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Concurrent Training and Detraining: The Role of Resistance and Aerobic Intensities

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"Being a teacher is not just a matter of having a body of knowledge and ability to control the lesson. This could be done with a computer and a stick. In order to be a teacher, it is also necessary to be able to establish human relations with the people to whom it is taught. Learning is a human process and arduous, the same can be said of teaching. Teaching implies simultaneously, emotions and pure reason."

Connell (1997, p. 91)

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A Doctoral Thesis is composed by numerous challenges, uncertainties, surprises, disappointments, satisfactions and achievements. It is a path that is only possible with the mobilization of energy, perseverance and vigor to find the best course, presenting the best options and selecting the best decisions.

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List of Publications

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Abstract

In recent years, the concurrent training has become one of the most interesting topics in Sports Sciences research. Most of the times, training for competitive sports require combining the resistance and aerobic training to maximize the athletes' performance. However, the combination of training load variables such as the intensity is still unclear and should be further investigated for the maximization of training programs. Thus, the purpose of the current thesis was to analyze the effects of different combinations of aerobic and resistance intensities during concurrent training on vertical jump, sprint, lower limb strength and cardiorespiratory fitness. In addition, it was verified the effects of a period of detraining that followed previous concurrent training with different aerobic or resistance training intensities. For this, the following steps were adopted: (i) a literature review of this subject; (ii) the analysis of the effect of a concurrent training against three different external loads during resistance training, followed by detraining, in strength and aerobic performances; (iii) the study of the effects of three different aerobic intensities combined with the same resistance training, followed by a detraining period, in aerobic and strength variables; (iv) the recommendation of practical remarks for coaches regarding the combination of aerobic intensity and resistance during concurrent training. The main conclusions of the study were: (i) there is few literature on the effects of aerobic and / or resistance training intensities when these are performed simultaneously; (ii) a concurrent training program of 8-week with different resistance loads combined with low intensity aerobic training improved strength and aerobic performances regardless of the training intensity used during resistance training; (iii) training loads greater than 55% of 1RM tended to cause greater improvements in explosive performances when combined with low-intensity aerobic training; (iv) beneficial effects on strength and aerobic development were found after 8 weeks of resistance training, regardless of the intensity of aerobic training; (v) low aerobic intensities can lead to a significant increase strength during concurrent training; (vi) 4 weeks of detraining decrease strength and aerobic parameters, but the losses were lower when high resistance training loads were combined with low intensity aerobic training, specially for aerobic-related variables. Therefore, these intensities are recommended when cardiorespiratory gains should be maintained for longer. These studies were the first step on the understanding of the ideal combination of resistance and / or aerobic intensities during concurrent training programs, but further studies are needed to deeply understand their effects on performance.

Key words

Aerobic training, resistance training, load-magnitude, detraining

Resumo

Nos últimos anos, o treino concorrente tornou-se um dos tópicos mais interessantes na investigação em Ciências do Desporto. Na maioria das vezes, o treino nos desportos competitivos requer a combinação de força e a resistência aeróbia para a maximizar dos atletas. No entanto, a combinação de variáveis de carga de treino, como a intensidade, ainda não está clara e deve ser investigada para a maximização dos programas de treino. Assim, o objetivo da presente tese foi analisar os efeitos de diferentes combinações de intensidades aeróbias e de força durante o treino concorrente, no salto vertical, no sprint, na força dos membros inferiores e na aptidão cardiorrespiratória. Além disso, verificou-se os efeitos de um período de destreino que se seguiu ao treino concorrente prévio com diferentes intensidades de treino de força e aeróbio. Para isso, foram adotados os seguintes passos: (i) uma revisão da literatura sobre este assunto; (ii) a análise do efeito de um treino concorrente contra três diferentes cargas externas durante o treino de força, seguido de destreino, em desempenho aeróbio e de força; (iii) estudo dos efeitos de três diferentes intensidades aeróbias combinadas com o mesmo treino de força, seguido por um período de destreino, em variáveis aeróbias e de força; (iv) recomendação de observações práticas para treinadores sobre a combinação de intensidade aeróbia e de força durante o treino concorrente. As principais conclusões provenientes deste trabalho foram as seguintes: (i) existe pouca literatura sobre os efeitos das intensidades de treino aeróbio e/ou de força quando estes são realizados simultaneamente; (ii) um programa de treino concorrente de 8 semanas com diferentes cargas de força combinado com treino aeróbio de baixa intensidade melhorou a força e o desempenho aeróbio, independentemente da intensidade de treino usada durante o treino de força (iii) cargas de treino maiores que 55% de 1RM tendem a causar maiores melhorias no desempenho explosivo quando combinadas com o treino aeróbio de baixa intensidade; (iv) efeitos benéficos na força e no desenvolvimento aeróbio foram encontrados após 8 semanas de treino de força, independentemente da intensidade do treino aeróbio; (v) baixas intensidades aeróbias podem levar a um aumento significativo da força durante o treino concorrente; (vi) 4 semanas de destreino, diminuem a força e os parâmetros aeróbios, mas com menos perdas quando altas cargas de treino de força foram combinadas com treino aeróbio de baixa intensidade, especialmente para variáveis relacionadas ao aeróbio. Portanto, essas intensidades são recomendadas quando os ganhos cardiorrespiratórios se pretendem manter por mais tempo. Estes estudos foram o primeiro passo para a compreensão da combinação ideal de força e / ou intensidades aeróbias durante os programas de treino concorrente, mas ainda são necessários mais estudos para entender profundamente os seus efeitos sobre o desempenho.

Palavras-chave

Treino aeróbio, treino de força, magnitude da carga, destreino

Resumen

En los últimos años, la capacitación concurrente se ha convertido en uno de los temas más interesantes en la investigación de Ciencias del Deporte. La mayoría de las veces, el entrenamiento para deportes competitivos requiere combinar la resistencia y el entrenamiento aeróbico para maximizar el rendimiento de los atletas. Sin embargo, la combinación de variables de carga de entrenamiento, como la intensidad, aún no está clara y se debe seguir investigando para maximizar los programas de entrenamiento. Por lo tanto, el propósito de la tesis actual fue analizar los efectos de diferentes combinaciones de intensidades aeróbicas y de resistencia durante el entrenamiento concurrente en el salto vertical, el esprint, la fuerza de las extremidades inferiores y la aptitud cardiorrespiratoria. Además, se verificaron los efectos de un período de desentrenamiento que siguió al entrenamiento simultáneo previo con diferentes intensidades de entrenamiento aeróbico o de resistencia. Para ello, se adoptaron los siguientes pasos: (i) una revisión bibliográfica de este tema; (ii) el análisis del efecto de un entrenamiento concurrente contra tres cargas externas diferentes durante el entrenamiento de resistencia, seguido por el desentrenamiento, la fuerza y el rendimiento aeróbico; (iii) el estudio de los efectos de tres intensidades aeróbicas diferentes combinadas con el mismo entrenamiento de resistencia, seguido de un período de desentrenamiento, en variables aeróbicas y de fuerza; (iv) la recomendación de comentarios prácticos para entrenadores sobre la combinación de intensidad aeróbica y resistencia durante el entrenamiento concurrente. Las principales conclusiones del estudio fueron: (i) hay poca literatura sobre los efectos de las intensidades de entrenamiento aeróbico y / o de resistencia cuando se realizan simultáneamente; (ii) un programa de entrenamiento concurrente de 8 semanas con diferentes cargas de resistencia combinadas con entrenamiento aeróbico de baja intensidad mejoró la fuerza y el rendimiento aeróbico independientemente de la intensidad de entrenamiento utilizada durante el entrenamiento de resistencia; (iii) las cargas de entrenamiento superiores al 55% de 1RM tendieron a causar mayores mejoras en los rendimientos explosivos cuando se combinan con el entrenamiento aeróbico de baja intensidad; (iv) se encontraron efectos beneficiosos sobre la fuerza y el desarrollo aeróbico después de 8 semanas de entrenamiento de resistencia, independientemente de la intensidad del entrenamiento aeróbico; (v) las bajas intensidades aeróbicas pueden llevar a un aumento significativo de la fuerza durante el entrenamiento concurrente; (vi) 4 semanas de desentrenamiento disminuyen la fuerza y los parámetros aeróbicos, pero las pérdidas fueron menores cuando las cargas de entrenamiento de alta resistencia se combinaron con el entrenamiento aeróbico de baja intensidad, especialmente para las variables relacionadas con el aeróbico. Por lo tanto, estas intensidades se recomiendan cuando las ganancias cardiorrespiratorias deben mantenerse durante más tiempo. Estos estudios fueron el primer paso para comprender la combinación ideal de resistencia y / o intensidades aeróbicas durante los programas de entrenamiento concurrentes,

pero se necesitan estudios adicionales para comprender en profundidad sus efectos en el rendimiento.

Palabras-clave

Entrenamiento aeróbico, entrenamiento de resistencia, magnitud de carga, desentrenamiento.

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List of Abbreviations

[La ⁻]	Blood lactate concentration
1RM	One-repetition maximum
1RM _{est}	Estimated one-repetition maximum
AT	Aerobic training
BP	Bench press
CG	Control group
CI	Confidence interval
CMJ	Countermovement jump
CT	Concurrent training
CV	Coefficient of variation
DT	Detraining period
ES	Effect sizes
FS	Full-squat
G _n	Experimental group n
HIG	High-intensity group
HIIT	High intensity interval training
HLG	High-load group
HR	Heart rate
HR _{max}	Maximal heart rate
ICC	Intra-class correlation coefficient
LIG	Low-intensity group
LLG	Low-load group
LP	Leg press
LT	Lactate threshold
MAS	Maximal aerobic speed
MIG	Moderate-intensity group
MLG	Moderate-load group
MLSS	Maximal lactate steady-state
MPV	Mean propulsive velocity
Post 1	Evaluation after training period
Post 2	Evaluation after detraining period
Pre	Initial evaluation
RM	Repetition maximum
RT	Resistance training
SD	Standard deviation
T10	10m Sprint time

T20	20m Sprint time
VO ₂ max	Maximum oxygen uptake
VO ₂ peak	Peak oxygen uptake
VT ₂	Second ventilator threshold
YYIRT	Yo-Yo intermittent recovery test
Z1	Below ventilatory threshold
Z2	Between ventilatory threshold and respiratory compensation threshold
Z3	Above respiratory compensation threshold

Chapter 1. General Introduction

Concurrent training (CT) usually refers to a training session or a program that combines some form of resistance and aerobic exertion (Docherty & Sporer, 2000; Fyfe et al., 2014; Kang & Ratamess, 2014). In fact, several sports require the organization of training programs that combine resistance and aerobic components to optimize athletes' performances (Leveritt et al., 1999; Nader, 2006; Toraman & Ayceman, 2005). This simultaneous training of both regimens looking for cardiorespiratory and strength adaptations is widely debated by sport professionals and researchers due to the major need for overall improvement of the athletes' capacities. This kind of training regimen is sometimes believed to be an efficient way for performance improvement but evidences still struggling with some issues regarding training planning and organization. Indeed, this training method depends on the type, intensity, duration and frequency of training for the greater efficacy (Bishop & Jenkins, 1999; Chtara et al., 2005; McCharthy et al., 1995). Moreover, in addition to these training load variables, the specific development of aerobic or resistance also depends on whether they are combined in the same training period (Bell et al., 2000; Hakkinen et al., 2003; McCarthy et al., 2002).

In recent years, the CT has acquired considerable attention from researchers, mainly due to the common use by coaches and athletes and by some controversial scientific evidences (Cadore et al., 2012; Cadore et al., 2014; García-Pallarés and Izquierdo, 2011). While some studies have shown that concurrent training can affect the development of muscle strength and power (García-Pallarés and Izquierdo, 2011; Izquierdo-Gabarren et al., 2010; Leveritt et al., 2003; Davis et al., 2008a; Davis et al., 2008b; Silva et al., 2012), others indicated that a simultaneous work of resistance and aerobic exercises did not increase strength variables, and aerobic capacity development (Davis et al., 2008; Ronnestad et al., 2012). From this, it is easily understood that there is much to know and understand on the CT issue.

One of the problems that arise when combining both physical qualities is strongly associated with the "interference" that each training type exerts on the other. In fact, CT has been criticized due to the potential for competing adaptations of resistance and aerobic training. Over last decades, several studies have reported the interference effect on the development of muscle strength when resistance and aerobic were trained simultaneously (Dudley & Djamil, 1985). The majority of the studies found that the magnitude of the increased strength was always higher in those that only performed resistance training compared to the combined training groups (e.g. Izquierdo et al., 2005; Izquierdo et al., 2004). Several mechanisms have been suggested as being responsible for interference of aerobic exercises on strength gains (García-Pallarés & Izquierdo, 2011). For instance, it was pointed out a negative effect of overreaching on neural adaptations (Cadore et al., 2010), the decrease on glycogen content

that promotes a chronic catabolic state (Bell et al., 2000), an interference effect on type I and II fibers (Putman et al., 2004) and/ or peripheral fatigue resulting from aerobic training that ultimately impairs strength performance gains (Lepers et al., 2001).

The details on designing a CT program become more relevant when the degree of interference between the two modes could be a concern. Although researchers are aware of the abovementioned interference phenomenon, it is suggested that, if training-load components are carefully programmed, CT can produce high-level of athletic performances (Coffey & Hawley, 2017). Recently, factors such as the training volume and intensity have been pointed out as a major concern for CT optimization, causing the interference on resistance and aerobic gains (Bishop & Jenkins, 1999; Chtara et al., 2005; McCarthy et al., 1995). Several studies have indicated that an interference effect exists between aerobic training and resistance training in situations where the weekly training volume is high (Bell et al., 2000; Hennessy & Watson, 1994; Hickson, 1980; Jones et al., 2013; Karavirta et al., 2011). It seemed quite clear that high volumes of aerobic training, by increasing the frequency and/or duration of aerobic exercise, resulted in the inhibition of strength, whereas low volumes of aerobic training did not. One explanation presented by research on how aerobic exercise volumes affect strength outcomes is related to increased fatigue and the consequent conditioning of the resistance training performance and thus compromising chronic adaptations (Coffey & Hawley, 2017).

Regarding the intensity of both aerobic training and resistance components of CT, studies are scarce and with no clear conclusions. The few studies on this issue focused mainly on exercise intensities during the aerobic part of CT training. These showed that a CT program improved performance variables in the experimental groups, regardless of the intensity used (Esteve-Lanao et al., 2007; Fyfe et al., 2016; Petré et al., 2018; Silva et al., 2012; Sousa et al., 2018; Varela-Sanz et al. 2016; Wong et al., 2009). When higher aerobic intensities were used, maximal oxygen uptake (VO_{2max}) and aerobic power seemed to attain greater gains (Fyfe et al., 2016; Petré et al., 2018). Contrarily, it seemed to exist a trend toward greater neuromuscular adaptations when higher resistance training loads were used combined with low to moderate aerobic training intensities (Petré et al., 2018). The interference of CT in strength adaptations was suggested to occur because of the intensity of aerobic training and their distribution throughout the season. It was reported that interference on strength gains only occurs at high-intensities of aerobic training, as those close to VO_{2max} (Varela-Sanz et al., 2016).

Other studies focused on the distribution of intensities during a long-term CT program and it was suggested that the polarized model (i.e.: low-volume, high-intensity aerobic exercise combined with high-volume low-intensity training) would be the most effective training intensity distribution for reducing the interference in neuromuscular performance (Esteve-

Lanao et al., 2007, Varela-Sanz et al., 2016). Running performance was approximately 25% greater with polarized training compared to the traditional distribution (Esteve-Lanao et al., 2007). Moreover, the upper and lower body maximum strengths increased 24% and 47% after 8 weeks of polarized training, respectively (Varela-Sanz et al., 2016). However, clear conclusions are difficult to report, whereas the studies compare different designs, methods, as well the intensities are also different. So, further investigation is needed for understanding the influence of resistance and aerobic intensities when combining both training modes during preparation to optimize athletes' performances.

To better understand CT effects and to optimize training programs design, it is also fundamental to know the response after the CT cessation. In fact, interruptions in the training process due to illness, post-season vacation, or other factors are ordinary in most of sports (Karavirta et al., 2009, Faigenbaum et al., 2009, Faigenbaum et al., 1996). The magnitude of this reduction may depend on the duration of the detraining period (DT), beyond the levels reached by the subject's formation (Garrido et al., 2010). Although the losses caused by the detraining occur more significantly in the first weeks of its application, the physical state of the athlete stays above the pre-training levels for a period that should be proportional to the period in which they are training. That is, the longer the training period, the longer the detraining period needed for severe performance decrements (Zatsiorsky, 2006). However, this issue is few studied and needs further development, specifically in CT context. Knowing the effects of training on subsequent detraining period will allow to better understand how to design a training program, either to optimize and reduce performance losses, or to better understand how to combine the periodization models regarding the training load and recovery phases to maximize gains and final competitive performance (Marques, 2004; Marfell-Jones et al., 2006).

It is then understood that different designs of CT have been studied, but few is known about the combination of intensities that should be combined for better performances. Considering the abovementioned, the main purpose of the current thesis was to analyze the effects of different combinations of aerobic and resistance intensities during concurrent training, on vertical jump, sprint, leg strength, and cardiorespiratory fitness. In addition, it was our secondary purpose to verify the effects of a detraining period following a CT program differing in the intensities used, by assessing those same strength and aerobic parameters.

Considering the abovementioned general purpose, the thesis is developed according to the following sequence:

- Chapter 2 presents a systematic review based on the early studies regarding the effects of the intensity used during concurrent training on performance, followed by a detraining period.

- Chapter 3 shows the experimental studies developed to accomplish the main purpose of this thesis:
 - Study 2 aims to analyze the training and detraining effects of concurrent aerobic training and resistance training against three different external loads on strength and aerobic variables.

 - Study 3 intends to verify the effects of three different aerobic intensities combined with the same resistance training on strength and aerobic performances.

 - Study 4 was developed based on the previous results and purposes to provide practical recommendations for coaches regarding the combination of aerobic and resistance intensities during concurrent training.

Then, a general discussion of the results is obtained on the studies performed (Chapter 4), followed by the main conclusions and limitations of the thesis (Chapter 5). Some suggestions for future researches are also presented (Chapter 6).

Chapter 2. Literature review

Study 1

Concurrent training followed by detraining: a brief review on the effect of aerobic and resistance exercise intensities

Abstract

Background. Concurrent resistance and aerobic training (CT) has been used to maximize performance. However, this combination should be carefully programmed as there are some factors, such as the intensity, that may interfere in training adaptations. **Objectives.** We conducted a systematic review to synthesize and analyze the scientific evidence regarding aerobic and resistance exercise intensities during CT and their effect on performance variables. Furthermore, the effects of exercise intensity on a subsequent detraining period were assessed to better understand the impact of CT intensity. **Methods.** A search was conducted using five databases for original articles published between January 1980 and July 2018. A total of eight studies met the inclusion criteria, and the Cochrane risk of bias tool was used to assess the risk of bias. The results were recalculated to determine changes and effect sizes. **Results.** CT improved performance regardless of exercise intensity used (4-47%). When higher aerobic intensities were used, aerobic gains were increased (5-9%). Greater neuromuscular adaptations were found when higher resistance loads were combined with low to moderate aerobic training (AT) (10-14%). The polarized training intensities distribution throughout the season showed to maximize aerobic gains (4-7%) and strength (24-47%). In addition, a training cessation for 2-4 weeks reversed the training-induced gains. **Conclusion.** Although further research is needed, it seems that higher intensities of AT or resistance training (RT) induce greater aerobic or neuromuscular gains, respectively. Nevertheless, we should be aware of an interference effect on strength for higher aerobic intensities and performance reductions with detraining (DT).

Introduction

Concurrent training (CT), which involves a combination of resistance and aerobic regimens, has attracted strong attention from the scientific community in recent years due to its potential to simultaneously induce cardiorespiratory and neuromuscular gains (Joo, 2018). While some researchers have shown that CT affects the development of muscle strength and power (i.e., interference effect) (Davis et al., 2008, 2011; Garcia-Pallares & Izquierdo, 2011; Izquierdo-Gabarren, et al., 2010; Leveritt et al., 2003; Silva et al., 2012), others have indicated that CT has no inhibitory effect on strength and aerobic development (Alves et al., 2016; Cadore et al., 2011; Docherty & Sporer, 2000; Gravelle & Blessing, 2000; Hakkinen et al., 2003; Leveritt et al., 1999; McCarthy et al., 2002; Sale et al., 1990; Wong et al., 2009). The interference between strength and aerobic training (AT) can be explained by several factors related to the training program, such as the volume, intensity, and training frequency (Bishop & Jenkins, 1999; Chtara et al., 2005; McCharthy et al., 1995) or even physical fitness level and age (Millet et al., 2002; Paavolainen et al., 1999).

The management of both resistance and aerobic exercise variables can maximize performance but also expose athletes to overreaching or overtraining if improperly performed (Coffey & Hawley, 2017). Varying modalities, intensities, frequencies and volumes of training have been shown to affect the magnitude of molecular signaling and protein synthesis (Fyfe et al., 2014; Schoenfeld, 2010), which will therefore influence the degree of interference between exercise modes. Thus, the degree of the interference effect can vary depending on programming variables (Coffey & Hawley, 2017; Schoenfeld, 2010). Several studies have indicated that an interference effect exists between AT and resistance training (RT) in situations where the weekly training volume is high (Bell et al, 2000; Hennessy & Watson, 1994; Hickson, 1980; Jones et al., 2013; Karavirta et al., 2011). It seems quite clear that high volumes of AT, such as by increasing the frequency and/or duration of aerobic exercise, resulted in the inhibition of strength, whereas low volumes of AT did not. One explanation presented by research on how aerobic exercise volumes affect strength outcomes is related to increased fatigue and the consequent limitation of RT performance and/or compromised chronic adaptations (Coffey & Hawley, 2017). Nevertheless, it is still not clear what happens when the intensities of the AT or/and RT performances are manipulated.

Researchers focused on CT have recently tried to understand its effects by studying the detraining (DT) period after a CT program. A better understanding of the DT experience is essential for the maintenance of training-induced improvements. To the best of our knowledge, no systematic review has comprehensively examined the literature regarding the effects of CT performed with different intensities and of the subsequent DT period on performance. In addition, knowing that high volumes seem to affect results, it may be relevant to understand the role of intensity during AT or/and RT in performance. Analyzing studies that have evaluated

CT intensities would provide coaches and sports scientists with valuable knowledge and strategies to effectively combine aerobic exercise with bouts of RT when seeking improved performance in training and competition. Therefore, the current review aims to synthesize and analyze research findings on the effects of different CT intensities on performance and on the subsequent DT period.

Methods

Search strategy

A systematic review was conducted according to PRISMA (Preferred Reporting Items for Systematic reviews and Meta-analyses) guidelines (Moher et al., 2015). A disciplined literature search was independently conducted by two researchers using the Web of Science, PubMed, ScienceDirect, Scholar Google, and Scopus databases. An extensive literature search was conducted from January 1, 1980, to July 30, 2018, to identify studies related to CT with different intensities, and the effects of DT were reported for young adults. The search was performed using the Boolean search method, which limited the search results with operators including AND/OR to only those documents containing key terms relevant to the scope of this review, such as “concurrent training”, “detraining”, “intensities”, and “young adults”.

Eligibility criteria

The included studies focused on experimental interventions related to CT and DT in young adults (between 18 and 35 years old) with performance-related outcomes (i.e. time, velocity, strength, aerobic capacity and power). Studies written in English that were published in a peer-reviewed journal on CT and DT in healthy young adults were included. Review articles (qualitative review, systematic review, and meta-analysis), theses, dissertations, conference abstracts and proceedings were not considered. Regarding the research question, studies were categorized into the following two main groups: i) concurrent training and ii) detraining. The information extracted from the selected studies was based on research design, aim, subjects, procedures and findings.

Study selection

The initial search identified 2470 initial studies. After removing duplicates and studies with different types of intervention (e.g., longitudinal studies), subjects with other chronological ages (children, elderly), and subjects who did not include a session of CT in the protocol, 2459 studies were excluded. From the remaining studies, the full texts of 11 original research articles were assessed for eligibility, and those that did not meet the inclusion criteria were excluded

(e.g., inconclusive information on study procedures). For the qualitative analysis, a total of 8 studies were considered relevant for a detailed analysis. The earliest of these studies was published in 2007 (Esteve-Lanao et al., 2007), and the most recently published study was from 2018 (Joo, 2018). The articles were grouped according to the CT intervention (n=7) or to the presence of detraining (n=2). A detailed flow chart describing the process of selecting the relevant studies is shown in Figure 1.

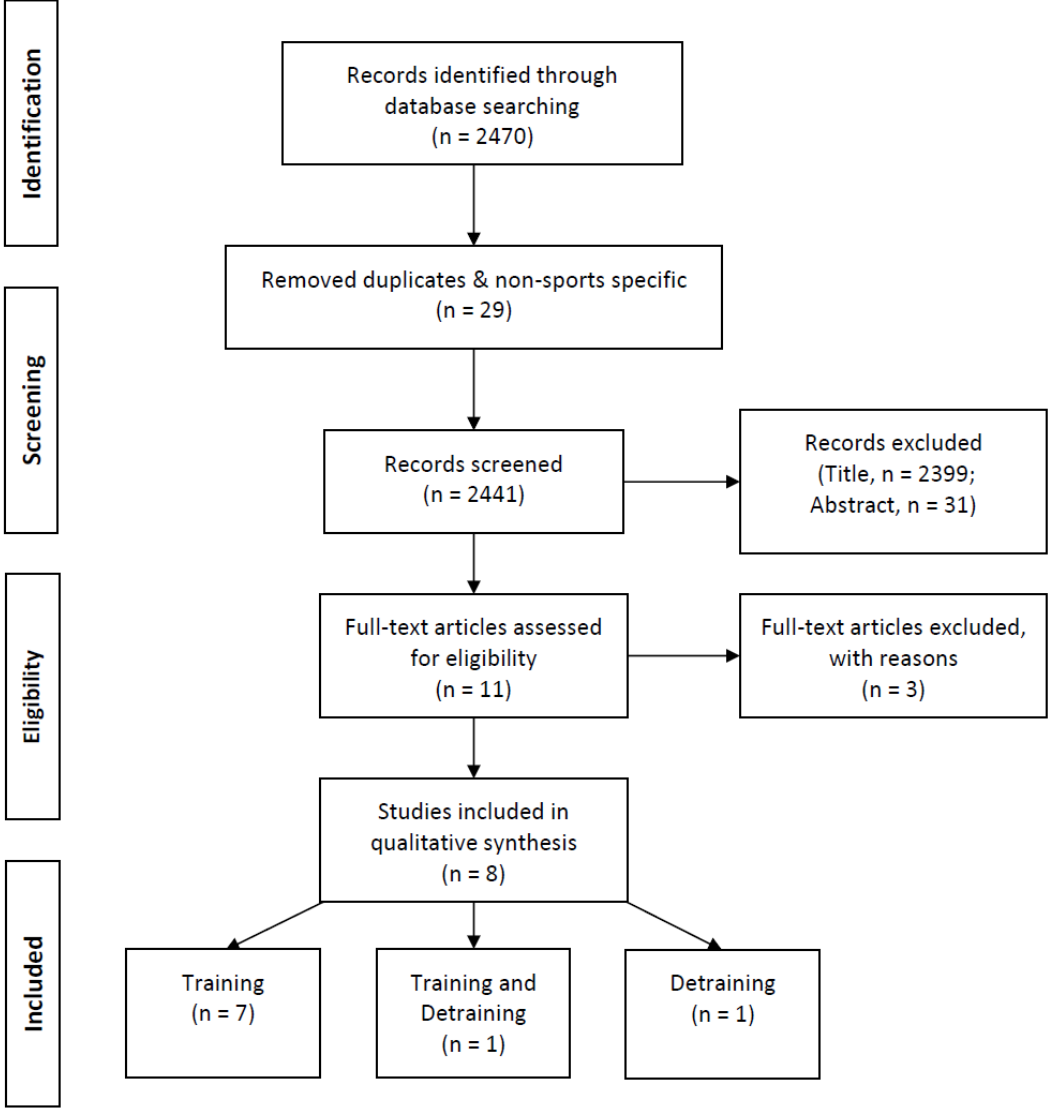


Figure 1. PRISMA study flow diagram

Data analysis

Assessment of risk of bias

Quality analysis of the identified studies was conducted independently by two researchers using methods recommended by The Cochrane Collaboration (Higgins & Green, 2011). Any conflict was resolved by including a third member. All relevant biases, such random sequence generation, allocation concealment, blinding of participants, personnel and outcomes, incomplete outcome data, selective outcome reporting, and other sources of bias, were checked, and the studies were graded. The following classifications were used: low risk, high risk, or unclear risk (either lack of information or uncertainty regarding the potential for bias). Review Manager software (RevMan, Copenhagen, The Nordic Cochrane Centre) version 5.3.5 was used to create risk-of-bias graphs.

Statistical analysis

The results of the included studies were recalculated to determine the percentage of change for each variable during training programs ($[(\text{post} - \text{pre})/\text{pre}] \times 100$). Moreover, effect sizes (ES) provided for within-subjects' comparisons to determine magnitude of changes during implementation, and when not provided by studies results, a calculation is performed using the Excel spreadsheet by (Lakens, 2013). The magnitude of the effect was classified as small ($d = 0.2$), intermediate ($d = 0.5$) or large ($d = 0.8$) (Cohen, 1988).

Results

Table 1 presents a summary of the studies that monitored the intensity variations of CT in young adults (athletes and nonathletes). Of the seven studies included in the current review, most included assessments of neuromuscular maximal performance and aerobic capacity. The tests most commonly used to evaluate strength were the countermovement jump (CMJ) and one repetition maximum (1RM) test. Aerobic speed and/or oxygen uptake were variables used to evaluate cardiorespiratory fitness. Most of the subjects were males between 20 and 30 years of age. Another important issue was related to the training program duration, which ranged from 5 weeks to 20 weeks of implementation.

Table 1 - Characteristics of the studies included in the review

Author	Subjects	Age	Duration	Outcomes
Esteve-Lanao et al. [2007]	12 runners (male)	27.0	20 weeks	HR; HRpeak
Wong et al. [2010]	39 professional soccer players (male)	24.6	8 weeks	Jump height; Ball-shooting; Sprint (10m; 30m); Yo-yo test; MAS; HRmax
Silva et al. [2012]	44 physically active (female)	23.5	11 weeks	Knee extension; Leg press; Bench press; Isometric and isokinetic peak torque
Varela-Sanz et al. [2016]	35 sport science students (male and female)	18-27.0	8 weeks	Sprint (10m; 30m); CMJ; 1RM; VO ₂ max
Fyfe et al. [2016]	23 physically active (male)	29.6	8 weeks	1RM leg press and bench press; CMJ; VO ₂ peak; LT; Body composition
Sousa et al. [2018]	32 physically active (male)	20.6	12 weeks	Sprint (10m; 20m); CMJ; 1RM; VO ₂ max
Petré et al. [2018]	16 high-level athletes (male)	27.3	6 weeks	VO ₂ max; VO ₂ max Time limit; [LA-]; MLSS
Joo, C.H. [2018]	20 semi-professional soccer players (male)	22.1	5 weeks	Sprint (30m); Repeated sprints (34.2m); Yo-Yo test; Arrowhead agility test

[LA-]: Blood lactate concentration; 1RM: 1 maximal repetition; CMJ: Countermovement jump; HR: heart rate; HRmax: maximal heart rate; HRpeak: heart rate peak; LT: lactate threshold; MAS: maximal aerobic speed; MLSS: maximal lactate steady-state; VO₂max: maximal oxygen uptake; VO₂max time limit: time at maximal oxygen uptake;

The analyzed studies were mainly focused on the exercise intensities during the aerobic component of CT training (Table 2). From the seven selected studies, all experimental interventions improved performance variables, regardless of the intensity used in CT. Nevertheless, when higher aerobic intensities were used, maximal oxygen uptake (VO₂max) and aerobic power seemed to also improve (Fyfe et al., 2016; Petré et al., 2018). Moreover, greater neuromuscular adaptations were found when higher RT loads were used with low to moderate AT intensities (Petré et al., 2018; Sousa et al., 2018). The interference from CT in strength adaptations may potentially occur by two main causes: the intensity of AT and the intensity distribution. In fact, it was reported that interference only occurs at intensities close to VO₂max (Varela-Sanz et al., 2016).

Focusing on the distribution of exercise intensities during a long-term CT program, it was suggested that the polarized model (i.e.: low-volume, high-intensity aerobic exercise combined with high-volume low-intensity training) would be the most effective training intensity distribution for reducing the interference in neuromuscular performance (Esteve-Lanao et al., 2007; Varela-Sanz et al., 2016). Running performance was approximately 2% greater with polarized training compared to the traditional distribution (Esteve-Lanao et al., 2007). Moreover, the upper and lower body maximum strengths increased 24% and 47% after 8 weeks of polarized training, respectively (Varela-Sanz et al., 2016).

Table 2 - Effects of intensity during concurrent training in performance

References	Main aim	Intervention	Main findings*
Esteve-Lanao et al., [2007]	To compare different loads distribution	G1 (n=6): Z1= 80%; Z2 = 10%; Z3 = 10% G2 (n=6): Z1 = 65; Z2 = 25%; Z3 = 10%	[10.4 km time]**G1: -7%, ES=2.1; G2: -5%, ES=1.4
Wong et al., [2010]	Effect of high-intensity CT	CG (n=19): Soccer training G1 (n=20): Soccer training + high intensity CT (RT 4x6RM; AT 120%MAS).	[CMJ]** G1: +4%, ES=1.4 [30m time]** G1: -3%, ES=2.8 [YYIRT] G1: 20%, ES=2.4 [MAS] G1: 3%, ES=1.8
Silva et al., [2012]	Effects of different intensities and types of aerobic exercise	G1 (n=10) = RT + 20min continuous running 95% VT ₂ ; G2 (n=11) = RT + 20min interval running 1min at vVO ₂ max, 1min of active recovery at 50% vVO ₂ max; G3 (n=11) = RT + continuous cycle ergometer 95% VT ₂ G4 (n=12) = RT	[1RM LP] G1: 41%, ES=1.5; G2: 47%, ES=1.5; G3: 39%, ES=1.2; G4: 53%, ES=1.4 [1RM BP] G1: 19%, ES=0.7; G2: 18%, ES=0.7; G3: 17%, ES=0.9; G4: 21%, ES=0.6
Varela-Sanz et al., [2016]	Influence of intensity distribution	G1 (n=12) = Traditional-based training: 24-37 min of running at 65-75% MAS + 3-5 x 10-12RM; G2 (n=12) = Polarized training: 35-65min of brisk walking at 30-40% MAS + 3-5 x 5RM or 2-4 x15RM. CG (n=11) = No CT training	[CMJ] G1: -7%, ES=0.4; CG: -8%, ES=0.7 [1RM SQ] G1:40%, ES=1.4; G2:47%, ES=1.4 [1RM BP] G1: 17%, ES=0.7; G2: 24%, ES=0.8 [MAS] G1:4%, ES=0.4; G2:4%, ES=0.3
Fyfe et al. [2016]	Effects of different intensities and types of CT	G1 (n=7) = moderate continuous training 80-100% LT + ~ 65-90%1RM G2 (n=8) = high intensity interval training 120-150% LT + ~ 65-90%1RM G3 (n=8) = ~ 65-90%1RM	[1RM LP]** G1: 27%, ES=0.8; G2: 29%, ES=1.2; G3: 39%, ES=1.3 [1RM BP] G1: 15%, ES=0.4; G2: 16%, ES=0.6; G3: 21%, ES=0.5; [CMJ power] G3: 13%, ES=0.9 [Peak aerobic power] G2: 9%, ES=0.3
Sousa et al., [2018]	Compare different external loads of RT during CT	G1 (n=9) = 40-55% 1RM + 20min (75% MAS) G2 (n=9) = 55-70% 1RM + 20min (75% MAS) G3 (n=8) = 70-85% 1RM + 20min (75% MAS) CG (n=6) = No training	[CMJ] G1: 12%, ES=0.6; G2: 14%, ES=0.9; G3: 12%, ES=0.3 [10m time] G2: -1%, ES = 0.3; G3: -4%, ES=0.6 [1RM SQ] G1: 14%, ES=0.6; G2: 10%, ES=0.4; G3: 11%, ES=0.5 [VO ₂ max] G1: 15%, ES=0.6; G2: 12%, ES=0.6; G3: 12%, ES=1.0
Petré et al., [2018]	Effects of different combinations of AT	G1 (n=8) = CT low volume and HIIT at ~150% VO ₂ max (4-12 min) G2 (n=8) = CT high volume and medium-intensity continuous AT at 70% VO ₂ max (40-80min)	[VO ₂ max] G1: 5% ES=0.6 [1RM SQ] G1:14%, ES=0.8; G2: 12%, ES=0.7

* only main findings and statistically significant between pre and post-training are presented; ** p<0.05 between groups; AT = aerobic training; BP= bench press; CG = control group; CMJ: countermovement jump; CT = concurrent training; Gn = Experimental group n; HIIT = high intensity interval training; LT = lactate threshold; LP = leg press; MAS = maximal aerobic speed; RM= repetition maximum; RT = resistance training; SQ= squat; VO₂max = maximal oxygen uptake; VT₂ = second ventilatory threshold; YYIRT= Yo-Yo intermittent recovery test; Z1= below ventilatory threshold; Z2 = between ventilatory threshold and respiratory compensation threshold; Z3 = above respiratory compensation threshold.

Among studies on exercise intensities during CT, only two focused on the issue of DT. Table 3 presents a summary of the studies that monitored the effects of DT on physical performance in

young adults. Sousa et al. (2018) reported that CT loads in RT seem to influence the reversibility of the training effects after a DT period of 4 weeks. In the same study, the gains in explosive strength obtained from low, moderate and high training loads combined with low-intensity aerobic training decreased between 12% and 14% after DT. In accordance with this finding, Joo (2018) verified that two weeks of DT after a competitive season resulted in marked decreases in repeated sprints and agility variables of elite soccer players.

Table 3 - Effects of concurrent training intensities after detraining

References	Main aim	Intervention	Main findings
Sousa et al., [2018]	Compare different external loads of RT during CT followed by 4-weeks DT	DT of 4weeks after CT for 8 weeks G1 = 40-55% 1RM + 20min (75% MAS) G2 = 55-70% 1RM + 20min (75% MAS) G3 = 70-85% 1RM + 20min (75% MAS)	[CMJ] G3: -6%, ES=0.6 [20m time] G2: 2%, ES= 0.8; G3: 4%, ES=0.7 [1RM SQ] G1: -7%, ES=0.3 [VO ₂ max] G2: -15%, ES=0.9; G3: -9%, ES=0.9
Joo [2018]	Effects of HIT with reduced volume and training cessation	G1 = DT combined with high-intensity AT (3x 12min at 80-90% of HRmax) G2 = DT with no physical activity. DT for 2 weeks after a soccer season	[Agility] G1: 2%, ES=0.5; G2: 1%, ES=0.3 [Yo-Yo] G2: -20%# [Repeated sprints time] G2: 5%#

AT = aerobic training; CT = concurrent training; DT = detraining period; Gn = Experimental group n; MAS = maximal aerobic speed; RM= repetition maximum; RT = resistance training; VO₂max = maximal oxygen uptake; # no data was available for ES calculation and for exact percentage.

Risk of bias in the included articles

The included studies were randomized, but few described the sequence of the randomized sequence. Some were not clear regarding the blinding outcome assessment, or this was performed by the main researcher of the study, which reveals high risk of bias (Figure. 2 and 3).

	Random sequence generation (selection bias)	Allocation concealment (selection bias)	Blinding of participants and personnel (performance bias)	Blinding of outcome assessment (detection bias)	Incomplete outcome data (attrition bias)	Selective reporting (reporting bias)	Other bias
Esteve-Lanao et al. 2007	?	?	-	?	+	+	-
Fyfe et al., 2016	-	?	+	?	+	+	+
Joo 2018	+	+	+	?	+	+	?
Petré et al., 2018	?	?	+	?	+	?	+
Silva et al., 2012	?	?	?	+	+	+	+
Sousa et al., 2018	-	?	+	?	+	+	+
Varela-Sanz et al., 2016	-	?	?	-	+	+	?
Wong et al., 2010	-	?	+	-	+	+	?

Figure 2. Judgements about each risk of bias item for each included study (“+” low risk; “?” unclear risk; “-” high risk)

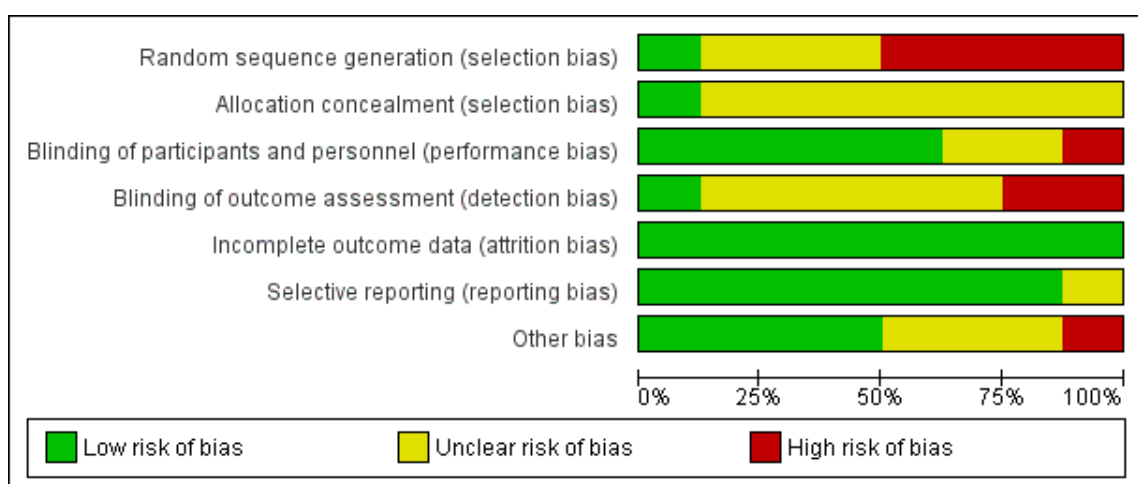


Figure 3. Risk of bias item presented as percentages across all included studies

Discussion

The current review aimed to analyze the findings provided in the literature regarding the exercise intensities used during CT and their effects on performance variables. Moreover, the effects of exercise intensities during CT on a subsequent DT period were also assessed to better understand the impact of CT intensities and how it is reflected after a cessation of training. The studies on this topic were relatively recent, with increased interest in the last two decades. CT has been studied since the early 1980s; however, only recently have researchers focused on the issue of training intensity. The few studies gathered showed improved strength and cardiorespiratory performance regardless of the different intensities used in AT and/or RT during CT. Nevertheless, there seems to exist a trend toward lower strength improvements when high aerobic intensities, despite the increased aerobic adaptations. Neuromuscular performance also seemed to be dependent on RT intensity, recording greater gains with higher external loads as long as RT was combined with an aerobic workout of medium/low intensity.

The latest increase in interest regarding CT may be due to its potential to simultaneously provide gains in cardiorespiratory fitness and strength (Beni, 2012; Kang & Ratamess, 2014) as well as the time requirement and convenience of this training program for competitive sports (Alves et al., 2012). In several sports, CT is a usual method of training, as it combines the specific motions of sports, such as swimming or running, with RT to improve performance [e.g., Balsalobre-Fernandez et al., 2016; Botonis et al., 2016; Crowley et al., 2017; Ronnestad & Mujika, 2014). Our search revealed that among the studies on CT intensity, only a few reported data on professional athletes [Esteve-Lanao et al., 2007; Petré et al., 2018; Wong & Chaouachi, 2010). Nonathletes are also an important cohort, and they were studied in several reports (Joo, 2018; Silva et al., 2012; Sousa et al., 2018; Varela-Sanz et al., 2016), but research on CT training with a focus on performance should be developed with competitive subjects.

The study of the intensity during CT was mostly restricted to the aerobic component. For instance, Silva et al. (2012) reported that different intensities of AT, combined with the same RT, twice a week for eleven weeks, does not seem to differently affect the strength development. Thus, it would be suggested that different intensities of AT enhance athletes' performances. Concordantly, Fyfe et al. (2016) evidenced that eight weeks of high-intensity or moderate-intensity of cycling for 15 to 33 min combined with the same RT improved maximal strength and neuromuscular performance. However, when compared with RT alone, both intensities similarly attenuated improvements in maximal lower-body strength (1RM and CMJ). So, we should highlight the similarity of the gains between the different training intensities, but we should not disregard the interference effect on strength gains by the moderate and high-intensities used.

It seems difficult for the researchers to investigate different aerobic intensities during CT without changing the volumes or methods of training. This is easily explained by the high intensities used, that require some rest or even reduction of the exercise duration, resulting in changes of training methods. As evidenced by Fyfe et al. (2016), two different methods of AT are usually compared (continuous vs. interval) and this could affect the conclusions obtained. Recently, Petré et al. (2018) compared different AT intensities (low volume of high intensity interval training vs. high volume of moderate continuous training) combined with the same RT. They found, in former competitive athletes, that strength improved with high and low intensities of AT, but VO_{2max} only improved when training at higher AT intensities. This suggested that higher aerobic intensities should be used during CT for greater aerobic performances. Moreover, it should be stated that when higher intensities were used, they were combined with lower volume training sessions.

From the selected studies, only Sousa et al. (2018) focused on the intensities of RT in CT. Sousa and colleagues (2018) suggested strength training programs with low, moderate and high external loads combined with low-intensity AT to produce gains in strength and aerobic capacities. Moreover, they suggested that higher loads of RT combined with low-intensity AT were efficient in improving explosive efforts. However, it remains unknown what happens if CT is combined with a high-intensity AT regimen. Higher intensities of AT can cause greater metabolic perturbation in type II muscle fibers and potentially compromise anabolic responses from strength training (Gollnick et al., 1974; Thomson et al., 1979). Thus, these findings highlight the importance of further knowledge on the intensities of RT during CT so that coaches could minimize the interference phenomenon and efficiently improve performance.

Research on CT issues has also focused on the distribution of training intensities throughout the season (Esteve-Lanao et al., 2007; Varela-Sanz et al., 2016). In this sense, the longest experimental research study was developed by Esteve-Lanao et al. (2007), whom sought to understand how the day-to-day AT intensity should be distributed and combined with the same RT program. The training intensity was typically divided into more or less arbitrary intensity zones, and the authors aimed to verify the effects of a traditional training program emphasizing moderately high-intensity aerobic training or those of a new trend of polarized training emphasizing the low-intensity zone. The runners who combined RT with AT emphasizing low-intensity training zones found greater performance enhancements than the others. Interestingly, others suggested that 8 weeks of traditional training-based regimens (i.e.: moderate volume and intensity of CT) produced similar improvements in neuromuscular and cardiorespiratory fitness as polarized training (Varela-Sanz et al., 2016). These results could be due to the few weeks of training implementation and because the sample was not composed of athletes but of sport science students. Therefore, training intensity distribution seems to be irrelevant for training programs lasting a few weeks for nonathletes, but polarized training is

suggested as the most effective training intensity distribution for improving competitive performance (Esteve-Lanao et al., 2007).

Regarding the DT period, only two studies analyzed the effects of CT intensities during training cessation (Joo, 2018; Sousa et al., 2018). Both studies revealed that the training-induced gains may be compromised with short-term detraining (2 - 4 weeks), leading to a return to baseline values (Joo, 2018; Sousa et al., 2018). Sousa et al. (2018) demonstrated that a 4-week period of training cessation compromised training-induced gains in young men, mainly in VO₂max and sprint time variables. In the study by Joo (2018), only 2 weeks of DT after a competitive season markedly decreased performance. Importantly, no differences were observed regarding the previous intensities of CT in both studies. Therefore, despite scarce evidence, it seemed that regardless of the intensities of the previous CT program, only 2-4 weeks of training cessation can cause severe loss of performance. In addition, to return to a previous level of ability, it was suggested that a similar or longer period of retraining using high-intensity AT methods was required (Joo, 2018).

The information gathered here was predicted to be helpful for coaches and professionals seeking to improve the training program design and consequently improve performance. Moreover, it was clear that this subject is still unknown, and that further research is required. It is important to understand the effect of different RT intensities and/or different AT intensities and then investigate methods of combining these exercise modalities. Moreover, more research on competitive athletes should be conducted. Athletes may be able to continuously improve strength during short-term periods due to their high level of stress tolerance, but over long-term periods, they might be negatively affected by adaptation mechanisms, interference effects and /or fatigue (Coffey & Hawley, 2017). Therefore, additional longer longitudinal studies should be developed to analyze the interference of CT at different intensities and how performance changes over time.

To the best of our knowledge, no detailed systematic review has comprehensively examined the literature regarding the effects of the intensities used in a CT training program, specifically in the AT or/and RT component. However, we found some limitations in the comparison of the results presented by the different investigations, and recommendations concerning optimal intensities to use during CT were designed based on the present data. It is worth noting that there were differences in the subject's characteristics (athletes and nonathletes) and even in the training programs (frequency, intensities, type) between the included studies that conditioned the analysis. Furthermore, only few studies were found on this issue and some methodological quality flaws compromised general conclusions. Moreover, longer periods of intervention should be studied for better understanding of this subject.

Conclusion

In brief, despite the lack of longitudinal studies on CT intensities and performance, it seems evident that CT with different intensities positively influences the performance of young adults. Furthermore, short-term training cessation (2-4 weeks) compromises the training-induced gains. The few studies revealed greater strength and neuromuscular performance gains when the CT program combined high-intensity RT with low-intensity AT, and an interference effect seemed to exist for higher aerobic intensities. Higher aerobic intensities should be used to improve cardiorespiratory fitness, but improvements in strength could be compromised. Regarding the intensity distribution during the aerobic regimen, the polarized model may be better at reducing interference in neuromuscular performance. Nevertheless, we should be cautious and consider these findings to be tendencies, while being aware that further research is needed on this matter. The information shown in this review could provide useful tools for coaches to develop efficient training programs.



Chapter 3. Experimental Studies

Study 2

Concurrent training followed by detraining: does the resistance training intensity matter?

Abstract

The aim of the present study was to analyze the training and detraining (DT) effects of concurrent aerobic training (AT) and resistance training (RT) against three different external loads on strength and aerobic variables. Thirty-two men were randomly assigned to four groups: low-load (LLG, n=9), moderate-load (MLG, n=9), high-load (HLG, n=8), and control group (CG, n=6). RT consisted of full squat (FS) with a low-load (40-55% one repetition maximum [1RM]), a moderate-load (55-70% 1RM) or a high-load (70-85% 1RM) combined with jump and sprint exercises. AT was performed at 75% of the maximal aerobic speed (MAS) for 15-20 min. The training period lasted for 8-weeks, followed by 4-weeks DT. Pre, post-training and post-DT evaluations included 20m running sprints (0-10m: T10; 0-20m: T20), shuttle run test, countermovement jump test (CMJ), and loading test (1RM) in FS. All the experimental groups showed improvements ($p < 0.05$) in all the parameters assessed, except the LLG for T10 and the HLG for T20. The LLG, MLG and HLG showed great changes in 1RM and maximum oxygen uptake (VO_{2max}) compared with the CG ($p < 0.05$), whereas the HLG and MLG showed a greater percentage change than the CG in T10 ($p < 0.001$) and CMJ ($p < 0.05$). The 4-week DT period resulted in detrimental effects in all variables analyzed for all three experimental groups. In conclusion, our results suggest that strength training programs with low, moderate, or high external loads combined with low-intensity AT could be effective for producing significant gains in strength and aerobic capacities. Moreover, the higher loads used increased gains in explosive efforts.

Key words: Endurance training, weight training, load-magnitude, sprint performance, jump performance, full squat training

Introduction

Concurrent training (CT) has become a contemporary topic for coaches, strength and conditioning professionals and researchers because a large number of sports require both strength and aerobic capacities for maximize performance (Lo et al., 2011; Nader, 2006; Wilson et al., 2012). However, Aerobic and resistance trainings produce divergent metabolic and morphological adaptations with little overlap between them (Fyfe et al., 2014; Nader, 2006). Therefore, it seems necessary to find optimal combinations of both types of training regimes to obtain maximum simultaneous development of resistance and aerobic capacities.

Studies analyzing the neuromuscular adaptations and performance improvements associated with CT have reported inconsistent results. While CT does not alter the ability to positively adapt to aerobic training (AT) (Docherty & Sporer, 2000; Wilson et al., 2012), most studies have indicated that CT regimens appear to inhibit strength, hypertrophy and power development compared with resistance training (RT) alone (Hakkinen et al., 2003; Hickson, 1980; Kraemer et al., 1995). Nevertheless, some experiments have reported little or no negative effect on strength gains with the addition of AT (Balabinis et al., 2003; McCarthy et al., 1995; Sillanpaa et al., 2008).

In addition to large influence of the interindividual variation in response to a training program (Karavirta et al., 2011; Mann et al., 2014), the effects of CT on strength gains may vary markedly due to a large number of design factors, including the mode, frequency, duration, type of exercises, volume and intensity used during both RT and AT, different sequences and recovery times between RT and AT sessions, training history of participants, and dependent variables selected (Garcia-Pallares & Izquierdo, 2011; Leveritt et al., 2003; Wilson et al., 2012). The effect of most of these variables has already received considerable attention in previous studies and reviews (Nader, 2006; Wilson et al., 2012). However, to the best of our knowledge, a question that remains ignored in the literature is the possibility of manipulating the load magnitude during RT. In addition, most of resistance exercises used in studies analyzing the effect of CT on physical performance (Bell et al., 1991; Dolezal & Potteiger, 1998; Hakkinen et al., 2003; Hickson, 1980; Izquierdo et al., 2005; Karavirta et al., 2011; Kraemer et al., 1995) were open-chain, isolated, isotonic or machine-based exercises (i.e. leg extension and flexion, seated hamstring curl, leg curl, leg press, isometric plantar flexion, calf rise). It appears that RT programs which preferably include open-chain exercises may not provide adequate movement pattern specificity for optimal performance improvements in closed-chain sporting movements such as running (Beattie et al., 2014). Therefore, it has been indicated that future investigations should include traditional multi-joint resistance exercises because are believed to be superior for eliciting optimal neuromuscular adaptations and increasing the force capabilities of the leg musculature (Beattie et al., 2014). Since (i) the training load seems to

be the most important variable to consider when designing a RT program (Fry, 2004), and (ii) the exercises selected in a RT programme can influence the magnitude of neuromuscular adaptations (Beattie et al., 2014), gains in strength and aerobic variables during CT may be directly influenced by the load magnitude and exercise used during RT. Thus, the first aim of the present study was to analyze the effect of three CT programs that only differed in the load magnitude used during the full squat (FS) training on performance in vertical jump, sprint, leg strength and aerobic capacity.

Additionally, interruptions in training sessions due to several factors are normal in any sport (Kraemer et al., 2002; Mujika & Padilla, 2000, 2001; Ormsbee & Arciero, 2012). For this reason, knowing the effects of a detraining (DT) period could be important for designing better training strategies. The DT adaptations following AT or RT alone have been widely studied in different populations (Eastwood et al., 2012; Faigenbaum et al., 1996; Kraemer et al., 2002; Lo et al., 2011; Meylan et al., 2014) Unfortunately, the effect of training cessation after CT has received less scientific attention (Carvalho et al., 2009; Santos et al., 2011, 2012; Toraman, 2005). Moreover, although abrupt cessation of intense physical training is associated with a decline of physical performance (Mujika & Padilla, 2000, 2001), DT-induced changes in performance after CT are linked with multiple factors (Hasegawa et al., 2015; Lo et al., 2011; Meylan et al., 2014; Santos et al., 2012; Toraman, 2005; Toraman & Ayceman, 2005) among which is included the relative intensity used during previous resistance program. Therefore, the second aim of the present study was to analyze the effects of 4-week DT following CT programs differing in load magnitude used during RT on different resistance and aerobic parameters.

Methods

Experimental Approach to the Problem

An experimental research design was used to compare the effects of three concurrent resistance and aerobic training programs only differing in load magnitude used during RT (40-55% one repetition maximum [1RM] vs. 55-70% 1RM vs. 70-85% 1RM) on physical performance, and the subsequent DT adaptations. To address this, thirty-six male physically active men were randomly assigned to control group (CG) or RT group with low loads (LLG), moderate loads (MLG) or high load (HLG). The players assigned to experimental groups performed RT combined with endurance, while players assigned to CG merely undertook daily life activities. All the experimental groups trained twice a week for 8 weeks using a CT regimen. All subjects were evaluated using a battery of tests performed in two sessions separated by a 48 h rest interval. During the first testing session, the participants performed the 20 m running sprints and the 20 m shuttle run test. During the second testing session, subjects executed the countermovement

jump test (CMJ), and an isoinertial loading test in FS exercise. During the 2 weeks preceding this study, four preliminary familiarization sessions were undertaken to ensure a proper execution technique in both FS and CMJ exercises. To evaluate the DT effects, the resistance and aerobic parameters were tested after four weeks of training cessation. Throughout this period, the participants were asked refrain from participating in regular exercise programs aimed at developing or maintaining strength and aerobic capacity.

Subjects

Thirty-six male physically active men volunteered to participate in this study. After an initial evaluation, the participants were matched according to their estimated one-repetition maximum ($1RM_{est}$) in FS exercises and then randomly assigned to four groups depending on the loading magnitude used during RT, as follows: i) a low-load group (LLG, 40-55% 1RM), a moderate-load group (MLG, 55-70% 1RM), a high-load group (HLG, 70-85% 1RM), and a control group (CG). Due to injury or illness, four participant (one from the HLG and three from the CG) were absent from the post-testing sessions. Thus, of the 36 initially enrolled participants, only 32 successfully completed the entire study. Player characteristics are displayed in Table 1. Participants in the CG were asked not to perform any type of RT or AT during the experimental period. All the participants provided written informed consent to the experimental procedures after the possible benefits and risks of participation were explained to them. The investigation was conducted in accordance with the Declaration of Helsinki and was approved by the local Research Ethics Committee.

Table 1. Subject characteristics.

Variable	Group			
	LLG (n = 8)	MLG (n = 9)	HLG (n = 9)	CG (n = 6)
Age (years)	20.6 ± 0.9	20.6 ± 1.6	20.6 ± 1.9	20.7 ± 2.3
Height (m)	1.80 ± 0.1	1.80 ± 0.0	1.80 ± 0.1	1.80 ± 0.1
Body Mass (Kg)	71.8 ± 8.3	68.5 ± 10.4	67.8 ± 4.6	70.1 ± 4.8

Values are mean ± SD.

LLG: Low-load group; MLG: Moderate-load group; HLG: High-load group; CG: Control group

Procedures

Neuromuscular performance was assessed before (Pre), after the 8-week training period (Post 1), and after the 4-week DT period (Post 2) using a battery of tests performed in two sessions separated by a 48h rest interval. Testing sessions were performed at the same time of day for each participant under the same environmental conditions (~20°C and ~60% humidity). Body mass and height (Seca Instruments, Ltd., Hamburg, Germany) were measured prior to the warm-up protocol in the first testing session. Strong verbal encouragement was provided during all tests to motivate participants to give a maximal effort.

Running sprints: Each participant performed three 20m sprints separated by a 3min rest. Photocell timing gates (Brower photocells, Wireless Sprint System, USA) were placed at 0, 10 and 20m so that the times needed to cover 0-10m (T10) and 0-20m (T20) could be determined. A standing start with the lead-off foot placed 1 m behind the first timing gate was used. The average of the best two sprints was used for the analysis. Warm-up consisted of 5 minutes of running at a self-selected intensity, 5 minutes of joint mobilization exercises, followed by several sets of progressively faster 30-m running accelerations. Reliability for T20 as measured by the coefficient of variation (CV) was 3.8%, while the intra-class correlation coefficient (ICC) was 0.94.

Shuttle run test: The 20m multistage shuttle run test was administered according to the original version described by Léger (1988). The initial running velocity was set at 8.5 km·h⁻¹ and was gradually increased in 0.5 km·h⁻¹ each minute (González-Badillo et al., 2015). The test was terminated when a participant failed to reach the appropriate marker in the allotted time twice or could no longer maintain the pace. The number of laps completed was recorded. Estimated maximum oxygen consumption (VO_{2max}, ml·kg⁻¹·min⁻¹) was calculated based on the maximal speed (MAS) reached before participants were unable to keep up with the audio recording, as follows: $-27.4 + 6 \cdot \text{MAS}$ (Leger et al., 1988).

Vertical jump test: The jump height was determined using a contact mat connected to an electronic power timer, control box and handset (Globus Ergojump, Italy). Each participant performed three maximal CMJs with their hands on their hips, separated by 1min rests. The highest value was recorded for the subsequent analysis. The ICC was 0.96, and the CV was 3.2%.

Isoinertial squat loading test: A Smith machine (Multipower Fitness Line, Peroga, Murcia, Spain) was used for this test. A detailed description of the testing procedures used in this study was recently reported elsewhere (González-Badillo et al., 2015). The initial load was set at 17 kg and progressively increased in 10 kg increments until the attained mean propulsive velocity (MPV) was ~1.00 m·s⁻¹ (range 0.95-1.05m·s⁻¹) (González-Badillo et al., 2015). The participants performed 3 repetitions with each load, with 3min recovery. A linear velocity transducer (T-Force System, Ergotech, Murcia, Spain) was used to register bar velocity. The 1RM_{est} was

calculated based on the MPV attained against the heaviest load lifted, as follows: $(100 \cdot \text{load}) / (-5.961 \cdot \text{MPV}^2) - (50.71 \cdot \text{MPV}) + 117$ (Sánchez-Medina et al., 2017).

Training program

The descriptive characteristics of the training programs completed by each group are presented in Table 2. The RT session comprised FS, vertical jump and sprint exercises. Approximately 2-3min rest periods were allowed between each set and exercise. The participants were instructed to perform all exercises at maximal intended velocity to obtain the highest possible gains (Parejo-Blanco et al., 2014). The loads used by each participant in the FS exercise were assigned according to 1RM_{est} obtained in the initial isoinertial squat loading test. Thus, the relative intensity of the FS exercise progressively increased from 40% to 55% 1RM, 55% to 70% 1RM, and 70% to 85% 1RM for LLG, MLG and HLG, respectively. Because strength was expected to increase with training, an intermediate isoinertial squat loading test was carried out after 4 weeks of training in order to perform the necessary load adjustments for each training group. AT was performed 20 min after the participants completed the RT. All the experimental groups completed the same AT regimen, which consisted of 15-20 min performing the 20 m shuttle run exercise at 75% of the maximal individual speed reached during the 20 m multistage shuttle run test. As for strength training, participants were assessed in the 20 m shuttle run test after 4 weeks of training in order to perform the necessary adjustments for each training group. At least 2 trained researchers supervised each workout session and recorded the compliance and individual workout data during each training session. All participants were instructed to maintain their normal daily activities throughout the study. The participants did not undertake any additional strength or AT activities during the testing, training, and DT periods.

Statistical analysis

Exercise	Sessions														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Full Squat (% 1RM: SxR)															
LLG	40:3x8	40:3x8	40:3x8	45:3x8	45:3x8	45:3x8	50:3x6	50:3x6	50:3x6	55:3x6	55:3x6	55:3x6	50:3x6	50:3x6	40:3x6
MLG	55:3x8	55:3x8	55:3x8	60:3x6	60:3x6	60:3x6	65:3x6	65:3x6	65:3x6	70:3x6	70:3x6	70:3x6	65:3x6	65:3x6	60:3x6
HLG	70:3x8	70:3x8	70:3x8	75:3x8	75:3x8	75:3x6	80:3x5	80:3x5	80:3x5	85:3x5	85:3x5	85:3x5	80:3x5	80:3x5	75:3x8
CMJ	2x5	2x5	2x5	2x5	2x5	2x5	3x5	3x5	3x5	3x5	3x5	3x5	3x5	3x5	2x5
Sprint (SxD)	2x30m	2x30m	2x30m	3x30m	3x30m	3x30m	3x20m	3x20m	3x20m	4x20m	4x20m	4x20m	3x20m	3x20m	2x20m
20m Shuttle Run	15 min	15 min	15 min	20 min	20 min	20 min	20 min	20 min	15 min	15 min	15 min	15 min	20 min	20 min	20 min
(Tx%MAS)	x 75%	x 75%	x 75%	x 75%	x 75%	x 75%	x 75%	x 75%	x 75%	x 75%	x 75%	x 75%	x 75%	x 75%	x 75%

LLG: Low-load group; MLG: Moderate-load group; HLG: High-load group; CG: Control group; 1RM: One-repetition maximum; SxR: Sets x repetitions; SxD: Sets x distance; Tx%MAS: Time (min) x percentage of the maximal speed reached for each participant during the 20 m multistage shuttle run test.

The values of each variable are presented as mean \pm standard deviation (SD). Homogeneity of variance across groups (LLG vs. MLG vs. HLG vs. CG) was verified using the Levene test, whereas the normality of distribution of the data was examined with the Shapiro-Wilk test. A 4 (group: LLG, MLG, HLG, CG) \times 3 (time: Pre, Post 1, Post 2) repeated measures analysis of variances (ANOVA) was calculated for each variable. Sphericity was checked using *Mauchly's* test. Percentage of change for each variable was calculated $[(\text{post} - \text{pre}/\text{pre}) \times 100]$ and a one-way ANOVA was conducted to examine between-group differences with *tukey* post-hoc comparisons (LLG vs. MLG vs. HLG vs. CG) to clarify the interaction. In addition to this null hypothesis testing, the data were assessed for clinical significance using an approach based on the magnitudes of change (Hopkins et al., 2009). The effect sizes (ES) were calculated using Cohen's *d* (Faigenbaum et al., 1996) to estimate the magnitude of the training effect on the selected neuromuscular variables within each group. The threshold values for assessing the magnitudes of the standardized effects were 0.20, 0.60, 1.20 and 2.00 for small, moderate, large and very large magnitudes, respectively. Probabilities were also calculated to establish whether the true (unknown) differences were lower than, similar to, or higher than the smallest worthwhile difference or change (0.2 multiplied by the between-subject SD) (Hopkins et al., 2009). The quantitative chances of obtaining higher or lower differences were evaluated as follows: 1%, almost certainly not; 1-5%, very unlikely; 5-25%, unlikely; 25-75%, possible; 75-95%, likely; 95-99%, very likely; 99%, almost certain. If the chances of having higher or lower values than the smallest worthwhile difference were both $>5\%$, the true difference was assessed as unclear. Inferential statistics based on the interpretation of the magnitude of effects were calculated using a purpose-built spreadsheet for the analysis of controlled trials (Hopkins, 2006). The statistical analyses were performed using SPSS software version 18.0 (SPSS, Inc., Chicago, IL, USA). Statistical significance was established at the $p \leq 0.05$ level.

Results

Data for all variables analyzed were homogeneous and normally distributed ($p > 0.05$). There were no significant differences between groups at baseline for any analyzed variable. The mean values, percentage of change and intra-group ES for all variables analyzed during Pre, Post 1 and Post 2 are reported in Table 3 (LLG), Table 4 (MLG), and Table 5 (HLG).

Table 3. Changes in selected neuromuscular performance variables from pre-training to post-training and detraining period for LLG.

Variable	Pre	Post 1	Post 2	Pre vs. Post 1		Pre vs. Post 2		Post 1 vs. Post 2				
				value Δ ($\pm 90\%$ CI)	ES ($\pm 90\%$ CI)	value Δ ($\pm 90\%$ CI)	ES ($\pm 90\%$ CI)	value Δ ($\pm 90\%$ CI)	ES ($\pm 90\%$ CI)			
T10 (s)	1.87 \pm 0.11	1.84 \pm 0.09	1.90 \pm 0.10	0.148	-1.3 \pm 1.0	0.20 \pm 0.15	0.573	1.6 \pm 2.0	-0.24 \pm 0.31	0.129	2.9 \pm 2.3	-0.44 \pm 0.34
T20 (s)	3.21 \pm 0.15	3.16 \pm 0.16	3.22 \pm 0.15	0.007	-1.5 \pm 0.6	0.29 \pm 0.12	1.000	0.5 \pm 0.6	-0.09 \pm 0.18	0.042	2.0 \pm 1.2	-0.38 \pm 0.22
CMJ (cm)	33.8 \pm 5.1	37.7 \pm 5.3	34.2 \pm 5.1	0.002	11.6 \pm 3.9	0.61 \pm 0.19	1.000	1.3 \pm 6.6	0.07 \pm 0.36	0.077	-9.3 \pm 6.4	-0.54 \pm 0.33
1RM _{est} (kg)	81.9 \pm 17.0	92.4 \pm 18.5	85.5 \pm 16.0	0.004	13.9 \pm 5.6	0.57 \pm 0.22	0.058	5.8 \pm 3.8	0.25 \pm 0.16	0.018	-7.1 \pm 3.4	-0.33 \pm 0.16
VO ₂ max (ml·kg ⁻¹ ·min ⁻¹)	41.0 \pm 8.5	46.7 \pm 7.2	42.2 \pm 5.0	0.000	15.2 \pm 5.0	0.56 \pm 0.17	1.000	4.3 \pm 9.6	0.17 \pm 0.36	0.089	-9.5 \pm 5.7	-0.40 \pm 0.25

Data are mean \pm SD

LLG: Low-load group; Pre: Initial evaluation; Post 1: Evaluation after training period; Post 2: Evaluation after detraining period; Δ : Percentage of change; ES: Intragroup effect size; CI: Confidence interval; T10: 10-m sprint time; T20: 20-m sprint time; CMJ: Countermovement jump; 1RM_{est}: Estimated one-repetition maximum; VO₂max: Estimated maximal oxygen uptake.

Table 4. Changes in selected neuromuscular performance variables from pre-training to post-training and detraining period for MLG.

Variable	Pre	Post 1	Post 2	Pre vs. Post 1		Pre vs. Post 2		Post 1 vs. Post 2	
				<i>p</i> -value	Δ ($\pm 90\%$ CI) ES ($\pm 90\%$ CI)	<i>p</i> -value	Δ ($\pm 90\%$ CI) ES ($\pm 90\%$ CI)	<i>p</i> -value	Δ ($\pm 90\%$ CI) ES ($\pm 90\%$ CI)
T10 (s)	1.83 \pm 0.06	1.81 \pm 0.07	1.87 \pm 0.09	0.034	-1.0 \pm 0.6 0.27 \pm 0.15	0.174	2.0 \pm 1.7 -0.51 \pm 0.47	0.015	1.8 \pm 0.9 -0.77 \pm 0.33
T20 (s)	3.12 \pm 0.12	3.05 \pm 0.13	3.17 \pm 0.11	0.003	-2.3 \pm 0.8 0.56 \pm 0.20	0.214	1.6 \pm 1.4 -0.37 \pm 0.33	0.009	4.0 \pm 1.8 -0.92 \pm 0.41
CMJ (cm)	34.2 \pm 4.9	38.8 \pm 3.8	36.6 \pm 5.0	0.005	13.9 \pm 6.4 0.85 \pm 0.37	0.164	7.2 \pm 6.6 0.46 \pm 0.40	0.115	-5.9 \pm 4.1 -0.40 \pm 0.29
1RM _{est} (kg)	84.2 \pm 16.7	92.6 \pm 18.6	89.5 \pm 16.9	0.022	9.9 \pm 4.7 0.40 \pm 0.18	0.165	5.5 \pm 4.6 0.23 \pm 0.19	0.267	-4.0 \pm 3.8 -0.17 \pm 0.17
VO ₂ max(ml·kg ⁻¹ ·min ⁻¹)	43.9 \pm 6.8	49.0 \pm 5.7	41.9 \pm 6.7	0.001	12.1 \pm 4.7 0.64 \pm 0.23	0.591	-4.7 \pm 5.4 -0.27 \pm 0.31	0.001	-15.0 \pm 4.8 -0.91 \pm 0.31

Data are mean \pm SD

MLG: Moderate-load group; Pre: Initial evaluation; Post 1: Evaluation after training period; Post 2: Evaluation after detraining period; Δ : Percentage of change; ES:

Intragroup effect size; CI: Confidence interval; T10: 10-m sprint time; T20: 20-m sprint time; CMJ: Countermovement jump; 1RM_{est}: Estimated one-repetition maximum;

VO₂max: Estimated maximal oxygen uptake.

Table 5. Changes in selected neuromuscular performance variables from pre-training to post-training and detraining period for HLG.

Variable	Pre	Post 1	Post 2	Pre vs. Post 1		Pre vs. Post 2		Post 1 vs. Post 2				
				value	Δ ($\pm 90\%$ CI) ES ($\pm 90\%$ CI)	value	Δ ($\pm 90\%$ CI) ES ($\pm 90\%$ CI)	value	Δ ($\pm 90\%$ CI) ES ($\pm 90\%$ CI)			
T10 (s)	1.87 \pm 0.09	1.81 \pm 0.09	1.87 \pm 0.06	0.013	-3.6 \pm 1.7	0.63 \pm 0.31	1.000	0.1 \pm 2.1	-0.01 \pm 0.37	0.035	3.8 \pm 2.2	-0.65 \pm 0.37
T20 (s)	3.12 \pm 0.12	3.07 \pm 0.10	3.14 \pm 0.07	0.153	-1.6 \pm 1.3	0.37 \pm 0.31	0.906	0.9 \pm 1.4	-0.20 \pm 0.33	0.037	2.5 \pm 1.5	-0.56 \pm 0.34
CMJ (cm)	34.7 \pm 3.0	39.0 \pm 4.1	36.9 \pm 4.5	0.002	12.3 \pm 4.4	1.27 \pm 0.43	0.259	5.9 \pm 6.0	0.63 \pm 0.62	0.300	-5.7 \pm 5.5	-0.64 \pm 0.64
1RM _{est} (kg)	85.3 \pm 17.3	94.6 \pm 16.2	90.4 \pm 17.2	0.003	11.4 \pm 4.6	0.47 \pm 0.18	0.071	6.2 \pm 4.4	0.26 \pm 0.44	0.085	-4.7 \pm 3.5	-0.21 \pm 0.16
VO ₂ max (ml·kg ⁻¹ ·min ⁻¹)	43.6 \pm 4.4	48.9 \pm 4.5	44.5 \pm 6.0	0.000	12.2 \pm 2.8	1.00 \pm 0.22	1.000	1.7 \pm 5.2	0.15 \pm 0.45	0.011	-9.4 \pm 4.4	-0.86 \pm 0.42

Data are mean \pm SD

HLG: High-load group; Pre: Initial evaluation; Post 1: Evaluation after training period; Post 2: Evaluation after detraining period; Δ : Percentage of change; ES: Intragroup effect size; CI: Confidence interval; T10: 10-m sprint time; T20: 20-m sprint time; CMJ: Countermovement jump; 1RM_{est}: Estimated one-repetition maximum; VO₂max: Estimated maximal oxygen uptake.

All the experimental groups showed improvements ($p < 0.05 - 0.001$) in all the variables assessed except the LLG in T10 and the HLG in T20 (Tables 3, 4 and 5). No changes took place in the CG. The magnitude of change for LLG was from *small* (T10, T20, $1RM_{est}$ and maximum oxygen uptake [VO_{2max}]) to *moderate* (CMJ). For MLG, the standardized effects were *small* (T10, T20 and $1RM_{est}$) and *moderate* (CMJ and VO_{2max}), whereas for HLG, the qualitative outcome relative to ES was *small* (T20 and $1RM_{est}$), *moderate* (T10 and VO_{2max}) or *large* (CMJ), depending to the assessed variable.

After the training period, significant “time \times group” interactions were observed for T10 ($p < 0.001$), CMJ ($p < 0.01$), $1RM_{est}$ ($p < 0.01$) and VO_{2max} ($p < 0.001$), whereas there was no “time \times group” interaction in T20 ($p = 0.349$). The one-way ANOVA indicated that all the experimental groups showed significantly greater percent changes from Pre to Post 1 for $1RM_{est}$ ($p < 0.05 - 0.01$) and VO_{2max} ($p < 0.05 - 0.05$) compared to CG, whereas the HLG and MLG also showed greater percentage of change than CG in T10 ($p < 0.001$) and CMJ ($p < 0.05$), respectively (Table 6; Figure 1).

The 4-week DT period produced an important detriment effect on all the variables analyzed for all the experimental groups. Most of these variables returned to initial values or lower after the rest period (Tables 3, 4 and 5). In fact, no differences were found between Pre and Post 2 in any studied variable for any experimental group. In addition, no significant differences were found between the three-trained groups and the CG at Post 2 for any variable.

Table 6. Changes in selected neuromuscular performance variables from initial evaluation (pre) to final evaluation (post) between groups.

	P value between groups	Changes observed for post- vs. pre		
		Standardized differences (Cohen: 90% CI)	Percent changes of better/trivial/worse effect	
T10				
LLG vs. CG	0.148	0.38 (0.13 to 0.63)	89/11/0	Likely
MLG vs. CG	0.254	0.43 (0.14 to 0.71)	91/9/0	Likely
HLG vs. CG	0.000	0.80(0.45 to 1.16)	99/1/0	Very Likely
LLG vs. MLG	1.000	0.05 (-0.16 to 0.25)	11/87/3	Likely Trivial
LLG vs. HLG	0.108	-0.40 (-0.72 to -0.07)	0/15/85	Likely harmful
HLG vs. MLG	0.057	0.52 (0.15 to 0.88)	93/7/0	Likely
T20				
LLG vs. CG	1.000	0.11 (-0.06 to 0.28)	18/81/0	Likely Trivial
MLG vs. CG	0.436	0.29 (0.08 to 0.49)	77/23/0	Likely
HLG vs. CG	1.000	0.14 (-0.14 to 0.42)	35/62/3	Unclear
LLG vs. MLG	1.000	-0.19 (-0.39 to 0.02)	0/54/46	Possibly harmful
LLG vs. HLG	1.000	-0.03 (-0.32 to 0.27)	10/75/15	Unclear
HLG vs. MLG	1.000	-0.18 (-0.54 to 0.17)	5/49/46	Unclear
CMJ				
LLG vs. CG	0.159	0.50 (0.22 to 0.78)	96/4/0	Very Likely
MLG vs. CG	0.031	0.67 (0.28 to 1.05)	97/3/0	Very Likely
HLG vs. CG	0.093	0.69 (0.31 to 1.08)	98/2/0	Very Likely
LLG vs. MLG	1.000	-0.13 (-0.52 to 0.26)	8/55/37	Unclear
LLG vs. HLG	1.000	-0.04 (-0.41 to 0.32)	13/64/23	Unclear
HLG vs. MLG	1.000	-0.12 (-0.65 to 0.41)	15/45/40	Unclear
1RM_{est}				
LLG vs. CG	0.004	0.48 (0.30 to 0.66)	99/1/0	Very Likely
MLG vs. CG	0.043	0.36 (0.20 to 0.53)	95/5/0	Likely
HLG vs. CG	0.016	0.41 (0.25 to 0.58)	98/2/0	Very Likely
LLG vs. MLG	1.000	0.16 (-0.11 to 0.43)	39/59/2	Possibly
LLG vs. HLG	1.000	0.10 (-0.17 to 0.37)	26/71/3	Possibly
HLG vs. MLG	1.000	0.06 (-0.19 to 0.31)	17/79/4	Likely Trivial
VO₂max				
LLG vs. CG	0.004	0.54 (0.33 to 0.74)	99/1/0	Very Likely
MLG vs. CG	0.035	0.54 (0.28 to 0.80)	98/2/0	Very Likely
HLG vs. CG	0.037	0.73 (0.51 to 0.95)	100/0/0	Most Likely
LLG vs. MLG	1.000	0.13 (-0.14 to 0.39)	32/66/2	Possibly
LLG vs. HLG	1.000	0.14 (-0.11 to 0.39)	34/64/2	Possibly
HLG vs. MLG	1.000	0.00 (-0.31 to 0.32)	15/71/14	Unclear

CI: confidence interval; LLG: Low-load group; MLG: Moderate-load group; HLG: High-load group; CG: Control group; T10: 10-m sprint time; T20: 20-m sprint time; CMJ: countermovement jump; 1RM_{est}: estimated one-repetition maximum; VO₂max: estimated maximal oxygen uptake. Note: all differences are presented as improvements for the first group compared with the second group (i.e., LLG vs. CG), so that negative and positive differences are in the same direction.

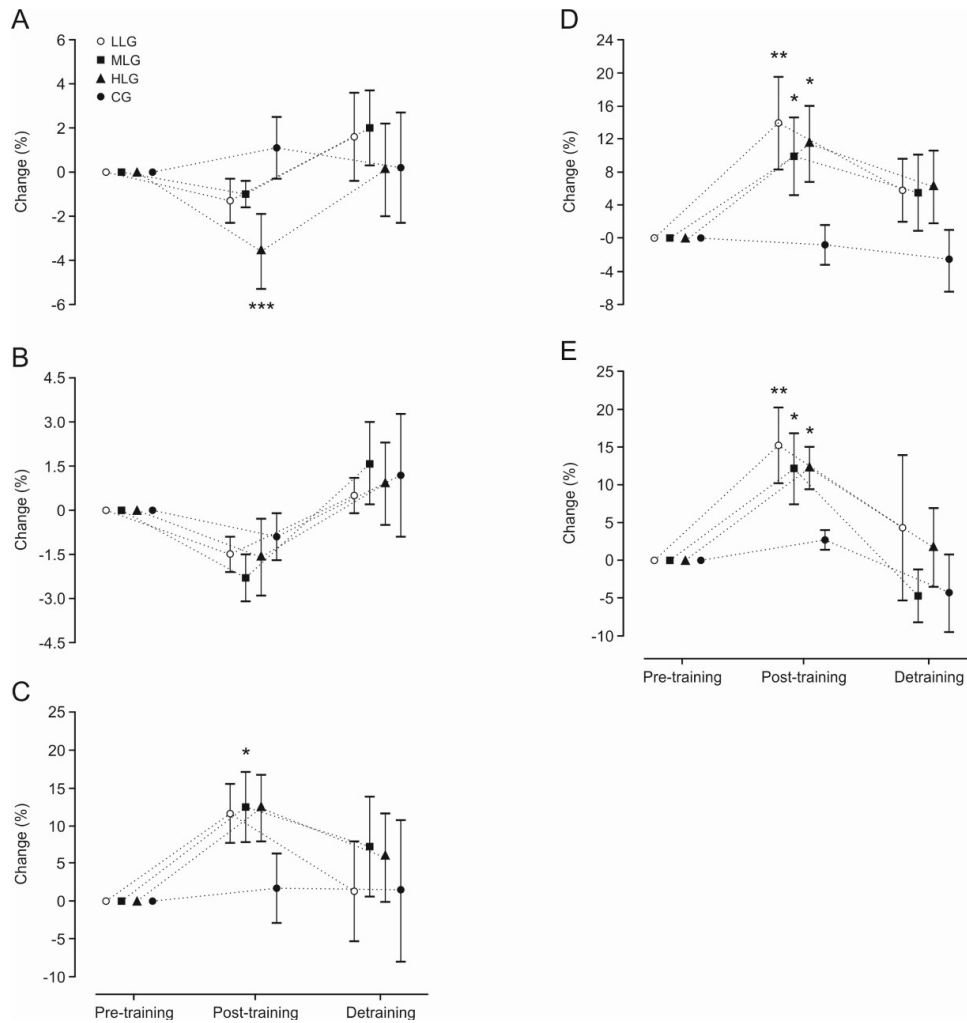


Figure 1. Relative changes in performance variables (A: T10; B: T20; C: CMJ; D: 1RM_{est}; E: VO₂max) from baseline in the low-load (LLG), moderate-load (MLG), high-load (HLG) and control group. Error bars represent 90% of confidence interval of changes from baseline to post-training and baseline to detraining. Statistically significant differences respect to CG: * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

Discussion

To the best of our knowledge, this was the first study focused on analyzing the training and DT effects after CT programs differing in the relative intensity (%1RM) used during RT regime on strength and aerobic performance in physical active men. The main finding of the present study was that the all three experimental groups showed significant and practical improvements in different performance variables including jump, running sprint, maximal strength and VO₂max. Thus, it appears that RT programs consisting in FS exercise with low (40 - 55% 1RM), moderate (55 - 70% 1RM), or high (70 - 85% 1RM) loads combined with the same low-intensity AT (75% VO₂max) could be equally effective for producing significant gains in strength and aerobic capacities. In addition, the DT period resulted in significant performance decrements in all

variables assessed for all experimental groups. These results could be of great interest for coaches and strength and conditioning professionals to optimize training programs in those sports modalities to require combinations of both components of AT and RT for maximize performance.

Strength performance

All three experimental groups showed significant ($p < 0.05 - 0.01$) improvements in $1RM_{est}$ after training period. However, changes reported in LLG (13.9%; ES: 0.57), MLG (9.9%; ES: 0.40) and HLG (11.4%; ES: 0.47) were lower than those reported in previous studies (~20%) (Hakkinen et al., 2003; Izquierdo et al., 2005; McCarthy et al., 2002) and meta-analyses (ES:1.30) (Wilson et al., 2012) that assessed the effects of CT on strength development in untrained male participants. Although have been described that continuous AT would be predicted to have minimal interference on strength gains using either high load or moderate load RT protocols (Docherty & Sporer, 2000; Garcia-Pallares & Izquierdo, 2011), it is possible that the short rest period between RT and AT in the present study (~20 min) may have induced a greater degree of interference than previous studies (Wilson et al., 2012). Thus, our results confirmed the need to separate RT and AT sessions to optimize strength gains (Docherty & Sporer, 2000; Garcia-Pallares & Izquierdo, 2011). In addition, the use of only one resistance exercise (full squat) has also been able to influence in the lower gains found in the present study compared to other studies (Dolezal & Potteiger, 1998; Hakkinen et al., 2003; Izquierdo et al., 2005; McCarthy et al., 2002) in which several resistance exercises were used (e.g., knee flexion and extension, leg curl, leg press, calf raise). Comparison between experimental groups showed no significant differences in strength gains between LLG, MLG and HLG. However, the analysis of practical inferences resulted in a *possible* better effect on $1RM_{est}$ for LLG compared to MLG and HLG. These results are in agreement with previous studies indicating that RT programs that include training with moderate to high loads and repetitions at or near the point of muscle failure lead to lower strength gains compared with the use of a moderate number of repetitions for not training to repetition failure (Docherty & Sporer, 2000; Garcia-Pallares & Izquierdo, 2011; Izquierdo-Gabarren et al., 2010; Mora-Custodio et al., 2016).

Sprint and Vertical Jump Performance

Only few studies (Chtara et al., 2008; Hunter et al., 1987; McCarthy et al., 1995) have analyzed the effect of CT on jump performance, while, to the best of our knowledge, no studies have examined the influence of CT on running sprints in adult individuals. In the present study, all three combinations resulted in low-moderate improvements in CMJ (11.6 - 13.9%; ES: 0.61 - 1.27) and sprint times (1.0 - 3.5%; ES: 0.20 - 0.63). These improvements in CMJ were greater than previous studies conducted with untrained individuals (9.0 - 3.3%). Thus, although AT

(continuous and high-intensity run training) has been reported to cause deterioration in the capacity of the neuromuscular system to rapidly generate force (Hennessy & Watson 1994), it appears that adding explosive exercises (jumps and accelerations) along with the full-squat exercise executing each repetition at maximal intended velocity could attenuate the interference on adaptations to short and high intensity efforts.

Regarding the load magnitude used during resistance training, the present study showed no significant differences for Pre-Post changes in jump and sprint variables between experimental groups. However, there was a slight trend toward greater intra-group ES for HLG compared with LLG and MLG in T10 and CMJ. In addition, HLG showed a *likely* greater effect than LLG and MLG in T10, while practically worthwhile difference was *possibly* more beneficial in favour of MLG compared to LLG. For the rest of comparisons, the differences between LLG, MLG and HLG were *unclear*. These results appear to be in contrast with a recent meta-analysis (Seitz et al., 2014) which indicated that high-load RT alone resulted in lesser sprint ES (ES = 0.52) compared with lower loads (ES = 0.97). However, our results seem to indicate that, when RT is combined with continuous AT, using moderate to high loads is more effective for improving jump and sprint performance than those with low loads.

Aerobic Performance

The training period resulted in similar improvements in VO₂max for all three experimental groups. These changes (~12 - 15%) were comparable to those reported in previous studies (~7 - 18%) performing CT or aerobic regimens alone (Bell et al., 1991; Hakkinen et al., 2003; Hichson, 1980; Hunter et al., 1987; McCarthy et al., 1995). Therefore, although the present study did not include a group that underwent AT alone, our results appear to be in line with previous reports, suggesting that CT does not affect the development of VO₂max in untrained or resistance-trained individuals. In addition, as a remarkable contribution of the present study, our results suggest that load magnitude used during RT do not effect on changes in aerobic performance, as no significant differences were found in VO₂max gains between LLG, MLG and HLG.

Detraining Effect

The DT period resulted in a marked and similar reduction in physical performance for all three experimental groups, with a partial (CMJ and 1RM_{est}) or complete (T10, T20 and VO₂max) reversals of the adaptations obtained during 8-week training period. This is in accordance with previous studies that have shown important VO₂max declines (4-14%) with short-term training cessation in trained and untrained individuals (Mujika & Padilla, 2000). However, studies conducted with elementary school students using CT have shown both significant loss (Santos et al., 2011) and no changes (Santos et al., 2012) in this variable. In relation to sprint

performance, several studies using a CT training period (Meylan et al., 2014; Santos et al., 2011, 2012) have shown that the sprint time in 10, 20 and 30 m remained unchanged or only decreases slightly during the DT period. Discrepancies with our results could be due to differences in the age of the participants and the training program configurations (Meylan et al., 2014; Santos et al., 2011, 2012).

According to several studies and review analyzing the effect of DT period after CT training or RT alone (Kraemer et al., 2002; Mujika & Padilla, 2000), the loss of maximal strength (4 - 7%) and CMJ height (5 - 9%) in the present study were lower compared aerobic performance. Since CMJ performance depends largely on the maximal strength of the leg extensors (Franco-Marquez et al., 2015; Wilson et al., 2004), it is possible that the lower reduction in CMJ performance was associated with the maintenance of $1RM_{est}$. In accordance with our results, other studies have shown no significant changes in CMJ performance after 4-6 weeks of cessation of resistance training (Kannas et al., 2015; Karavirta et al., 2011; Marques & González-Badillo, 2006). However, it appears that when RT is combined with AT, both maximal strength and CMJ height trend to descend to a greater extent after DT period (Santos et al., 2011, 2012).

The present study has some limitations need to be addressed. Obviously, one of the main limitations of the present study is the low number of subjects in each group. Thus, some effects are associated with large confidence limits for the intra- and between-group change differences. Therefore, we can not be sure whether differences within and between groups would have been clearer with a greater number of subjects in each experimental group. In addition, the present study evaluated the efficacy of aerobic training and a specific RT regimen consisting in FS exercise alone. It is possible that the use of only one resistance exercise may have been a limitation for strength gains during CT. In addition, this type of RT has also been able to influence the degree of loss of physical performance during the DT period. However, since the main aim of the present study was to analyze the training and DT effects of combined RT programs against three different external loads with the same AT on strength and aerobic variables, we consider it appropriate not to include additional resistance exercises to avoid increasing the number of confounding factors such as number of exercises, rest time between exercises, type of exercises (e.g., multi-join vs. isolated, closed- vs. open-chain, isoinertial vs. isotonic), or fatigue accumulated. However, a comparison of the relative efficacy of different RT regimens combined with different AT seems to be an interesting topic for future research. Finally, we should acknowledge that different participants, for instance, experienced ones could lead to other results and further investigation should also be developed in this regard.

Conclusions

In brief, the results of the present study indicated that 8-weeks of RT programs with different loads combined with low-intensity AT improved strength and aerobic capacities, regardless of training intensity used during resistance training. Despite the similar improvements, RTs with loads higher than 55% of $1RM_{est}$ are suggested to increase changes in explosive efforts, such as short runs (T10 m) and CMJ. In addition, 4-weeks of DT compromised previous gains, mainly in VO_{2max} and sprint time variables.

Practical Applications

The results seems to suggest that performing RT with low, moderate, or high external loads combined with low-intensity AT regimen is beneficial for strength and aerobic development in healthy adult men. Furthermore, choosing higher loads during RT can lead to increased gains in explosive efforts. Despite our data highlight that 8-weeks of training are sufficient to verify enhancements, it takes only 4-weeks without training to return to the initial values. This should be considered when designing CT in sports clubs to improve its efficiency. Thereupon, this experiment provides a new path in order to integrate both strength and aerobic regimens in the same session.

Study 3

Concurrent training followed by detraining: the influence of different aerobic intensities

Abstract

The aim of this study was to verify the effects of different aerobic intensities combined with the same resistance training (RT) on strength and aerobic performances. Thirty-nine males were randomly assigned to a low-intensity (LIG), moderate-intensity (MIG), high-intensity (HIG), and a control group (CG). The training program consisted of full squat (FS), jumps, sprints, and running at 80% (LIG), 90% (MIG), or 100% (HIG) of the maximal aerobic speed (MAS) for 16-20 minutes. The training period lasted for 8 weeks, followed by 4 weeks of detraining (DT). Evaluations included 20 m sprints (0-10 m: T10; 0-20 m: T20), shuttle run, countermovement jump (CMJ), and strength (estimated one repetition maximum ($1RM_{est}$)) in FS. There were significant improvements from pre- to post-training in T10 (LIG: 4%; MIG: 5%; HIG: 2%), T20 (3%; 4%; 2%), CMJ (9%; 10%; 7%), $1RM_{est}$ (13%; 7%; 8%), and oxygen uptake (VO_{2max} ; 10%; 11%; 10%). Comparing the changes between the experimental groups, $1RM_{est}$ gains were significantly higher in the LIG than HIG (5%) or MIG (6%). Furthermore, there was a tendency for higher gains in LIG and MIG compared with HIG, with “possibly” or “likely” positive effects in T10, T20, and CMJ. DT resulted in performance decrements, but minimal losses were found for VO_{2max} in LIG (-1%). Concurrent training (CT) seems to be beneficial for strength and aerobic development regardless of the aerobic training (AT) intensity. However, choosing lower intensities can lead to increased strength and are recommended when the cardiorespiratory gains should be maintained for longer.

Key Words: Endurance training, strength training, sprint, jump, full squat.

Introduction

Concurrent training (CT) is widely described in the literature as an effective training method for improving aerobic capacity, muscle strength and power (Hennessy & Watson, 1994; Leveritt et al., 2003). However, combining resistance (RT) and aerobic training (AT) has been reported to attenuate the training response induced by either type of training alone (Garcia-Pallares & Izquierdo, 2011; Gollnick et al., 1974). This interference phenomenon (Garcia-Pallares & Izquierdo, 2011), appears to be associated with a greater inhibitory effect on strength development than on aerobic capacity when CT is conducted (Izquierdo-Gabarron et al., 2010). Nevertheless, some studies have shown no antagonistic effects on strength (McCarthy et al., 2002) or aerobic performance (Mikkola et al., 2007) following CT compared to performance following either form of stand-alone training. This fact could be due to the physiological adaptations induced by CT, which seem to be dependent on the order, volume and intensity of the stimulus applied during the training session (Leveritt et al., 2003).

Notably, a variety of CT protocols have been assessed in previous research (Leveritt et al., 2003; Sousa et al., 2018). In fact, the benefits and limitations of training sequence and the effects on health and performance have already been well documented (Chtara et al., 2005; Kang & Ratamess, 2014). However, only a few studies have focused on the training intensity distribution during CT, which seems to be a major issue when programming AT and RT simultaneously (Chtara et al., 2008; De Souza et al., 2007; Sousa et al., 2018). Some authors have suggested that the intensity during AT is a possible cause of interference when AT is combined with RT, pointing out that interference only occurs at intensities close to the maximal oxygen uptake (VO_{2max}) (Chtara et al., 2008; De Souza et al., 2007). Indeed, Chtara et al. (2008) found interference in the strength and power gains when aerobic exercise was performed at a velocity associated with VO_{2max} (vVO_{2max}). In another study, De Souza et al. (2007) investigated the acute effects of two aerobic exercises (aerobic threshold vs. vVO_{2max}) on maximal dynamic strength (one-repetition maximal test (1RM)) and local muscular endurance (number of repetitions at 80% of 1RM) and found that only the higher intensity aerobic exercise impaired local muscular endurance. It seems that a more pronounced chronic interference effect occurs in higher rather than lower aerobic intensities; however, these studies only focused on acute but not long-term effects.

To the best of our knowledge, only Fyfe et al. (2016) compared different intensities of AT during a short-term CT program regimen. Despite the gains observed after 8 weeks of different CT protocols, these authors suggested that CT incorporating either high-intensity (120 to 150% of the lactate threshold intensity) or moderate-intensity (80 to 100% of the lactate threshold intensity) aerobic stimulation similarly attenuates improvements in maximal lower-body strength compared with RT alone. Importantly, only moderate and high intensities were studied, and two different methods of training were compared simultaneously (interval and

continuous), thus affecting the conclusions obtained. Considering that a better understanding of the effects of CT with different aerobic intensities seems necessary, the primary purpose of the current study was to analyze the effect of three CT programs that only differed in the intensity of the AT program on performance in vertical jumping, sprint, leg strength, and aerobic capacity.

Another issue regarding CT is the effect caused by interruptions in training programs. This detraining (DT) period usually occurs during a season due to injuries or even recovery from a previous training period (Kraemer et al., 2002; Mujika & Padilla, 2000; Ormsbee & Arciero, 2012). Understanding the effect of DT may be important to better understand previous adaptations caused by CT and thus essential in the design of efficient training programs. Several authors have reported a decrease in strength gains and aerobic capacity previously acquired after a reduction in muscular activity associated with a reduction or cessation of training (Faigenbaum et al., 1996, 2009). Unfortunately, the effects of DT after a CT period are still poorly studied in the literature, especially when different intensities are applied. Recently, Sousa et al. (2018) verified that different 8-week RT programs with different loads combined with low-intensity aerobic training improved strength and aerobic capacities. However, 4 weeks of DT resulted in detrimental effects for all different intensities used during RT. Nevertheless, DT-induced changes caused by a CT program may be related to multiple factors (Hasegawa et al., 1994; Meylan et al., 2014), and the AT intensity used during the training period may be essential. Therefore, the second aim of the present study was to analyze the effects of a 4-week DT period following CT programs comprising different aerobic intensities.

Methods

Experimental Approach to the Problem

When properly combined, CT can produce benefits in both strength and aerobic performance, but the distribution of the training intensities must be carefully planned. The latest research on this problem focused on the loading magnitude of RT; however, this question has yet to be solved regarding the aerobic component of CT. An experimental research design was used to compare the effects of three concurrent RT and AT programs only differing in training intensity used during AT (80% maximal aerobic speed [MAS] vs. 90% MAS vs. 100% MAS) on physical performance and the DT adaptations. Higher aerobic intensities were hypothesized to compromise strength gains during the CT period and result in higher performance impairments after the DT period.

The participants were randomly assigned to the experimental groups performing RT combined with AT of different intensities, while those assigned to the control group (CG) merely undertook daily-life activities (without training). All experimental groups performed the CT

training program twice a week for 8 weeks. Strength performance seems to be negatively affected by previous aerobic exertion (Ratamess et al., 2016); therefore, the literature recommends that intrasession exercise sequences should consist of resistance followed by AT. RT was the same across the experimental groups, consisting of full squat (FS) (70-85% of one repetition-maximum: $1RM_{est}$), jumps and sprints, and designed based on recent evidences (Sousa et al., 2018).

All subjects were evaluated in two sessions separated by a 48-h rest interval. During the first testing session, the participants performed 20 m sprints and a 20 m shuttle run test. During the second testing session, subjects executed the countermovement jump test (CMJ) and an isoinertial strength assessment in the FS exercise. During the 2 weeks preceding this study, four preliminary familiarization sessions were undertaken to ensure properly executed technique in both the FS and CMJ exercises. To evaluate the DT effects, the same tests were performed after four weeks of training cessation. Throughout this period, the participants were asked to refrain from participating in regular exercise programs aimed at developing or maintaining strength and aerobic capacity.

Subjects

Thirty-nine physically active men volunteered to participate in this study. Participants were physically active sport science students with RT experience ranging from 6 months to 2 years (at least 2 sessions per week). After an initial evaluation, the participants were matched according to their estimated MAS in the shuttle run exercise and then randomly assigned to four groups depending on the training intensity used during aerobic training, as follows: i) a low-intensity group (LIG, 80% MAS), a moderate-intensity group (MIG, 90% MAS), a high-load group (HIG, 100% MAS), and a control group (CG). Due to injury or illness, three participants from the CG were absent from the post-testing sessions. Thus, of the 39 initially enrolled participants, only 36 successfully completed the entire study. The subjects' characteristics are displayed in Table 1. All participants were informed about the experimental procedures and potential risks before they provided their written informed consent. The investigation was conducted in accordance with the Declaration of Helsinki and was approved by the local research ethics committee.

Table 1. Subject characteristics.

Variable	Group			
	LIG (n = 10)	MIG (n = 10)	HIG (n = 10)	CG (n = 6)
Age (years)	21.2 ± 1.5	21.0 ± 2.0	21.1 ± 2.2	20.7 ± 2.3
Height (m)	1.80 ± 8.1	1.77 ± 4.3	1.75 ± 4.7	1.80 ± 0.1
Body Mass (Kg)	72.5 ± 8.5	74.5 ± 9.1	72.4 ± 9.1	70.1 ± 4.8

Values are mean ± SD. LIG: Low-intensity group; MIG: Moderate-intensity group; HIG: High-intensity group; CG: Control group

Procedures

The variables were assessed before (Pre), after the 8-week training period (Post 1), and after the 4-week DT period (Post 2) in two sessions separated by a 48-h rest interval. Testing sessions were performed at the same time of day for each participant under the same environmental conditions (-20 °C and -60% humidity). Body mass and height (Seca Instruments, Ltd., Hamburg, Germany) were measured prior to the warm-up protocol in the first testing session. Strong verbal encouragement was provided during all tests to motivate participants to give maximal effort.

Sprints. Each participant performed three 20 m sprints separated by a 3 minutes rest. Photocell timing gates (Brower photocells, Wireless Sprint System, USA) were placed at 0, 10 and 20 m so that the times needed to cover 0-10 m (T10) and 0-20 m (T20) could be determined. A standing start with the lead-off foot placed 1 m behind the first timing gate was used. The average of the best two sprints was used for the analysis. Warm-up consisted of 5 minutes of running at a self-selected intensity, 5 minutes of joint mobilization exercises, followed by several sets of progressively faster 30 m running accelerations. Reliability for T20 as measured by the coefficient of variation (CV) was 3.7%, while the intra-class correlation coefficient (ICC) was 0.94 (95% Confidential interval (CI): 0.91 - 0.97).

Shuttle run test. The 20 m multistage shuttle run test was administered according to the original version described by Léger (1988). The initial running velocity was set at 8.5 km·h⁻¹ and was gradually increased in 0.5 km·h⁻¹ each minute (Léger et al., 1988). The test ended when a participant failed to reach the appropriate marker in the allotted time twice or could no longer maintain the pace. The number of laps completed was recorded. VO₂max (ml·kg⁻¹·min⁻¹) was calculated based on the MAS reached before participants were unable to keep up with the audio recording, as follows: -27.4 + 6 · MAS (Léger et al., 1988).

Vertical jump test. The jump height was determined using a contact mat connected to an electronic power timer, control box and handset (Globus Ergojump, Italy). After an specific warm-up consisting of 2 sets of 10 squats without load and 5 CMJs (20 s rest interval), each participant performed three maximal CMJs with their hands on their hips, separated by 1 minute rests. The highest value was recorded for the subsequent analysis. The ICC was 0.98 (95% CI: 0.97 - 0.99), and the CV was 2.9%.

Isoinertial strength assessment. A Smith machine (Multipower Fitness Line, Peroga, Murcia, Spain) was used for this test. A detailed description of the testing procedures used in this study was recently reported elsewhere (González-Badillo et al., 2015, Sanchez-Medina et al., 2017). The initial load was set at 17 kg and progressively increased in 10 kg increments until the attained mean propulsive velocity (MPV) was $\sim 1.00 \text{ m}\cdot\text{s}^{-1}$ (range $0.95\text{-}1.05 \text{ m}\cdot\text{s}^{-1}$) (González-Badillo et al., 2015). The participants performed 3 repetitions with each load, with 3 minutes recovery. A linear velocity transducer (T-Force System, Ergotech, Murcia, Spain) was used to register bar velocity. The 1RM_{est} was calculated for each individual from the MPV attained against the heaviest load (kg) lifted in the progressive loading test, as follows: $(100 \cdot \text{load}) / (-5.961 \cdot \text{MPV}^2) - (50.71 \cdot \text{MPV}) + 117$ (Sanchez-Medina et al., 2017).

Training program

The descriptive characteristics of the training programs completed by each group are presented in Table 2. The RT session comprised FS, CMJ and sprint exercises and 2-3 minutes rest periods were allowed between each set and exercise. The participants were instructed to perform all exercises at maximal intended velocity to obtain the highest possible gains (Parejo-Blanco et al., 2014). The loads used by each participant in the FS were assigned according to 1RM_{est} obtained in the initial isoinertial squat strength assessment. Thus, the relative intensity of the FS exercise progressively increased from 70% to 85% 1RM_{est} for all three experimental groups. Because strength was expected to increase with training, an intermediate strength assessment was carried out after 4 weeks of training to perform the necessary load adjustments for each participant.

AT was performed 20 minutes after the participants completed the RT to guarantee that required intensities were performed properly (Sousa et al., 2018). This consisted of 16-20 minutes performing the 20 m shuttle run exercise until reaching 80% (LIG), 90% (MIG) or 100% (HIG) of the MAS reached during the 20 m multistage shuttle run test. As for RT, participants were assessed in the 20 m shuttle run test after 4 weeks of training to perform the necessary adjustments for each participant. At least 2 trained researchers supervised each workout session and recorded the individual workout data during each training session. All participants were instructed to maintain their normal daily activities throughout the study. The participants

did not undertake any additional strength or AT activities during the testing, training, and DT periods.

Table 2. Characteristics of the training program performed by the LIG, MIG and HIG groups

Exercise	Sessions														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Full Squat (% 1RM: SxR)	70:3x8	70:3x8	70:3x8	75:3x8	75:3x8	75:3x6	80:3x5	80:3x5	80:3x5	85:3x5	85:3x5	85:3x5	80:3x5	80:3x5	75:3x8
CMJ (SxR)	2x5	2x5	2x5	2x5	2x5	2x5	2x5	3x5	3x5	3x5	3x5	3x5	3x5	3x5	2x5
Sprint (SxD)	2x30m	2x30m	2x30m	3x30m	3x30m	3x30m	3x20m	3x20m	3x20m	4x20m	4x20m	4x20m	3x20m	3x20m	2x20m
20m Shuttle Run (SxT)	4x4	4x4	4x4	4x4	5x4	5x4	5x4	5x4	5x4	5x4	5x4	5x4	5x4	5x4	5x4
LIG (%MAS)	80%	80%	80%	80%	80%	80%	80%	80%	80%	80%	80%	80%	80%	80%	80%
MIG (%MAS)	90%	90%	90%	90%	90%	90%	90%	90%	90%	90%	90%	90%	90%	90%	90%
HIG (%MAS)	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%

1RM: One-repetition maximum; SxR: Sets x repetitions; SxD: Sets x distance; SxD: Sets x time; CMJ: Countermovement jump; LIG: Low-intensity group; MIG: Moderate-intensity group; HIG: High-intensity group; %MAS: Percentage of the maximal speed reached for each participant during the 20 m multistage shuttle run test.

Statistical analysis

The values of each variable are presented as mean \pm standard deviation (SD). Homogeneity of variance across groups (LIG vs. MIG vs. HIG vs. CG) was verified using the Levene test, whereas the normality of distribution of the data was examined with the Shapiro-Wilk test. Data for all variables analysed were homogeneous and normally distributed ($p > 0.05$). A 4 (group: LIG, MIG, HIG, CG) \times 3 (time: Pre, Post 1, Post 2) repeated measures analysis of variances (ANOVA) was calculated for each variable. Sphericity was checked using *Mauchly's* test. Percentage of change for each variable within and between groups were calculated and a one-way ANOVA was conducted to examine between-group differences with *tukey* post-hoc comparisons (LIG vs. MIG vs. HIG vs. CG) to clarify the interaction. In addition to this null hypothesis testing, the data were assessed for clinical significance using an approach based on the magnitudes of change (Hopkins et al., 2009). The effect sizes (ES) were calculated using Cohen's *d* (Faigenbaum et al., 1996) to estimate the magnitude of the training effect on the selected strength variables within each group. The threshold values for assessing the magnitudes of the standardized effects were 0.20, 0.60, 1.20 and 2.00 for small, moderate, large and very large magnitudes, respectively (Hopkins et al., 2009). Probabilities were also calculated to establish whether the true (unknown) differences were lower than, similar to, or higher than the smallest worthwhile difference or change (0.2 multiplied by the between-subject SD) (Hopkins et al., 2009). The quantitative chances of obtaining higher or lower differences were evaluated as follows: 1%, almost certainly not; 1-5%, very unlikely; 5-25%, unlikely; 25-75%, possible; 75-95%, likely; 95-99%, very likely; 99%, almost certain. If the chances of having higher or lower values than the smallest worthwhile difference were both $>5\%$, the true difference was assessed as unclear. Inferential statistics based on the interpretation of the magnitude of effects were calculated using a purpose-built spreadsheet for the analysis of controlled trials (Hopkins, 2006). The statistical analyses were performed using SPSS software version 18.0 (SPSS, Inc., Chicago, IL, USA). Statistical significance was established at the $p \leq 0.05$ level.

Results

There were no significant differences between groups at baseline for any analysed variable. The mean values, percentage of change and intra-group ES for all variables analysed during Pre, Post 1 and Post 2 are reported in Table 3.

Table 3. Changes in neuromuscular performance variables from pre-training to post-training and detraining period for each experimental group.

Variable	Pre	Post 1	Post 2	Pre vs. Post 1		Pre vs. Post 2		Post 1 vs. Post 2				
				p-value	Δ ($\pm 90\%$ CI)	p-value	Δ ($\pm 90\%$ CI)	p-value	Δ ($\pm 90\%$ CI)	ES		
Low intensity group												
T10 (s)	1.95 \pm 0.08	1.88 \pm 0.08	1.89 \pm 0.08	0.001	-3.7 \pm 2.0	0.76	0.003	-3.1 \pm 1.7	0.63	0.980	0.6 \pm 0.4	0.13
T20 (s)	3.32 \pm 0.15	3.23 \pm 0.17	3.26 \pm 0.15	0.002	-2.8 \pm 1.3	0.54	0.049	-1.9 \pm 0.9	0.37	0.863	0.9 \pm 0.6	0.17
CMJ (cm)	34.7 \pm 4.1	37.9 \pm 5.4	36.7 \pm 4.8	0.000	8.9 \pm 3.6	0.64	0.004	5.6 \pm 1.6	0.41	0.048	-3.0 \pm 2.5	0.23
1RM _{max} (kg)	82.4 \pm 21.7	92.2 \pm 21.1	84.7 \pm 18.9	0.000	12.8 \pm 3.2	0.40	0.217	3.6 \pm 3.2	0.12	0.000	-8.1 \pm 2.3	0.28
VO _{2max} (ml·kg ⁻¹ ·min ⁻¹)	41.4 \pm 8.0	45.5 \pm 8.0	45.5 \pm 7.5	0.000	10.3 \pm 4.1	0.47	0.000	10.5 \pm 5.9	0.48	1.000	0.2 \pm 5.1	0.01
Moderate-intensity group												
T10 (s)	1.95 \pm 0.14	1.86 \pm 0.13	1.92 \pm 0.10	0.000	-5.1 \pm 2.5	0.87	0.111	-1.7 \pm 1.6	0.30	0.000	3.2 \pm 1.9	0.57
T20 (s)	3.28 \pm 0.20	3.16 \pm 0.17	3.23 \pm 0.16	0.000	-3.7 \pm 1.9	0.65	0.046	-1.5 \pm 0.9	0.26	0.031	2.1 \pm 1.5	0.38
CMJ (cm)	33.5 \pm 6.0	36.9 \pm 6.6	35.2 \pm 6.4	0.000	10.3 \pm 2.0	0.49	0.012	5.2 \pm 1.9	0.26	0.003	-4.6 \pm 1.8	0.24
1RM _{max} (kg)	83.4 \pm 21.3	89.3 \pm 21.7	81.0 \pm 21.6	0.000	7.4 \pm 1.6	0.25	0.184	-3.1 \pm 1.9	0.11	0.000	-9.7 \pm 2.2	0.36
VO _{2max} (ml·kg ⁻¹ ·min ⁻¹)	42.5 \pm 8.7	46.9 \pm 7.3	44.7 \pm 7.4	0.000	11.3 \pm 4.7	0.47	0.072	5.9 \pm 4.8	0.25	0.005	-4.8 \pm 1.2	0.22
High-intensity group												
T10 (s)	1.96 \pm 0.11	1.92 \pm 0.11	1.96 \pm 0.11	0.261	-1.6 \pm 0.6	0.26	1.000	0.3 \pm 1.1	0.05	0.013	1.9 \pm 0.9	0.31
T20 (s)	3.34 \pm 0.18	3.27 \pm 0.15	3.31 \pm 0.15	0.014	-2.1 \pm 0.9	0.41	0.731	-0.9 \pm 0.8	0.17	0.384	1.2 \pm 0.5	0.23
CMJ (cm)	33.6 \pm 4.7	36.1 \pm 4.5	35.8 \pm 4.0	0.000	7.4 \pm 2.5	0.49	0.002	6.6 \pm 2.2	0.45	1.000	-0.7 \pm 1.6	0.05
1RM _{max} (kg)	84.0 \pm 19.1	90.8 \pm 20.5	81.5 \pm 19.0	0.000	8.1 \pm 1.6	0.30	0.155	-3.1 \pm 3.3	0.12	0.000	-10.4 \pm 2.5	0.42
VO _{2max} (ml·kg ⁻¹ ·min ⁻¹)	42.0 \pm 8.4	46.1 \pm 7.7	43.1 \pm 7.8	0.000	10.3 \pm 3.7	0.45	0.766	2.9 \pm 2.3	0.13	0.005	-6.7 \pm 1.6	0.32

Data are mean \pm SD

Pre: Initial evaluation; Post 1: Evaluation after training period; Post 2: Evaluation after detraining period; Δ : Percentage of change; ES: Intragroup effect size; CI: Confidence interval; T10: 10-m sprint time; T20: 20-m sprint time; CMJ: Countermovement jump; 1RM_{max}: Estimated one-repetition maximum; VO_{2max}: Estimated maximal oxygen uptake.

All the experimental groups showed significant improvements ($p < 0.05 - 0.001$) in all the variables assessed, except the T10 in HIG (Tables 3). No changes took place in the CG. The intra-group ES for LIG ranged from *small* (T20, $1RM_{est}$ and VO_{2max}) to *moderate* (T10 and CMJ). For MLG, the standardized effects were *small* (CMJ, $1RM_{est}$ and VO_{2max}) and *moderate* (T10 and T20), whereas for HLG, the qualitative outcome relative to ES was *small* for all the variables analysed.

After the training period, statistically significant “time x group” interactions were observed for T10 ($p < 0.01$), CMJ ($p < 0.01$), $1RM_{est}$ ($p < 0.01$) and VO_{2max} ($p < 0.01$), whereas there was no interaction in T20 ($p = 0.137$). Table 4 compares the changes from Pre to Post 1 between the LIG, HIG, MIG and CG. When compared to CG, all the experimental groups (LIG, MIG and HIG) showed significantly greater percent of changes from Pre to Post 1 in CMJ ($p < 0.05$), $1RM_{est}$ ($p \leq 0.001$) and VO_{2max} ($p < 0.05$). The LIG and MIG also showed greater percentage of changes than CG in T10 ($p < 0.05 - 0.01$). Comparing the changes observed in the experimental groups, greater changes were found in $1RM_{est}$ for the LIG compared to MIG and HIG ($p < 0.05$), with “possibly” better changes. Furthermore, it seems that there was a tendency for higher gains in LIG and MIG compared with HIG, with “possibly” or “likely” positive effects in T10, T20, and CMJ.

After 4-week DT period, most of the variables analysed showed an important detriment effect for all the experimental groups. A significant performance decrement was experienced for MIG in all the variables assessed between Post 1 and Post 2 (Table 3). The LIG group showed significant lower values in CMJ ($p < 0.05$) and $1RM_{est}$ ($p < 0.001$) after the rest period, whereas HIG showed significant performance losses in T10 ($p < 0.05$), $1RM_{est}$ ($p < 0.001$) and VO_{2max} ($p < 0.01$). In addition, no significant differences were found between the three-trained groups and the CG at Post 2 for any variable.

Table 4. Changes in neuromuscular performance variables from initial evaluation (*pre*) to final evaluation (*post*) between groups.

	Changes observed for Post 1- vs. Pre				
	p-value	Δ ($\pm 90\%$ CI)	ES	Percent changes of better/trivial/worse effect	
T10 **					
LIG vs. CG	0.015	4.6 \pm 3.9	0.86	99/1/0	Very Likely
MIG vs. CG	0.002	5.8 \pm 3.9	0.81	100/0/0	Almost Certainly
HIG vs. CG	0.269	2.7 \pm 3.9	0.41	94/6/0	Likely
LIG vs. MIG	0.775	-1.2 \pm 3.4	0.19	7/44/49	Unclear
LIG vs. HIG	0.404	2.0 \pm 3.4	0.36	78/21/1	Likely
MIG vs. HIG	0.073	3.2 \pm 3.4	0.46	91/9/0	Likely
T20					
LIG vs. CG	0.365	1.8 \pm 3.0	0.33	82/18/0	Likely
MIG vs. CG	0.095	2.6 \pm 3.0	0.47	92/8/0	Likely
HIG vs. CG	0.702	1.2 \pm 3.0	0.23	59/41/0	Possibly
LIG vs. MIG	0.816	-0.8 \pm 2.6	0.15	6/53/41	Unclear
LIG vs. HIG	0.912	0.6 \pm 2.6	0.12	31/66/3	Possibly
MIG vs. HIG	0.429	1.5 \pm 2.6	0.27	63/35/2	Possibly
CMJ **					
LIG vs. CG	0.038	7.2 \pm 6.9	0.43	89/11/0	Likely
MIG vs. CG	0.011	8.6 \pm 6.9	0.41	94/6/0	Likely
HIG vs. CG	0.043	5.7 \pm 12.6	0.33	79/21/0	Likely
LIG vs. MIG	0.931	-1.3 \pm 6.0	0.08	2/81/17	Likely Trivial
LIG vs. HIG	0.889	1.6 \pm 6.0	0.10	28/68/4	Possibly
MIG vs. HIG	0.559	2.9 \pm 6.0	0.16	34/66/0	Possibly
1RM_{est} **					
LIG vs. CG	0.000	13.7 \pm 5.3	0.40	100/0/0	Almost Certainly
MIG vs. CG	0.001	8.2 \pm 5.3	0.25	87/13/0	Likely
HIG vs. CG	0.000	8.9 \pm 5.3	0.29	95/5/0	Very Likely
LIG vs. MIG	0.014	5.5 \pm 4.6	0.17	33/67/0	Possibly
LIG vs. HIG	0.043	4.7 \pm 4.6	0.15	34/66/0	Possibly
MIG vs. HIG	0.968	-0.8 \pm 4.6	0.03	0/100/0	Most Likely Trivial
VO₂max **					
LIG vs. CG	0.148	7.8 \pm 9.6	0.52	98/2/0	Very Likely
MIG vs. CG	0.082	8.8 \pm 9.6	0.54	98/2/0	Very Likely
HIG vs. CG	0.151	7.7 \pm 9.6	0.37	94/6/0	Likely
LIG vs. MIG	0.986	-1.0 \pm 8.3	0.04	6/80/14	Unclear
LIG vs. HIG	1.000	0.0 \pm 8.3	0.00	7/85/7	Unclear
MIG vs. HIG	0.985	1.1 \pm 8.3	0.04	13/82/5	Unclear

CI: confidence interval; LIG: Low-intensity group; MIG: Moderate-intensity group; HIG: High-intensity group; CG: Control group; T10: 10-m sprint time; T20: 20-m sprint time; CMJ: countermovement jump; 1RM_{est}: estimated one-repetition maximum; VO₂max: estimated maximal oxygen uptake; Δ : percentage of change between groups; ES: intergroup effect size; Statistically significant interaction 'time x group': ** p < 0.01. Note: all differences are presented as improvements for the first group compared with the second group (i.e., LLG vs. CG), so that negative and positive differences are in the same direction.

Discussion

The current study aimed to verify the effects of different AT intensities combined with the same RT on strength and aerobic performances. All experimental groups showed improvements in the assessed variables, specifically the jump, sprint running, maximal strength and VO_{2max} . Thus, AT programs with low (LIG), moderate (MIG), or high (HIG) intensities appear to be equally effective for producing gains in strength and aerobic fitness. Curiously, the LIG showed higher gains in maximal strength compared to the HIG and MIG. In addition, a cessation period of 4 weeks of training resulted in decreased performances. Nevertheless, the LIG showed smaller performance decrements during this period. These findings reveal that, although all the AT intensities result in improvements, the lower intensity tend to result in higher gains after training and minor losses after DT.

The goal of CT is to maximize the benefits associated with both AT and RT usually achieved by single-mode training. There are many sports where a combination of both are required for successful performance (Coffey & Hawley, 2017). However, combining these two exertation modes, resistance and aerobic, is challenging. Several studies have shown that there is an interference effect, for instance, blunting power and/or strength gains when aerobic exercises are added to an RT program (Fyfe et al., 2016). These mechanisms are not well understood but comprise several factors that affect acute and chronic fatigue and exercise anabolic responses (Coffey & Hawley, 2017). Thus, the influence on either fatigue or the anabolic response could be caused by the load magnitude, which, for instance, is mainly influenced by the intensity of exertation. A previous study from our lab (Sousa et al., 2018) analyzed the effects of different resistance intensities during a CT program on strength and aerobic performance. Despite similar improvements, RT with medium and high loads ($>55\% 1RM_{est}$) was suggested to increase changes in explosive efforts such as short runs and CMJ. Nevertheless, the interference effect of AT intensity is still unknown.

In the present study, the three different aerobic intensities added to the same RT program showed significant improvements in all variables assessed, with the exception of the short run (T10) in the HLG. This effort lasted for less than 2 s, and some interference effect of the higher aerobic intensity could be speculated to exist during training. In fact, previous research has suggested that AT during CT can impair ballistic and strength adaptations (Leveritt et al., 2003). Accordingly, the evaluated variables that demanded a higher participation of Type II muscle fibers, such as short sprints, showed a higher percentage of change when training with lower aerobic intensities, but not with higher aerobic intensities.

Aerobic training has been reported to cause deterioration in the capacity of the neuromuscular system to generate force (Hennessy & Watson, 1994). However, with the addition of explosive exercises along with FS, executing all at the maximal intended velocity, may attenuate the

interferences on CMJ and short-run adaptations. In the current study, a higher aerobic stimulation intensity seems to be associated with fewer gains. Comparing the changes from pre- to post training between groups, we found no significant differences in T10, T20 or CMJ. Nevertheless, there was a slight trend toward a greater intragroup effect size in the LIG and MIG than in the HIG in T10, T20 and CMJ. These higher probabilities of better effects (Table 4) for the lower intensities showed a tendency for the existence of interference effects according to aerobic intensities.

The gains in $1RM_{est}$ were lower than those reported by previous studies (~20%) that assessed the effects of CT on strength (Izquierdo et al., 2005; McCarthy et al., 2002; Sousa et al., 2018), perhaps because of the use of only one resistance exercise (FS) in this study. However, a similar magnitude of improvements was found when using a similar RT protocol during CT (Sousa et al., 2018). Interestingly, those that trained with lower aerobic intensities (LIG) showed possibly better $1RM_{est}$ results after 8 weeks of CT. Previous research observed that high-intensity AT (e.g., repeated sprints; high-intensity interval training) when performed concurrently with resistance exercises attenuated the anabolic response (Coffey et al., 2009). Higher aerobic intensities seem to increase glycogen depletion predominantly in Type II muscle fibers (Gollnick et al., 1974), which may intensify residual fatigue (Hulston et al., 2010) and inhibit central regulators of cellular activity, such as activated protein kinase (Derave et al., 2000). Protein kinases play critical roles in regulating growth and reprogramming metabolism, and with their increased inhibition, muscle regeneration and training adaptations can be compromised (Mihaylova & Shaw, 2011).

The training period resulted in similar improvements in VO_{2max} for all experimental groups (10-11%), agreeing with previous researches on CT (7 - 18%) (Hopkins et al., 2009). Unclear inferences were found between groups, showing the level of similarity between the gains in VO_{2max} . This fact is curious because the only thing that changed during the training program was the intensity of aerobic training and this would be expected to change the VO_{2max} adaptations. Moreover, previous found that different training intensities showed dissimilar cardiorespiratory fitness changes (Balabinis et al., 2003; Kelly et al., 2008). Particularly, the VO_{2max} responses seem to be dependent on the intensity of training in the context of single-mode exercise (Balabinis et al., 2003; Kelly et al., 2008). A CT regimen has been previously shown to stimulate cardiorespiratory adaptation through elevation of VO_{2max} (Bell et al., 1991; Harriss & Atkinson, 2011; Izquierdo et al., 2005). The combination of the two modes of exercise, especially when aerobic exertion follows RT, causes metabolism to increase aerobic needs and the cardiovascular system to adapt concordantly (Shaw et al., 2009; Volpe et al., 1993). However, to our knowledge, the current study was the first to analyze different intensities during AT when combined with RT, using the same method of exertion, and reporting no different gains in response.

The DT period resulted in a reduction in most of the variables analyzed in the experimental groups. The training adaptations persisted longer after the LIG program, with no significant declines in T10, T20 or VO₂max. Several studies using a CT program have shown that sprint times of 10, 20 and 30 m remained unchanged or slightly decreased after a DT period (Meylan et al., 2014). In contrast, previous evidence has reported relevant VO₂max declines (4-14%) with short-term training cessation in trained and untrained individuals (Mujika & Padilla, 2000). The current findings associated with VO₂max in the MIG and HIG were supported by those observations. The training cessation caused significant losses in T10, 1RM_{est} and VO₂max in the HIG and in all variables in the MIG. The LIG was the only group in which VO₂max did not diminish after the DT period, suggesting higher chronic adaptations. In contrast, strength variables (1RM_{est} and CMJ) decreased in this training program after DT. CMJ performance depends largely on the maximal strength of leg extensors (Franco-Marquez et al., 2015), and thus, a reduction in the 1RM_{est} due to the strength loss that usually occurs without training could be also reflected in CMJ. Interestingly, despite the reduction in 1RM_{est} in the HIG, there was not a reduction in CMJ. This lack of an effect of DT could be because of the specific neuromuscular demands of the type and intensity of the aerobic exercise. The aerobic exercise used required a constant and rapid change in running direction. When the running intensity is higher, there is a greater change in acceleration to stop, change direction and start running again. This change in acceleration could lead to an increased solicitation of the neuromuscular system and overload during the CT period in the HIG. Therefore, different rates of adaptation and high-intensity training could be required for extra recovery and to attain better CMJ performance between the second and third evaluations.

Several limitations should be addressed to this study. One of the main limitations of the study was the small number of subjects in each group; thus, we cannot be sure that the differences within and between the groups would have been clearer with a greater number of participants. In addition, the study evaluated the effects of aerobic and RT consisting of lower-limb exertion only, which may have constituted a limitation in improving and maintaining the strength gains after the CT period. However, the main aim was to analyze the training and DT effects of an RT program combined with three different AT regimens. We chose not to include additional resistance exercises to avoid increasing the number of confounding factors, such as the number of exercises, rest time, type of exercises, or fatigue accumulation, following the example of previous studies (Sousa et al., 2018). Finally, analyzing the responses of different participants, such as females only, would be interesting, and further investigations should be developed in this regard.

In brief, the results of this study indicated that 8 weeks of RT programs combined with AT with low, moderate and high intensities improved strength and aerobic capacities regardless of the intensity used during aerobic exertion. A remarkable contribution of this study is that the LIG was the one with the highest gains in maximal strength compared to the HIG and MIG.

Moreover, the impairment caused by the 4 weeks of DT seemed to have less impact in the LIG, with higher maintenance of previous gains, especially regarding cardiorespiratory fitness.

Practical Applications

The results suggested that performing the same RT followed by AT with low, moderate or high intensities is beneficial for strength and aerobic development in healthy adults. Furthermore, choosing lower intensities during AT (i.e. < 80% MAS) can lead to increased strength gains in explosive efforts. These aerobic intensities should also be used during CT when the gains in cardiorespiratory fitness should be maintained for longer periods after training cessation. These findings should be considered to design CT programs for competitive and noncompetitive sports to efficiently integrate both resistance and aerobic regimens in the same training session.

Study 4

Concurrent training intensities: a practical approach for program design

Abstract

The performance depends on the interaction of several physical variables. On this, most of these sports need both strength and aerobic capacities to improve overall performance. Therefore, combining resistance and aerobic training, usually named as concurrent training (CT), has been used in recent years as useful training regimen to improve simultaneously strength and aerobic performances according to specific sport's needs. But this combination is usually challenging and can influence training adaptations, being a problematic issue for coaches. The main objective of this article is to provide coaches with a practical proposal of CT to improve athlete's performance on different sports.

Key words: aerobic; resistance; detraining; programming

Introduction

The performance of physical activities aiming to develop both aerobic capacity and strength within the same training session or in different sessions is usually termed as concurrent training (CT) and it has been a research target in recent years (Kang & Ratamess, 2014). From the early stages, the studies have pointed out that CT might compromise aerobic and/or strength gains (Cadore et al., 2010). However, recent findings contrarily suggested that CT may even enhance individual performances in aerobic and resistance parameters (Botonis et al., 2016). Therefore, it was understood the importance of combining the several variables in a proper way to obtain better results.

The interference between resistance (RT) and aerobic training (AT) can be caused by several factors associated with the training program, such as the volume, intensity and/or training load distribution (Chtara et al., 2005). Regarding the volume, it was found that strength gains were compromised by high weekly training volume, considering frequency and/or duration of exercitation (Jones et al., 2013). Unfortunately, regarding the volume, only few and very recent evidences exists about the manipulation of the intensities of the AT and/or RT performance (Sousa et al., 2018a,b). Consequently, this could be a major issue when programming both AT and RT, namely in sports where these two variables are crucial.

The training intensity used by several experiments about CT has been quite different, which leads us to believe that it could influence to a great extent both the results of aerobic and resistance parameters (Arazi et al., 2011; Fyfe et al., 2014). It is well established that the intensity during RT alone plays an important role in subsequent adaptations (Stoggl & Sperlich, 2014). Likewise, there are some indicators that training intensity can influence performance improvements, particularly when AT and RT are combined (Petré et al., 2018). For example, previous studies argued that low-volume, high-intensity RT alone (e.g.: maximal RT or plyometric/explosive RT) could induce improvements in aerobic and resistance performance than moderate intensity (Rønnestad & Mujika, 2014).

Strength and conditioning professionals have been advised to prescribe programs that include both RT and AT concurrently, to obtain better results with more efficiency and quickness (Kang & Ratamess, 2014). For this, coaches and professionals should know how to program a specific CT regarding volume, intensity, duration, periodization models, to conjugate the loads and obtain increased performances. Thus, the main objective of this paper is to provide the knowledge and recommendations for coaches to efficiently design a CT training to improve sports performance.

Intensities during concurrent training

Several researches showed that there was a performance enhancement after a period of 8-weeks of CT (Varela-Sanz et al., 2016; Wong & Chaouachi, 2010). Moreover, this performance was accomplished by resistance and aerobic gains followed the training period and this suggest the beneficial effect of CT after a short period of implementation. This reveals that CT can be used for resistance and aerobic development. However, some cautions should exist regarding the combination of RT and AT loads. For instance, Souza et al. (2007) concluded that maximal strength gains and muscle endurance may be compromised when trained in combination with high intensity aerobic exercises (close to maximal oxygen uptake). Similar findings were observed by Chtara et al. (2008). These authors found a reduction in strength and muscular power output after 12 weeks of CT comprising high-intensity aerobic exercises. Both authors suggested that the decreased performance was caused by the fatigue generated during the AT, that compromised either the RT or the muscle adaptations.

The interference effect was deeply investigated by Kraemer et al. (1995), that examined the morphological adaptations of muscle fiber during a CT for 12 weeks (4 times per week) in physically active men. They verified that there were increases in type I, IIA, and IIC fibers in the group that trained only resistance, increased IIA fibers for those ones that RT and AT simultaneously, and a decrease in type I and IIC fibers for those that performed only AT. These results indicated that there might be a decrease in the adaptations of RT when it is combined with AT regimen. Interestingly, it seems that RT adjuvates the aerobic adaptations of training, but not the contrary. This was confirmed by others that suggested that CT as more effective to improve aerobic performance than AT alone (Hakkinen et al., 2003; Kraemer et al., 1995).

In the availed literature we could also found that there was no interference of one ability over the other when trained concurrently (Alves et al., 2016; Balabinis et al., 2003). Alves et al. (2016) compared the effects of RT alone, intrasession of combined RT and AT, and intersession of combined RT and AT. The results showed that both groups that performed resistance and aerobic concurrently obtained higher gains in explosive strength and aerobic capacity when compared with the group that performed RT only. In the study of Balabinis et al. (2003), the group that trained concurrently obtained similar gains in strength and muscular power when compared with the group that trained only resistance. This inconsistency regarding the CT interference effect are being now understood as a result of several programming factors, where the intensity of AT and/or RT should be considered and are believed to be the main issue.

The intensity is usually seen as a major influence of training program and adaptations (Stoggl & Sperlich, 2014). The change in the training intensity could affect the magnitude of molecular signaling and protein synthesis (Fyfe et al., 2014), that will therefore influence the degree of

interference between exercise modes and can also vary depending on programming variables (Coffey & Hawley, 2017; Fyfe et al., 2014). Only recently, the research focused on this issue in CT programming and only few studies compared the combination of different intensities in RT or AT, seeking to find the more adequate for higher enhancements (Petré et al., 2018; Sousa et al., 2018a,b; Varela-Sanz et al., 2016). Most of studies tried to compare different training loads distribution and different methods of training, making hard to understand the reasons for the training adaptations.

To our knowledge, Sousa et al. (2018a,b) were the first that tried to understand the effects of using different resistance training loads or different aerobic intensities, respectively. Regardless of the RT intensity, low, moderate or high, combined with the same low-intensity AT resulted in beneficial effects for both resistance and aerobic development (Sousa et al., 2018a). However, the authors found that choosing higher loads during RT can also lead to explosive increments during vertical jump and short sprint efforts (Sousa et al., 2018a). When combining the same RT with high, moderate or low-intensity AT, it was the lowest intensity that resulted in higher gains in maximal strength, with similar gains in cardiorespiratory fitness (Sousa et al., 2018b). Additionally, both revealed that, regardless of the intensity, it took only 4 weeks to return to baseline values. Nevertheless, combining moderate-high resistance loads with low intensity AT revealed higher gains and lower losses after 4 weeks of detraining (DT).

Program design: an example

Most individual and team-sports require several physical capacities for optimal performance, such as muscle strength, speed, power and cardiorespiratory fitness (Wilson et al., 2012). For some of the sports, the success only arrives when a good performance is achieved in all those capacities, being more important than only one. In fact, athletes must be physically prepared for repeated sprints (Clanton & Dwight, 1997), jumps, changes of direction (Marques & Gonzalez-Badillo, 2006), throws and shots (Granados et al., 2007; Marques et al., 2007). In fact, most athletes need to develop strength to apply their abilities as well as cardiorespiratory fitness to recover and/or to maintain high levels of performance throughout the game, event, or season.

As stated before, several studies have shown that the CT program design could safely implemented in order to improve a wide variety of athletic performance variables, such as strength and aerobic fitness (Arazi et al., 2011; Marta et al., 2013). For example, seven weeks of CT in basketball players were effective to improve vertical jump performance compared to isolated RT (Balabinis et al., 2003). Other study conducted during the preseason period in elite soccer players showed that CT improved explosive strength (Helgerud et al., 2011).

Our research lab has been working for the last decade on CT and recently we could verify that it is quite possible to optimize CT adaptations in just 8 weeks of training when properly designing and distributing the training intensities. In the first study, Sousa et al (2018a) reported 8 weeks of RT programs with different loads combined with load intensity AT improved strength and aerobic capacities similarly, but it was suggested that RT with higher loads [$>55\%$ one maximum repetition (1RM)] combined with low-intensity of AT, maximized the explosive efforts gains [e.g.: countermovement vertical jump (CMJ) and short sprints]. Knowing this, the authors compared the use of these RT loads combined with different AT intensities and found that they improved similarly resistance and aerobic capacities. However, the low intensity group obtained higher gains in maximal strength compared with moderate and high intensity group (Sousa et al., 2018b).

Based on recent findings from our lab and others, we present a practical example for eight weeks of implementation of CT, performed twice a week. Therefore, we provided a practical application to enhance lower extremities strength, muscular power and aerobic performances. This CT it can be used by individual or team-sports in which those physical abilities are required, such as jumps, repeated sprints, maximum lower-limbs strength. Our research design respected three main general principles of progression, specifically: progressive overload, variation and specificity as recommended by Kramer & Ratamess (2004). The first weeks were designed to the initial adaptation to training and, at the same time, on the enhancement of the explosive strength gains, focusing in lower RT loads and lower AT volume. For example, data from previous research (Alemeier et al., 1994) suggested that adaptations within the fast fiber production (IIb to IIa) occurred during early phase of training, despite there were no changes in slow to fast fibers.

Table 1 - Recommendations for combining intensities during concurrent training

	Recommendations
General	<p>A minimum of 6 weeks periods for positive effects;</p> <p>At least 2 times a week in a concurrent design (resistance and aerobic);</p> <p>Training should comprise specific exercises according to each sport</p> <p>Two weeks of detraining is allowed without performance losses (i.e., injury, recovery);</p>
Resistance training component	<p>High velocity movements should be used;</p> <p>Exercises with external loads (e.g. squat or bench press) combined with ballistic movements (e.g. ball throwing, jumps);</p> <p>Ballistic exercises should be included in the beginning;</p> <p>Few repetitions per set (< 8) and large intervals (> 2min);</p> <p>Progression should increase the number of sets instead of repetitions;</p> <p>External loads should be moderated-high (>55% 1RM).</p>
Aerobic training component	<p>Aerobic training should follow the resistance training;</p> <p>Low intensities (< LT or <75% maximal aerobic capacity) should be used;</p> <p>High intensities (> VO₂max) should be performed for cardiorespiratory gains;</p> <p>Polarized model for training should be followed during a season (65% below ventilatory threshold and 10% above respiratory compensation threshold)</p>

LT: lactate threshold; VO₂max: maximal oxygen uptake; RM: repetition maximum

Considering that training programs should be specific, and the adaptations related to the use of specific RT programs to meet training objectives (Sáez de Villareal et al., 2013), we included full-squat (FS), CMJ, and sprint to contribute for anaerobic muscle adaptation to training. The rest period between each set and exercise should be 2-3 minutes. One of the most important things is that the participants should be instructed to perform all exercises at maximal intended velocity to obtain the highest possible gains (Izquierdo et al., 2005). The loads used by each participant in the FS were assigned according to 1RM obtained in the initial isoinertial squat strength assessment. Thus, the relative intensity of the FS exercise progressively increased from 70% to 85% 1RM. Because strength was expected to increase with training, an intermediate strength assessment can be carried out after 4 weeks of training to perform the necessary load adjustments for each athlete. Between the RT and the AT, each athlete should rest for 15 - 20 minutes, so that required intensities can be performed properly (Kraemer et al., 1995). This

training component was designed to be simple to evaluate and control in a real-context, consisting of 16 to 20 minutes of 20 m shuttle run exercise at 80% of maximal individual speed (MAS) reached during a previous 20 m multistage shuttle run test.

In our program, we used a low-repetitions model to allow the athletes to reproduce all repetitions at maximal intended velocity. When we want to increase the load, coaches must change the external load or increase the number of sets but not repetitions. On this, Campos et al. (2002) compared the effects of three different RT programs on adaptations within the vastus lateralis muscle, for 8 weeks. All training regimens caused similar changes in fibers, from IIB to IIA conversions, but curiously, they found that maximal dynamic strength improved the most for the low repetition training (comparing with medium and high repetitions), raising the question that perhaps more repetitions (more exercises) are not necessarily good. This way and considering that the suggested CT program requires 72h of recovery between each session (Kraemer & Ratamess, 2004), it is expectable that athletes can perform the specific training of their sport in a non-fatigue state and be able to maximize their technical ability.

We choose to provide an example of 8-weeks because, despite nervous system plays a significant role in the early phases of adaptation to training (Sale, 2003), within a period of 4 to 8 weeks of training muscle hypertrophy becomes evident (Kraemer et al., 1995; Phillips, 2000). Moreover, most of the training regimens used cycles of 4 to 8 weeks of preparation, not only in competitive training but also during RT programming. Usually, 8 weeks is the baseline used there are a lot of investigations that used these eight weeks' time period. For example, Botonis et al. (2016) recently observed that CT with high-intensity AT during precompetition season seems to be an effective regimen to enhance swimming performance. They used a training program of 8-weeks duration, the time that a pre-competition preparation could last for water-polo season in real context. Recently, Rivière et al. (2017) studied the use of different RT with elastic bands and found that 6-weeks of CT could lead to improved upper-body strength, velocity and power in elite youth rugby players. So, despite our example comprised 8-weeks, we think that this can be expanded and replicated to a longer period.

Each training phase usually lasts 2 to 10 weeks, and the complete training cycle ranges from 8 to 35 weeks (Hartmann et al., 2015). If we consider for periods of prolonged competition (e.g.: 26 consecutive weeks), it would require intensity manipulation on a weekly or microcycle basis. Periodization is the systematic variation of volume and intensity (Plisk & Stone, 2003), although it is problematic to speak separately from one another. It has been demonstrated that the fluctuation of workload increases can stimulate performance gains (Stone et al., 1999). In fact, the periodized variation with the specific sequencing of the volume and intensity offers an optimized method of improvement (Stone et al., 1999). In our opinion, knowing this and the effects of CT following a DT period, we should be aware that a minimum of 8-weeks should be used during CT and a maximum of 2 weeks of unloading should be used to avoid any loss of

previous gains in resistance and aerobic variables. This DT period could also allow a maximization of previous gains by a supercompensation effect (Zatsiorsky et al., 2006). It is also important to be aware that some of the latest research on intensity during CT focused on the distribution of the load throughout a season, and a polarized model is suggested (Varela-Sanz et al., 2016).

This CT training could be implemented also for team-sports, in combination with refining work and technical and tactical conditioning. It could be applied during a critical time of the season for players who often compete 2 or 3 times a week in national and/or international competitions. However, in these cases, the physical and psychological recovery time should be considered. Furthermore, in Table 2 we provide some recommendations for helping the coaches to design their own CT program.

Table 2. Example of an 8-weeks concurrent training program to improve lower body strength and cardiorespiratory performance.

Exercise	Sessions															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Full Squat (% 1RM: SxR)	70:3x6	70:3x6	70:3x8	70:3x8	75:3x6	75:3x8	75:3x8	75:3x8	80:3x5	80:3x5	80:3x5	80:3x5	85:3x5	85:3x5	85:3x5	85:3x5
CMJ (SxR)	2x4	2x4	2x5	2x5	2x5	2x5	2x5	2x5	2x5	3x5	3x5	3x5	3x5	3x5	3x5	3x5
Sprint (SxD)	2x30m	2x30m	2x30m	2x30m	3x30m	3x30m	3x30m	3x30m	3x20m	3x20m	3x20m	4x20m	4x20m	4x20m	3x20m	3x20m
20m Shuttle Run (total duration and intensity as %MAS)	16 min	16 min	16 min	16 min	16 min	20min	20min	20 min	20 min	20 min	20 min	20 min	20 min	20 min	20 min	20 min
	80%	80%	80%	80%	80%	80%	80%	80%	80%	80%	80%	80%	80%	80%	80%	80%

1RM: One-repetition maximum; SxR: Sets x repetitions; SxD: Sets x distance; CMJ: Countermovement jump; %MAS: Percentage of the maximal speed reached for each participant during the 20 m multistage shuttle run test.

Summary

Studies of CT have been shown beneficial effects on athletes' performance, once properly combined. Thus, the intensity of RT and/or AT seems to play an essential role for higher gains. The few researches gathered showed improved strength and cardiorespiratory performances regardless of the different intensities used in AT and/or RT during CT. However, there is a tendency for higher neuromuscular gains when higher RT intensities were combined with low intensity of AT. Also, higher aerobic adaptations were found when lower aerobic intensities are used. Knowing this, and the fact that DT periods longer than 2 weeks can compromise previous gains, coaches can design a CT training program that aims to improve strength and cardiorespiratory fitness and optimize athlete performance.

Chapter 4. General Discussion

The purpose of this investigation was to analyze the effects of the intensities used during aerobic (AT) or resistance training (RT) when performed concurrently, on several neuromuscular (jumps, sprint, leg strength) and aerobic performances (maximum oxygen uptake [Vo_2max]). In addition, a detraining (DT) period following concurrent training (CT) programs was tested to understand previous effects of the intensity performed. The lack of research on the intensity during CT for efficient performance in young adults was the starting point of our research protocol. Our findings suggested a beneficial effect of 8-weeks of RT programs consisting in full-squat (FS) with three different loads combined with the same low-intensity AT, with increased changes in explosive efforts for the higher ones. When managing the intensities of the AT, the higher gains in maximal strength were found with the lower intensities, despite all showed to improve neuromuscular performance and cardiorespiratory fitness, combined with the same RT. Our data also showed that a period of 4 weeks of DT resulted in severe loss of previous gains, regardless of the intensities used during previous AT or/RT program. Nevertheless, fewer losses seemed to exist when lower intensities of AT were combined with moderated to high intensities of RT. This allowed to suggest a training program for coaches and strength and conditioning professionals to optimize training programs in those sports that require the combination of both components of resistance and aerobic for maximize performance.

The initial work of this thesis was to conduct a review that comprised the published studies about the intensities used in CT (study 1). In the last few years the research on CT has been increased. However, we observed that the knowledge on the use of different intensities during AT and/or RT when performed concurrently was limited. Most of the common research on this subject was related with the load distribution, mainly during aerobic component (Petré et al. 2018; Wong et al. 2010; Esteve-Lanao et al. 2007). It seemed evident that CT with different intensities positively influences the performance in young adults (Petré et al. 2018). Furthermore, a DT period of 2 to 4 weeks is enough to compromise the training induced gains (Joo, 2018). This happens regardless of the intensity used. Moreover, to our knowledge, until our first experimental study (Sousa et al., 2018), no other study investigated the effects of intensity of one training component (aerobic or resistance) and maintaining similar the other. Only this design will be able to provide confident results on the effects of the intensities. Some studies exist but on AT load distribution during season or comparing different intensities but different methods of training at the same time (Fyfe et al., 2016).

An issue found during the development of the review that was common to several research papers was the interference phenomenon (Coffey and Hawley, 2017). This was found to be a major cause of the impairment of specific adaptations to CT, but few tried to explain how it

works. Indeed, it was suggested that intensity could represent one main factor regarding the influence of aerobic adaptations over strength or vice-versa. Given the abovementioned main observations, it seemed relevant to examine the impact of RT intensity during a CT program followed by DT on performance (study 2). Despite our first experimental study appear on the review, it was only developed after. The revision process of the review was extended implicating that our first experimental study was published slightly before the conclusion of this process. Thus, this paper was included in the final version of the review, as suggested by reviewers. Our findings showed a beneficial effect of 8-weeks of RT programs consisting in FS with low (40-55% one repetition maximum [1RM]), moderate (55-70% 1RM), or high (70-85% 1RM) loads combined with the same low-intensity AT (75% maximal aerobic speed [MAS]). These gains were verified in jump, running sprint, maximal strength and VO_2 max. These are reliable variables usually associated with performance in most of individual and team-sports, and so, relevant for the present study (e.g. Edge et al., 2005; Marques and Izquierdo, 2014). Despite the similar improvements, there was a slight trend toward greater intra-group improvements for RT with loads higher than 55% of 1RM in explosive efforts, such as short runs (T10 m) and countermovement jump (CMJ). Moreover, a 4-weeks period of DT resulted in severe performance decrements for all the participants.

A great number of CT programs have been assessed in previous research (Leveritt et al., 2003; Varela-Sanz et al., 2017). However, only few studies focused on the training intensity distribution during CT, which seems to be a major issue when programming AT and RT simultaneously (Chtara et al., 2008; De Souza et al., 2007; Sousa et al., 2018). To the best of our knowledge, the abovementioned experimental study was the first to focus on training and DT effects on strength and aerobic performances after CT programs that differed in the intensity used during the RT. All the findings highlight the beneficial effect of CT, but when strength was combined with continuous AT, it appeared that training programs with moderate to high loads were more effective for improving jump and sprint performance than those with low loads. These are relevant indicators for coaches and sport professionals, to be considered when designing a training program combining AT and RT. Furthermore, it gave clear suggestion that higher resistance loads should be used for better neuromuscular performances, when combined with low intensity AT. However, it still to realize the ideal intensity for the AT component.

The second experimental study (study 3) aimed to analyse the effects of CT with different aerobic intensities and to verify their effects on subsequent DT period. Only Fyfe et al. (2016) compared different intensities of AT during a short-term CT program, but besides comparing different intensities, the authors compared also different training methods and low intensities of AT were not studied. In our study, the same RT was combined with running at 80%, 90% or 100% of MAS determined in previous shuttle run exercise for 16 - 20 minutes. After 8-weeks all experimental groups showed improvements in the assessed variables, but the lower aerobic

intensities revealed higher gains in maximal strength and smaller performance decrements after DT. Previous research has suggested that AT during CT can impair ballistic and strength adaptations (Leveritt et al., 1999). However, with the addition of explosive exercises along with FS, all performed at the maximal intended velocity, might diminished the interference effect on vertical jump, short-run and maximal strength adaptations. The better results after training with the lowest aerobic intensities could be because of the higher interference previously attributed to the high-intensity AT (Coffey et al., 2009). It seems that higher intensities increased glycogen depletion in Type II muscle fibers (Gollnick et al., 1974), which may intensify residual fatigue (Hulston et al., 2010) and inhibit central regulators of cellular activity, such as activated protein kinase (Derave et al., 2000). This way, muscle regeneration and training adaptations could be hindered or compromised (Mihaylova & Shaw, 2011).

Based on the previous results, a training program was designed (study 4), providing practical recommendations for coaches regarding the combination of AT and RT intensities during CT for improvement of neuromuscular performance, maximal strength and cardiorespiratory fitness. Based on recent findings from our lab and others, we present a practical example for eight weeks of implementation of CT, performed twice a week. The main goals of the example provided are the improvement of performance, particularly lower-limbs, the improvement of maximum strength and ability to jump (explosive strength) and the enhancement of agility and acceleration without loss of balance. This program was developed for the improvement of lower limbs neuromuscular performance and cardiorespiratory fitness. Therefore, it can be used by individual or team-sports in which those physical abilities are required, such as jumps, repeated sprints, and maximum lower-limbs strength.

Training programs should be specific, and adaptations seem to be related to the use of specific RT programs to meet training objectives (Kraemer et al., 2004). It is important to report that our research was conducted based only on lower limbs exertion. If we want to evaluate the effects of different RT or AT when, and this is mostly performed by the lower-limbs, than we should focus on the physical work in those limbs. In our research we were trying real understanding of the interference of AT and RT in this case. To include more than one exercise for lower limbs training, we were increasing the confounding factors of our study. With these papers we were trying to understand the very basis of CT and lower limbs maximal strength, vertical jump performance and running are the most common and usually related with several sports performances (e.g. Bishop et al., 2011; Marques & Izquierdo, 2014).

The ideal combinations of resistance and/or aerobic intensities during CT programs are far from being well known, but the first step has been taken and should be continued. There are several more intensities and methods of combining and designing training program that must be accomplished to deeply understand its effects on performance. Most of sports modalities depend on this combination of RT and specific AT and it could determine the success or failure.

Some main limitations of this thesis should be addressed:

- The CT programs were performed for 8 weeks and this might be considered a short period;
- It was not possible to study the responsible mechanisms for the effects found (i.e. lactate, hormones, electromyography and others);
- The VO_2max was estimated by equation, based on the shuttle run test and breath-by-breath mechanisms would be more precise;
- Larger samples could allow more consistent results;
- Only lower-limb exercitation was performed which may have constituted a limitation in improving and maintaining the strength gains after the training period;
- Only males' young adults were evaluated and we should be aware of this when discussion the main findings of the study.

Chapter 5. Overall Conclusions

The main findings of this work emphasize the positive effects of concurrent resistance (RT) and aerobic training (AT) on young adults. Data also showed the importance of the combination of intensities of aerobic and RT, determining some important conclusions that should guide the concurrent training (CT) structure. The conclusions of the present thesis were:

- i. There is a lack of research on the effects of aerobic and/or resistance training intensities when concurrently executed on performance;
- ii. CT program for 8 weeks of RT with different loads combined with low-intensity AT improved strength and aerobic performances, regardless of training intensity used during RT;
- iii. RTs loads higher than 55% of 1RM are suggested to cause greater improvements in explosive efforts when combined with low intensity AT;
- iv. As for RT intensities, beneficial effects on strength and aerobic development were found after 8-weeks, regardless of the AT intensity;
- v. Choosing lower AT intensities can lead to increased strength;
- vi. Decreased performances were found after 4-weeks of detraining (DT) in both experimental studies, but, minor detriments, specifically in VO_{2max} , were found when high RT loads were combined with low-intensity AT. So, these intensities are recommended when the cardiorespiratory gains should be maintained for longer.

Chapter 6. Suggestions for future investigations

The effects of different intensities during aerobic (AT) or/and resistance training (RT) in performance are far from being well-known and further researches are needed to support our evidences. Thus, a few indications for possible future investigations are listed below:

- To replicate these studies but with different intensities of RT combining with different AT program and perhaps increasing the number of participants;
- To replicate these studies but with longer training periods and adding some physiological variables to better understand the training adaptations (VO_2 , heart rate, temperature, lactate, hormones);
- To compare different methods of AT and/or RT performed at the suggested intensities from our experimental studies;
- To verify the effects of combining different intensities of AT and RT in different participants, for instance, experienced ones and/or females;

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