UNIVERSIDAD MIGUEL HERNÁNDEZ DE ELCHE

DEPARTAMENTO DE PSICOLOGÍA DE LA SALUD

Programa de Doctorado en Psicología de la Salud

Effects of Power Training with Optimal Load and Repetitions

Doctoral thesis

A dissertation presented by
José Manuel Sarabia Marín

Graduate in Physical Activity and Sport Science

Elche, 2015

El Dr. D. Juan Carlos Marzo Campos, director del Departamento de Psicología de la Salud de la Universidad Miguel Hernández de Elche.

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Que el trabajo de investigación titulado: “EFFECTS OF POWER TRAINING WITH OPTIMAL LOAD AND REPETITIONS” realizado por D. José Manuel Sarabia Marín bajo la dirección de Dr. D. Manuel Moya Ramón y Dr. D. Rafael Sabido Solana sea depositado en el departamento y posteriormente defendido como Tesis Doctoral en esta Universidad ante el tribunal correspondiente.

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D. Rafael Sabido Solana

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DEDICACIÓN

Esta tesis está dedicada a mis padres, quienes me han brindado la oportunidad de llegar hasta aquí y especialmente a Laura, quien ha estado a mi lado aguantando todos estos años, pero sobre todo por ayudarme siempre a levantarme y seguir adelante. Eres mi guía y no quiere perderme en las sombras.

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Abstract

The proposes of this dissertation were to examine the effects of used optimal load and repetitions when performing power training in mechanical, physiological and psychological variables, and compare the influence of various rest interval durations used between sets in bench press throw with optimal load. The following are major findings of the dissertation. A short-term power training period with optimal load and repetitions produces improvements in power variables (i.e. jump height, throw distance, and peak power). The training load impact on the athlete was low when we used the optimal repetitions number (i.e. minor hormonal changes and less mood disturbance). The improvements in power output when use this method of power training must be associated with neural changes. Two resting minutes between sets was enough to maintain the power output using the optimal load in the bench press throw. This dissertation indicates that the power training with optimal load and repetitions may be considered as a great power training method, especially in sports with condensed competitive calendars, where the preparatory periods are time limited. Therefore, it is demonstrate the importance of individualization of training load when the aim is to improve the power output in a short-training period. However is suggested that future research should continue to investigate the factors that are associated with the adaptation to this method and the possible different effects in athletes with power training history. The findings of this dissertation also indicate that two minutes of rest between sets is enough in the bench press throw with optimal load. It is suggested that further research is needed with different ballistics and non-ballistics exercises and optimal load and repetitions to identify the optimal recovery time for them.

***Key Words**: strength training, cortisol, testosterone, mood states, rest interval*

Resumen

Los objetivos de esta tesis son examinar los efectos mecánicos, fisiológicos y psicológicos que provoca usar la carga y repeticiones óptimas en un entrenamiento de potencia, y comparar los efectos de diferentes duraciones del tiempo entre series en el ejercicio del press banca lanzado al utilizar la carga óptima. A continuación se presentan las principales aportaciones de esta tesis. Un periodo corto de entrenamiento con la carga y repeticiones óptimas produce mejoras en diferentes variables de potencia (altura de salto, distancia de lanzamiento y pico de potencia). El impacto de la carga de entrenamiento en el deportista es menor cuando se utiliza el número de repeticiones óptimo (Menores cambios hormonales y del perfil del estado de ánimo). Las mejoras en potencia, cuando se usa este método de entrenamiento, pueden ser asociadas a cambios neurales ya que no se ha objetivado un efecto hipertrófico sobre la musculatura. Dos minutos de recuperación entre series son suficientes para mantener la potencia al usar la carga óptima en el press banca lanzado. Esta tesis indica que el entrenamiento de potencia con la carga y repeticiones óptimas puede ser considerado un buen método, especialmente en deportes con una alta densidad competitiva y con periodos preparatorios limitados en el tiempo. Por tanto, esto demuestra la importancia de la individualización de la carga de entrenamiento cuando el objetivo del entrenamiento es la mejora de la potencia en periodos cortos de tiempo. Sin embargo, se sugiere que en futuros trabajos de investigación se debería continuar investigando los factores asociados a la adaptación producida por este método y los efectos que tiene en deportistas con un historial previo de entrenamiento de potencia. Las aportaciones de esta tesis también indican que dos minutos de recuperación entre series son suficientes en el press banca lanzado, pero esto no es extrapolable a otros ejercicios, por lo que se sugiere que en futuros trabajos se investigue cual es el tiempo óptimo de recuperación para otros ejercicios (tanto balísticos como no balísticos) cuando se utilizan la carga y repeticiones óptimas.

Palabras clave: *entrenamiento de fuerza, cortisol, testosterona, estado de ánimo, tiempo de recuperación*

01

General Introduction

1.1. Muscle power

Throws, jumps, changes of directions and hits occur in many sports. All of these movements require an application of force in a short time (McBride, Triplett-McBride, Davie, & Newton, 1999; Terzis, Georgiadis, Vassiliadou, & Manta, 2003), so power is a determining factor in sports (Gabbett, Kelly, & Pezet, 2007; Sheppard et al., 2008; Stone, Sanborn, et al., 2003; Wisløff, Castagna, Helgerud, Jones, & Hoff, 2004). Therefore, strength training programmes are usually focused on the development of muscle power to improve performance (Cormie, McGuigan, & Newton, 2010a, 2010b; Smilios et al., 2013).

To understand the main variables that bring about power production it is important to define power and how it is mathematically calculated, because that can help us to understand the advantages of each training method. Mechanical power can be defined as the ratio between work and time or the force multiplied by the movement velocity (Knudson, 2009):

$$Power = Work/Time$$

$$Power = Force \times Distance/Time$$

$$Power = Force \times Velocity$$

Since power is the product of force and speed, both components are needed in the training of muscular power, as they are closely related: when the movement speed increases, the force that the muscles can produce decreases (Figure 1) (Cormie, McGuigan, & Newton, 2011; Kawamori & Haff, 2004). Therefore, when referring to the maximum power that can be generated in a movement, this is located at a point between the maximum force and speed (Figure 1), which varies depending on the movement performed (Kawamori & Haff, 2004; Siegel, Gilders, Staron, & Hagerman, 2002). In the literature, the load used to produce maximum power is called 'optimal load' (Cormie et al., 2011; Kawamori & Haff, 2004) (Figure 1).

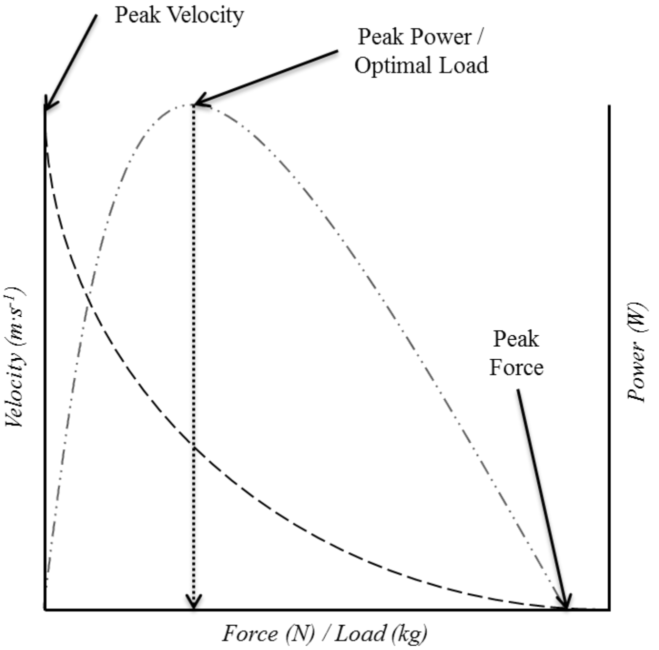

***Figure 1** Relationship between force-velocity, force-power and optimal load. Adapted from Kawamori and Haff (2004).*

We must also consider the protocol used in calculating the optimal load as an important aspect (instruments, body mass, eccentric phase depth and power variable analysed). Currently, there are many valid and reliable instruments for evaluating the power generated in a movement, such as force plates (Cormie, McBride, & McCaulley, 2007; Crewther, Kilduff, Cunningham, Cook, & Yang, 2010; Hansen, Cronin, & Newton, 2011; Walsh, Ford, Bangen, Myer, & Hewett, 2006), position transducers (Crewther et al., 2010; Drinkwater, Galna, McKenna, Hunt, & Pyne, 2007; Garnacho-Castano, Lopez-Lastra, & Mate-Munoz, 2015; Gomez-Piriz, Sanchez, Manrique, & Gonzalez, 2013), accelerometers (Crewther et al., 2010; Feldmann, Weiss, Ferreira, Schilling, & Hammond, 2010; Gomez-Piriz et al., 2013), video capture devices (Dias et al., 2011; Nuzzo, Anning, & Scharfenberg, 2011), jump mats (J. Garcia-Lopez, Morante, Ogueta-Alday, & Rodriguez-Marroyo, 2013; Nuzzo et al., 2011) and photocells (J. Garcia-Lopez et al., 2013). However, not all these instruments use the same variables for power output calculation (e.g. displacement, acceleration, and vertical ground reaction force and flight time) (Dugan, La Doyle, Humphries, Hasson, & Newton, 2004;

McMaster, Gill, Cronin, & McGuigan, 2014). In addition, in take-off exercises it is important to consider the athlete’s body mass to calculate the power output (Smilios et al., 2013). If the body mass is not included, the mobilized load will be underestimated and the power output obtained will be significantly different, and will even show the optimal load with a different external load (Dugan et al., 2004; Smilios et al., 2013). Another important aspect to consider is the eccentric phase depth, which also results in greater jump heights, throw distances (i.e. jump squat and bench press throw) and changes in peak power (Clark, Bryant, & Pua, 2010; McBride, Kirby, Haines, & Skinner, 2010). Finally, it is also important to take into consideration the power variable used. In the main, two variables are used: peak power, defined as the maximum instantaneous power reached during the concentric phase, and average power, calculated as the area under the concentric part of the power-time curve (McMaster et al., 2014; Sapega & Drillings, 1983). These two variables reach their maximum value at different loads in a specific exercise (Dugan et al., 2004; McMaster et al., 2014). If the ultimate goal of ballistic exercises is to maximize height or distance, it is logical to measure and report the parameter most associated with their performance (i.e. peak power) (Dowling & Vamos, 1993; Dugan et al., 2004).

Maximum power production is influenced by multiple mechanisms such as muscle architecture and composition, levels of neural activation, and the complexity of the technique to be performed (MacIntosh & Holash, 2000).

Muscle contractile capacity is influenced by a range of morphological factors, mainly the predominant type of fibres. A high correlation between the percentage of fast muscle fibres in the evaluated muscle and power output has been shown (Cormie et al., 2011; Coyle, Costill, & Lesmes, 1979; Faulkner, Claflin, & McCully, 1986; Terzis et al., 2003). Furthermore, the muscle cross-sectional area (CSA), which has a high correlation with the maximum force output, also contributes to developing a high power level (Oliver et al., 2013; Secomb et al., 2015; Shoepe, Stelzer, Garner, & Widrick, 2003). In addition, tendon properties also influence the function of the contractile elements, because greater stiffness may increase the force transmission and therefore also affect the maximum power production (Secomb et al., 2015).

The ability to produce maximum power is not only influenced by the characteristics of the muscle, but also by the ability of the nervous system to activate it (Cormie et al., 2011). In accordance with the size principle proposed by Henneman (1957) and replicated by many current studies (Holt, Wakeling, & Biewener, 2014; Raikova, Aladjov, Celichowski, & Krutki, 2013; Rodriguez-Falces & Place, 2013), the recruitment order of the motor units is always in order of increasing size of motor neurons (i.e. from type I to type IIb fibres). According to this principle, when the force requirements increase, more and larger motor units are recruited. However, those motor neurons that have a higher trigger threshold (i.e. type II fibres) develop higher power levels and therefore are desirable when high peak power in a short application time is necessary. Apparently, there are exceptional situations that don’t follow the size principle, such as ballistic movements, where trained subjects are able to recruit type II fibres almost exclusively (Haff, Whitley, & Potteiger, 2001; Komi, 1993).

The nature of movements influences the power development. The contraction type involved (i.e. eccentric, concentric or isometric) is an important factor in developing power and it is important to take it into account. However, the predominant types of contraction in both daily and sports movements are those that include a stretch-shortening cycle (SSC). In addition, these types of movements develop higher power levels due to the elastic energy released, mainly by the tendon, during the concentric phase (Takarada, Hirano, Ishige, & Ishii, 1997). On the other hand, movements that involve multi-joint muscle groups and without an active braking phase (e.g. bench press throw) will enable further development of power (Cormie et al., 2011; Newton, Kraemer, Häkkinen, Humphries, & Murphy, 1996; Toji & Kaneko, 2004).

While the aim of training is to improve muscle power, it should be noted that high values of maximum strength are important for developing high mechanical strength and the ability to apply high levels of force in a short time (rate of force developed [RFD]) and transform it into a shortening velocity of muscle fibre (Haff & Nimphius, 2012). Hence, there is considerable debate about what training load ranges are suitable for muscle power development, since the improvement of any of these three components (i.e. muscle architecture and composition, neural activation and technique complexity) will be reflected in an increase of power output.

1.2. Methods of power training

Historically, there have been different training methods in terms of the best approach for developing muscular power depending on the load to be used (Cormie et al., 2011). The first method suggests the use of high-resistance (i.e. > 70% of one repetition maximum [1RM]) and low-velocity (strength-oriented) training (Komi, 1993; Poprawski, 1987; Smilios et al., 2013; Spassov, 1988; Verkhoshansky & Lazarev, 1989), while the second method proposes the use of low-resistance (i.e. < 50% of 1RM) and high-velocity (speed-oriented) training (Kirby, Erickson, & McBride, 2010; McBride, Triplett-McBride, Davie, & Newton, 2002). The third method suggests that training would be done with the previously defined optimal load (Cormie et al., 2011; Kawamori & Haff, 2004) or close to it (Cronin & Sleivert, 2005; Haff & Nimphius, 2012; Kawamori & Haff, 2004; G. J. Wilson, Newton, Murphy, & Humphries, 1993). Although there are arguments for using each method, it is difficult to select one as the best method to optimize maximum force, RFD and power output, and therefore mixing all these methods throughout one’s sporting life is probably the best option (Cronin & Sleivert, 2005; Haff & Nimphius, 2012; Kawamori & Haff, 2004; Newton & Kraemer, 1994).

We must also bear in mind the types of exercises used during power training. In this case, there is enough evidence to show that ballistic exercises are more appropriate for developing power than conventional exercises (Haff et al., 2001;

Komi, 1993; Lake, Lauder, Smith, & Shorter, 2012). This is mainly because during ballistic exercises the load acceleration time is longer than with non-ballistic exercises, thereby developing greater strength, speed and power (Newton et al., 1996). Non-ballistic exercises are characterized by having a propulsive part followed by a final active braking during the concentric phase of movement (Sanchez-Medina, Perez, & Gonzalez-Badillo, 2010), thereby reducing the force application time in each repetition.

Therefore, if we focus exclusively on the development of power output, the use of ballistic exercises with optimal load seems one of the most suitable methods (Cormie et al., 2011; Kaneko, Fuchimoto, Toji, & Suei, 1983; McBride et al., 2002; Moss, Refsnes, Abildgaard, Nicolaysen, & Jensen, 1997; Toji & Kaneko, 2004; Toji, Suei, & Kaneko, 1997; G. J. Wilson et al., 1993).

1.3. Adaptations to power training

Although the exact adaptation mechanisms that occur after training with the optimal load are not known, it can be affirmed that changes in power performance are given both structurally and neurally. Improvements in the execution of ballistic movements have been observed with greater use of SSC, through a greater application of force in the eccentric phase (Bobbert & Casius, 2005; Cormie et al., 2010a, 2010b). A greater application of force leads to changes in the pennation angle (Cormie et al., 2010a, 2010b; Secomb et al., 2015) and the percentage of type II fibres in the musculature (J. M. Wilson et al., 2012). Furthermore, the neural level has documented changes in muscular activation, with increases in the electromyographic activity (EMG) ratio at low loads and close to the optimal load (Cormie et al., 2010a, 2010b). This explains in part the change that can be observed in the force-velocity curve (Figure 2), confirming the changes in power output (Cormie et al., 2010a, 2010b; Kaneko et al., 1983).

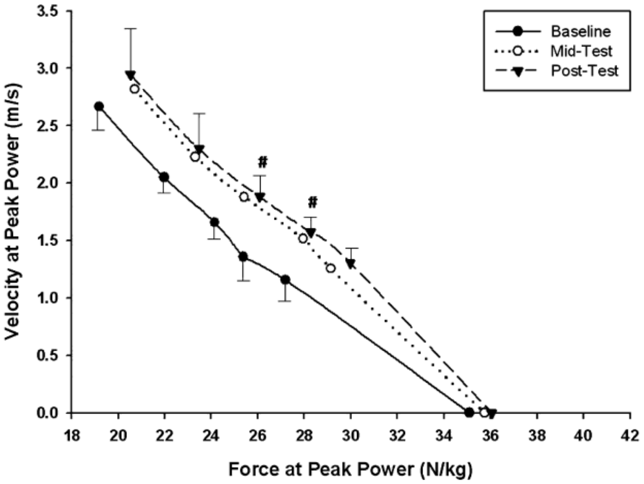

***Figure 2** Graphical representation of the changes in the force-velocity curve after training with the optimal load. Adapted from Cormie et al. (2010a).*

The mechanical, hormonal and metabolic stimuli are mainly responsible for this improvement (Enoka, 2002). The mechanical stimulus (e.g. high tensions, stretching and time under tension) appears to be the most important for producing strength adaptations (Enoka, 2002). After knowing the wide load ranges that can produce improvements in power levels, it seems that the most important factors are associated with kinematics and kinetic variables. Therefore the intention to move the load at maximum speed is the necessary mechanical stimulus for power adaptations (Behm & Sale, 1993; Cormie et al., 2011).

Endocrine system stimulation is another adaptive response modulator in any strength training (Crewther, Keogh, Cronin, & Cook, 2006). The interaction between anabolic (e.g. testosterone and growth hormone) and catabolic (e.g. cortisol) hormones regulates the balance between synthesis and degradation protein (Crewther et al., 2006; Kraemer & Ratamess, 2005). Increasing this stimulus is generally associated with increased CSA (Crewther, Cronin, Keogh, & Cook, 2008; Hayes, Grace, Baker, & Sculthorpe, 2015), which would not be a desired effect for some athletes due to the weight gain associated with it. Changes in both acute and chronic hormone levels appear to be mediated by factors such as the decline in the adenosine triphosphate/adenosine monophosphate ratio (Beaven, 2010). In the literature, there is no consensus on establishing a response pattern associated with so-called power loads (Crewther et al., 2006; Leite et al., 2011; Mero, Komi, Kyllönen, Pullinen, & Pakarinen, 1992). Thus, the structure of the session has a key role in modulating hormone secretion and adaptive response.

The metabolic response, mainly represented by acute changes in muscle (e.g. lactate and creatine kinase circulation, and muscle temperature), is another of the factors that regulate the adaptive response. Increased circulating metabolites have an impact on the mechanical muscle performance and therefore on future adaptations (Allen, Lamb, & Westerblad, 2008; de Salles et al., 2009; Fitts, 2008). These changes negatively affect the maximum power output, limiting force and/or shortening velocity during contraction (Allen et al., 2008; Fitts, 2008). A good power training prescription should avoid these situations of acute fatigue, and that would enhance the quality of the training sessions and subsequent adaptations.

These mechanical, hormonal and metabolic stimuli that occur with power training are reflected in improvements in performance. In fact, in previous studies (Cormie et al., 2010a; G. R. Harris, Stone, O'Bryant, Proulx, & Johnson, 2000; N. K. Harris, Cronin, Hopkins, & Hansen, 2008; McBride et al., 2002; G. J. Wilson et al., 1993; Winchester et al., 2008), in which short power training periods have been performed (i.e. 4–12 weeks) with ballistic exercises, improvements have been observed in a wide range of measures related to sporting performance in many modalities. The most prominent improvements in sporting performance are in the height of jump (N. K. Harris et al., 2008; G. J. Wilson et al., 1993), the speed in distances between 10 and 40 metres (Cormie et al., 2010a; N. K. Harris et al., 2008; McBride et al., 2002; G. J. Wilson et al., 1993), the 1RM (G. R. Harris et al., 2000; N. K. Harris et al., 2008; McBride et al., 2002) and in different kinetic variables such as the RFD, the peak power, velocity and force (Cormie et al., 2010a; McBride et al., 2002; Winchester et al., 2008).

1.4. Training load and optimal load

Having defined what mechanical power is, and the adaptive changes resulting from power training, we will continue with a description of the different variables that affect the training load (i.e. intensity, volume and density), focused on the optimal load use.

1.4.1. Intensity

The optimal load varies significantly across different exercises because the mechanical power output is influenced by the nature of the movement (Bevan et al., 2010; Cormie, McCaulley, Triplett, & McBride, 2007; Dugan et al., 2004; Jandacka & Uchytil, 2011; Kawamori & Haff, 2004; Siegel et al., 2002). Ballistic exercises can generate large forces against low loads due to continuous acceleration throughout the movement (Lake et al., 2012).

Generally, in single-joint muscles the power is maximized at around 30 % of the maximum force (Toji & Kaneko, 2004). However, in multi-joint muscles and overall movements (e.g. specific sports movements), the percentage varies and a range cannot be established. For example, the optimal load for a jump squat is ranges between 0 and 30 % of 1RM in the back squat (Cormie, McCaulley, et al., 2007; Soriano, Jiménez-Reyes, Rhea, & Marín, 2015), while for a bench press throw it ranges between 30 and 45 % of 1RM in the bench press (Newton et al., 1997), and in Olympic movements, such as the snatch or clean-up, it ranges between 70 and 80 % of 1RM (Kawamori et al., 2005; Soriano et al., 2015).

Although both the jump squat and bench press throw are ballistic exercises, the optimal load differs when it is expressed as a percentage of 1RM due to differences in the thrown load. In the jump squat, both body mass and external load are mobilized, while in the bench press throw only the external load is thrown, so we can talk about ‘take-off’ or ‘throwing’ exercises.

Although the jump squat and Olympic movements are performed at similar angles in lower-limb joints, the optimal load in each one is different (Cormie, McCaulley, et al., 2007). In addition, the optimal load in multi-joint exercises may vary depending on the athlete’s level and training history (Cormie et al., 2011). Previous studies have shown that athletes with significantly higher maximum strength have the optimal load located in higher 1RM percentages than others (Driss et al., 2001; Stone, O'Bryant, et al., 2003).

Therefore, it seems logical that the current recommendation is to identify the optimal load for each subject and exercise (Argus, Gill, Keogh, & Hopkins, 2014; Soriano et al., 2015).

1.4.2. Volume

Generally we tend to separate the variables related to the training load, but these variables are interdependent on each other, so those changes in repetitions per set or in the work/rest ratio influence the magnitude of the stimulus (Tran, Docherty, & Behm, 2006). The relationship between the number of repetitions performed per set and the maximum number of repetitions with a specific load is an important factor that is associated with the intensity, volume and metabolic response to training (Sanchez-Medina & Gonzalez-Badillo, 2011). Some authors have reported that the main effects of training (i.e. neural, hypertrophic and metabolic) and their associated adaptations mainly depend on the total number of repetitions performed (Izquierdo-Gabarren et al., 2010) and the loss of speed/power during each set (Sanchez-Medina & Gonzalez-Badillo, 2011). In this regard, in order to avoid undesirable or negative effects in performance (such as loss of velocity), some authors have proposed that only 50 % of possible repetitions for a specific load in each set should be performed (González-Badillo, Gorostiaga, Arellano, & Izquierdo, 2005; González-Badillo, Izquierdo, & Gorostiaga, 2006; Gorostiaga et al., 2012; M. Izquierdo et al., 2006). However, these recommendations appear to be not very specific because the velocity loss during a set is dependent on many factors, including the training experience. The previous recommendations found in the literature indicated that a loss of around 10–15 % of maximum velocity of execution (Bosco, Luhtanen, & Komi, 1983; McBride et al., 2002) is enough to promote undesirable effects such as the stimulation of slow fibres (Fry, 2004). Thus, if a power training with optimal load needs to maintain mechanical power in each set, only the number of repetitions that allows the maintenance of maximum mechanical power should be executed (Legaz-Arrese, Reverter-Masia, Munguia-Izquierdo, & Ceballos-Gurrola, 2007). No previous studies have estimated or established what the number of repetitions to perform by load used is. Even so, it is expected that this number could vary depending on the athlete's experience and level and the exercise type.

Again, the recommendation is that the number of repetitions for each set should be individualized for both the athlete and the exercise.

1.4.3. Density

The last component of the training load, and also the most forgotten in both practical and scientific fields, is the density of the training sessions. The density or rest time between sets in power training should be one that allows each repetition to be performed with maximum mechanical power. Just like other factors that determine the training load, changes in density affect all the other variables (Willardson & Burkett, 2008), and this has been identified as a critical variable that can affect both acute and chronic adaptations that occur during power training programmes (de Salles et al., 2009). Physiologically, the power output is highly dependent on the anaerobic metabolism, which requires at least 4 minutes to achieve a full recovery from an exhaustive effort (R. C. Harris et al., 1976). The use of short rest periods during power training has been related to increases in lactic metabolism participation and power output decreases (Abdessemed, Duche, Hautier, Poumarat, & Bedu, 1999). Even so, there is considerable debate about what the ideal resting time for power training is, probably due to the variety of methods used to study them. We have not found previous studies or data on the maintenance of mechanical power, but we can find recommendations for isoinertial (i.e. bench press) or isokinetic (i.e. knee flex-extension) exercises to maintain (acute effect) or improve (chronic effect) muscle power. These recommendations show that long resting times (160–300 s) compared with short resting times (40–60 s) result in better power output effects (Abdessemed et al., 1999; Pincivero, Lephart, & Karunakara, 1997). However, in the jump squat exercise no differences have been identified between using 30 or 240 s (Nibali, Chapman, Robergs, & Drinkwater, 2013; Robinson et al., 1995). Therefore, once again the exercise type and the muscle involved would seem to be taken into account during the prescription of density. In addition, training with the optimal number of repetitions and load may enable maintenance of mechanical power for more sets with shorter resting periods.

1.5. Aim of the thesis and research hypotheses

The aim of this thesis is to determine the effect of power training individualization with the optimal load on psycho-physiological and mechanical variables, and to determine the optimal resting time in the bench press throw exercise with this power training methodology.

Three studies were proposed to develop this project:

a) Mechanical, hormonal and psychological effects of a non-failure short-term strength training program in young tennis players.
b) The rest interval required for power training with a load that maximized power output in the bench press throw exercise.
c) The effects of training at an individualized optimum power zone vs. non-failure power training recommendations.

These were the starting hypotheses:

a) Acute effects on junior tennis players:

H1: Short-term power training programmes induce improvements in both peak strength and power output and maximum number of repetitions without mechanical power loss.

H2: Power training based on maintenance of mechanical power has a low impact on the hormone baseline levels and stress psychological variables based on the absence of metabolic fatigue.

b) Resting times:

H3: The resting time between sets during a session with the optimal load in the bench press throw exercise will be lower than recommended by the literature for power training, without producing severe changes in metabolic rate.

c) Differences between power training without reaching muscle failure (NF) and using optimal repetitions and load (OP):

H4: The use of higher percentages of 1RM and higher metabolic fatigue produces higher maximal strength gains in NF.

H5: The use of the optimal number of repetitions and load produces higher and faster increases in power output at different submaximal loads.

H6: Follow the recommendations of NF produces greater and earlier power losses during sets.

H7: Follow the recommendations of NF produces greater impact of training load on basal hormone concentrations.

02

Study 1

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Mechanical, Hormonal and Psychological Effects of a Non-Failure Short-Term Strength Training Program in Young Tennis Players

by

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Abstract: This study examined the effects of a 6-week non-failure strength training program in youth tennis players. Twenty tennis players (age: 15.0 ± 1 years, body height: 170.9 ± 5.1 cm, body mass: 63.3 ± 9.1 kg) were divided into experimental and control groups. Pre and post-tests included half squats, bench press, jump squats, countermovement-jumps and side-ball throws. Salivary cortisol samples were collected, and the Profile of Mood States questionnaire was used weekly during an anatomical adaptation period, a main training period and after a tapering week. The results showed that, after the main training period, the experimental group significantly improved ($p < 0.05$) in mean and peak power output and in the total number of repetitions during the half-squat endurance test; mean force, power and velocity in the half-squat power output test; Profile of Mood States (in total mood disturbance between the last week of the mean training period and the tapering week); and in squat-jump and countermovement-jump height. Moreover, significant differences were found between the groups at the post-tests in the total number of repetitions, mean and peak power during the half-squat endurance test, mean velocity in the half-squat power output test, salivary cortisol concentration (baselines, first and third week of the mean training period) and in the Profile of Mood States (in fatigue subscale: first and third week of the mean training period). In conclusion, a non-failure strength training protocol improved lower-limb performance levels and produced a moderate psychophysiological impact in youth elite tennis players, suggesting that it is a suitable program to improve strength. Such training protocols do not increase the total training load of tennis players and may be recommended to improve strength.

Key words*: power output, resistance training, cortisol, mood states, youth athletes.*

Introduction

Tennis involves intermittent, high-intensity efforts interspersed with periods of low-intensity activity, during which active recovery (between points) and passive periods (between changeover breaks in play) take place, over an extended period of time (i.e. in some cases > 5 h) (Fernandez-Fernandez et al., 2009). Throughout matches and practice sessions, players are constantly required to execute explosive actions (i.e. accelerations, decelerations, changes of directions, and strokes) with precision and within a very short period of time, highlighting power as a key determinant of tennis success (Fernandez-Fernandez et al., 2009; Reid & Schneiker, 2008). Therefore, the optimal design and implementation of training strategies that enhance power seem to be important for coaches and players.

The effectiveness of a strength training program depends on the application of appropriate training loads, which is related to the proper handling of training variables such as intensity, volume, and frequency, among others (Kraemer & Ratamess, 2004). Coaches and sport scientists in the field of strength training have attempted to identify proper handling of training variables to determine the training stimulus that maximises performance enhancement, although the optimal combination of such training variables is still under debate (González-Badillo et al., 2005; M. Izquierdo et al., 2006). It has been suggested that the main effect (i.e. neural, hypertrophic, metabolic, and hormonal responses) and subsequent adaptations to strength training partially depend on the total number of repetitions performed by an athlete (Izquierdo-Gabarren et al., 2010). In this regard, training leading to repetition failure (inability to complete a repetition in a full range of motion due to fatigue) or not leading to failure has been of interest in the past two decades (Drinkwater et al., 2005; M. Izquierdo et al., 2006; Rooney, Herbert, & Balnave, 1994). The primary role of training leading to repetition failure has been related to the increase of the motor unit activation capacity and high stress levels to the tissues, which would increase protein synthesis in order to repair damaged muscle during the training process (Drinkwater et al., 2005; Rooney et al., 1994).

Short-term training (< 9 wk) leading to repetition failure produces greater improvements in strength when compared with a non-failure training approach (Drinkwater et al., 2005; Rooney et al., 1994). However, other studies have reported that training to failure results in a small effect and may not be necessary for optimal strength gains, because the incurred fatigue reduces the force and velocity a muscle can generate (Folland, Irish, Roberts, Tarr, & Jones, 2002; Legaz-Arrese et al., 2007; Sanborn et al., 2000).

In sports requiring maximum power, strength exercises should be performed explosively, reaching the maximum velocity allowed by the load used (Jones, Hunter, Fleisig, Escamilla, & Lemak, 1999; Munn, Herbert, Hancock, & Gandevia, 2005). A reduction by more than 5–10 % of the execution velocity could deflect the training effect towards endurance, promoting non-desired effects (i.e. stimulation of slow fibres), and not towards reaching maximum power (Fry, 2004). However, in modalities in which strength demands are not very high (i.e. recruitment of all fast fibres and depletion of PCr stores are not required), it is possible that the execution of fewer repetitions while maintaining power levels would not have great relevance. In tennis, although there has been little research to substantiate the efficacy of strength training programs for players (Reid & Schneiker, 2008), based on previously mentioned mechanical demands (i.e. power generation during strokes and movements), it seems that the development of maximum-strength levels is not required. Thus, it can be argued that the use of training programs not leading to muscular failure (i.e. programs based on the maintenance of mechanical power), and only using those repetitions that maintain maximum power, would be useful to increase the overall power demands in tennis players (M. Izquierdo et al., 2006; Legaz-Arrese et al., 2007; Sanborn et al., 2000).

In addition to the mechanical aspects (i.e. power output), the homeostatic hormonal changes in response to strength training have been thought to play an important role in strength development (Kraemer & Ratamess, 2005), and the acute response of several hormones (i.e. testosterone, human growth hormone and cortisol) has been suggested as a useful marker of chronic strength training stress (Kraemer & Ratamess, 2005). Salivary cortisol (SC), as a representative marker of circulating free cortisol (Hellhammer, Wust, & Kudielka, 2009), has been recommended as an index of training stress in sport settings, because it avoids the stress caused by venepuncture, thus reducing artificially high values due to an anticipatory effect (Gatti & De Palo, 2011). In tennis, SC has been used to determine the acute psychophysiological stress responses during training cycles and competitive single matches (Filaire, Alix, Ferrand, & Verger, 2009; Rouveix, Duclos, Gouarne, Beauvieux, & Filaire, 2006), although there is no information about the responses in tennis players during a strength training program. Together with the hormonal changes produced by exercise, it also seems important to measure the impact of manipulating training variables (i.e. volume, intensity) in the athletes' mood states (Leunes & Burger, 2000). The Profile of Mood States (POMS), which reflects an individual's mood in six primary dimensions (i.e. Depression-dejection, Tension-anxiety, Anger-hostility, Vigour-activity, Fatigue-inertia, and Confusion-bewilderment), has been widely used in sports to evaluate the psychological state of athletes (Jones et al., 1999; McNair, Lorr, & Droppleman, 1997). High values on the Vigour-activity scale and low values on the remaining scales are desirable for athletic performance.

Thus, the aim of this study was to analyse the effects of a short-term strength training program not leading to failure in young tennis players. Additionally, SC and mood states were also monitored in order to detect any possible relationship between performance changes (i.e. power output) and psychophysiological stress.

Methods

Experimental Approach

A randomised, controlled and longitudinal (i.e. pretest-posttest) design was used in the present study. Before any baseline testing, all of the participants attended a laboratory for a familiarisation session to introduce the testing or training procedures, and also, to ensure that any learning effect was minimised for the baseline measures. Training was conducted during the pre-season (September to November). Pre (T1) and post-tests (T2) included: Parallel half squats, Supine bench press, Jump squats (SJ), Countermovement Jumps (CMJ) and Side Medicine Ball Throws. Moreover, hormonal (SC) and psychological data (POMS) were recorded once a week (Sundays). The training intervention consisted of eleven weeks divided into: four weeks for an anatomical adaptation period (AAP); six weeks for a main training program (MTP), and a tapering week (TW) (Figure 3). The subjects were divided into two groups according to their characteristics: an experimental group (EG; n = 11) and a control group (CG; n = 9). Both groups, EG and CG, performed the AAP before the pre-tests. During the MTP, the CG followed their regular tennis training. All of the tennis-training programs (EG and CG group) were controlled and matched by volume (90 min per session, 4 sessions a week) and intensity (average sessions between 75–85 % of the individual heart rate reserve (HRR)). The MTP was included at the end of the tennis training sessions and consisted of 12 sessions (2 sessions a week; Tuesdays and Thursdays) of ~ 30 min. Because the subjects were coming from tennis training, they only performed a specific warm-up, including two main exercises: supine bench press with free weights and parallel half squat using a Smith machine. The relative intensity (~ 60 % of 1 repetition maximum (1RM)) and rest periods (3 min) between sets were constant during the program. The number of sets increased from 3 to 6 during the MTP, with a volume decrease in the 3rd and 6th week (i.e. 50 % and 40 %, respectively). The number of repetitions per set was individually adjusted and did not change throughout the MTP, because the aim was to maintain mechanical power for the entire training session.

Participants

A total of 20 competitive youth male tennis players (age: 15.0 ± 1 years, body height: 170.9 ± 5.1 cm, body mass: 63.3 ± 9.1 kg and 18.3 ± 6.0 % body fat) involved in regular tennis competition at the national level (i.e. national ranking between 150 and 250) volunteered to take part in the study. The mean training background of the players was ~ 5 years, which focused on tennis-specific training (i.e. technical and tactical skills) and aerobic and anaerobic training (i.e. on- and off-court exercises). Players had no regular experience in strength training, with partial experience (i.e. familiarisation sessions) in a variety of plyometric (e.g. medicine ball, hopping) and injury-prevention exercises (e.g. elastic tubing and core training). Before participation, the experimental procedures and potential risks were explained fully to the subjects, and written informed consent was obtained from the players and their parents. The study was approved by the institutional review committee of Miguel Hernández University (Elche, Spain), and it conformed to the recommendations of the Declaration of Helsinki.

Procedures

Jump Tests

Squat jumps (SJ) and Countermovement jumps (CMJ) were performed on a contact platform (Globus, Italy), in accordance with Bosco et al. (1983). Each player performed 3 maximal jumps interspersed with approximately 30 s of passive recovery, and the greatest height for each jump was recorded.

Side medicine ball throw.

Players performed a forehand and backhand medicine ball throw according to previously established methods (Roetert & Ellenbecker, 2007). Players stood sideways to the starting line and simulated a forehand/backhand stroke, tossing a 3 kg ball as far as possible, with the back leg in contact with the ground, and without crossing the line after the throw. The distance from the line to the point where the ball landed was measured, and the best performance of three trials was recorded to the nearest 5 cm.

Supine bench press and parallel half-squat muscular performance.

Lower and upper body maximal strength was assessed using the estimated 1RM bench press and parallel half-squat actions, and was calculated using the Brzycki (1993) 1RM formula (RM = W / [102.78 – 2.78 (R)] / 100; W = weight used; R = maximal number of repetitions performed). Subjects performed a warm-up set of 10 repetitions at 40–60 % of the perceived maximum intensity. Three to six subsequent attempts were then made to determine the 1RM. Subjects were allowed to perform a maximum of 8 repetitions during the bench press and parallel half squat. Three to five min rest periods were used between lifts to ensure optimal recovery (Mayhew et al., 1995). For the supine bench press, the test began with the subject lowering the barbell from a fully extended arm position above the chest until the barbell was positioned 1 cm above the subject's chest. From that position (supported by the bottom stops of the measurement device), the subject was instructed to perform a purely concentric action (as fast as possible) maintaining a shoulder position of 90° abduction position. This completed a successful repetition. No bouncing or arching of the back was allowed. For the parallel half squat, the subjects began with the barbell on the shoulders with the knees and hips in the extended position. As the top of the thigh reached a position parallel to the floor, and after the verbal command "up", the subject ascended (as fast as possible) to a full knee extension of 180°. This test was performed using a Smith machine in which the barbell was attached at both ends with linear bearings allowing only vertical movements (M. Izquierdo et al., 2006).

Power output (i.e. leg and arm extensor muscles) was measured in the concentric portion actions of both exercises using a relative load of 60 % of 1RM (W-SQUAT and W-PRESS). Two testing trials were performed, and the best result was recorded for further analyses. Moreover, an endurance test in which each subject performed maximal repetitions to failure with a load of 60 % of 1RM was performed, for both bench press and parallel half squat (END-PRESS and END-SQUAT, respectively). During both exercises, barbell displacement, peak and average velocity ($m\cdot s^{-1}$), peak acceleration ($m\cdot s\cdot s^{-1}$), peak and average force (N), and peak and average power (W) were recorded by linking a rotary encoder to the end of the barbell (T-Force Dynamic Measurement System, Ergotech©, Spain), which recorded the position and direction of the barbell. The mean relative error in the velocity measurements was found to be < 0.25 %, whereas displacement was accurate to ± 0.5 mm (Sanchez-Medina & Gonzalez-Badillo, 2011).

The criterion for not leading to failure during exercise execution in MTP was to identify a significant decrease in movement velocity relative to the average velocity obtained within the first 2–3 repetitions in the endurance test (M. Izquierdo et al., 2006). The maximum power and average power of the best 3 repetitions were recorded. All of the data obtained from the rotary encoder were processed with customised software (Ergotech© Consulting, Spain).

Salivary Cortisol Samples.

Three saliva samples were collected on Sundays for 11 weeks at 8 a.m., 11 a.m. and 6 p.m.. Participants provided 5–10 ml of saliva in a plastic tube with cotton (Salivette®, Sarstedt, France). Participants were instructed to complete sampling before eating or drinking. Also, participants were told to thoroughly rinse their mouths with tap water before sampling, and they were instructed not to brush their teeth before completing the saliva sampling in order to avoid the contamination of the saliva with blood caused by microinjuries in the oral cavity (Filaire et al., 2009). The samples were then collected and frozen in the laboratory's refrigerator at -20°C until the assay. SC concentration was determined by Enzyme-Linked Immuno Sorbent Assay (ELISA) with a lower limit of sensitivity of 0.0537 µg/dl, and average intra- and inter-assay coefficients of variations (CVs) of 2.61 % and 7.47 %, respectively.

Profile of Mood States scores.

The tension, depression, anger, vigour, fatigue and confusion subscales of the Spanish version of the Profile of Mood States (POMS) questionnaire were used to evaluate exercise-related mental fatigue before and after the training intervention. Total mood disturbance (TMD) was calculated using the following formula: TMD = ((Anger + Confusion + Depression + Fatigue + Tension) – Vigour) + 100. The test was administered to all participants every Sunday at 11 a.m. by the same trained interviewer.

Statistical Analyses

Standard statistical methods were used for the calculation of means ± SD. Changes in kinematic variables were analysed with a 2-way interaction (time × group), with a series of repeated measures ANOVA, with time (T1 and T2) as the within-subjects factor, and a group (two levels: NFG, CG) as the between-subjects factor. Changes in the psychophysiological variables were analysed by a 2-way interaction (time × group) with a series of repeated measures ANOVA, with time (eight levels: baseline, six weeks intervention period, post intervention) as the within-subjects factor, and a group (two levels: NFG, CG) as the between-subjects factor. When a significant difference was found for either main effect (time or group), a Bonferroni post-hoc analysis was performed. SPSS V.20 was used for the statistical calculations. Effect sizes were calculated and interpreted according to > 0.2 (small), 0.5 (moderate) and > 0.8 (large). Statistical significance was set at the level of $p < 0.05$.

Results

The players' performance values (SJ, CMJ, side medicine ball throws, END-SQUAT, W-SQUAT, END PRESS and W-PRESS), which were obtained during T1 and T2, are presented in tables 1 and 2**Table 2**. After the intervention (T2), the results showed significant improvements in the SJ ($p = 0.002$; $\eta^2 = 0.54$), CMJ ($p = 0.041$; $\eta^2 = 0.34$), medicine side ball throw ($p = 0.001$; $\eta^2 = 0.49$), mean force ($p = 0.001$; $\eta^2 = 0.51$), power ($p = 0.008$; $\eta^2 = 0.42$) and velocity ($p = 0.026$; $\eta^2 = 0.36$) in W-SQUAT and total number of repetitions ($p = 0.001$; $\eta^2 = 0.73$), peak power ($p = 0.001$; $\eta^2 = 0.60$), and mean power of the first 3 repetitions ($p = 0.001$; $\eta^2 = 0.58$) in END-SQUAT for the EG, while there were no differences between the pre and post-tests in the CG for any of the variables analysed. The results also showed significant differences between the groups after T2 in mean velocity ($p = 0.033$; $\eta^2 = 0.25$) during W-SQUAT, total repetitions ($p = 0.001$; $\eta^2 = 0.53$), peak power ($p = 0.023$; $\eta^2 = 0.28$) and mean power ($p = 0.020$; $\eta^2 = 0.29$) in END-SQUAT.

No significant variations were observed in the bench press test for either group, with a non-significant increment ($p = 0.079$; $\eta^2 = 0.18$) in mean power for the EG (10.5 %), compared with a decrease in the CG (-4.1 %) at T2.

SC results showed significant differences between the groups in average baseline values ($p = 0.038$; $\eta^2 = 0.24$) in week 1 ($p = 0.016$; $\eta^2 = 0.31$) and 3 ($p = 0.020$; $\eta^2 = 0.30$) of MTP (Figure 4). Significant differences between the groups were also observed for the fatigue subscale in week 1 ($p = 0.041$; $\eta^2 = 0.24$) and 3 ($p = 0.029$; $\eta^2 = 0.26$) of MTP (Figure 5a), while a significant decrease in TMD was observed between week 6 of MTP and post-intervention for the EG ($p = 0.041$; $\eta^2 = 0.48$) (Figure 5b). The mean SC concentrations and the POMS scores for the EG and CG during the whole training period are presented in Figure 3.

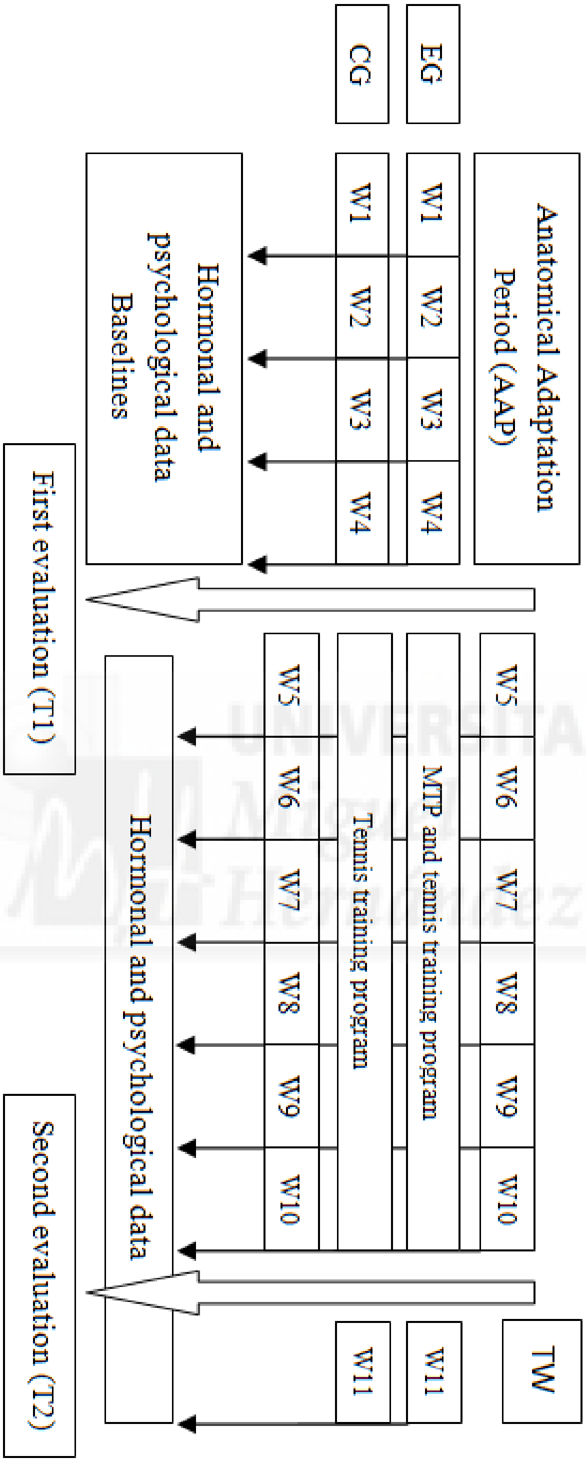

Figure 3 *Experimental design of study 1.*

Table 1 Mean ± SD values of upper body strength tests performed during T1 and T2.

			T1	**T2**	**ES (η^2)**
Side Ball throw	Dominant side (m)	EG	9.37 ± 1.01	10.60 ± 1.01 ‡‡	0.49
		CG	9.51 ± 1.56	10.07 ± 1.71	0.18
	Non-dominant side (m)	EG	9.07 ± 0.78	9.86 ± 1.06 ‡	0.42
		CG	9.46 ± 1.56	9.72 ± 1.40	0.06
W-PRESS	Velocity ($m \cdot s^{-1}$)	EG	0.55 ± 0.09	0.58 ± 0.08	0.09
		CG	0.61 ± 0.14	0.62 ± 0.13	0.01
	Force (N)	EG	328.0 ± 41.8	341.1 ± 48.8	0.30
		CG	285.2 ± 68.6	294.7 ± 68.7	0.37
	Power (W)	EG	182.1 ± 41.8	194.1 ± 39.6	0.14
		CG	170.2 ± 47.8	184.2 ± 74.8	0.09
END-PRESS	Rep. until failure	EG	15.0 ± 5.6	23.7 ± 9.4	0.56
		CG	8.6 ± 6.0	8.3 ± 2.4	0.41
	Rep. not leading to failure	EG	7.7 ± 3.2	11.0 ± 5.6	0.50
		CG	6.4 ± 5.9	6.7 ± 1.8	0.11
	Peak power (N)	EG	383.0 ± 104.4	514.7 ± 124.2	0.29
		CG	360.7 ± 105.7	379.1 ± 86.9	0.50
	Mean power (N)	EG	375.1 ± 102.5	500.4 ± 118.4	0.28
		CG	345.5 ± 103.2	368.1 ± 82.9	0.54

W-PRESS = Bench press power output test; END-PRESS = Bench press endurance test.

‡ *Significant differences from T1.* $p < 0.05$; ‡‡ *Significant differences from T1.* $p < 0.01$

Table 2 Mean ± SD values of lower limb tests performed during T1 and T2, and effect sizes (ES).

			T1	T2	ES (η^2)
Jump Tests	SJ (cm)	EG	28.45 ± 3.61	31.18 ± 2.27 ‡‡	0.54
		CG	31.71 ± 4.68	33.28 ± 3.59	0.38
	CMJ (cm)	EG	31.18 ± 3.57	32.45 ± 2.33 ‡	0.34
		CG	33.85 ± 3.57	33.57 ± 4.46	0.02
W-SQUAT	Velocity (m·s^{-1})	EG	0.57 ± 0.09	0.62 ± 0.13 *‡	0.36
		CG	0.55 ± 0.02	0.50 ± 0.06	0.40
	Force (N)	EG	627.9 ± 183.1	685.1 ± 181.8 ‡‡	0.51
		CG	700.8 ± 231.0	700.1 ± 231.4	0.23
	Power (W)	EG	351.6 ± 91.8	405.0 ± 105.2 ‡‡	0.42
		CG	380.8 ± 117.1	347.7 ± 111.4	0.38
END-SQUAT	Rep. until failure	EG	14.9 ± 5.6 *	23.73 ± 9.36 **‡‡	0.73
		CG	8.6 ± 6.0	8.29 ± 2.43	0.01
	Rep. not leading to failure	EG	7.6 ± 3.2	11.0 ± 5.6	0.37
		CG	6.4 ± 5.9	6.7 ± 1.8	0.01
	Peak power (N)	EG	383.0 ± 104.4	514.7 ± 124.2 *‡‡	0.60
		CG	360.7 ± 105.7	379.1 ± 86.9	0.07
	Mean power (N)	EG	375.1 ± 102.5	500.4 ± 118.3 *‡‡	0.58
		CG	345.5 ± 103.2	368.1 ± 81.9	0.11

SJ = Jump squat; CMJ = Countermovement Jump; W-SQUAT = Parallel half-squat power output test; END-SQUAT= Parallel half-squat endurance test. ‡ *Significant differences from T1.* $p < 0.05$; ‡‡ *Significant differences from T1.* $p < 0.01$; * *Significant differences in the CG.* $p < 0.05$; ** *Significant differences in the CG.* $p < 0.01$

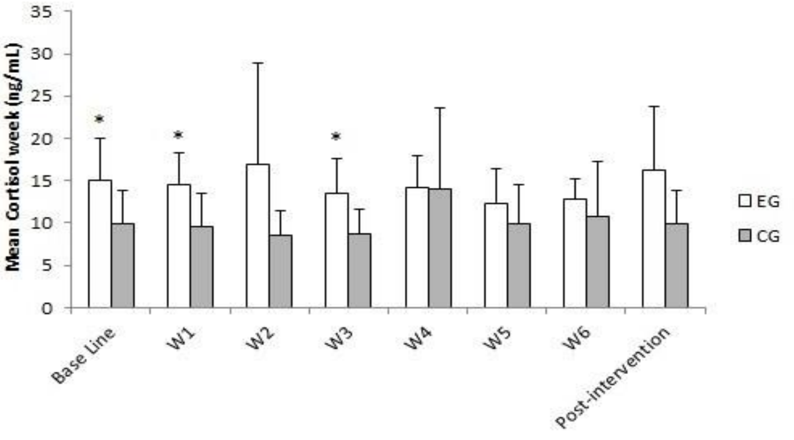

Figure 4 *Mean values of saliva cortisol concentrations during the intervention period.*Significant differences in the CG.* $p < 0.05$.

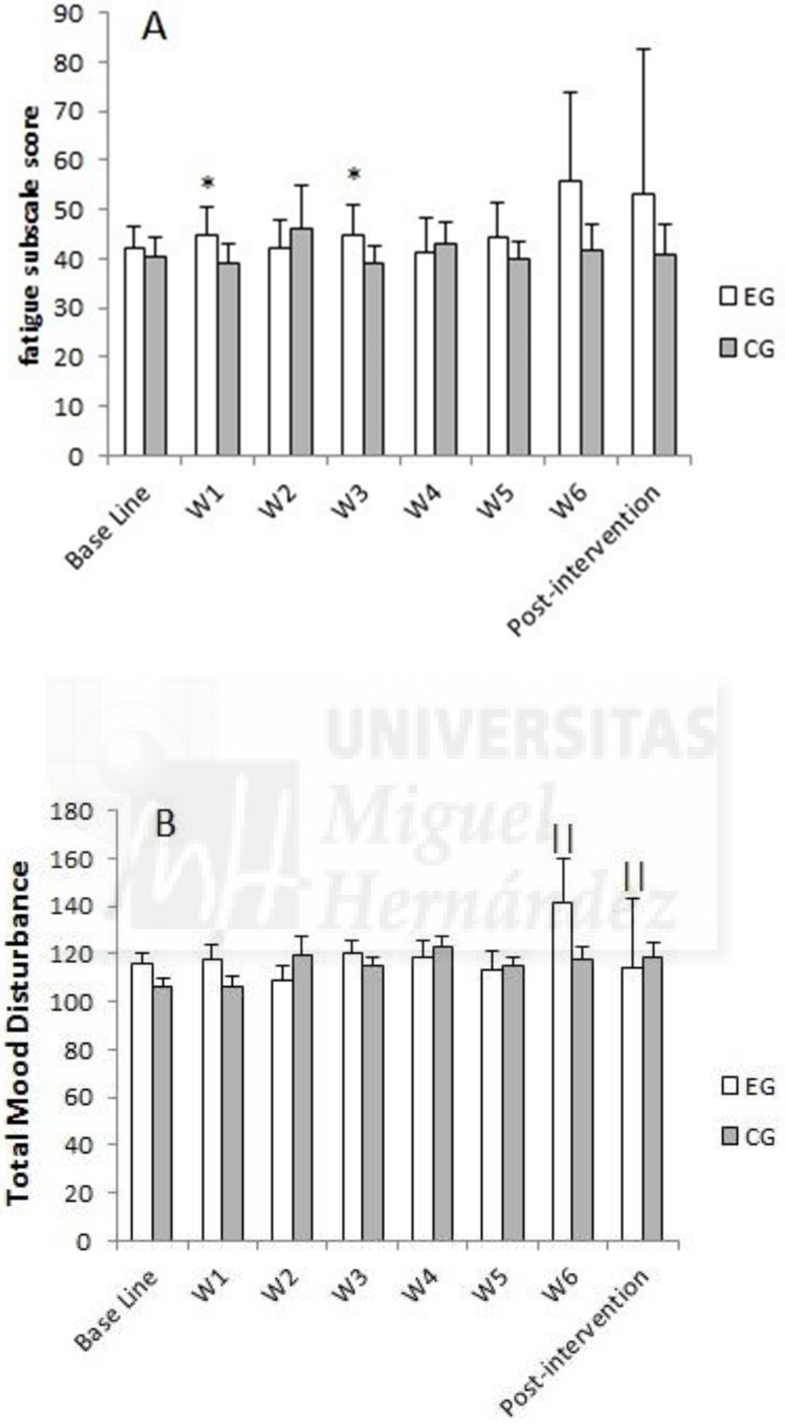

Figure 5 *(a) Fatigue subscale score POMS. Total mood disturbance during the intervention (b). *Significant differences in the CG. $p < 0.05$; ||Significant differences between weeks. $p < 0.01$.*

Discussion

The main findings of the present study were that, after a short-term strength training program not leading to muscular failure, there were improvements in the power performance (i.e. jumps, medicine ball throws and leg squats) of youth tennis players, with a moderate impact on their psychophysiological stress (i.e. small increases in cortisol, only in the first half of the training period, and small changes in the mood state, only during the tapering week).

After a 6-week strength training program not leading to failure, performance was improved in the parallel half squat, SJ, CMJ and side medicine ball throw. The results showed improvements in muscular power and the maximal number of repetitions of 8.5 % and 59.2 %, respectively, which are consistent with the data reported by M. Izquierdo et al. (2006), who found greater gains in muscular power (~ 29 %) and in the maximal number of repetitions performed during the parallel half squat (~ 69 %) when training not leading to muscular failure was performed.

With regard to the adaptations to strength and power training, lack of changes in athletes’ body mass (EG: 65.50 ± 6.87 and 65.99 ± 6.54 kg for T1 and T2, respectively) or the BMI (EG: 22.17 ± 2.30 and 22.29 ± 2.34 for T1 and T2, respectively) suggests that intrinsic muscular adaptations, motor coordination and neuromuscular activation are possible mechanisms for enhanced strength in the present study (Guy & Micheli, 2001). It is well known that neural adaptations dominate in the early stages of strength training programs, especially in youth and inexperienced athletes (Guy & Micheli, 2001). Moreover, these changes would be related to a better synchronisation of body segments and the related increased levels of motor coordination (Falk & Eliakim, 2003), supported by the significant improvements achieved in the EG in the jump tests in T2, with increases in the SJ and CMJ of 9.6 % and 4.1 %, respectively.

Regarding the training volume used in the present study, comparisons are difficult due to lack of studies focusing on this topic in tennis. The results are, however, in agreement with previous research reporting improvements in performance using moderate, rather than low or high volumes (González-Badillo et al., 2005) in young lifters, what suggests that training using high volumes does not seem to be necessary in order to achieve optimal strength improvements. In this regard, the training volume performed by the tennis players (~ 400 repetitions in 6 weeks) was relatively low compared to the study conducted by González-Badillo et al. (2005) (~ 2500 repetitions during 10 weeks), highlighting that, in a sport like tennis, in which strength demands are not maximal (Reid & Schneiker, 2008), and especially with youth athletes, training programs not leading to failure and without decreases in maximum execution velocity are effective for improving muscular strength and power. Moreover, it has been reported that strength training programs based on a high volume and leading to failure could induce overuse injuries and lead to overtraining situations (Willardson, 2007). This would be especially important in a sport like tennis, in which busy schedules limit the number of training sessions devoted to fitness development, especially during the competitive season. Moreover, in youth tennis players, we should give special care to situations in which a high frequency of specific training, combined with other activities, could increase the risk of injury (Kibler & Safran, 2005). During the past few years, it has been observed that tennis players devote a great amount of time to improve their tennis skills through technical and tactical training, with an average of 15–20 h of technical training per week, even at a young age (Crespo & Miley, 1998). As a consequence, training strategies aiming for short-term fitness improvements through a reduced number of weekly training interventions, like the one presented here, are warranted.

In contrast to the strength levels found in the lower body, upper body strength improvements were not significant. This is related to the use of free weights, which could produce greater co-activation in muscles involved in stabilising the shoulder joint during the bench press exercise, reducing the generated force due to the antagonist activation effect (Schick et al., 2010; Schwanbeck, Chilibeck, & Binsted, 2009). Nevertheless, we found improvements in medicine ball throw performance for both the dominant and non-dominant sides of 11.6 % and 8 %, respectively. As previously suggested, the better synchronisation of body segments (i.e. transfer from the lower to the upper body) and the related increased levels of motor coordination produced by the training intervention could be the mechanisms responsible for these changes.

Taking into consideration the psychophysiological responses, the present training intervention produced slight effects on the neuroendocrine system (SC) and mood state (POMS). In this regard, the results are consistent with previous research showing that a high strength training volume can stimulate large secretions of SC (Nunes et al., 2011). On the other hand, and according to the criteria suggested by previous authors (Berglund & Safstrom, 1994) to identify the risk of developing chronic fatigue, the training intervention used in the present study induced low levels of psychophysiological stress. However, caution should be used in interpreting the present data, because of the great inter-individual variability in SC baseline values (Salvador, Suay, Gonzalez-Bono, & Serrano, 2003).

SC and fatigue subscale values showed that the largest variations occurred during the first three weeks of MTP (W1 and W3). This could be related to the increase (W1) and decrease (W3) in the training load and suggests a delayed and cumulative effect of fatigue. Nevertheless, the increase in the training load (i.e. 16.7 % per week) did not produce a psychophysiological (i.e. SC and POMS) impairment in the EG, compared to the CG, even during W5, in which peak training volume was achieved. Lack of changes in these variables suggests a balance between the training program conducted during our study and the subjects' responses, which can be useful for non-experienced athletes (Faigenbaum et al., 2009). Moreover, the TMD results of the EG showed a significant decrease at the end of the training period (i.e. from W6 to post-intervention), with values returning to baseline levels, suggesting a positive adaptation to the training program and the sensitivity of the subscale fatigue for changes in the training volume (Leite et al., 2011).

It can be concluded that a non-failure strength-training protocol improved power output with a moderate psychophysiological impact on youth elite tennis players, suggesting that it is a suitable program to improve strength without large increases in total demands for these athletes. Moreover, we may consider this strength-training methodology as a good option for initial phases for non-experienced athletes.

03 Study 2

Under review in *Journal of Strength and Conditional Research*:

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The rest interval required for power training with a load that maximized power output in the bench press throw exercise.

by

Jose Luis Hernández-Davó, Rafael Sabido, Jose Manuel Sarabia, Jaime Fernández-Fernández y Manuel Moya

Abstract: This study aimed to test the influence of various rest interval (RI) durations used between sets on power output performance, physiological and perceptual variables during a strength training session using a load that maximized the power output in the bench press throw exercise. Thirty-one college students (18 males and 13 females) took part in the study. The experimental protocol consists of 5 sets of 8 repetitions of the bench press throw exercise with a load representing 40 % of the 1 repetition maximum (1RM). Subjects performed the experimental protocol on three different occasions, differing by the RI between sets (1, 2 or 3 minutes). During the sessions, power data (mean power and peak power), physiological (lactate concentration [La$^+$]) and perceptual (rating of perceived exertion [RPE]) variables were measured. In addition, delayed onset muscular soreness (DOMS) 24 and 48 h after the training session were reported. One-way repeated measures ANOVA showed that 1 min rest interval entailed higher power decreases and greater increases in values of physiological and perceptual variables compared with both 2 min and 3 min rest intervals. Nevertheless, no differences were found between 2 and 3 min rest intervals. Therefore, this study showed that, when training with an optimal load for the bench press throw exercise, 2 min RI between sets can be enough to avoid significant decreases in power output. Consequently, training sessions' duration could be reduced without causing excessive fatigue, allowing additional time to focus on other conditioning priorities.

Key words: *Resistance training, power training, optimal load.*

Introduction

Strength training is accepted as an essential constituent of training programs, independent of an individuals’ goal (Willardson, 2006). With the goal to obtain a specific target, strength training prescription involves the combination of several variables, including: types of exercises used; intensity [% 1-repetition maximum (1RM) or repetition maximum load]; volume (sets x repetitions); exercise sequence within a strength training session; repetition velocity; training frequency; and rest interval (RI) length between sets (Kraemer & Ratamess, 2004). Among these variables, RI between sets has received little attention. Current research indicates that the RI between sets is a critical variable affecting both acute and chronic adaptations to strength training programmes (de Salles et al., 2009). Thus, different RIs between sets (30–300 sec) have been suggested depending on the specific training goal of the strength training programme.

When training for muscular strength, 3–5 min between sets produces greater increases in absolute strength because of the maintenance of higher volumes and intensities during the sessions, while when targeting muscular hypertrophy, shorter RI (30–60 sec) may cause greater acute elevations in several hormones (e.g. growth factor) linked to increases in muscle size (Goto et al., 2004; Kraemer et al., 1990). Concerning muscular endurance, the findings are unclear, although short RIs (20-60 sec) seem to increase muscular endurance performance, as shown by higher repetition velocities and greater torque produced during a cycle test after training with these short RI (D. Garcia-Lopez et al., 2007; Hill-Haas, Bishop, Dawson, Goodman, & Edge, 2007). Finally, research has shown higher levels of muscular power output over multiple sets when comparing long (3–5 min) with short (1 min) RI (Abdessemed et al., 1999). Nevertheless, Nibali et al. (2013) found no differences in acute power output production across incremental loads (0–60 kg) between different RI (1–4 min) during jump squats. In relation to chronic adaptations on power output, Pincivero et al. (1997) showed greater improvements in peak power (PP) in a long RI group (160 sec) compared to a short RI group (40 sec) after 4 weeks of isokinetic knee extension training. Conversely, Robinson et al. (1995) did not find differing RI (30 vs 90 vs 180 sec) to influence vertical jump power output improvements after 5 weeks of training.

Therefore, there are conflicting findings about the influence of RI on acute responses and chronic muscular power adaptations. From a physiological point of view, power performance is highly dependent on the anaerobic energy metabolism (primarily the phosphagen system), which requires a minimum of 4 min for its full replenishment (R. C. Harris et al., 1976). Abdessemed et al. (1999) showed significant decreases in power output and significant increases in lactate concentration ($[La^+]$) when comparing 1 min to 3 and 5 min RI during bench press performed at 70 % of 1RM. Nevertheless, Willardson and Burkett (2008) showed no differences in strength gains comparing 2 vs 4 min RI despite the higher total volume performed by the 4 min RI group (7200 kg vs 5800 kg per mesocycle, approximately). Another important factor to consider regarding submaximal intensity lifts is whether or not sets are performed to failure. If sets are not performed to failure, then 2 min RI could be taxing enough because of reduced metabolic demand (Weiss, 1991). Jones, Bishop, Hunter, and Fleisig (2001) reported a trend for improvements in explosive outcomes [PP and peak velocity in loaded (30 and 50 % of 1RM) jump squats] in the light-load group after ten weeks of training compared with the heavy-load group using the same RI (2 min).

Furthermore, within a power training session, the use of relatively low external loads [which maximize power output (‘optimal load’)] and number of repetitions may allow the maintenance of power output over multiple sets with shorter RI. The greater influence of neural factors (e.g. motor unit recruitment, firing frequencies) in power training may induce a different type of fatigue compared with traditional (metabolic-dependent) resistance training. The use of an ‘optimal load’ has been suggested to provide an effective stimulus to elicit increases in maximal power output, leading to an efficient development of power production and dynamic athletic performance (Häkkinen, Komi, & Alen, 1985; G. J. Wilson et al., 1993).

However, despite the wide number of studies that have sought the RI required to maintain the training volume during strength training (i.e. number of repetitions up to failure), no studies have examined the influence of RI on acute power output maintenance when an optimal load is used. Therefore, the aim of this study was to check the influence of different RI in the ability to maintain power output during a power training session with a load that maximized power output in the bench press throw exercise.

Methods

Experimental approach to the problem

The study followed a within-subjects study design that examined the effects of RI between sets on power output performance and psycho-biological variables during the bench press throw exercise. Each participant attended 4 laboratory sessions in a 4-week period. The first session consisted of a 1RM test (bench press). The other 3 sessions consisted on the same strength training protocol (e.g. 5 sets of 8 repetitions), using an optimal load (e.g. 40 % of 1RM) for the bench-press throw exercise, but with different RI (e.g. 1, 2 or 3 min). Variables analysed were mean power (MP), PP, [La$^+$], rate of perceived exertion (RPE), and delayed onset muscular soreness 24 (DOMS24) and 48 (DOMS48) hours post-session. All subjects were familiarized with all equipment used for testing and training and two familiarization sessions were performed one week before the first testing session. Familiarization sessions consisted of 3 sets of 8 repetitions of the bench press throw exercise using 40 % of the subject's subjective 1RM. Furthermore, in an attempt to avoid diurnal variation in test measures, subjects were scheduled at approximately the same time for each testing and training sessions. To limit experimental variability, the same qualified investigator conducted all testing sessions.

Subjects

Thirty-one physically active college students, eighteen males (age = 24 ± 3 years; height = 1.79 ± 0.06 m; mass = 74 ± 10 kg; 1RM = 92 ± 19 kg) and thirteen females (age = 24 ± 3 years; height = 1.64 ± 0.06 m; mass = 60 ± 3 kg; 1RM = 41 ± 5 kg) took part in this study. All males and females were physically active with at least 12 months experience in strength training, and currently performing strength training sessions at least 2 days/week. In addition, males were required to bench press at least 100 % of their bodyweight, while females were required to bench press at least 60 % of their body weight. All subjects completed a health history questionnaire to document that they were free of cardiovascular disease, physiological disorders, or any other illness that may have increased the risk of participation or introduced unwanted variability in the results. All subjects were instructed to maintain their normal life-habits. Throughout the investigation, participants were requested to maintain their regular diets and normal hydration state, not to take any nutritional supplementation or anti-inflammatory medications, and to refrain from caffeine intake in the 3 hours before each testing session. Strength training sessions were not allowed at least 72 hours prior to the experimental sessions. Before participation, each subject provided written informed consent approved by the Ethics Committee of the University Miguel Hernández of Elche in accordance with the Declaration of Helsinki.

Procedures

Maximal dynamic strength assessment

The 1RM test for the bench press was performed using a Smith Machine (Technogym, Gambettola, Italy). Kinematic data were recorded by linking a rotary encoder to one end of the bar (T-Force system, Ergotech, Spain), which recorded the position of the bar with an analog-to-digital conversion rate of 1000 Hz and an accuracy of 0.0002 m (González-Badillo & Sánchez-Medina, 2010). The linear transducer was interfaced to a personal computer by means of a 14-bit analog-to-digital data acquisition board, where a specialized software application (T-Force Dynamic Measurement System) automatically calculated the relevant kinematic and kinetic parameters. Bar velocity was calculated by differentiation of bar displacement data with respect to time, then instantaneous acceleration (a) was obtained through differentiation of velocity-time data. Instantaneous force (F) was calculated as $F = m (a + g)$, where m is the moving mass (in kg) manually entered into the software, and g is acceleration due to gravity ($9.81\ m \cdot s^{-2}$). Finally, instantaneous mechanical power output (P) was calculated as the product of vertical force and bar velocity ($P = F \cdot v$). Peak power was taken as the maximum value of the power-time curve. The validity and reliability of this system have been previously established, with ICC values ranging from 0.81 to 0.91 and a coefficient of variation < 3.6 % (González-Badillo & Sánchez-Medina, 2010). For power variables analysis, only the propulsive concentric phase (without barbell flying) was analysed. The 1RM bench press was assessed using a previously established protocol (Baechle, Earle, & Baechle, 2004), which requires that subjects progressively increase resistance across attempts (e.g. beginning with 40 kg and 20 kg for males and females respectively) until the 1RM is achieved. Rest period between trials was at least 5 minutes. Subjects began by lying horizontally with the feet, gluteus maximus, lower back, upper back, and head firmly planted on the bench with elbows fully extended and gripping the bar. Subjects lowered the bar until the chest was touched lightly, approximately 3 cm superior to the xiphoid process. The elbows were extended equally with the head, hips, and feet remaining in contact with the floor throughout the lift. No bouncing or arching of the back was allowed. Testing was conducted by the same researcher and all conditions were standardized.

Experimental protocol

Three minutes after a warm-up consisting of 2 sets of 10 repetitions with the individual 50 % of 1RM, subjects performed 5 sets of 8 repetitions with a load representing 40 % of 1RM. Based on several studies (M Izquierdo et al., 2001; M. Izquierdo, Häkkinen, Gonzalez-Badillo, Ibanez, & Gorostiaga, 2002; Mayhew, Ware, Johns, & Bemben, 1997) a load of 40 % of 1RM can be considered as an optimal load to maximize power output in the bench press throw exercise.

Subjects performed the experimental protocol in three different sessions, differed by the RI between sets (1, 2 or 3 minutes). The order of the sessions was randomized. Through each set, subjects were encouraged to throw the barbell as high as possible, and during each throw, they were required to keep their head, shoulders, and trunk in contact with the bench and their feet in contact with the floor. No bouncing of the barbell was allowed. During the tests, both MP and PP output were recorded using the software provided by the T-Force system. For the data analysis, the following variables were calculated: MP and PP in each set, the percentage of change in both MP and PP with regards to the values obtained in the first set, and PP of each repetition.

[La$^+$] measures

[La$^+$] were determined from 25 µl capillarized blood samples drawn from the earlobe and analysed with a portable device (Lactate Scout, Senselab, Germany), with an accuracy of 0.1 mmol·L^{-1} (Tanner, Fuller, & Ross, 2010). Samples were taken one min before and after each protocol, and analysed at these time points by the portable lactate analyser.

Perceptual variables

RPE values were obtained using the Borg category scale (CR-10) (Borg, 1990). The CR-10 scale consists of a scale of exercise intensity defined between ‘rest’ (0) and ‘maximal’ (10). Subjects were asked “how hard do you feel the exercise was?” immediately after the last set of each protocol.

Delayed onset muscular soreness (DOMS) were reported by the subjects 24 and 48 h after each session. Subjects were asked “how painful do you feel your muscles?” giving their subjective feeling in a 0–10 scale (0 = no pain; 10 = a lot of pain) (Ojala & Hakkinen, 2013). All subjects reported no DOMS before all testing sessions.

Statistical analysis

All data were analysed using the statistical package SPSS 18.0 (SPSS Inc., Chicago, IL, USA). The normality of the outcome measures was tested using the Kolmogorov-Smirnov test. Due to statistical between-gender differences in 1RM, MP, PP, [La$^+$] and RPE, males and females data were analysed separately. A one-way repeated measure ANOVA was used to evaluate rest interval (1 vs 2 vs 3 min) influence in variables related to (1) mechanical (MP and PP), (2) physiological ([La$^+$]), and (3) perceptual (RPE and DOMS) variables. Statistical significance was set at $p < 0.05$. Cohen’s *d* and the standardized mean difference was used to calculate Effect Sizes (ES; mean difference / pooled SD) and interpreted for a recreationally trained sample according to Rhea (2004) as $d < 0.35$ (Trivial), 0.35–0.80 (Small), 0.80–1.50 (Moderate), and > 1.5 (Large).

Results

Physiological-perceptual variables

The physiological and perceptual variables analysed ([La$^+$], RPE and DOMS 24 and 48 h) with the 3 different RI are shown in table 3**Table 3**.

Males showed significantly higher values in [La$^+$] post (d = 1.19), [La$^+$] increase (d = 1.53), RPE (d = 1.08), DOMS24 (d = 0.75) and DOMS48 (d = 1.11) when using the 1 min RI compared with the 3 min RI ($p < 0.05$). RPE values were higher with the 1 min RI (d = 0.79) compared with the 2 min rest protocol. Moreover, when comparing the 2 with the 3 min RI, only DOMS24 were significantly higher (d = 0.9) using the 2 min RI ($p < 0.05$).

Females showed significantly higher values in [La$^+$] increase when using the 1 min RI compared with both the 2 min (d = 1.3) and the 3 min RI (d = 1.82) ($p < 0.05$). Results also showed significantly higher RPE values using the 1 min RI compared with the 3 min RI (d = 0.68) ($p < 0.05$).

Table 3 Physiological and perceptual data. Values are mean ± SD.

REST	**[La$^+$] pre (mmol·L^{-1})**	**[La$^+$] post (mmol·L^{-1})**	**[La$^+$] increase (mmol·L^{-1})**	**RPE**	**DOMS24**	**DOMS48**
Males						
1 min	3.9 ± 0.9	6.4 ± 1.1#	2.5 ± 0.9#	6.5 ± 1.6*#	2.4 ± 1.8#	1.5 ± 1.3#
2 min	4.1 ± 0.9	6 ± 0.9	2 ± 0.9	5.2 ± 1.6	2.8 ± 2.2#	1.6 ± 2.1
3 min	4 ± 0.5	5.3 ± 0.7	1.3 ± 0.6	4.7 ± 1.6	1.2 ± 1.3	0.4 ± 0.5
Females						
1 min	2.8 ± 0.4	4.6 ± 0.6	1.8 ± 0.4*#	4.8 ± 1.5#	2.2 ± 2	1 ± 1.2
2 min	2.8 ± 0.4	3.9 ± 0.8	1.1 ± 0.7	4.3 ± 1.9	2.2 ± 1.5	1.1 ± 1.2
3 min	3.1 ± 0.8	4 ± 1	0.9 ± 0.6	3.8 ± 1.4	1.5 ± 1.3	0.8 ± 0.9

*[La$^+$] = blood lactate concentration; RPE = rating of perceived exertion; DOMS24 = delayed onset muscular soreness 24 h post session; DOMS48 = delayed onset muscular soreness 48 h post session; * = significant differences (p < 0.05) with 2 min RI; # = significant differences (p < 0.05) with 3 min RI*

Kinematic variables

Data of kinematic variables are summarized in table 4. Among all the variables, only barbell flying time showed significant differences between RI conditions in males, being higher (297 vs 280 ms; $d = 0.97$), with 3min RI compared with 1min RI. There were no significant differences in time to PP, time to RFD_{max}, or concentric phase time neither in males nor in females.

Table 4 Kinematic data by rest interval in both males and females. Values are mean ± SD.

	Load (kg)	**Time to PP (ms)**	**Time to RFD_{max} (ms)**	**Concentric phase (ms)**	**Flying time (ms)**
Males	35.3 ± 7.8				
1 min		379 ± 45	43 ± 30	736 ± 63	280 ± 16
2 min		369 ± 42	58 ± 37	725 ± 56	289 ± 17
3 min		383 ± 42	46 ± 29	733 ± 48	297 ± 19*
Females	15.6 ± 1.6				
1 min		437 ± 44	81 ± 26	804 ± 42	313 ± 20
2 min		436 ± 53	78 ± 33	805 ± 51	314 ± 27
3 min		424 ± 56	71 ± 36	795 ± 51	319 ± 24

*PP = peak power; RFD_{max} = maximum rate of force development; * = significant difference ($p < 0.05$) with 1 min RI*

Power-related variables

Mean power

MP data with each RI are showed in Figure 6a (males) and 6b (females). Significant decreases ($p < 0.05$) in MP were observed with 1min RI commenced from the second set in both males and females. Comparing the values with the 1st set, MP was lower in the 2nd (321 vs 309 W; $d = 0.15$), 3rd (321 vs 303 W; $d = 0.23$), 4th (321 vs 294 W, $d = 0.36$) and 5th set (321 vs 288 W; $d = 0.41$) in males. In females, MP values were lower in the 2nd (118 vs 115 W; $d = 0.19$), 3rd (118 vs 113 W; $d = 0.31$), 4th (118 vs 110 W; $d = 0.55$) and 5th set (118 vs 108 W; $d = 0.67$).

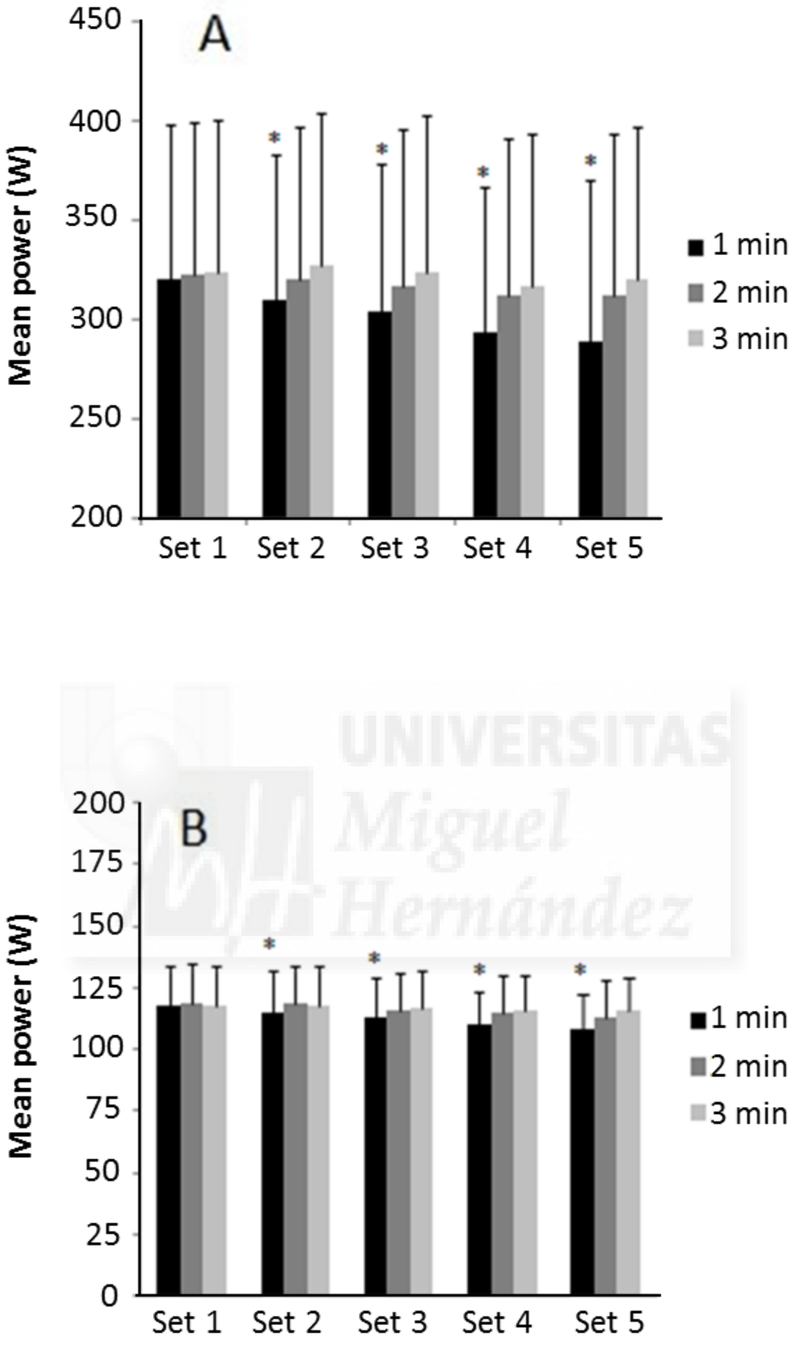

*__Figure 6__ MP values (±SD) obtained in males (A) and females (B) with the different RI used. * = Significant differences ($p < 0.05$) with the first set.*

Percent changes in MP comparing the RI protocols are presented in Figure 7. In males, the relative changes in MP values were significantly higher when using the 1 min RI compared with the 2 and 3 min RI from the 2nd to the 5th set ($p < 0.05$). When comparing the 1 min RI with the 2 min RI, values reported ranged between 3.4 % vs 0.5 % (2nd set) to 10.5 % vs 3.6 % (5th set) ($d = 0.82$ to 0.99), while values reported comparing the 1 min RI with the 3 min RI were 3.4 % vs -0.9 % (2nd set) to 10.5 % vs 1.2 % (5th set) ($d = 1.18$ to 1.39). In females results showed significant differences between the 1 and the 3 min RI, with the 1 min RI showing higher decreases ($p < 0.05$) from the 3rd (3.5 % vs 0.4 %) to the 5th set (7.5 % vs 1.5 %) ($d = 0.87$ to 1.07). In addition, a significantly greater decrease ($p < 0.05$) in mean power output was found in the 1 min RI compared with the 2 min RI only in the 2nd set (2.1 % vs 0.1 %, $d = 0.74$).

Figure 8 shows the relative decrease in PP output with each RI over the sets in both males (a) and females (b). In males, the relative decrease in PP in the 1 min RI was significantly higher compared with both the 2 min and the 3 min RI from the 2nd to the 5th set ($p < 0.05$). Comparing the 1 min vs the 2 min RI, percent change in PP values were significantly higher ($p < 0.05$) for 1 min RI from the 2nd (6.6 % vs 2.6 %) to the 5th (17.7 % vs 9.7 %) set ($d = 0.83$ to 1). In addition, the percent change in PP was significantly higher ($p < 0.05$) in the 1 min RI compared with the 3 min RI from the 2nd (6.6 % vs 1.2 %) to the 5th (17.7 % vs 7 %) set ($d = 1.09$ to 1.25). In females, results showed significant differences comparing the 1 min RI with both the 2 and 3 min RI from the 2nd to the 5th set ($p < 0.05$). Thus, significantly greater decreases in PP were found with the 1 min RI compared with the 2 min RI from the 2nd (5.7 % vs 0.8 %) to the 5th set (17 % vs 9.7 %) ($d = 0.75$ to 1.34). Comparing the 1 min RI with 3 min RI, significantly greater decreases were also found in PP for the 1 min RI: 5.7 % vs 1 % (2nd set) to 17 % vs 6.6 % (5th set) ($d = 0.99$ to 1.66).

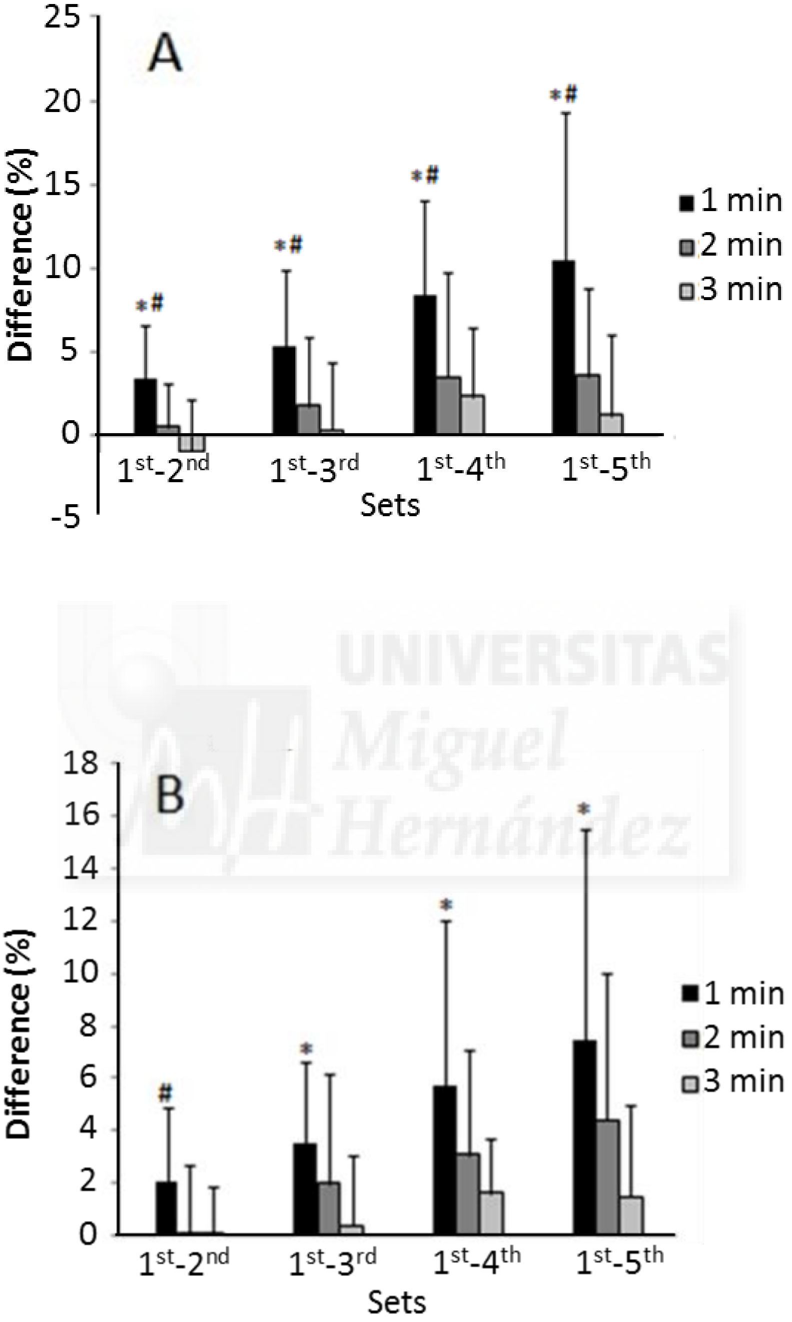

***Figure 7** Mean percent change (±SD) in MP obtained in males (A) and females (B) with the different RI used. * = Significant differences (p < 0.05) with 2 min RI; # = Significant differences (p < 0.05) with 3 min RI.*

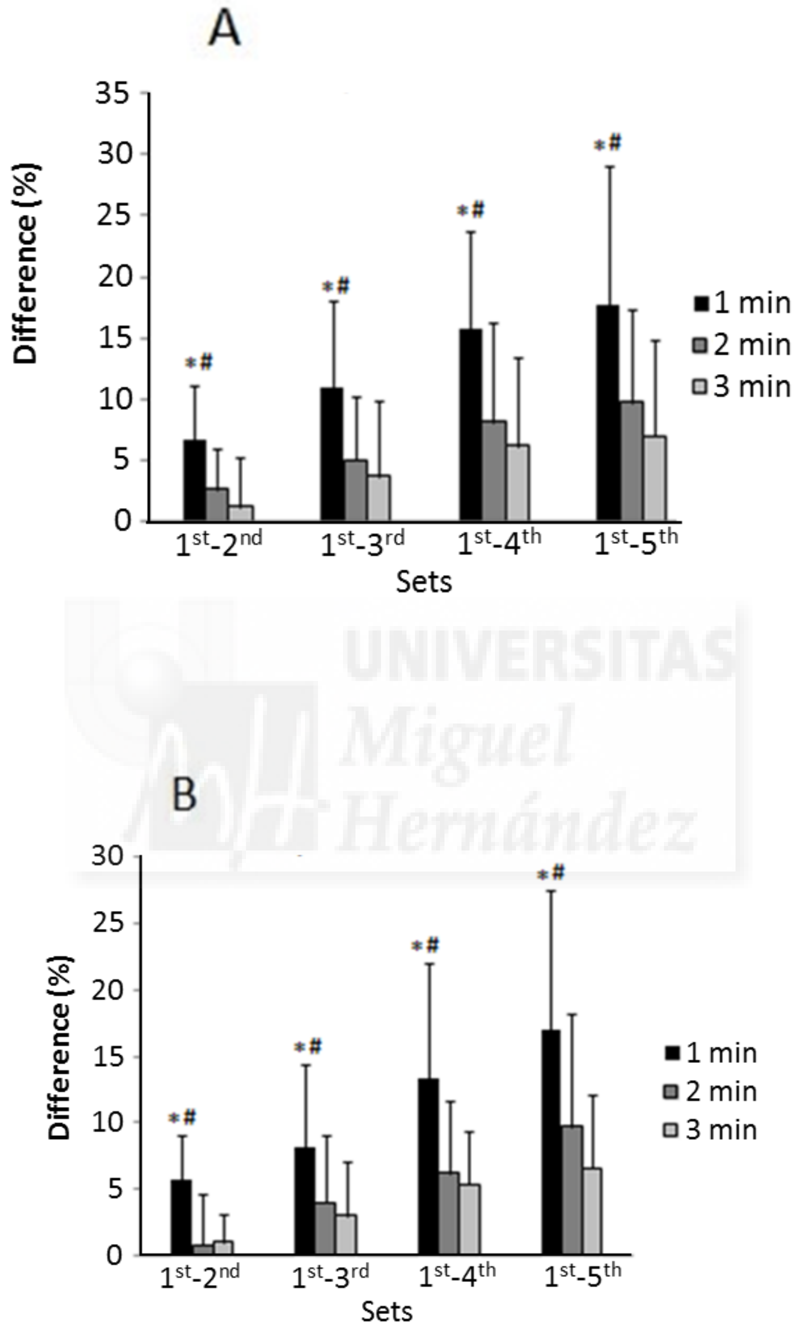

Figure 8 *Mean percent change (± SD) in PP obtained in males (A) and females (B) with the different RI used. * = Significant differences ($p < 0.05$) with 2 min RI; # = Significant differences ($p < 0.05$) with 3 min RI.*

Peak power

PP data with each RI are showed in tables 5 (males) and Table **6** (females). In males, significant decreases (*p* < 0.05) in PP were observed with 1min RI commencing from the second set: *d* = 0.23 (2nd set), 0.41 (3rd set), 0.6 (4th set) and 0.61 (5th set), with 2min RI commencing from the third set: *d* = 0.16 (3rd set), 0.27 (4th set) and 0.32 (5th set), and with 3min RI commencing from the fourth set: *d* = 0.22 (4th set) and 0.25 (5th set). In females, significant PP decreases (*p* < 0.05) were observed with 1min RI commencing from the second set: *d* = 0.4 (2nd set), 0.64 (3rd set), 1.03 (4th set) and 1.3 (5th set); with 2 min RI commencing from the fourth set: *d* = 0.47 (4th set) and 0.77 (5th set); and with 3 min RI commencing from the fourth set: *d* = 0.49 (4th set) and 0.62 (5th set).

Intra-set peak power

Tables 5 (males) and 6**Table 6** (females) show the evolution of PP within the sets with each RI protocol. There were no differences in the total number of repetitions performed without a significant decrease in PP (compared with PP value of the first set of each set) neither in males: 14, 15 and 12 repetitions with 1, 2, and 3min RI respectively; nor in females: 12, 13 and 13 with 1, 2 and 3min RI respectively.

Nevertheless, when comparing the PP of the last repetition over the sets with the different RI protocols, 1min RI showed significantly higher decrease (*p* < 0.05) compared with the decreases with both 2 (*d* ranging from 0.80 to 0.94) and 3 min RI (*d* ranging from 1.15 to 1.3) in males (Table 7). In females, PP decreases with 1min RI were higher than those obtained with 2min RI (*d* ranging from 0.86 to 1.16) and with 3 min RI (*d* ranging from 1.15 to 1.85). However, no differences were found between 2 and 3min RI protocols.

Table 5 Peak power values within sets by rest interval in males. Values are expressed in watts.

	Rep 1	**Rep 2**	**Rep 3**	**Rep 4**	**Rep 5**	**Rep 6**	**Rep 7**	**Rep 8**	**Average**
1 min									
Set 1	632	634	618	604	586*	566*	546*	528*	589
Set 2	618	602	587	562*	537*	517*	501*	482*	551#
Set 3	586	581	571	543*	508*	495*	475*	449*	526#
Set 4	564	557	537*	514*	478*	460*	443*	428*	498#
Set 5	559	559	538*	513*	473*	449*	427*	413*	491#
2 min									
Set 1	650	643	631	609*	592*	574*	559*	537*	600
Set 2	645	636	623	590*	576*	557*	540*	518*	586
Set 3	634	618	615	592*	569*	545*	522*	499*	574#
Set 4	620	605	594	569*	557*	530*	511*	476*	558#
Set 5	608	598	584	565*	541*	513*	500*	475*	548#
3 min									
Set 1	666	666	640	625*	606*	582*	565*	544*	612
Set 2	669	655	634*	618*	593*	579*	559*	536*	605
Set 3	652	640	627*	598*	584*	565*	538*	521*	591
Set 4	645	627	608*	582*	568*	546*	532*	501*	576#
Set 5	635	620	603	584*	566*	535*	529*	496*	571#

* = significant lower ($p < 0.05$) than first repetition of the set; # = significant lower ($p < 0.05$) than the first set

Table 6 Peak power values within sets by rest interval in females. Values are expressed in watts.

	Rep 1	**Rep 2**	**Rep 3**	**Rep 4**	**Rep 5**	**Rep 6**	**Rep 7**	**Rep 8**	**Average**
1 min									
Set 1	234	230	228	223	217*	212*	208*	200*	219
Set 2	227	226	216*	210*	203*	198*	190*	184*	207#
Set 3	224	221	215*	202*	194*	188*	180*	173*	200#
Set 4	214	210	207*	195*	183*	175*	169*	159*	189#
Set 5	210	205	200*	186*	169*	166*	158*	148*	180#
2 min									
Set 1	235	233	227	219*	211*	209*	200*	193*	216
Set 2	235	231	226	218*	211*	205*	198*	188*	214
Set 3	228	224	220*	212*	207*	199*	189*	180*	207
Set 4	223	221	214	204*	199*	192*	184*	179*	202#
Set 5	221	216	208*	196*	191*	180*	174*	166*	194#
3 min									
Set 1	237	230	226	219*	214*	211*	201*	194*	216
Set 2	232	232	221*	215*	207*	207*	202*	197*	214
Set 3	228	227	221	212*	208*	201*	196*	185*	210
Set 4	221	221	215	206*	200*	197*	188*	187*	204#
Set 5	222	222	207*	204*	198*	195*	185*	179*	202#

** = significant lower (p < 0.05) than first repetition of the set; # = significant lower (p < 0.05) than the first set*

Table 7 Peak power decrease (%) in the last repetition of each set when compared to the last repetition of the first set.

	2nd set	**3rd set**	**4th set**	**5th set**
Males				
1 min	9 ± 5.4*#	15.8 ± 9.8*#	19.6 ± 7.9*#	22.9 ± 13.3*#
2 min	3.9 ± 5.8	7.7 ± 7.2	12.5 ± 9.8	12.7 ± 10.2
3 min	1.5 ± 7.1	4.1 ± 10.4	8.1 ± 9.7	8.9 ± 11
Females				
1 min	8 ± 3.9◊#	12.9 ± 7.5*#	19.9 ± 11.2*#	25.2 ± 12.9*#
2 min	2.6 ± 5.1	7 ± 4.6	7.8 ± 7.6	14.3 ± 10.3
3 min	-2 ± 8.4	4.5 ± 6.8	2.9 ± 8.2	7 ± 8.2

** = significant differences (p < 0.05) with 2 min RI; ◊ = significant differences (p < 0.01) with 2 min RI # = significant differences (p < 0.01) with 3 min RI*

The individual responses of peak power decrease (i.e. % difference between the 1st and the 5th set) when using each RI are shown in Figure 9a (males) and b (females). In spite of subject's variability, the same tendency (sample average line) can be observed in both genders.

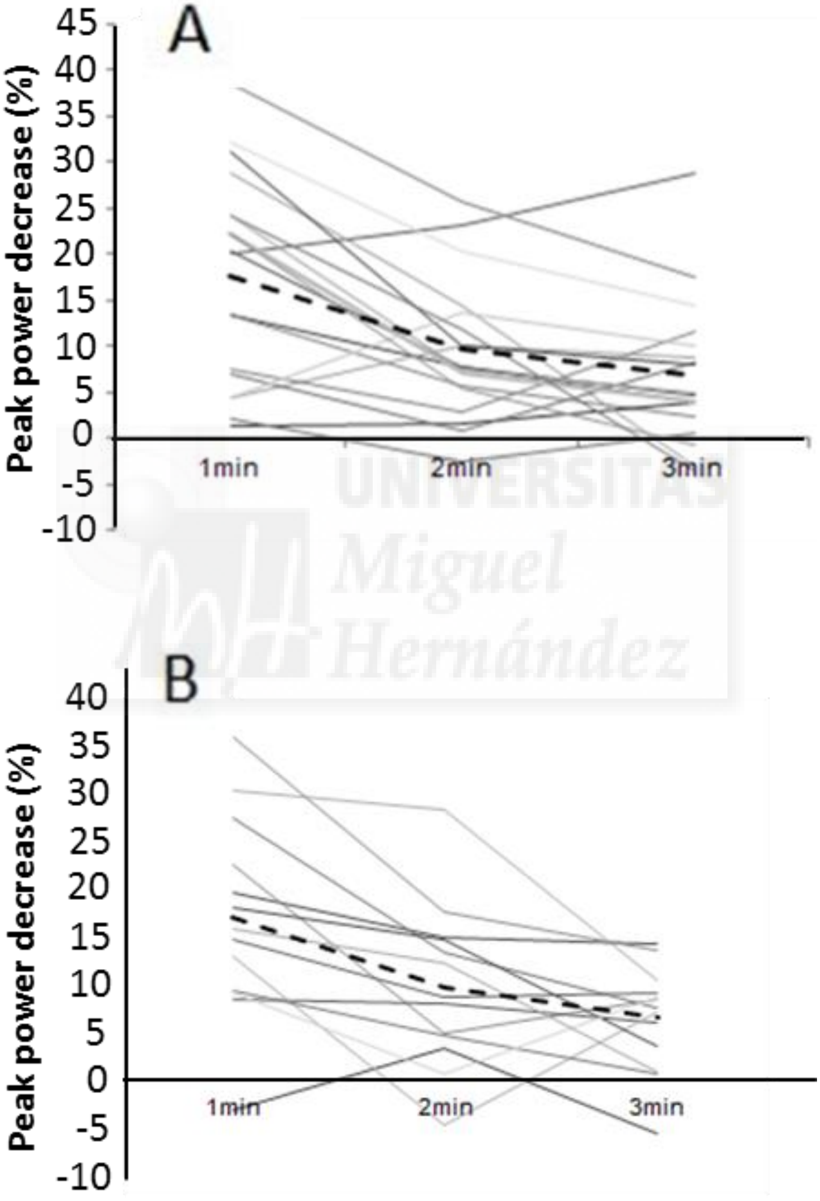

Figure 9 *Individual responses of PP decrease in males (A) and females (B) with the different RI used. Dashed line = sample average.*

Discussion

The aim of the present study was to test the influence of different RI on power output performance when training for maximizing muscular power with an optimal load in the bench press throw exercise. For that purpose, we compared three different RI: 1, 2 and 3 min. The main findings were that when training with an optimal load for developing muscular power in the bench press throw exercise, there were substantial differences in mechanical and physiological-perceptual variables comparing the 1 min RI with both 2 and 3 min RI. When using 1 min RI, results showed significant impairments in both, mechanical (e.g. MP and PP) and physiological-perceptual (e.g. [La^+], RPE) parameters, while no differences were found when comparing the 2 and 3 min RI.

In spite of the between-gender differences in some outcomes such as 1RM, mean and peak power output, [La^+] or RPE, the influence of the different RI used in this study has shown to be very similar in both genders. Therefore, throughout the discussion there are not between-genders differentiations, and all the explanations may be accepted for both males and females.

The results of the current study agree with those reported by Abdessemed et al. (1999) as 1 min RI entailed higher power decreases compared with 3 min RI. In the present study, decreases in MP were observed with 1 min RI, commenced from the second set, while no significant decreases in MP were found in both 2 and 3 min RI, neither in males nor in females over the 5 sets. These significant decreases in MP were significantly higher than those showed when resting 2 min (males) and 3 min (males and females) (Figure 7). When resting 1 min PP decreases commenced from the second set in both males and females, while no reductions were observed until the third set (2 min RI) and the fourth set (3 min RI) in males, and until the fourth set (in both 2 and 3 min RI) in females (see Figure 8). These significant impairments with short (1 min) RI were not found by Nibali et al. (2013), who recently showed that 1 min RI were enough to maintain PP output during light-loaded squat jumps, although this could be related to the lower training volume completed in that study (3 sets of 3 reps), which could hide larger power decreases using short (1 min) RI.

Although the number of repetitions within each set with a significant decrease in PP was not different between RI neither in males nor in females, when comparing the PP in the last repetition over the sets with the PP of the last repetition in the first set, 1 min RI showed higher percentage decrease than both 2 and 3 min RI (See table 7). Thus, although fatigue within sets seems to be similar in spite of the RI, short (1min) RI do not allow for full recovery before the initiation of the subsequent set, leading to a significantly higher accumulated fatigue in the last repetition over the sets.

From a physiological point of view, the greater decrease in power performance showed when resting 1 min was accompanied by a significant higher [La^+]. This increase in [La^+] reflects the greater use of the anaerobic system as a source of energy production, possibly leading to disturbances in several ions (e.g. H^+), and affecting muscle function (peak force and maximum muscle shortening velocity) as a result of lowered pH values (Weiss, 1991). In addition, Ratamess et al. (2007) showed higher increases in oxygen consumption, and greater respiratory exchange ratio with short RI (30 sec and 1 min), compared with 2, 3 or 5 min RI. These metabolic variables were highly correlated with fatigue rate during the bench press exercise. Concerning the influence of RI on neuromuscular fatigue, it could be hypothesized that 1 min RI causes changes in the motor unit recruitment pattern leading to contraction failures in fast-type motor units and, thus, affecting power output performance (Komi & Tesch, 1979). Indeed, it has been reported power output decreases due to impaired intermuscular coordination, expressed as changes in agonist-antagonist coactivation (O'Bryan, Brown, Billaut, & Rouffet, 2014; Samozino, Horvais, & Hintzy, 2007).

The slightly performance impairments showed when resting 2 min are in line with Scudese et al. (2013) who found no significant differences in repetitions completed using 2 min RI compared with either 3 or 5 min RI. In fact, Willardson and Burkett (2008) showed no differences in strength gains when comparing 2 and 4 min RI groups after 13 weeks intervention. Most studies have evaluated the effect of different RI on either the acute (Willardson, 2006; Willardson & Burkett, 2006) or chronic (Scudese et al., 2013; Willardson & Burkett, 2008) strength responses taking volume completed as performance criterion. Although training with loads that maximized power output has been shown useful to develop power output and to increase dynamic athletic performance (G. J. Wilson et al., 1993), it is still poorly-known how the choice of power output decrease as performance criterion can influence chronic power adaptations, and whether short (2 min) RI in power training may affect chronic development of muscle power, strength gains, hypertrophy or physiological variables (e.g. buffering changes).

The perceptual variables (RPE and DOMS scales) have been previously reported as sensitive tools to control training sessions' intensity (Radaelli et al., 2014; Robertson et al., 2000). Accordingly, RPE values were significantly higher for the 1 min RI compared with 2 min RI in males (25 %) and 3 min RI in both males and females (38 % and 26 % respectively). Scudese et al. (2013) lately showed similar RPE results, while 1 min RI entailed higher values compared with 3 min RI, although in this study differences between 1 and 2 min RI were not reported. On the other hand, the greater DOMS24 experienced by males when resting 1 and 2 min compared with 3 min RI, and DOMS48 comparing 1 vs 3 min RI demonstrate that longer between-session times are required for fully recovery when shorter RI are used, although it should be checked how DOMS values ranging from 1.5 to 2.8 (in a 0–10 scale) may affect strength/power production during a training session, since muscle pain can induce a reduction in the motor-evoked potentials and H-reflex (Le Pera et al., 2001). High correlations have been reported between several variables associated with muscular hypertrophy (i.e. structural damage of sarcomeres, tearing of the Z-lines) and DOMS (Clarkson & Newham, 1995; Flores et al., 2011), therefore, it could be hypothesized that shorter rest intervals (1 min) even in power training sessions, may lead to greater increases in muscle size.

The main limitations of the present study include the lack of neural measurements (i.e. surface EMG) that could provide information about neural fatigue in the different RI conditions and lack of measures of hormonal responses to different RI. Furthermore, the different strength/power profiles found in our male sample might have obscured its possible influence on power output decreases over multiple sets. Based on our results, future studies should investigate the effect of different RI on chronic power developments after continued power training exposure with shorter-than-traditional (2 min) RI, and the effect on athletic populations with different strength/power profiles.

Practical applications

To our knowledge, this is the first study aiming to check the influence of different RI on power output performance when training with an optimal load in the bench press throw exercise. Power training recommendations regarding RI seem to be load specific, and several factors may affect RI required between sets, such as athletes training experience or strength/power profiles, therefore, these facts should also be studied. Nevertheless, this study has shown that, when physically active men and women perform a power training session with an optimal load for the bench press exercise (40 % 1RM), 2 min RI between sets can be enough to avoid significant decreases in power output. In addition, this RI did not involve greater metabolic demand (measured as $[La^+]$) compared with 3 min RI. Therefore, when training for power development with an optimal load, 2 min RI makes possible the maintenance of performance during the training session avoiding high metabolic requirements. Consequently, excessively long rest intervals (i.e. 3–4 minutes) are not necessary, and may detract from other conditioning priorities. Further research on the effects of whether continued exposure to power training with these shorter RI may affect power output, strength gains and hypertrophy in a different way than traditional power training with large RI is warranted.

04 Study 3

Under review in *European Journal of Applied Physiology*:

Sarabia, J. M., Moya, M., Hernández-Davó, J.L., Fernandez-Fernandez, J., & Sabido, R. The effects of training at an individualized optimum power zone vs. traditional power training recommendation.

The Effects of Training at an Individualized Optimum Power Zone vs. traditional Power Training Recommendation.

by

Jose Manuel Sarabia, Manuel Moya, Jose Luis Hernández-Davó, Jaime Fernández-Fernández y Rafael Sabido

Abstract

Purpose The aim of this study was to compare the effects of two 8-weeks strength training programs (i.e. one with optimal load, and the second one following the non-failure power training recommendations) on mechanical and physiological variables.

Methods Twenty nine recreationally active young male were divided into three homogenous groups (Optimum power group [OP = 10], non-failure group [NF = 10] and a control group [CG = 9]). Training program consisted in two mesocycles of four weeks (2 sessions × week). Pre (T1), intermediate (T2) and post-tests (T3) included: anthropometry, one repetitions maximum (1RM), peak power output with 30, 40 and 50 % of 1RM (PPO) in the bench press throw. Salivary testosterone and cortisol concentrations were obtained in basal situation during testing weeks.

Results After the first mesocycle, OP increase PPO in each load used ($p < 0.05$, Small ES). After the 8-weeks training period, both experimental groups increase in 1RM ($p < 0.05$, Small Effect Size [ES]) and PPO in each load ($p < 0.01$, Small ES). Significant decreases in peak power during all sets compared with 1st set ($p < 0.01$, Small ES) and significant changes in salivary cortisol and testosterone for NF ($p < 0.05$; *Small to moderate ES*).

Conclusions Optimal load and repetitions will lead to a more efficient training program reducing the volume needed (i.e. time) and the physiological impact on the player.

Key words: *Optimal load, Strength training, Bench press throw, Cortisol, Testosterone*

Introduction

Strength and power are considered critical components of modern athletic performance. More specifically, power output is an important attribute in determining athletic ability and predicting success in different sports (McGuigan, Wright, & Fleck, 2012; Wisløff et al., 2004). Power may be affected by force- or velocity-oriented training methods. Thus, considerable debate exists concerning not only power training methods but also the optimal load needed to obtain power adaptations (Cormie et al., 2011). Historically, there have been different training methods regarding the best approach for developing explosive muscular power, ranging from high-resistance (i.e. > 70 % of one repetition maximum [1RM]), low-velocity training (strength-oriented) (Poprawski, 1987; Schmidtbleicher & Buehrle, 1987; Spassov, 1988; Verkhoshansky & Lazarev, 1989), passing by low-resistance (i.e. < 30 % of 1RM), high-velocity training(speed-oriented) (Kaneko et al., 1983; McBride et al., 2002) to intermediate-resistance (i.e. 50–70 % of 1RM), high-velocity (M. Izquierdo et al., 2002; Kawamori & Haff, 2004). Additionally, power training has a relative intensity (i.e. percentage of an exercise 1RM) usually defined as the optimal load (Cormie et al., 2011), in which both components of the power equation are optimized (force and velocity). This intensity produces the highest mechanical power, being considered the maximum point of a parabolic function (P_{max}) (Kawamori & Haff, 2004). Thus, previous several studies suggested the use of ballistic exercises with the individual optimal load as the most recommended training strategy to achieve power improvements (Cormie et al., 2010a; Cronin & Sleivert, 2005; Kawamori & Haff, 2004).

Although the exact mechanisms underlying superior adaptations after training with a specific load remain unidentified, it is theorized that training with optimal load provides a unique stimulus due to specific adaptations in the rate of neural activation (Häkkinen et al., 1985; Kaneko et al., 1983; McBride et al., 2002). This may be understood as due to favourable neural and muscle fibre adaptations increasing type II fibres with optimal load training (Tidow, 1995; J. M. Wilson et al., 2012). This is supported by previous research suggesting that training with the P_{max} resulted in superior improvements in maximal power production than other loading conditions (Cormie et al., 2011; G. J. Wilson et al., 1993).

Strength training prescription involves the combination of several variables not only the intensity (% of 1RM), including: type of exercises used; volume (sets × repetitions); exercise sequence within a strength training session; repetition velocity; training frequency; and rest interval length between sets (Cormie et al., 2011; Kraemer & Ratamess, 2005). It has been suggested that the main effect (i.e. neural, hypertrophic, metabolic) and subsequent adaptations to strength training depend, among other factors, on the total number of repetitions performed (Izquierdo-Gabarren et al., 2010) and velocity loss in each training set (Sanchez-Medina & Gonzalez-Badillo, 2011). In this regard, previous research argued that traditional strength training leads to repetition failure, and the speed of the repetitions slows naturally as fatigue increases, recommending (Sanchez-Medina & Gonzalez-Badillo, 2011). Thus, they recommended no to exceed around 50 % of the number of possible repetitions against any load (e.g. 6 repetitions of a 12RM load) (González-Badillo et al., 2005; González-Badillo et al., 2006; Gorostiaga et al., 2012; M. Izquierdo et al., 2006). However, this recommendation seems to be very general and it could be speculated that fatigue will emerge due to a > 5–10 % reduction of the execution velocity. This could deflect the training effect towards endurance, promoting non-desire effects (i.e. stimulation of slow fibres), and not reaching maximum power (Fry, 2004). Thus, power training based on maintenance of mechanical power in each set suggests that, only the number of repetitions that allow the maintenance of optimum power (i.e. 90 % related to the maximum power achieved for each load intensity) should be executed (Legaz-Arrese et al., 2007).

In addition to the mechanical aspects (i.e. power output), hormonal responses to strength training have been thought to play an important role in the development of strength (Crewther et al., 2006; Kraemer & Ratamess, 2005). Changes in resting concentrations of hormones such as cortisol and testosterone seem to reflect the current state of muscle tissue, and changes (e.g. elevations or reductions) may occur at various stages depending on the manipulation of training parameters (i.e. volume/intensity). Regarding power training, secretion patterns of cortisol and testosterone seem not to be consistent (Kraemer & Ratamess, 2005). Moreover, most of the previous research used non-equated volume and/or intensity training (Drinkwater et al., 2005; Folland et al., 2002; Rooney et al., 1994; Sanborn et al., 2000) resulting in a non-feasible comparison.

Thus, the aim of this study was to compare the effects of two 8-weeks strength training programs (i.e. one based on the maintenance of maximum mechanical power (non-power loss) with optimal load, and the second one following the non-failure power training recommendations) on mechanical and physiological variables.

Methods

Experimental Approach to the Problem

A controlled and longitudinal design (i.e. pre-test and post-test) was used. Before any baseline testing, all participants attended 2 familiarization sessions to introduce the testing and training procedures and to ensure that any learning effect was minimal. Pre (T1), intermediate (T2) and post-tests (T3) included: anthropometry, 1RM, maximum concentric mechanical power with 30, 40 and 50 % of 1RM (P30, P40 and P50, respectively) in the bench press throw exercise, and one set to failure with optimal load. Salivary testosterone (ST) and cortisol (SC) concentrations were obtained in basal situation during testing weeks. The subjects were divided into three homogenous groups according to the initial 1RM values: Optimum power group (OP = 10), non-failure group (NF = 10) and a control group (CG = 9). The training intervention consisted on eleven weeks (Figure 10) divided in: an 8-weeks main training program (MTP) (divided in two mesocycles: MESO-1 and MESO-2, respectively) and 3 testing weeks (T1, T2 and T3). The MTP consisted of 16 sessions (2 sessions × week) with 48 hours of rest between sessions.

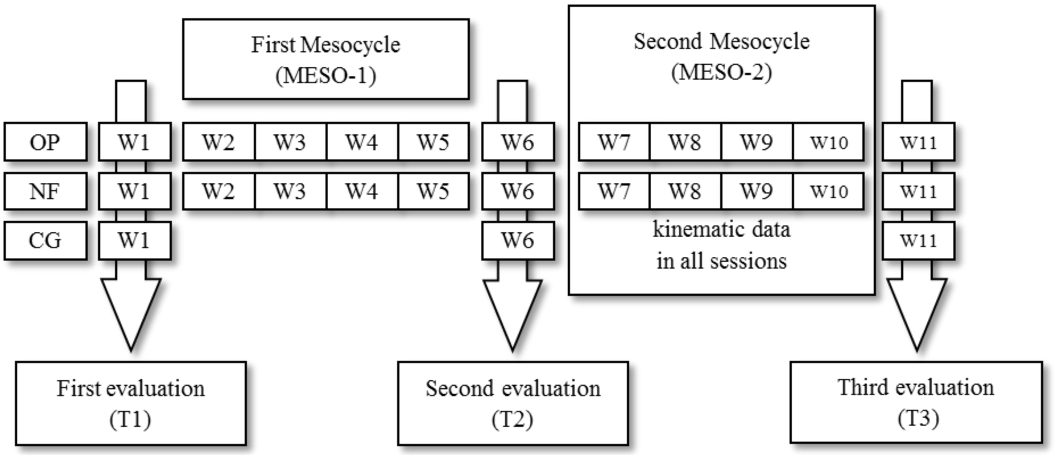

Figure 10 *Experimental design of study 3.*

Subjects

A total of 29 recreationally active young male college students (Table 8) volunteered to participate in the study. Before any participation, the experimental procedures and potential risks were fully explained to the subjects, and written informed consent was obtained. The procedure was approved by the institutional review committee of the Miguel Hernández University (Elche, Spain) and was conformed to the recommendations of the Declaration of Helsinki.

Table 8 Descriptive data. Mean ± SD.

Group	N	Age (yr)	Body Mass (kg)	Height (m)	Fat Mass (%)	Lean Muscle Mass (%)
Total	25	21.7 ± 1.7	71.5 ± 7.7	174.7 ± 5.8	12.6 ± 4.8	44.1 ± 4.0
OP	9	20.8 ± 1.7	71.7 ± 7.4	172.5 ± 6.2	11.8 ± 2.8	44.2 ± 3.6
NF	10	22.2 ± 1.6	74.2 ± 8.0	177.5 ± 5.6	14.5 ± 7.0	42.0 ± 4.5
CG	6	21.9 ± 1.5	68.5 ± 7.3	173.8 ± 5.1	11.4 ± 3.3	46.2 ± 3.1

OP = Optimum power group; NF = Non-failure group; CG = Control group

Procedures

Anthropometry

Body mass and height, wearing only shorts, were measured to the nearest 0.1 kg and 0.1 cm respectively using calibrated Oregon Scientific (GR101) scales and Seca Alpha stadiometer. Skinfolds, Girths and breadths were determined using calibrated skinfold callipers (Holtain LTD., Crymych, UK) by an accredited researcher and following the guidelines proposed by the International Society for the Advancement of Kinanthropometry (ISAK).

Bench press throw tests

During a first testing session, each subject was tested for 1RM in the bench press (González-Badillo & Sánchez-Medina, 2010) using isoinertial dynamometry (Model TF-100, T-Force System Ergotech, Murcia, Spain). The mean relative error in the velocity measurements was found to be < 0.25 %, whereas displacement was accurate to ± 0.5 mm (Sanchez-Medina & Gonzalez-Badillo, 2011). Before the 1RM test, joint mobilization followed by four warm-up sets in bench press were perform: (1) 20 repetitions at 30 % of 1RM, (2) 12 repetitions at 50 % of 1RM, (3) 6 repetitions at 70 % of 1RM, and (4) 1 repetition at 85 % of 1RM. In the second testing session, subjects performed 3 repetitions in their 30, 40 and 50 % of 1RM, using the bench press throw exercise, in order to measure maximum concentric mechanical power development (Argus et al., 2014; Baker, Nance, & Moore, 2001). Subsequently, a set to failure was performed using optimal load for each subject, and peak power output was used to determine the number of optimal repetitions for each subject. A 5 min rest period was given between sets (Mayhew et al., 1995).

Salivary Cortisol and Testosterone

Three saliva samples were collected on Sundays during T1, T2 and T3 at 8 h, 11 h and 18 h. Participants provided 5–10 ml of saliva in a plastic tube with cotton

(Salivette®, Sarstedt, France). Participants were instructed to complete sampling before eating or drinking. Also, participants were told to thoroughly rinse their mouths with tap water before sampling, and they were instructed not to brush their teeth before completing the saliva sampling in order to avoid the contamination of the saliva with blood caused by microinjuries in the oral cavity (Filaire et al., 2009). Samples were then collected and frozen in the laboratory's refrigerator at -20°C until assay. SC concentration was determined by Enzyme-Linked Immuno Sorbent Assay (ELISA), with a lower limit of sensitivity of 0.0537 µg/dl, and average intra- and inter-assay coefficients of variations of 2.61 % and 7.47 %, respectively.

Training program

Subjects performed a specific warm-up, including joint mobilization and supine bench press with a Smith machine. The intensity used for the OP was individualized using the optimal load on the bench press throw exercise (i.e. 41.7 % ± 5.8 of 1RM in the MESO-1). The volume for the OP was individualized based on the maximum number of repetitions in which the subject was able to developing more than 90 % P_{max} (i.e. 6.1 ± 2.6 repetitions in the MESO-1) (McBride et al., 2002). The volume in the TG was calculated as the average of performed repetitions per set for the OP (6 repetitions in the MESO-1). The intensity for the TG was established using the load in which the subjects were able to perform the double of prescribed repetition per sets (12RM) (Gorostiaga et al., 2012). In both groups the training load (intensity and volume) was adjusted in the MESO-2 based on data collected in T2 (Table 9). During both mesocycles, both groups performed 4 sets during the first two weeks and 5 sets during the last 2 weeks. Subjects were instructed and verbally encouraged to perform each repetition as fast as possible.

Table 9 Mean ± SD volume (repetitions) and intensity (% of 1RM) during the main training period for each experimental group.

Group	MESO-1		MESO-2	
	reps	**% of 1RM**	**reps**	**% of 1RM**
OP	6.1 ± 2.6	41.7 ± 5.8	5.4 ± 1.3	43.6 ± 5.0
NF	6.0	61.1 (12RM)	5.0	66.6 (10RM)

OP = Optimum power group; NF = Non-failure group; MESO-1 = First mesocycle of 4 weeks; MESO-2 = Second mesocycle of 4 weeks

Statistical Analyses

Standard statistical methods were used for the calculation of means ± SD. One-way ANOVA was used to determine any difference among the three groups' initial strength, power and anthropometric profile. The training-related effects were assessed by a MANOVA with repeated measures (time × groups). For analyse kinematic variables in MESO-2 sessions, data was grouped for analyse in function of the number of sets per session and repeat measures ANOVA was use. Where a significant difference was found for either main effect (time or group), Scheffè's post-hoc analysis was performed to locate the pairwise differences between the means. SPSS V.22 was used for statistical calculations. Statistical significance was accepted when $p < 0.05$. Cohen's d and the standardized mean difference (Cohen, 1988) was used to calculate Effect Size (ES) represented by 'd' and interpreted for a recreationally trained sample according to Rhea (2004) as $d < 0.35$ (Trivial), 0.35–0.80 (Small), 0.80–1.50 (Moderate), and > 1.5 (Large).

Results

At the beginning of the training program, no significant differences were observed between the groups in any measured variable. In addition, no significant changes in anthropometric data were found at any time and for any group.

Performance measures (1RM, P30, P40 and P50) obtained during T1, T2 and T3 are presented in table 10. After MESO-1, OP showed significant improvements in P30 ($p = 0.026$, $d = 0.38$), P40 ($p = 0.003$, $d = 0.46$) and P50 ($p = 0.015$, $d =$

0.42), while NF showed significant improvements in P50 ($p < 0.016$, $d = 0.36$). Significant differences were found between OP and CG in P30 ($p = 0.049$, $d = 0.64$) and P40 ($p = 0.014$, $d = 0.65$).

After the 8-week training period, OP and NF showed a significant increase in 1RM ($p = 0.008$, $d = 0.55$; $p = 0.028$, $d = 0.49$, respectively), P30 ($p < 0.000$, $d = 0.62$; $p = 0.001$, $d = 0.46$, respectively), P40 ($p < 0.000$, $d = 0.67$; $p = 0.001$, $d = 0.43$, respectively) and P50 ($p < 0.000$, $d = 0.63$; $p = 0.001$, $d = 0.47$, respectively). Significant differences were found between OP and CG in 1RM ($p = 0.009$, $d = 0.90$), P30 ($p = 0.001$, $d = 0.87$) and P40 ($p = 0.001$, $d = 0.67$). In addition, significant differences were found between NF and CG in P30 ($p = 0.004$, $d = 0.68$) and P40 ($p = 0.024$, $d = 0.43$).

Table 10 Mean ± SD values of the performing tests during T1, T2 and T3.

		T1	**T2**	**T3**
1RM (kg)	OP	77.4 ± 19.6	81.7 ± 19.7	88.1 ± 20.0††**
	NF	74.2 ± 18.8	78.3 ± 17.3	82.0 ± 17.9†
	CG	73.9 ± 8.3	75.3 ± 8.4	76.0 ± 10.9
P30 (watts)	OP	466.7 ± 148.0	523.3 ± 148.0†*	558.1 ± 115.5††**
	NF	464.2 ± 177.9	503.7 ± 176.1	538.4 ± 179.8††**
	CG	462.4 ± 78.8	477.9 ± 74.6	477.0 ± 88.2
P40 (watts)	OP	501.8 ± 144.2	567.8 ± 138.6††*	597.9 ± 140.0††**
	NF	499.0 ± 173.9	543.4 ± 170.5	568.1 ± 171.8††*
	CG	503.4 ± 84.1	524.4 ± 81.0	529.4 ± 102.4
P50 (watts)	OP	526.9 ± 120.7	584.0 ± 153.8†	612.3 ± 138.7††
	NF	495.2 ± 171.6	553.7 ± 195.2†	564.6 ± 182.5††
	CG	509.9 ± 88.5	528.6 ± 84.8	541.1 ± 91.0

*OP = optimum power group; NF = non-failure group; CG = control group; T1 = pre-intervention evaluation; T2 = evaluation after first 4 weeks training; T3 = post-intervention evaluation; 1RM = one repetition maximum; P30 = peak power output with 30 % of 1RM; P40 = peak power output with 40 % of 1RM; P50 = peak power output with 50 % of 1RM; † = significant differences from T1 $p < 0.05$; †† = significant differences from T1 $p < 0.01$; * = significant differences from CG $p < 0.05$; ** = significant differences from CG $p < 0.01$*

Results showed no differences in SC and ST values between groups during the entire intervention period (Figure 11 and Figure ***12***). However, NF showed a significant changes in SC and ST, decreasing from T1 to T3 in case of ST (*p* = 0.033; *d* = 0.43) and from T2 to T3 in case of SC (*p* = 0.020; *d* = 1.04).

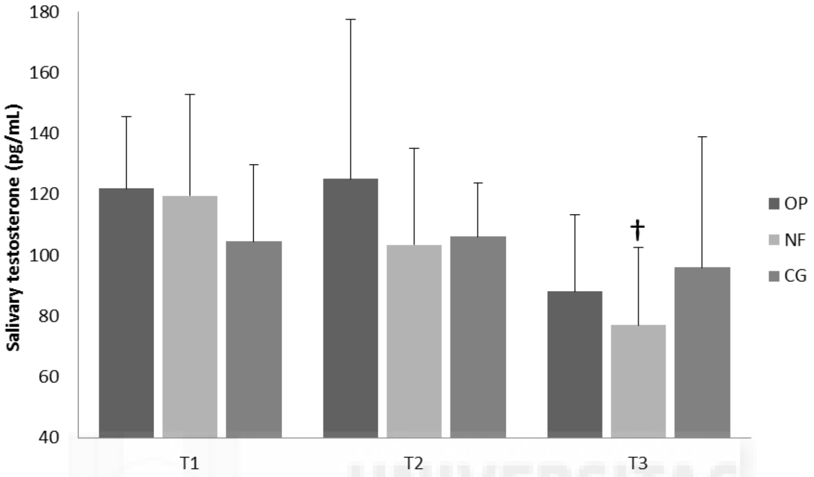

Figure 11 *Resting salivary testosterone concentration during MTP. OP = optimum power group, NF = non-failure group, T1 = pre-intervention evaluation, T2 = evaluation after first 4 weeks training, T3 = post-intervention evaluation. † = significant differences from T1 p < 0.05.*

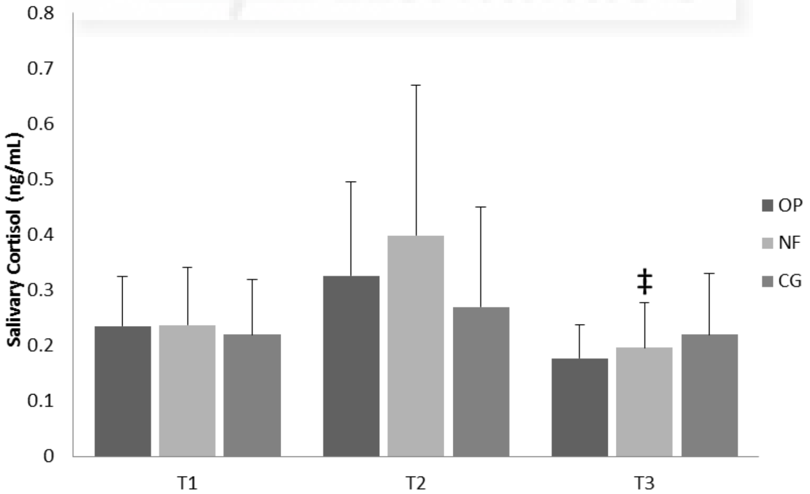

Figure 12 *Resting salivary cortisol concentration during MTP. OP = optimum power group, NF = non-failure group, T1 = pre-intervention evaluation, T2 = evaluation after first 4 weeks training, T3 = post-intervention evaluation. ‡ = significant differences from T2 p < 0.05.*

Kinematic data recorded during MESO-2 showed significant decreases in peak power during all sets compared with 1st set for NF (2nd set: $p < 0.01$, $d = 0.18$; 3rd set: $p < 0.01$, $d = 0.40$; 4th set: $p < 0.01$, $d = 0.61$), while OP showed a significant decrease only in the last set (4th vs 1st set: $p = 0.003$, $d = 0.21$) (Figure 13 and Figure 14).

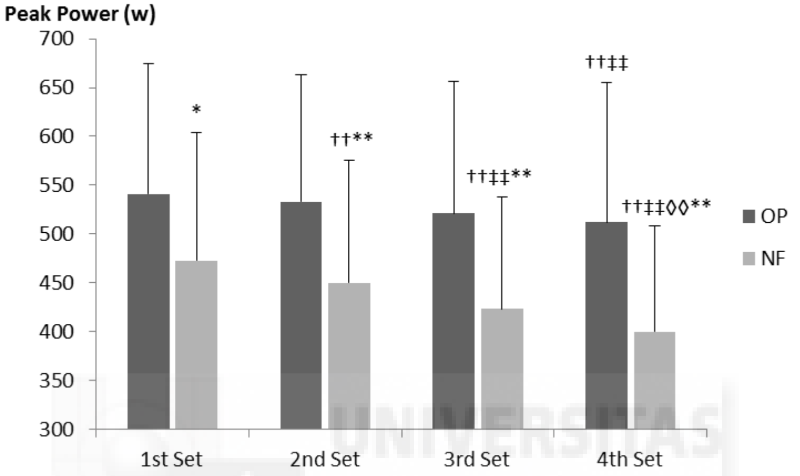

Figure 13 *Average in peak power for each set for 2 first weeks in MESO-2 (sessions with 4 sets). OP = optimum power group; NF = non-failure group; †† = significant differences from 1st set p < 0.01; ‡‡ = Significant differences from 2nd set p < 0.01; ◊◊ = Significant differences from 3rd set p < 0.01; * = Significant differences from OP p < 0.05; ** = Significant differences from OP p < 0.01*

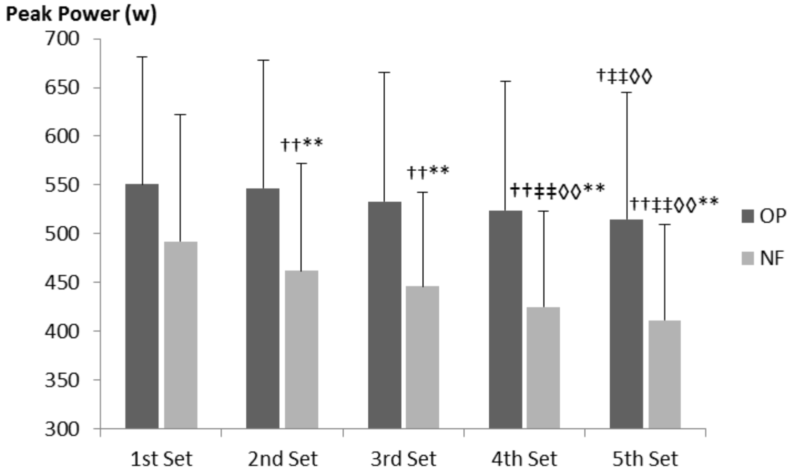

Figure 14 *Average in peak power for each set for 2 last weeks in MESO-2 (sessions with 5 sets). OP = optimum power group; NF = non-failure group; † = significant differences from 1st set p < 0.05; †† = significant differences from 1st set p < 0.01; ‡‡ = significant differences from 2nd set p < 0.01; ◊◊ = significant differences from 3rd set p < 0.01; ** = significant differences from OP p < 0.01.*

Discussion

Thus, the aim of this study was to compare the effects of two 8-weeks strength training programs (i.e. one based on the maintenance of maximum mechanical power (non-power loss) with optimal load, and the second one following the non-failure power training recommendations (i.e. 50 % of maximum number of repetitions) on mechanical and physiological variables. The main finding was that training for developing muscular power in the bench press throws exercise using optimal load and maintaining the mechanical power, produce improvements in power output compared with non-failure power method, after the MESO-1 (i.e. 4 weeks). Moreover, there were no changes in hormonal concentrations (i.e. SC and ST) and maintenance of power output during training sessions in the OP, resulting in a less physiological impact training method than NF.

Strength and power measures showed that performance was improved in bench press for both OP and NF after the 8-week training period, with increases in 1RM of 13.8 % and 10.5 %, respectively. Although comparisons are difficult, because the use of different methodologies, present results are similar to previous research reporting strength increases in training groups using an ‘optimal load’ approach (N. K. Harris et al., 2008; Loturco, Ugrinowitsch, Roschel, Tricoli, & González-Badillo, 2013; McBride et al., 2002)). N. K. Harris et al. (2008), evaluated two different 7-week strength training programs (i.e. one with optimal load, and a second one using 80 % of 1RM) and found significant improvements in 1RM of 15 % and 10.5 %, respectively, with no significant differences between groups. More recently, Loturco et al. (2013) using the optimal back-squat load and jump-squat exercises, reported significant improvements in 1RM and power output (i.e. 60 % of 1RM for back squat and 45 % of 1RM for jump-squat) after a 9-week training period. These changes in 1RM and power, also accompanied with no changes in lean mass, can be attributed to improvements in neural factors as motor unit recruitment, firing frequency, motor unit synchronization and inter-muscular coordination (Cormie et al., 2011).

Present study also showed improvements in power output with 30, 40, and 50 % of 1RM for OP, after 4 weeks of the training period. To the best of our knowledge no previous studies analysed less than six weeks of training, using similar training methodology (i.e. optimal load). In this regard, M. Izquierdo et al. (2006), analysing the effects of strength training leading to failure versus not to failure, found no significant changes in bench press power with 60 % of 1RM until the 11th training week (power was evaluated at 6th, 11th, and 16th week). Therefore, based on the present results we can suggest that individualized training loads (i.e. OP training group) lead to more time efficient improvements, with an average power output increase of 12 % after the first 4 training weeks, and 18 % after 8 weeks. We can speculate that these faster improvements are due to a reduction in metabolic demands and fatigue (Gorostiaga et al., 2012) caused by the training characteristics and, therefore, allowed higher neural adaptations (Folland & Williams, 2007).

In addition to performance measures, hormonal changes revealed higher impact over hypothalamic-pituitary-adrenal axis for NF (McEwen, 1998), showing a tendency of decreasing ST and increasing SC values after 4 weeks of training, which could indicate a potential state of catabolism associated with overreaching phase during strength training periods (Kraemer & Ratamess, 2005). On the other hand, OP resulted in lower levels of SC accompanied with stable levels of ST. Similar trends were reported in previous research, with decreased SC values after 6 weeks of non-failure power training (M. Izquierdo et al., 2006), and no hormonal changes for high power resistance (10 × 5 reps with 70 % of 1RM in back squat) (Fry & Lohnes, 2010). This could explain the differences in improvements of power between OP and NF after 4 weeks of training, as overreaching periods are usually associated with a longer rebound time to achieve performance improvements, as in the NF (Volek et al., 2004). Results of the present study showed a progressive performance (i.e. peak power) decrease from the 1st set in the NF. Similar changes in power output or in velocity have been previously reported (Casey, Constantin-Teodosiu, Howell, Hultman, & Greenhaff, 1996; Gorostiaga et al., 2012; M. Izquierdo et al., 2006) and have been associated with muscle glycogen and phosphocreatine (PCr) reductions, particularly in Type II fibres (Casey et al., 1996). Gorostiaga et al. (2012) analysing muscle metabolism during consecutive 5-repetitions sets with 10RM, found similar power output decreases (~20 %) than in the present study, together with significant changes in PCr, creatine and lactate. In addition these authors found correlations between peak power output decreases and metabolic parameters (e.g. ATP and lactate). On the contrary, in the OP this suggested metabolic fatigue appeared in the last set of each training session, with a peak power decrease of ~ 5 %.

Conclusions

In conclusion, results obtained in the present study suggest that individualized power training based on the maintenance of maximal power output (Optimal load and repetitions mobilized only at maximum power), lead to a reduced physiological impact (i.e. SC and ST) and neuromuscular fatigue than previous recommendations of non-failure sets (50 % of maximum number of repetitions) for power training. Therefore, we recommend the individualization of load training not only by load used in power training but also in the number of repetitions to perform in each set. This will lead to a more efficient training program reducing the volume needed (i.e. time) and the physiological impact on the player. Thus, training with the optimal load is especially recommended to develop maximum muscular power in short time-periods (i.e. around 4 weeks). This will be very useful in many sports with condensed competitive calendars, where the preparatory periods are time limited (i.e. tennis, football).

05 Epilogue

The studies included in this thesis were designed to examine the psycho-physiological and mechanical effects of individualization and optimization of power training variables (Figure 15). As indicated in the introduction (Chapter 1), these variables are interrelated and the lack of adaptation to the goal in any of them can reduce the effects that training has on the final performance.

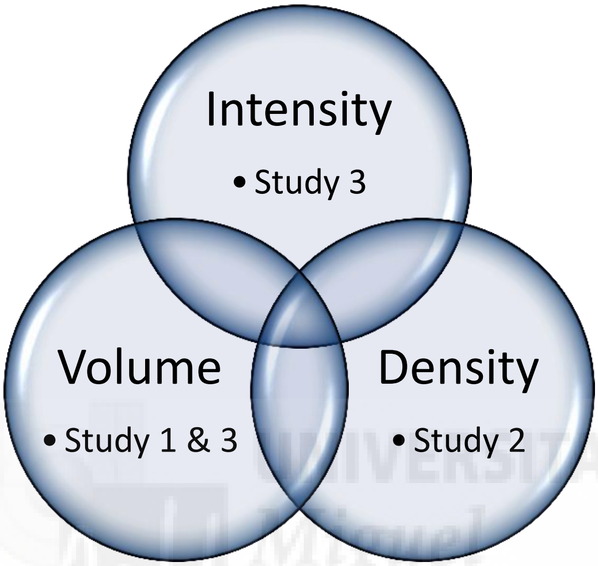

Figure 15 *Graphical representation of the influence of different variables of training load and the correspondence with the thesis studies.*

Major contributions

The following summarizes the major contributions of this thesis:

- A short-term power training period (i.e. 4–6 weeks) based on the maintenance of mechanical power produces improvements in jump height, medicine ball throw distance, peak power and number of repetitions without power loss (Studies 1 and 3).

- The training load impact on the athlete was low when we used the optimal repetition number and load. Minor changes in behavioural variables associated with fatigue (i.e. POMS subscales) and hormone levels (i.e. ST and SC) were produced. Moreover, these values returned to their baseline in a few days, showing a fast training assimilation (Studies 1 and 3).

- The gains in power output must be associated with neural changes, because the subjects had no hypertrophy (i.e. girths and muscle mass unchanged) after training periods (Studies 1 and 3).

- Two resting minutes between sets was enough to maintain the power output using the optimal load in the bench press throw exercise (Study 2).

- A power training with individualized training load (i.e. optimal load and repetitions) and adjusted resting times between sets provided more efficient training sessions (Studies 1, 2 and 3).

Study limitations and future research

This thesis has some limitations that we have considered and discussed in relation to each study. These limitations can serve as a starting point for future studies.

- *To extend the athlete sample with previous history of power training.* The aim of these works will be to improve the training systems for athletes. Given the controversy regarding the differential effects of optimal load power training on subjects trained or untrained and more or less strong (Cormie et al., 2010b; Stone, O'Bryant, et al., 2003), it is necessary to know the effects of this training methodology on them.

- *Resting times for other ballistic exercises.* As with conventional exercises (Abdessemed et al., 1999; Nibali et al., 2013), it is possible that not all ballistic exercises need the same resting time to prevent the onset of fatigue during training sessions. Therefore, in future works it would be of interest to study the effect of different resting times in other ballistic exercises.

- *Identify the muscle and neural adaptations to the optimal load.* Improvements in power output observed in these studies have not been related to an increase in the CSA, which has been associated with other structural and neural factors. Future studies should add technical measures that will enable demonstration of specific changes involved in training with this methodology (Carroll, Selvanayagam, Riek, & Semmler, 2011).

- *Effect of power training with optimal load and repetitions on hormonal and metabolic responses.* Hormonal and metabolic responses to this training methodology are not clear in the current scientific literature, mainly due to the large amount of training structures used. In this thesis, part of this problem is addressed, but the subject sample was small and the acute power training effect was not controlled.

- *Training with optimal load focused on health improvement.* Today power training is becoming increasingly important in the field of health, because it seems to be more effective for improving functionality and fall prevention than resistance strength training (Huijing & Jaspers, 2005; M. Izquierdo & Cadore, 2014). The optimization of the training load for this population could provide faster adaptations and better assimilation of the load.

Principales aportaciones

A continuación se presentan las principales contribuciones de esta tesis:

- Un periodo corto de entrenamiento de potencia (4–6 semanas) basado en el mantenimiento de la potencia mecánica, produce mejoras en la altura de salto, la distancia de lanzamiento con un balón medicinal, el pico de potencia y el número de repeticiones sin pérdida de potencia (Estudios 1 y 3).

- El impacto de la carga de entrenamiento en el deportista es menor cuando se usa la carga y el número de repeticiones óptimos. Se producen menores cambios en variables comportamentales asociadas a la fatiga (Sub-escalas del cuestionario POMS) y en los niveles hormonales (ST y SC). Además estos valores vuelven a su situación basal en pocos días tras el entrenamiento, mostrando una rápida asimilación de la carga (Estudios 1 y 3).

- Las mejoras en potencia pueden ser asociadas a cambios neurales, ya que los sujetos no mostraron signos de hipertrofia muscular (los perímetros musculares no variaron) después del entrenamiento (Estudios 1 y 3).

- Dos minutos de recuperación entre series fue suficiente para mantener la potencia durante el ejercicio de press banca lanzado usando la carga óptima (Estudio 2).

- Un entrenamiento de potencia con una individualización de la carga de entrenamiento (carga y repeticiones óptimas) y un tiempo de recuperación ajustado entre series puede aportar sesiones de entrenamiento más eficientes (Estudios 1, 2 y 3).

Limitaciones y líneas futuras de trabajo

Esta tesis tiene algunas limitaciones que se han intentado tener en consideración y discutirlas en cada uno de los estudios aquí presentados. Estas limitaciones pueden servir como un punto de partida para futuras investigaciones y así se van a tratar a continuación.

- *Aumentar la muestra de deportistas con historial previo de entrenamiento de potencia.* El objetivo de esta tesis es mejorar los sistemas de entrenamiento de potencia en deportistas, pero dada la controversia existente en relación a las posibles diferencias que puede existir entre la respuesta a un entrenamiento con carga óptima entre sujetos entrenados o no y con mayores o menores niveles de fuerza (Cormie et al., 2010b; Stone, O'Bryant, et al., 2003), es necesario conocer los efectos de esta metodología de entrenamiento en estos sujetos.

- *Tiempos de recuperación para otros ejercicios balísticos.* Al igual que ocurre con los ejercicios tradicionales (Abdessemed et al., 1999; Nibali et al., 2013), es posible que no todos los ejercicios balísticos necesiten los mismos periodos de recuperación para evitar la aparición de la fatiga durante las sesiones de entrenamiento. Por tanto, en futuros trabajos parece interesante estudiar el efecto de diferentes tiempos de recuperación en otros ejercicios balísticos como el jump squat.

- *Identificar las adaptaciones específicas que se producen a nivel neural y muscular con el entrenamiento con la carga óptima.* Las mejoras de potencia observadas en los trabajos presentados no se han asociado con aumentos del área de la sección transversal, asociándolos por tanto a otros cambios estructurales y neurales. En trabajos futuros debería incorporarse técnicas de medida que permitieran identificar los cambios específicos que se producen al entrenar con esta metodología de potencia (Carroll et al., 2011).

- *Efectos del entrenamiento de potencia con la carga y repeticiones óptimas sobre la respuesta hormonal y metabólica.* La respuesta hormonal y metabólica con este tipo de entrenamientos de potencia no parece clara en la literatura científica, principalmente debido a la gran variedad que existe en las estructuras de los entrenamientos usados. En esta tesis, se intenta abordar parte de este problema pero la muestra de sujetos es baja y no se controló el efecto agudo de las sesiones.

- *Utilización del entrenamiento con carga óptima en la mejora de la salud.* Hoy en día el entrenamiento de potencia está comenzando a tener gran importancia en el campo de la salud, debido a que parece ser más efectivo para la mejora de la funcionalidad y la prevención de caídas que el entrenamiento de fuerza-resistencia (Huijing & Jaspers, 2005; M. Izquierdo & Cadore, 2014). La optimización de la carga de entrenamiento para esta población pude producir rápidas adaptaciones y una mejor asimilación de la misma.

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