Soler, E., Arakama, A., Morin, A.2, mayo, X., Jaric, S. Reliability and concurrent validity of Force velocity parameters obtain from linear and curvilinear regression models". 23th Annual Congress of the European College of Sport Science, Dublin (July 2018). Oral Presentation
- Fariñas, J., Giraldez -García, M.A., Mayo, X., Carballeira, E**., Rial-Vázquez, J**., Iglesias-Soler. Cross-education effect depends on set configuration of biceps curl strength training. 23th Annual Congress of the European College of Sport Science, Dublin (July 2018). Oral Presentation
- **Rial-Vázquez, J**; Iglesias-Soler, E; Fariñas, J; Rúa-Alonso, M; Rodríguez Quintana, S. Changes in Force-Velocity Profile performing different resistance training programmes differing in set configuration for parallel squat exercise. X International Congress of the Spanish sport science association, A Coruña (November 2018) Poster
- **Rial-Vázquez,** J; Iglesias-Soler, E; Fariñas, J; Rúa-Alonso, M; Rodríguez Quintana, S. Changes in Force-Velocity Profile performing different resistance training programmes differing in set configuration for bench press exercise. X International Congress of the Spanish sport science association, A Coruña (November 2018). Poster
- Fariñas, J; Iglesias-Soler, E; Giráldez-García, M. A; Carballeira, E; **Rial-Vázquez, J**; Mayo, X; Fernández-Del-Olmo, M. Cross-education effect depends on set configuration in elbow flexors strength training. X International Congress of the Spanish sport science association, A Coruña (November 2018). Poster
- Rúa-Alonso, M; **Rial-Vázquez, J**; Fariñas, J. Heartbeat-to-beat blood pressure recording with Task Force System. X International Congress of the Spanish sport science association, A Coruña (November 2018). Practical workshop

- **Rial-Vázquez, J**. Iglesias-Soler, E. Fariñas-Rodríguez, J. Rúa-Alonso, M. (2019) Changes in the location on Force-Velocity relationship of force and velocity performed with the 1RM load after two resistance training programs differing in set configuration. 24th Anual Congress of the European College of Sport Science. Praga, Czech Republic (July 2019). Oral Presentation
- Rúa-Alonso, M. Iglesias-Soler, E. Mayo, X**. Rial-Vázquez, J**. Fariñas, J. (2019) Acute changes in heart rate variability afater resistance training sessions differing in set configuration. 24th Annual Congress of the European College of Sport Science. Praga, Czech Republic, (July 2019). Oral Presentation
- Rúa-Alonso, M., Iglesias-Soler, E., Mayo, X., **Rial-Vázquez, J**., Farinas, J. Similar velocity loss between men and women during resistance training sessions differing in set configuration. International Sport Forum Congress, Madrid (November, 2019). Oral Presentation.
- Rúa-Alonso, M., Iglesias-Soler, E., Mayo, X., Rial-Vázquez, J., Farinas, J. Acute effect on glycolytic involvement after resistance training sessions differing in set configuration. XI Symposium on Metabolism - Ageing & Metabolism, O Porto. (October 2019). Poster.
- **Rial-Vázquez, J**., Iglesias-Soler, E., Rúa-Alonso, M., Farinas, J. Evolution of the velocity los and the glycolytic involvement throughout two resistance training programmes differing in set configuration. International Sport Forum Congress, Madrid (November, 2019). Poster.
- Fariñas, J; Iglesias-Soler, E; Giráldez-García, M. A; Carballeira, E; **Rial-Vázquez, J**; Mayo, X; Fernández-Del-Olmo, M. Cross education in a knee extension exercise depends on set configuration of resistance training. 24th Annual Congress of the European College of Sport Science. Praga, Czech Republic, (July 2019). Poster

- Farinas, J., Iglesias-Soler, E., Giráldez-García, M.A., Carballeira, E., **Rial-Vázquez, J.**, Fernández del Olmo, M., Mayo, X. Cross education is modulated by set configuration. International Sport Forum Congress, Madrid (November, 2019). Oral presentation
- Carballeira-Fernández, E., Clavel San Emeterio, I., **Rial-Vázquez, J.**, Rúa-Alonso, M., Iglesias-Soler, E. Physical fitness related to health of school children in Galicia using DAFIS tool. International Congress CAPAS-Ciudad. Huesca (november 2019). Oral presentation.

International stay

Inditex Scholarship

International stay in the Laboratory Sport, Expertise, Performance (SEP, AE7370) at the French Institute of Sport Expertise and Performance (INSEP) from the 1st of April to the 30th of June 2019.

I improved my knowledge about the F-V profile regarding sprints in a high-performance environment. Concretely the principal projects that we carried out were related to the biomechanical analysis of motorized resistance sprint and to the sprint parameters depending on the motorize resistance and the evaluation of its reproducibility.

Stay supervisor: Giuseppe Rabita.