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Ciências Sociais e Humanas

**Concurrent training in prepubertal children:
different combination approaches between
resistance and aerobic training in physical fitness
variables**

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“The pessimist sees difficulty in every opportunity. The optimist sees the opportunity in every difficulty.”

Winston Churchill

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Abstract

Concurrent training has been investigated over the last three decades, amongst scientific community. This is an interesting topic for researchers due to the controversial results in literature, specifically in a school environment. Therefore, the purpose of this work was to analyze the effects of different combination approaches between resistance and aerobic training on explosive strength and aerobic capacity in a large sample of prepubertal children. Additionally, we intended to investigate the effects of training exercise mode alone on overall physical fitness in prepubertal children. For the accomplishment of these purposes the following sequence was used: i) reviewing the available literature; ii) assessing three different training methods (intra-session concurrent training, concurrent training in different sessions, and resistance training alone) and analyzing their effects on explosive strength and VO₂max adaptations; iii) comparing two different intra-session concurrent training sequences on explosive strength and VO₂max during 8-weeks training period; iv) proposing multiple linear regression models for determining distinct strength parameters and VO₂max performances according to specific training programs with 8-weeks duration. The main conclusions found suggest that i) there is a limited research on training-induced physical fitness variables in prepubertal children; ii) the concurrent training performed in different sessions can be performed without implications on prepubertal children' growth, as it is also effective for training-induced explosive strength and VO₂max; iii) the concurrent training (intra-session or different sessions) and resistance training alone provide similar neuromuscular adaptations in prepubertal girls and boys; iv) the intra-session concurrent training, regardless the order, improve prepubertal children performance on explosive strength and VO₂max; v) it is possible to develop indirect predictive models for each training method with 8-weeks duration. Our findings provide useful remarks about the effects of different combination approaches between resistance and aerobic training on explosive strength and aerobic capacity in prepubertal children. These results can be helpful for coaches, teachers and researchers to optimize explosive strength and cardiorespiratory fitness training in sports club and school-based programs, as well as a reliable source for further researches.

Key words

Prepubertal children, physical fitness, intra-session concurrent training, order.

Resumo

Nos últimos trinta anos, o treino concorrente tem vindo a ser investigado pela comunidade científica. Não obstante, demonstra ser um tema interessante devido aos resultados controversos na literatura, nomeadamente em contexto escolar. Assim sendo, o propósito deste trabalho foi analisar os efeitos de diferentes combinações entre o treino de força e o treino aeróbio na força explosiva e na capacidade aeróbia em crianças pré-púberes. Além disso, pretendemos ainda investigar os efeitos do treino isolado na aptidão física em crianças pré-púberes. Para a concretização desses objetivos foi utilizada a seguinte sequência: i) revisão de literatura; ii) avaliação de três métodos de treino diferentes (treino concorrente na mesma sessão, treino concorrente em sessões diferentes e treino de resistência isolado) e análise dos seus efeitos na força explosiva e no consumo máximo de oxigénio ($VO_2\text{max}$); iii) comparação de ordens diferentes de treino concorrente na mesma sessão na força explosiva e $VO_2\text{max}$ durante um período de 8 semanas; iv) estudo de múltiplos modelos de regressão linear para determinar diferentes parâmetros de força e $VO_2\text{max}$, tendo em conta programas de treino específicos. As principais conclusões encontradas sugerem que: i) existe pouca investigação acerca das variáveis de condicionamento físico induzidas pelo treino em crianças pré-púberes; ii) o treino concorrente em sessões distintas pode ser realizado sem implicações para a saúde e normal crescimento das crianças, como ainda demonstra ser efetivo na melhoria de força explosiva e $VO_2\text{max}$; iii) o treino concorrente (sessões distintas ou na mesma sessão) e o treino de resistência isolado induzem adaptações neuromusculares idênticas em raparigas e rapazes pré-púberes; iv) o treino concorrente na mesma sessão, independentemente da ordem, melhora a performance na força explosiva e $VO_2\text{max}$ em crianças pré-púberes; v) é possível desenvolver métodos preditivos indiretos para cada método de treino com duração de 8 semanas. Estes resultados podem ser profícuos para treinadores, professores e investigadores no sentido de otimizar a força explosiva e o treino de aptidão cardiorrespiratória em clubes desportivos, escolas, como também serem considerados uma fonte segura para futuras investigações.

Palavras-Chave

Crianças pré-púberes, aptidão física, treino concorrente, ordem.

Resumen

En los últimos treinta años, el entrenamiento concurrente se ha investigado en la comunidad científica. Es un tema interesante para los investigadores debido a resultados contradictorios en la literatura, sobre todo en el contexto escolar. Por lo tanto, el propósito de este estudio fue analizar los efectos de diferentes combinaciones de entrenamiento de fuerza y aeróbico en la fuerza explosiva y la capacidad aeróbica en niños prepúberes. Además, tuvimos la intención de investigar los efectos del entrenamiento aislado en la condición física de los niños prepúberes. Para alcanzar estos objetivos se utilizó la siguiente secuencia: i) una revisión de la literatura; ii) evaluación de tres métodos diferentes de entrenamiento (entrenamiento concurrente en la misma sesión, sesiones diferentes de entrenamiento concurrente y entrenamiento de fuerza aislado) y análisis de su efecto sobre la fuerza explosiva y el consumo máximo de oxígeno ($VO_2\text{max}$); iii) comparación de diferentes órdenes de entrenamiento concurrente en la misma sesión en el fuerza explosiva y $VO_2\text{max}$ durante ocho semanas; iv) estudio de varios modelos de regresión lineal para determinar los diferentes parámetros de fuerza y $VO_2\text{max}$, teniendo en cuenta los programas de entrenamiento específicos. Los principales resultados sugieren que: i) no hay muchos estudios sobre las variables de aptitud física inducidas por el entrenamiento en niños prepúberes; ii) el entrenamiento concurrente cumplido en diferentes sesiones se puede lograr sin consecuencias para la salud y el crecimiento normal de los niños, ya que sigue siendo eficaz en la mejora de la fuerza explosiva y el $VO_2\text{max}$; iii) el entrenamiento concurrente (diferentes sesiones o en la misma sesión) y el entrenamiento de resistencia aislada inducen adaptaciones neuromusculares similares en niños y niñas prepúberes; iv) el entrenamiento concurrente en la misma sesión, independientemente del orden, mejora el rendimiento de la fuerza explosiva y el $VO_2\text{max}$ en niños prepúberes; v) se puede desarrollar métodos indirectos de predicción para cada método de entrenamiento con duración de ocho semanas. Estos resultados pueden ser rentables para los entrenadores, profesores e investigadores con el fin de optimizar la fuerza explosiva y de entrenamiento de la aptitud cardiorrespiratoria en clubes deportivos, escuelas, así como una fuente fiable para la investigación futura.

Palabras-Clave

Niños pré-púberes, condición física, entrenamiento concurrente, orden.

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List of Abbreviations

A	Aerobic training alone
AR	Intra-session concurrent aerobic and resistance training
BFP	Body fat percentage
BMI	Body mass index
C	Control group
CM Jump	Counter movement vertical jump
CT	Concurrent training performed in different sessions
MAV	Maximal individual aerobic volume
R	Resistance training alone
RA	Intra-session concurrent resistance and aerobic training
SL Jump	Standing long jump
VO ₂ max	Maximal oxygen uptake
1kg Ball-Throw	Chest 1kg medicine ball throw
3kg Ball-Throw	Chest 3kg medicine ball throw
20m Sprint	20m sprint running

Chapter 1. General Introduction

Physical fitness has been considered an important component to improve the child holistic development, being a significant health-related marker in childhood (Kvaavik et al., 2009; Ortega et al., 2008). Indeed, physical fitness has been defined as the aptitude to perform physical tasks without fatigue (Mondal, 2006), evidencing to be a complex and bidirectional concept that comprises health-related (cardiorespiratory endurance, muscular strength and endurance, body composition and flexibility) and sport performance-related components (agility, equilibrium, coordination, speed, power and reaction time) (Caspersen et al., 1985; Garber et al., 2011). Improving these parameters in children's performance can bring significant benefits such as improvements on cardiorespiratory performance, cardiovascular health, total and abdominal adiposity, anxiety control, self-esteem, academic performance, and decreases on depression levels (Cepero et al., 2011; Kvaavik et al., 2009; Marta et al., 2012). Moreover, it has been reported the longevity of physical fitness levels from childhood to the adulthood (Eisenmann et al., 2005; Stratton et al., 2008).

Although the benefits of physical activity are well known, there was a significant decrease in the physical activities and consequently low physical fitness levels from childhood to adolescence over the last decades (Matton et al., 2007; Moreno et al., 2007; Trost et al., 2002; Viñas et al., 2006). These decreases can be explained by arise of sedentary behaviour, physiological and psychological factors (Tomkinson & Olds, 2007). However, low physical fitness levels have been also associated to many serious health problems (Steele et al., 2008; Tambalis et al., 2013). Considering the abovementioned, the efforts to increase physical fitness levels in youth should be a priority (Cepero et al., 2011).

Children should benefit from the development of strength and cardiovascular variables (Ortega et al., 2008; Taanila et al., 2011), but the best way to achieve these improvements remains unclear. For a while, most of the pediatric research focused on activities that enhanced cardiorespiratory fitness, ignoring the muscular strength development (Cepero et al., 2011). Nevertheless, recent researches demystified the idea that resistance training would lead to injuries as well negatively influence the normal growth of children (Blimkie, 1993; Docherty et al., 1987; Faigenbaum et al., 1996) by reporting unique benefits to children when appropriately prescribed and supervised (Faigenbaum et al., 2009; Faigenbaum & Myer, 2010). More recently emerged another method of conditioning, the concurrent training, which seems to be able to produce gains in cardiorespiratory and muscular fitness simultaneously (Kang & Ratamess, 2014).

In a sport context, the scientific research showed ambiguous effects caused by concurrent training. Some investigations reported a negative influence of concurrent training on muscle strength and/or power development (Henessy & Watson, 1994; Izquierdo et al., 2005), while others showed positive effects on maximal aerobic capacity (Kraemer et al., 2001; Silva et al., 2012), muscular strength (Davis et al., 2008; Shaw et al., 2009), muscular endurance (Kraemer et al., 1995), and body composition (Rahnama et al., 2007). The inconsistencies behind these researches may be explained by the studies design and/or training protocols (García-Pallarés & Izquierdo, 2011). Even so, the abovementioned studies have investigated concurrent training in young, adult and elderly populations. Little is known about this topic and its effects as far as prepubertal children performance concerns (Marta et al., 2013). Therefore, it seems important to investigate the effects of different approaches between resistance and aerobic training on explosive strength and cardiorespiratory fitness in this population (Study 2).

More than those variables that typically characterize a training program (i.e. volume, intensity, frequency), concurrent training might be characterized by training design, specifically intra-session concurrent training or in different days (i.e. resistance exercise on Monday, aerobic exercise on Tuesday, and so on) (Kang & Ratamess, 2014), and intra-session concurrent training sequence (aerobic prior to resistance training or vice-versa) (Chtara et al., 2005). The literature is far from be consensual concerning to the efficacy of concurrent training performed on the same day (Craig et al., 1991) or in the alternate days (Glowacki et al., 2004). Sale et al. (1990) reported that concurrent training in the same day instead of different days might inhibit the strength development but not maximal oxygen uptake (VO_2max). Whereas Doma & Deakin (2013) suggested that intra-session concurrent training impaired running performance the following day and may compromise adaptation compared to alternate-day concurrent training. In addition, Marta et al. (2013) show that intra-session concurrent training does not impair strength development in prepubertal children.

Concerning to the intra-session concurrent training, its exercise sequence was suggested as a relevant variable in the concurrent training prescription (Chtara et al., 2005; García-Pallarés & Izquierdo, 2011) and may define the magnitude of impairment in strength (Leveritt et al., 1999) or aerobic development (Chtara et al., 2005) after concurrent training. Early researches focused on the concurrent training sequence effects on performance and health (Chtara et al., 2005; Kang & Ratamess, 2014) concluded that optimum training sequence was determined by the individual purposes of the training program. In practical context, performing aerobic prior to resistance training produce aerobic gains, while performing resistance prior to aerobic training appears to be more adequate to obtain strength improvements (Kang & Ratamess, 2014). Even so, to the best of our knowledge, the literature only has focused on the effects of intra-session concurrent training order in adults' performance (Cadore et al., 2011, 2012, 2013; Chtara et al., 2005). Thus, it seems pertinent

and useful to investigate the effects of different intra-session concurrent training order in prepubertal children (Study 3).

Throughout the years, several studies presented different training programs to improve physical fitness (Alves et al., 2016a, 2016b; Benson et al., 2007; Kang & Ratamess, 2014). But, it is also known that different kind of training develops each strength and/or aerobic parameters differently (Kang & Ratamess, 2014). Predictive models are not new in sports science research. However, until now most of them were developed to explain acute performances responses based on biomechanical, physiological or/and anthropometric measures (Barbosa et al., 2010; Morais et al., 2016), to predict aerobic capacity ($VO_2\text{max}$) or maximal strength (1RM) (Hoffman et al., 2003; Reynolds et al., 2006), and not to understand and predict the responses to different training programs. In fact, a prediction of possible gains or decreases in strength and aerobic performances in a concurrent training context remains unknown and a research on this area should be performed (Study 4).

Considering the aforementioned, the main purpose of this thesis was to analyze the effects of different combination approaches between resistance and aerobic training [concurrent training design (concurrent training performed simultaneously during the same session or concurrent training performed in different sessions) and intra-session training sequence (aerobic prior to resistance training or resistance prior to aerobic training)] on explosive strength and aerobic capacity in prepubertal children. Additionally, we also intended to provide multiple linear regression models to predict distinct strength variables and $VO_2\text{max}$ performances in 8-weeks training programs in children.

The thesis was developed following to the above sequence:

Chapter 1 composes a general introduction where are mentioned the main thematics of this work.

Chapter 2 presents a literature review (Study 1) based on the early researches concerning the different approaches of training methods in prepubertal children performance.

Chapter 3 focus the experimental studies established to achieve the main purpose of this thesis:

Study 2 aims to compare the effects of different approaches between resistance and aerobic training and resistance training alone on the explosive strength and aerobic capacity in prepubertal children.

Study 3 was developed to analyze the interference of resistance and aerobic training order on explosive strength and aerobic capacity in prepubertal children.

Study 4 purposes to provide multiple linear regression models to determine distinct strength parameters and VO_2max performances according to specific training programs during an 8-weeks period.

Chapter 4 shows a general discussion of the obtained results on the performed studies.

Chapter 5 evidences the main conclusions and limitations of the thesis.

Chapter 6 proposes some suggestions for future research.

In order to complement the present thesis some additional studies were accomplished, being presented in appendix I and appendix II.

Chapter 2. Literature Review

Study 1

Concurrent training in prepubertal children: an update

Abstract

This study affords an update review over the state of art regarding the importance of physical fitness and the significance of different combination approaches between resistance and aerobic training, as well conditioning methods exercise alone on improvements of physical fitness, specifically explosive strength and cardiorespiratory fitness in prepubertal children. The main research conclusions can be summarized as: i) Resistance training can be an effective and reliable to improve muscle strength in prepubertal children; ii) A proper and quantifiable exercise frequency and intensity in aerobic training remains unclear; iii) No differences have been found between prepubertal girls and boys on strength and on aerobic capacity improvements after intra-session concurrent training, resistance or aerobic training alone; iv) In adults, concurrent resistance and aerobic training seems to be more effective on improvements of aerobic capacity than aerobic training alone; v) Aerobic training biomechanically specific to the concurrent resistance training may minimize adaptation interference when concurrently training; vi) In adolescents, concurrent resistance and aerobic training is equally effective to improve explosive strength compared to resistance training alone, and more efficient in aerobic capacity than resistance training alone; vii) Optimum training sequence was determined by the individual purposes of the training program; viii) Performing aerobic prior to resistance training produces aerobic gains, while performing resistance prior to aerobic training appears to be more adequate to obtain strength improvements; ix) In adults, performing concurrent training in different sessions seems to be more effective to improve muscular strength than intra-session concurrent training.

Key words: Prepubertal, physical fitness, sequence, concurrent training.

Introduction

Physical fitness is considered a powerful health-related indicator in childhood (Ortega et al., 2008b) and an important element to the holistic child development (Kvaavik et al., 2009; Marta et al., 2013; Ortega et al., 2008b). It is a complex and bidirectional concept that involves health-related and sport performance-related components (Caspersen et al., 1985, Garber et al., 2011). Even recognizing its importance for children by all community, a significant decrease in the practise of physical activity and consequently low physical fitness levels among children was found over the last decade (Matton et al., 2007; Moreno et al., 2007; Viñas et al., 2006). This seemed to be the main cause of most of health issues during childhood, for instance cardiovascular disease (Steele et al., 2008; Tambalis et al., 2013). Thus, it is important to consider children and adolescents as the primary prevention of diseases-related to sedentary lifestyle (Martínez-Vizcaíno & Sánchez-López, 2008). Concerning to the abovementioned, the efforts to increase physical fitness levels in youth should be a priority (Cepero et al., 2011).

Most of the pediatric research based on training programs focused on activities that enhance cardiorespiratory fitness, neglecting the neuromotor fitness conditions based on muscular strength (Cepero et al., 2011). Yet, improvements in muscular fitness, speed and agility, rather than cardiorespiratory fitness, seem to have a positive effect on skeletal health (Kemper et al., 2000; Santos et al., 2012). Therefore, recent investigations indicated that resistance training provide benefits to children and adolescents (Faigenbaum & Myer, 2010; Kemper et al., 2000; Santos et al., 2012), being considered a reliable and effective method of conditioning (Faigenbaum et al., 2009b). Nevertheless, another conditioning method, called concurrent training, has been investigated over the last decades. Indeed, it was suggested to provide gains in cardiorespiratory and muscular fitness simultaneously (Kang & Ratamess, 2014). To the best of our knowledge, little is known about the effects of concurrent training on prepubertal children performance (Greenleaf et al., 2010; Marta et al., 2013). Moreover, the effects of intra-session concurrent training order were only investigated in adults (Cadore et al., 2011, 2012b, 2013; Chtara et al., 2005). Therefore, it seems to be important to investigate the effects of different approaches between resistance and aerobic training on explosive strength and cardiorespiratory fitness in prepubertal children. Furthermore, this investigation can be useful to coaches, teachers and researchers to optimize explosive strength and cardiorespiratory fitness training in sports club and school-based programs, as well as a reliable source for further researches.

Physical Fitness in childhood

Physical fitness has been considered an important health-related marker in childhood and a significant element for normal child growth and development (Kvaavik et al., 2009; Marta et al., 2013; Ortega et al., 2008b; Rowland, 2007). In fact, it is recognised a positive relation between the physical fitness development and health. The enhancement on physical fitness levels provide several benefits in children, as improvements on cardiorespiratory performance, cardiovascular health, muscular strength, total and abdominal adiposity, depression levels decreases, better anxiety control, self-esteem increases, and higher academic performance (Cepero et al., 2011; Kvaavik et al., 2009; Marta et al., 2012; Shore et al., 2008).

Although there are reliable evidences about the several benefits associated to good physical fitness levels, some researchers indicated a decline on physical activity practise and decreases on physical fitness levels among children over the last few decades (Aaron et al., 2002; Matton et al., 2007; Trost et al., 2002). This overview may be attributed to a perceptible refusal of children in physical education classes and regular physical activity (Roetert, 2004), but also to sedentary behavioral, physiological and psychological factors (French et al., 2001; Tomkinson & Olds, 2007). So, it seems to be relevant to promote improvements of physical fitness levels in youth (Cepero et al., 2011), whereas favourable behavioural and biological effects during childhood may support to reduce the risk of developing chronic diseases into later life (Ortega et al., 2008a; Rowland, 2007).

Resistance training

Youth resistance training is becoming universal as a qualified method of conditioning by medical, fitness, and sports organizations (Faigenbaum & Westcott, 2009a; South African Sports Medicine Association, 2008). Early scientific researches evidence that resistance training can provide exclusive benefits for children and adolescents when properly designed and well-supervised (Faigenbaum et al., 2009b; Vaughn & Micheli, 2008). Indeed, resistance training has innumerable health-related benefits such as decreases on cardiovascular disease (García-Artero et al., 2007; Ortega et al., 2012) and chronic disease risks as diabetes, obesity (Wijndaele et al., 2007), improvements on bone health (Pitukcheewanont et al., 2010; Vicente-Rodriguez et al., 2004), body composition (Sadres et al., 2001; Santos et al., 2014), psychosocial well-being (Falk & Eliakim, 2003; Yu et al., 2008), motor control skills (Falk & Eliakim, 2003; Hass et al., 2001), muscular and explosive strength in children and adolescents (Benson et al., 2007; Falk & Mor, 1996a).

In the last three decades, resistance training was not recommended for children as it was believed to lead to injuries and long-term health consequences as damage of growth plates and premature closure of epiphyses, while at the same time thought to be ineffective in strength improvements (Blimkie, 1993; Docherty et al., 1987; Faigenbaum et al., 1996). However, scientific researches highlighting positive results such as bone mineral density improvements, muscular and endurance improvements in prepubertal and pubertal subjects after a resistance training beyond normal growth and maturation (Benson et al., 2007; Steinberger, 2003). Furthermore, children can improve muscular strength after 8 to 12 weeks of a resistance training program with two training sessions per week (Dahab & McCambridge, 2009). In early meta-analyses (Falk & Tenenbaum, 1996b; Payne et al., 1997) gains in muscle strength were suggested to be closely 13 - 30% greater than those which should be hoped from growth and maturation (Falk & Tenenbaum, 1996b).

The physiological mechanisms behind training-induced strength gains during preadolescence have been attributed mainly to neurological adaptations (i.e., increased motor unit activation, changes in motor unit coordination, recruitment) than hypertrophic factors (Malina, 2006; Ozmun et al., 1994; Ramsay et al., 1990), reporting differences with adults which attribute these improvements to hormonal and neural mechanisms (Faigenbaum et al., 2004; Ramsay et al., 1990). Concerning to the prepubertal gender differences, some researchers reported that there is no difference in strength between prepubertal girls and boys (Faigenbaum et al., 2003).

A reasoned compilation of scientific researches suggests that youth resistance training should be an important component of youth fitness programs, health promotion objectives, and injury prevention (Faigenbaum et al., 2009b). On this, Tsolakis et al. (2004) examined the influence of 8-weeks progressive resistance training program (3 times per week, 3 X 10 repetitions maximum [RM]) on strength in prepubertal males (11.8±0.8 years). The 2-months resistance training program resulted in 17.5% increase in isometric strength in experimental trained group compared with control group. Sadres et al. (2001) analyzed the effect of 2 school years (21months) of a twice-weekly resistance training program (1-4 set of 3-6 exercises, with 5-30 repetitions/set, load ranged 30 - 70% 1RM) on muscle strength in prepubertal males (9.2 ± 0.3 years). The results showed significantly increases in experimental group on muscle strength (knee extensors: 83% and knee flexors: 63%). Curiously, these evidences were corroborated by Szymanski and colleagues (2007) which suggested that longer program duration, higher frequency and intensity have a greater influence on the magnitude of strength changes. Regarding injury prevention, early studies that included experimental protocols with resistance training demonstrated effectiveness to reduce sports related injuries in youth (Abernethy & Bleakley, 2007; Micheli et al., 2000). Concerning to the health promotion purposes, Sung et al. (2002), analyzed the effects of resistance training (6 weeks, twice-weekly, circuit of 20 exercises repetitions, load ranged 75

- 100% 10RM) in prepubertal children (8-11 years) on blood lipid profile. The authors observed improvements on fat free mass (2.3%, $p < 0.05$) in experimental group after implemented program.

Aerobic training

Aerobic fitness reports to the body's capacity to transport oxygen from the environment and use it in muscle work. It is not only mentioned as a performance's determiner in a wide range of activities, but also a health-related mark since more than two decades ago when Blair et al. (1989) demonstrated that higher aerobic fitness measured during an additional treadmill exercise test was associated with reduced all-cause mortality in adults (Andersen & Haraldsdóttir, 1994; Malina et al., 1995). In a health context, aerobic training has been associated with a lower risk of diabetes, coronary heart disease, and obesity in children (Boreham et al., 2002; Ortega et al., 2007). Moreover, higher levels of cardiorespiratory fitness are associated with a healthier cardiovascular profile later in life (Ortega et al., 2007; Ruiz et al., 2009). In performance context, aerobic training aims to increase maximal oxygen uptake ($VO_2\text{max}$) or other physical fitness markers (i.e., lactate/ventilator threshold, exercise efficiency) (Baquet et al., 2003).

Child-based studies have widely focused on improving fitness levels for either athletic performance or for its relationship with health outcomes (Matos & Winsley, 2007). However, training-induced adaptations in aerobic fitness have been a matter of long-lasting controversy in children. Several studies have concluded that aerobic training did not produced significant changes in $VO_2\text{max}$ before puberty (Kobayaski et al., 1978; Mirwald et al., 1981), being explained by the existence of a maturational threshold (Katch, 1983). However, other researchers have shown significant improvements in $VO_2\text{max}$ in the same age (Pfeiffer et al., 2008; Shephard, 1992). But, this controversy may be clarified by the differences in experimental design (Armstrong & Welsman, 1990; Baquet et al., 2003).

Early reviews reported that the magnitude of training-induced changes in children might be smaller than that expected in adolescents and adults (Armstrong & Welsman, 2002; Mahon, 2000; Pate & Ward, 1990). As Armstrong & Welsman (2002) mentioned "children are not mini-adults", and their responses appear to be differently on exercise stimulus comparing to the adults (Matos & Winsley, 2007). Yet, a sufficient training stimuli must be provided for a significant enhancement of the $VO_2\text{max}$ in children (Carazo-Vargas & Moncada-Jiménez, 2015)

and the magnitude of the response will be influenced by exercise intensity and frequency (Baquet et al., 2003).

Regarding to the training frequency, some researches revealed that the gain in peak VO_2 was improved in prepubertal children by doing exercise program at least two sessions per week. Baquet et al. (2002) observed the effects of a 7-week (twice per week) of high intensity aerobic intermittent training programme on peak VO_2 of prepubertal children. The peak VO_2 improved by 8.2% in experimental group, while no alterations were noticed for control group. Mandigout et al. (2001) showed a significant increase about 7.1% in VO_{2max} after implementing an aerobic training programme during 13 weeks (three sessions per week). In fact, these evidences are consistent with Baquet and colleagues (2003). These authors stated that, independently of sex or pubertal status, mean peak VO_2 increase was around 5-6%, or even 8-10% when considered studies that only showed significant training effect.

There is a controversy concerning to the training intensity in children. It is reported that children need to train at a higher exercise intensity to elicit increases in aerobic fitness (Matos & Winsley, 2007). Furthermore, Massicotte & Macnab (1974) analyzed three different groups of prepubertal boys set distinct training intensities for each group. The results evidenced that only boys who performed at highest intensities (approximately 88% heart rate maximum) evidenced an increase about 11 % in peak VO_2 . However, the results of Carazo-Vargas & Moncada- Jiménez (2015) contrasts with previous evidences. The authors found that moderate exercise intensity (approximately 60% of an individual's heart rate maximum) provided adequate stimulus for a VO_{2max} improvement. Hereupon, the children's ability to improve their aerobic capacity by aerobic training is demonstrated. However, further experimental research is required to define a proper and quantifiable exercise frequency and intensity (Carazo-Vargas & Moncada-Jiménez, 2015).

Regarding to the prepubertal gender differences', there was no difference in aerobic capacity improvements between boys and girls. Baquet and colleagues (2002) applied a 7-week aerobic training programme (twice a week) in prepubertal children and observed identical responses in aerobic performance, peak VO_2 increase 9.5% in prepubertal boys and 7.2% in prepubertal girls.

Concurrent resistance and aerobic training

The compatibility of resistance and aerobic training performed simultaneously, called as concurrent training (Fyfe et al., 2014), has been investigated over the last three decades (Arazi et al., 2011; Davis et al., 2008a, 2008b).

Concurrent training seems to be a potential strategy for preventing and stabilizing multiple disease states due to its capacity to induce adaptations within skeletal muscle that neutralize a number of disorders impacting upon functional capacity and metabolic health, including sarcopenia (Pijnappels et al., 2008; Reeves et al., 2004), type II diabetes, and obesity (Kelley et al., 1996, 2002). However, concurrent training has become a recurrent topic for researchers due to the controversial results of different studies (Cadore et al., 2014; García-Pallarés & Izquierdo, 2011). Hickson (1980) reported a compromised adaptation induced by concurrent training compared with training exercise mode alone (Leveritt et al., 1999), calling the phenomenon as ‘interference effect’ (Wilson et al., 2012). In fact, some studies reported that concurrent training may affect the development of muscle strength and/or power (García-Pallarés & Izquierdo, 2011; Henessy & Watson, 1994; Izquierdo et al., 2005; Izquierdo-Gabarrén et al., 2010), while others contradicted by showing a positive effect of concurrent training on maximal aerobic capacity (Glowacki et al., 2004; Kraemer et al., 2001; McCarthy et al., 1995; Silva et al., 2012), muscular strength (Baker, 2001; Davis et al., 2008a; Davis et al., 2008b; Glowacki et al., 2004; Gorostiaga et al., 1999; Gravelle & Blessing, 2000; Kraemer et al., 1995; Shaw et al., 2009), muscular endurance (Hickson, et al., 1988; Kraemer et al., 1995), and body composition (Rahnama et al. 2007). However, these studies have investigated concurrent training in young, adult and elderly populations (Chtara et al., 2005, Davis et al., 2008a, 2008b, Holviala et al., 2010; Takeshima et al., 2007). There are a limited number of studies that explored concurrent training in prepubertal children (Marta et al., 2013).

Some variables have been suggested to affect concurrent training beyond those that typically characterize a training program (i.e. frequency, intensity, volume) such as: training design [i.e. concurrent training performed simultaneously during the same session, in the same day (i.e. in the morning and in the evening) or in different days (i.e. resistance exercise on Monday, aerobic exercise on Tuesday, and so on), or during specific training cycles] (Kang & Ratamess, 2014), and intra-session training sequence (i.e. aerobic prior to resistance training, or resistance prior to aerobic training) (Chtara et al., 2005).

Intra-session concurrent training

The intra-session resistance and aerobic training has been reported to be usual in physical fitness training programs due to time constraints and convenience (Alves et al., 2012).

However, this training design represents a specific challenge as the fatigue produced from one type of exercise may negatively influence the magnitude and quality of exercise in the other type reporting to possible interference effect (Davis et al. 2008a, 2008b). In fact, Cadore et al. (2010) reported increases about 50% in knee extensor strength from resistance training alone group compared with concurrent training group. Gergley (2009) also found higher values in the resistance training alone group, but creatively presented significant improvements in concurrent training group where cycling was added to aerobic training compared with the group where resistance training was combined with running. This evidence supported that aerobic training biomechanically particular to the concurrent resistance training may minimize adaptation interference when concurrently training. The efficiency of intra-session concurrent training in aerobic capacity have been confirmed though the study of Chtara et al. (2005). This study presented even larger increases in maximal oxygen uptake in the concurrent training group where aerobic precedes resistance training when compared to aerobic training alone group. Additionally, Santos et al. (2011, 2012) compared the effects of an 8-weeks training period of resistance training alone (R) and concurrent resistance and aerobic training (RA) on body composition, explosive strength and $VO_2\text{max}$ adaptations in adolescent's girls and boys. It was found similar improvements on explosive strength in both experimental groups (girls: R 8.0% and RA 12.0%; boys: R 10.3% and RA 14.4%), but improvements on $VO_2\text{max}$ were only observed in intra-session concurrent resistance and aerobic training (girls: RA 4.0%; boys: 4.6%). In the same line of thinking, Marta and colleagues (2013) reported an equally effectiveness of concurrent training group on training-induced explosive strength (R: 5.3%; RA: 5.2%), and more efficient than resistance training alone in $VO_2\text{max}$ (R: 0.8%; RA: 3.3%) in prepubertal children.

Order of intra-session concurrent training

Since resistance and aerobic training are performed concurrently, seems to be important to understand if there is an optimal training design or sequence for improving the physiological adaptations to exercise (Collins & Snow, 1993). The intra-session exercise sequence might be an important variable in the concurrent training prescription (Chtara et al., 2005; García-Pallarés & Izquierdo, 2011) and may define the magnitude of impairment in strength (Leveritt & Abernethy, 1999) or aerobic capacity (Chtara et al., 2005) development after concurrent resistance and aerobic training.

Performing aerobic exercise prior seems to be reliable because it can serve as a sufficient warm-up of muscle prior to the start of resistance exercise (Kang et al., 2009). But this sequence may result in a peripheral fatigue that consequently reduces performance during the resistance training. In the other hand, performed resistance exercise prior to aerobic exercise express a greater increase in lipolysis during subsequent aerobic exercise, suggesting that this exercise sequence may be more beneficial metabolically (Kang et al., 2009).

However, early researches focused on the concurrent training sequence effects on performance and health (Chtara et al., 2005; Kang & Ratamess, 2014) concluded that optimum training sequence was determined by the individual purposes of the training program.

In practical issues, performing aerobic prior to resistance training produces aerobic gains, while performing resistance prior to aerobic training appears to be more adequate to obtain strength improvements (Kang & Ratamess, 2014). Chtara et al. (2005) examined the effects of the concurrent sequencing order training during 12 weeks (twice per week) on aerobic performance and capacity of male students. It was reported greater improvements of $VO_2\max$ and aerobic performance in experimental group which perform aerobic prior to resistance exercise (13.7%; 8.6%, respectively), compared to resistance prior to aerobic exercise (11.0%; 4.7%, respectively) and aerobic training alone group (10.1%; 5.7%, respectively). Additionally, Cadore et al. (2011) have supportively shown similar magnitude improvements in maximal aerobic power in the concurrent training group where aerobic preceded resistance training (10.0%, $p < 0.05$) and in the aerobic training alone group (10.6%).

Separate day concurrent training

Concurrent training has been investigated by its potential to provide about gains in cardiorespiratory and muscular fitness simultaneously (Kang & Ratamess, 2014). However, adaptations to exercise training, performance improvements and training outcomes are highly specific to the mode of activity performed (Küüsma, 2013).

Sale et al. (1990) reported that the design of separate day resistance and aerobic training may be more effective to improve muscular strength than resistance and aerobic training on the same day. Concordantly, García-Pallarés & Izquierdo (2011) found that, the strength gains were significantly higher in the group that performed the training sessions on different days. Furthermore, Häkkinen et al. (2003) showed that after an extended training period of 21-weeks both concurrent resistance and aerobic as well as resistance training alone group resulted in similar gains in maximal lower body strength, but it was not the case in rapid force production. In fact, those inversely affected gains in strength and power can be observed especially when high volumes, intensities, and/or frequencies are employed (Chtara et al., 2008; Hickson, 1980; Kraemer et al., 1995; Sale et al., 1990).

To acquire optimal adaptations in muscle strength and power, as well as to minimize interference phenomenon, training frequency should not be in excess. Concurrent training showed to be detrimental for strength gains only when frequency is more than 3 days per week (García-Pallarés & Izquierdo 2011). In addition, interference in the improvement of physical fitness is usually observed only during a long (>7-8 weeks) training period (Hickson,

1980; Izquierdo et al., 2003). In studies where the training frequency have not exceeded 3 days per week increases in maximum strength were detected following concurrent training periods between 8 and 16 weeks (Izquierdo-Gabarren et al., 2010; McCarthy et al., 2002) and ≥ 20 weeks (García-Pallarés et al. 2010; Häkkinen et al., 2003). This is consistent with Sillanpää and colleagues (2008) that analyzed the effects of a 21-weeks (twice a week) of resistance and/or aerobic training on body composition and physical fitness of older man. The authors observed similar gains in maximal concentric force in the resistance training alone group (22.0%) and concurrent training group (23.0%), as well an improvement in maximal oxygen uptake in aerobic training alone and concurrent training group (both with improvements by 11.0%), with no changes in control group (C).

Conclusions

The importance of physical fitness specially during childhood is consensual and in order to improve it, and consecutively several health related and sport performance parameters, different conditioning methods could be suggested, such as: resistance training alone, aerobic training alone or even concurrent resistance and aerobic training. Regarding the resistance training, scientific researches underlining its efficiency on improving bone density, muscular and endurance strength of children without compromising their normal growth. Concerning to the aerobic training, it has been proved its effectiveness on improvements of children aerobic capacity. Lastly, the intra-session concurrent training has been demonstrated as an effective method to improve explosive strength and $VO_2\text{max}$ in children. However, further investigation is needed to know the effects of different approaches between resistance and aerobic training on explosive strength and cardiorespiratory trainability in prepubertal children.

The main findings of this review can be mentioned as:

- i) Resistance training can be an effective and reliable to improve muscle strength in prepubertal children;
- ii) A proper and quantifiable exercise frequency and intensity in aerobic training remains unclear;
- iii) No differences have been found between prepubertal girls and boys on strength and in aerobic capacity improvements after intra-session concurrent training, resistance or aerobic training alone;
- iv) In adults, concurrent resistance and aerobic training seems to be more effective on improvements of aerobic capacity than aerobic training alone;
- v) Aerobic training biomechanically specific to the concurrent resistance training may minimize adaptation interference when concurrently training;

- vi) In adolescents, concurrent training can be equally effective to improve explosive strength compared to resistance training alone, and more efficient in aerobic capacity than resistance training alone;
- vii) Optimum training sequence was determined by the individual purposes of the training program;
- viii) Performing aerobic prior to resistance training produces aerobic gains, while performing resistance prior to aerobic training appears to be more adequate to obtain strength improvements;
- ix) In adults, performing concurrent training in different sessions seems to be more effective to improve muscular strength than intra-session concurrent training;
- x) The effects of concurrent resistance and aerobic (intra-session and different sessions), as well its intra-session sequence in prepubertal children, has still to be investigated.

Future Researches

After summarizing all research findings, researchers should suggest future investigation in order to explore unclear issues in the available literature. Some of those main issues could be pointed:

- i) The effects of concurrent resistance and aerobic training on physical fitness in prepubertal children;
- ii) The magnitude of differences between intra-session and separate-session on physical fitness;
- iii) The magnitude of intra-session concurrent resistance and aerobic training order on physical fitness.

Chapter 3. Experimental Studies

Study 2

Concurrent training in prepubertal children: the effects of eight weeks of resistance and aerobic training on explosive strength and VO₂max

Abstract

The purpose of this study was to compare the effects of 8-week training periods of resistance training alone (R), combined resistance and aerobic training in the same session (RA) or in two different sessions (CT) on explosive strength and maximal oxygen uptake (VO₂max) in prepubertal children. One hundred and sixty-eight healthy children, aged 10-11 years old (10.9±0.5), were randomly selected and assigned to three training groups to train twice a week for 8 weeks: R (n=41), RA (n=45), CT (n=38) groups and a C group (n=44; no training program). The C maintained the baseline level and trained-induced differences were found in the experimental groups. Differences were observed in the 1 and 3 kg medicine ball throws (R: 5.8 and 8.1%, respectively; RA: 5.7 and 8.7%, respectively; CT: 6.2 and 8%, respectively, p<0.001), in the counter movement vertical jump and in the standing long jump (R: 5.1 and 5.2%, respectively; RA: 4.2 and 7%, respectively; CT: 10.2 and 6.4%, respectively, p <0.001). In addition, the training period induced gains in the 20m time (R: 2.1%; RA: 2.1%; CT: 2.3%, p<0.001). It was shown that the experimental groups (RA, CT, and R) increased VO₂max, muscular strength and explosive strength from pre- to post-training. The higher gains were observed for concurrent training when it was performed in different sessions. These results suggest that concurrent training in two different sessions appears to be an effective and useful method for training-induced explosive strength and VO₂max in prepubertal children. This could be considered an alternative way to optimize explosive strength training and cardiorespiratory fitness in school-based programs.

Key words: Resistance, Aerobic, Exercise, Youth, Power.

Introduction

Physical fitness has declined worldwide in recent decades among children and adolescents (Matton et al., 2007). The effect of a sedentary lifestyle has become a major public health threat (Moro et al., 2014) that is highly associated with cardiovascular, cardiorespiratory and musculoskeletal diseases (McPhail et al., 2014). Nowadays, physical fitness has emerged as a determinant factor of current and future health status (Ortega et al., 2008; Smith et al., 2014) and as a main element for the preservation and enhancement of health, quality of life, and holistic development during childhood (Marta, 2012). Moreover, it is often assumed that physical activity during childhood and adolescence has a positive influence on adult health (Mäkkinen et al., 2010). Here, schools could provide an excellent setting to enhance and promote physical activity by implementing safe training programs (Marques et al., 2011; Marta et al., 2013b).

The children should benefit from the development of strength and cardiovascular parameters and these two important health-related physical fitness components (Ortega et al., 2008; Taanila et al., 2011). The concurrent training, by combining aerobic and resistance regimens would allow children to associate the benefits of both activities into a single training session (Cadore & Izquierdo, 2013; Pugh et al., 2015). However, Glowacki et al. (2004) reported that it could hinder aerobic adaptations and attenuation of strength development because of an inhibitory effect on muscle (García-Pallarés & Izquierdo, 2011; Izquierdo et al., 2005). This effect is known as the “interference phenomenon” (Dudley & Djamil, 1985; García-Pallarés & Izquierdo, 2011). Afterwards, it was reported that concurrent training impairs the development of strength and muscular power but did not affect the development of aerobic capacity compared to both forms of stand-alone training (Izquierdo-Gabarren et al., 2010; Santos et al., 2012). Nevertheless, some studies have shown no antagonistic effects on strength (McCarthy et al., 2002) or aerobic performance (Mikkola et al., 2007) following concurrent training. It seemed that the physiological adaptations that followed concurrent training are dependent on the type and degree of the stimulus applied during the training session (Baar, 2006) and the incorporation of recovery post training (Leveritt et al., 1999). These could result in beneficial effects of concurrent training and recent studies tried to clarify it, namely in child population (Marta et al., 2013a, 2013b; Santos et al., 2012).

Other main issue about this methodology is the sequential order for better results. Two decades ago, Sale et al. (1990) reported that concurrent training in the same day instead of different days might inhibit the strength development but not VO_2 max. Recently, Chtara et al. (2005) confirmed that aerobic training followed by resistance training produced greater improvements in aerobic performance than the reverse order or the separating the training

methods, thus highlighting the relevance of concurrent training. On this, it is important to note that this study was conducted in adults. The inconsistencies across these findings may be explained by the studies designs and/or training protocols (Leveritt et al., 2003). These included the mode of aerobic exercise, variations in the intensity and volume of the strength and aerobic training, different sequences of the resistance and aerobic training sessions, distinct recovery periods between the resistance and aerobic sessions and variations in the frequency of training sessions per week (Arazi et al., 2011; Fyfe et al., 2014). Nevertheless, the effects of concurrent resistance and aerobic training and its consequences in prepuberty are yet to be investigated.

Along with the scarce results regarding the effects of resistance training and aerobic combinations, to the authors' best knowledge, there are no data regarding the effect of intra-session concurrent aerobic and resistance training or separately components in prepubertal population. Such data would give insight into the influence of concurrent training in explosive strength adaptation and aerobic capacity. Therefore, the current study aimed to compare the effects of an 8-week of the stimulus training period with different training activities performed during the same training session or during different training sessions on explosive strength and $VO_2\text{max}$ parameters in prepubertal children. The established hypothesis submitted in this article is that prepubertal children can increase their explosive strength performances by concurrent training sessions conducted separately over a consecutive 8-week period. We also hypothesize that $VO_2\text{max}$ increases independently from the different combination approaches.

Methods

Experimental Approach to the Problem

The aim of the current study was to compare the effects of 8-week training periods of resistance training alone (R), concurrent resistance and aerobic training in the same session (RA) or in two different sessions (CT) on explosive strength and $VO_2\text{max}$ in prepubertal children. The study followed a repeated measures design with each participant being randomly assigned into a specific program or a control group (no training program), and evaluated in pre- and post-test momentum. Concerning the training protocol applied, it was verified in previous studies (Marta et al., 2013b; Santos et al., 2012) strength and cardiovascular improvements in children using the same training protocol. Based on those studies and in the knowledge of an experienced coach and researcher, it was structured a training program, comprising specific sets, repetitions and drills. Moreover, concurrent resistance and aerobic training in different sessions was chosen because there were no reports about its effects in prepubertal children.

Subjects

The sample consisted of 168 prepubertal children (aged 10.9 ± 0.5 years) from the school cluster Santa Clara (Guarda, Portugal), that were randomly assigned into different training programs. The height and body mass of the entire sample was as follows: 1.43 ± 0.07 m, and 40.0 ± 8.8 kg, respectively.

The inclusion criteria were children aged between 10 and 11.5 years old (without a chronic pediatric disease or orthopedic limitation and without a regular oriented extra-curricular physical activity (i.e., practice of some sport in an academy). For the entire sample, participation in a minimum of 14 or 30 training sessions (depending the experimental group) was required to be included in the analysis.

Before data collection and the beginning of the training, each participant reported any health problems, physical limitations, physical activity habits and training experiences for the last 6 months. Thereafter, maturity levels based on Tanner stages (Duke et al., 1980) were self-assessed, and to minimize the effects of growth, only children that were self-assessed in Tanner stages I-II were selected. No subject had regularly participated in any form of training program prior to this experiment. Efforts were made to collect a sample for making comparable groups. After local ethics board approval, ensuring compliance with the declaration of Helsinki, the participants (prepubertal children) were informed about the study procedures, risks and benefits, and a written informed consent was signed by the parent/guardian of the subjects.

Procedures

Sample Procedures

One hundred and sixty eight healthy children recruited from a Portuguese public high school were randomly assigned to 3 experimental groups (8-week training, twice a week, from January 14 to March 15, 2013) and 1 control group (C) as follows: 1 group performing resistance training alone (R: n= 41, 22 girls, 19 boys); another group performing concurrent resistance and aerobic training in the same session (RA: n= 45, 24 girls, 21 boys); the third performing concurrent resistance and aerobic training in different sessions (CT: n= 38, 17 girls, 21 boys); and the control group (C: n= 44, 23 girls, 21 boys) - no training program. This last group followed the physical education class curriculum and did not have a specific training program. The assigned groups were determined by a chance process (a random number generator on a computer) and could not be predicted. This procedure was established according to the "CONSORT" statement. The participants were randomly assigned into 1 of 4 intervention arms. Randomization was performed using R software version 2.14 (R Foundation

for Statistical Computing). Before the start of the training, all the sample subjects attended physical education classes twice a week, with duration of 45 and 90 minutes each class, respectively. Typical physical education classes with an intensity low to moderate included various sports (team sports, gymnastics, dance, adventure sports, among others) with an evident pedagogical focus.

Training Procedures

The training program was implemented additionally to physical education classes. Prior to the training, the subjects warmed up for approximately 10 minutes with low to moderate intensity exercises (e.g., running, sprints, stretching and joint specific warm-up). Joint-rotations included slow circular movements, both clockwise and counter-clockwise, until the entire joint moved smoothly. Stretching exercises included back and chest stretches, shoulder and side stretches, wrist, waist, quadriceps, groin, and hamstring stretches. At the end of the training sessions, all subjects performed 5 minutes of static stretching exercises such as kneeling lunges, ankle over knee, rotation and hamstrings. After the warm-up period, all the training groups were submitted to a resistance training program composed of 1 and 3 kg medicine ball throws, jumps onto a box (from 0.3 to 0.5 m), vertical jumps above a 0.3-0.5 m hurdle and sets of 30 to 40 m of speed running.

After completion of the resistance training for the RA, CT and R groups, the RA group performed a 20m shuttle run exercise, whereas the CT group performed a 20m shuttle run exercise in an alternate session (on the next day) after the warm-up. This aerobic task was developed based on an individual training volume that was set to approximately 75% of the established maximum aerobic volume achieved on a previous test. After 4 weeks of training, the RA and CT subjects were reassessed using 20m shuttle run tests to readjust the volume and intensity of the 20m shuttle run exercise. Each training session lasted approximately 45 minutes (resistance training) to 60 minutes (concurrent training). It is important to mention that CT performed resistance training alternate with aerobic training in different days (Resistance - Aerobic - Resistance - Aerobic). The rest period between sets was 1 minute and that between exercises was 2 minutes. Both R and RA trained on the same day of the week (with 2/3 days between training sessions) and at the same morning hour. CT trained between Monday and Thursday (with 3 days between training sessions) on the same morning hour that R and RA groups.

Before the start of the training, subjects completed two familiarization sessions to practice the drill and routines they would further perform during the training period (i.e., power training exercises and 20m shuttle run test). During this time, the children were taught about the proper technique on each training exercise, and any of their questions were properly answered to clear out any doubts. During the training program there was a constant concern to ensure the necessary security and maintenance of safe hydration levels, as well as to

encourage all children to do their best to achieve the best results. Clear instructions about the importance of adequate nutrition were also delivered. For the 20m shuttle run, the instructions were given with the aid of a multi-stage fitness test audio CD of the FITNESSGRAM® test battery. Throughout the pre- and experimental periods, the subjects reported their non-involvement in additional regular exercise programs for developing or maintaining strength and aerobic performance besides institutional regular physical education classes. A more detailed analysis of the program can be found in table 1.

Table 1 - Training Program Design (sets x repetitions/distances).

1kg Ball-Throw - Chest 1 kg Medicine Ball Throw (cm); 3kg Ball-Throw - Chest 3kg Medicine Ball Throw (cm); SL Jump - Standing Long Jump (cm); CM Jump - Counter Movement Vertical Jump (cm); 20m Sprint - 20m Sprint Running (s); MAV- maximal individual aerobic volume.

Sessions						
Exercise	1	2	3	4	5	6
1kg Ball-Throw	2x8	2x8	2x8	2x8	2x8	2x8
3kg Ball-Throw	2x8	2x8	2x8	2x8	2x8	2x8
SL Jump	2x4	2x4	2x4	2x4	2x4	2x4
CM Jump	1x5	1x5	1x5	1x5	2x5	2x5
20m Sprint	2x20 m	2x20 m	2x20 m	2x20 m	3x20 m	3x20 m
20m Shuttle Run (MAV)	70%	70%	70%	70%	75%	75%
Sessions						
Exercise	7	8	9	10	11	12
1kg Ball-Throw	2x8	2x8	3x8	3x8	3x8	3x8
3kg Ball-Throw	2x8	2x8	2x8	2x8	3x6	3x6
SL Jump	2x4	2x4	3x4	3x4	3x4	3x4
CM Jump	2x5	2x5	2x5	2x5	3x5	3x5
20m Sprint	3x20 m	3x20 m	3x20 m	3x20 m	3x30 m	3x30 m
20m Shuttle Run (MAV)	75%	75%	75%	75%	80%	80%
Sessions						
Exercise	13	14	15	16		
1kg Ball-Throw	3x8	3x8	3x8	3x8		
3kg Ball-Throw	3x6	3x6	3x6	3x6		
SL Jump	4x4	4x4	4x4	4x4		
CM Jump	3x5	3x5	3x5	3x5		
20m Sprint	3x30 m	3x30 m	3x30 m	3x30 m		
20m Shuttle Run (MAV)	80%	80%	80%	80%		

The experimental groups were assessed for upper and lower body explosive strength (chest 1 and 3 kg medicine ball throws and jumps, respectively), running speed (20m sprint running), and VO_2 max (20m shuttle run test) before and after the 8-weeks of the training program. The testing assessment procedures were always conducted in the same indoor environment, and the same weekly in the schedule. Each subject was familiarized with the power training tests (ball throws, jumps, and sprint) and with the 20m multistage shuttle run test. The same

researcher performed the training program, anthropometric and physical fitness assessments, and data collection.

Testing Procedures

Anthropometric Measurements. All anthropometric measurements were assessed according to international standards for anthropometric assessment (Marfell-Jones et al., 2006) and were obtained prior to any physical performance test. The participants were barefoot and wore only underwear. Body mass (in kg) was measured to the nearest 0.1 kg using a standard digital floor scale (Seca, model 841, Germany). To evaluate body height (in cm), a precision stadiometer with a scale range of 0.10 cm was used (Seca, model 214, Germany).

20-meter Multistage Shuttle Run. This test involved continuous running between 2 lines 20m apart in time to recorded beeps. The subjects ran between the 2 lines, turning when signalled by the recorded beeps. After about 1 min, a sound indicates an increase in speed, and the beeps will be closer together. This continues each minute (level). The common version with an initial running velocity of 8.5km/h and increments of 0.5km/h each minute (Léger et al., 1988) was used. When the participants failed to reach the line on 2 consecutive occasions, they were stopped and the number of completed 20m laps was recorded. Estimated VO_2max ($\text{ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$) was calculated by Léger's equation (Léger et al., 1988). The 20m Shuttle Run test has shown an ICC of 0.97.

Chest Medicine Ball Throw (1 and 3 kg). This test was performed according to the protocol described by Mayhew et al. (1997). The subjects were seated with the backside of their trunk touching a wall. They were required to hold medicine balls (Bhalla International - Vinex Sports, Meerut - India) that weighed 1 kg (Vinex, model VMB-001R, perimeter 0.72 m) and 3 kg (Vinex, model VMB-003R, perimeter 0.78 m) with their hands (abreast of chest) and throw the ball forward for the maximum possible distance. Hip inflection was not allowed, nor was withdrawal of the trunk away from the wall. Three trials were given, and the furthest throw was measured (in cm) from the wall to the first point at which the ball contacted the floor. One minute of rest was provided between the 3 trials. The intraclass correlation coefficients (ICC) for the chest 1 kg and 3 kg medicine ball throws data were both ~0.98.

Standing Long Jump (SL Jump). This test was assessed using the EUROFIT test battery (Adam et al., 1988). The participants stood with their feet slightly apart (toes behind a starting line) and jumped as far forward as possible. Three trials were given, and the furthest distance was measured (in cm) from the starting line to the heel of the foot nearest to this line. The standing long jump has shown an ICC of 0.94.

Counter Movement Vertical Jump (CM Jump). This test was conducted on a contact mat that was connected to an electronic power timer, control box and handset (Globus Ergojump, Italy). From a standing position, with their feet shoulder-width apart and hands placed on the pelvic girth, the subjects performed a counter movement with their legs before jumping. Such movement makes use of the stretch-shorten cycle in which the muscles are pre-stretched before shortening in the desired direction (Linthorne, 2001). The subjects were informed that they should try to jump vertically as high as possible. Each participant performed three jumps with a 1 minute recovery between attempts. The highest jump (in cm) was recorded. The counter movement vertical jump has shown an ICC of 0.91.

20-meter Sprint Running (20m Sprint). On a 20m length track, the subjects were required to cover the distance in the shortest time possible. The time (in sec) to run 20m was obtained using photocells (Brower Timing System, Fairlee, VT, USA). Three trials were performed, and the best time scored (seconds and hundredths) was registered. The 20m sprint running (time) has shown an ICC of 0.97.

Statistical Analysis

Statistical analyses were performed using Statistical Package for Social Sciences (SPSS) v22.0® for Windows and statistical significance was set at $p \leq 0.05$. Standard statistical methods were used to calculate the means and standard deviations. The normality of the distribution was verified by the Kolmogorov-Smirnov test. The within-subject reliability of the aerobic and strength tests was determined using the intraclass correlation (ICC) and 95% confidence interval (CI 95%). We performed a univariate analysis (one-way ANOVA and Qui-Squared test) to compare physical performance variables, age, body mass index (BMI) and body fat percentage (BFP) at baseline between groups. To evaluate the changes from pre-treatment and post-treatment we used a paired t-test for each group and we performed a multivariate analysis of covariance (MANCOVA) with sex and group as fixed-effect and age, BMI, BFP, and physical performances variables as covariates. The normality of the residuals was validated by the Kolmogorov-Smirnov test, and the homogeneity of the variance-covariance matrix was validated by the Box M test. This assumption was not verified, and we used the Pillai's trace test statistics. An analysis of covariance (ANCOVA) was estimated for each dependent variable, followed by Bonferroni's post-hoc comparison tests. From the ANCOVA, it was also possible to analyze the effect size of group on the physical performance variables.

Results

At baseline (table 2), there were no differences among the groups on sex, age, BMI, BFP, and all physical performance variables, except on $VO_2\max$ ($F(1,161) = 11.49$, $p < 0.001$). Bonferroni test showed that the $VO_2\max$ was significantly lower on the CT group than the other experimental groups.

Table 2 -Univariate Analysis.

Percentage (%) of sex, mean \pm SD of age, body mass index (BMI), body fat percentage (BFP), maximal oxygen uptake ($VO_2\max$), and muscle strength variables in resistance training alone (R), intra-session concurrent resistance and aerobic training (RA), concurrent training performed in different sessions (CT), and control group (C). $VO_2\max$ - Multistage Shuttle Run ($ml \cdot kg^{-1} \cdot min^{-1}$); 1kg Ball-Throw - Chest 1 kg Medicine Ball Throw (cm); 3kg Ball-Throw - Chest 3kg Medicine Ball Throw (cm); SL Jump - Standing Long Jump (cm); CM Jump - Counter Movement Jump (cm); Sprint - 20m Sprint Running (s).

	R	RA	CT	C	p
Sex					
#1 Female, n (%)	22 (53.7)	24 (53.3)	17 (44.7)	23 (52.3)	0.841
Male, n (%)	19 (46.3)	21 (46.7)	21 (55.3)	21 (47.7)	
Age, mean + SD	10.8 \pm 0.4	10.8 \pm 0.5	11.0 \pm 0.5	10.9 \pm 0.5	0.062
BMI, mean + SD	19.3 \pm 3.4	19.3 \pm 3.0	19.2 \pm 2.9	19.2 \pm 3.1	0.997
BFP, mean + SD	22.5 \pm 7.7	22.6 \pm 8.2	21.4 \pm 8.6	21.6 \pm 7.0	0.845
$VO_2\max$	44.1 \pm 3.1	44.4 \pm 3.3	41.1 \pm 2.2	44.8 \pm 3.6	0.000****
#2 1kg Ball-Throw	347.8 \pm 59.8	358.2 \pm 62.6	336.5 \pm 72.7	364.3 \pm 55.9	0.205
3kg Ball-Throw	224.0 \pm 38.9	224.4 \pm 40.8	235.1 \pm 49.6	224.3 \pm 44.3	0.608
SL Jump	124.7 \pm 13.1	130.6 \pm 17.5	128.3 \pm 23.0	132.6 \pm 19.6	0.240
CM Jump	21.3 \pm 4.5	22.3 \pm 4.0	23.8 \pm 6.1	22.2 \pm 4.7	0.154
20m Sprint	4.4 \pm 0.2	4.4 \pm 0.3	4.4 \pm 0.4	4.4 \pm 0.3	0.997

**** $p < 0.001$; #1 - Qui-squared test; #2 - One-way ANOVA

Test - retest reliability measurements of physical performance variables (table 3) showed ICC values from 0.808 to 0.991, demonstrating very good results.

Table 3 - Intraclass correlation (95% confidence interval for ICC) of maximal oxygen uptake ($VO_2\max$) and muscle strength variables in resistance training alone (R), intra-session concurrent resistance and aerobic training (RA), concurrent training performed in different sessions (CT), and control group (C).

	Overall	R	RA	CT	C
$VO_2\max$	0.850 (0.802 - 0.887)	0.915 (0.847 - 0.954)	0.873 (0.781 - 0.928)	0.808 (0.660 - 0.895)	0.914 (0.848 - 0.952)
1kg Ball-Throw	0.979 (0.972 - 0.985)	0.985 (0.972 - 0.992)	0.986 (0.974 - 0.992)	0.991 (0.983 - 0.995)	0.982 (0.968 - 0.990)
3kg Ball-Throw	0.951 (0.934 - 0.963)	0.981 (0.964 - 0.990)	0.967 (0.940 - 0.981)	0.981 (0.964 - 0.990)	0.912 (0.844 - 0.951)
SL Jump	0.925 (0.899 - 0.944)	0.963 (0.932 - 0.980)	0.940 (0.894 - 0.967)	0.969 (0.942 - 0.984)	0.870 (0.773 - 0.927)
CM Jump	0.898 (0.864 - 0.924)	0.931 (0.875 - 0.963)	0.929 (0.874 - 0.960)	0.855 (0.739 - 0.922)	0.938 (0.888 - 0.965)
20m Sprint	0.970 (0.959 - 0.978)	0.963 (0.931 - 0.980)	0.973 (0.951 - 0.985)	0.986 (0.974 - 0.993)	0.973 (0.952 - 0.985)

Explosive strength measures have increased significantly on R group, except on VO₂max. Explosive strength measures have also increased significantly on RA and CT groups. C group presented no statistical increases on the explosive strength measures (table 4). These results did corroborate the hypothesis that VO₂max increases independently from the different combination approaches.

Table 4 - Mean \pm SD and paired t-test to maximal oxygen uptake (VO₂max) and muscle strength variables pre- and post-training momentum in resistance training alone (R), intra-session concurrent resistance and aerobic training (RA), concurrent resistance and aerobic training in different sessions (CT), and control group (C). VO₂max - Multistage Shuttle Run (ml.kg⁻¹.min⁻¹); 1kg Ball-Throw - Chest 1 kg Medicine Ball Throw (cm); 3kg Ball-Throw - Chest 3kg Medicine Ball Throw (cm); CM Jump - Counter Movement Jump (cm); SL Jump - Standing Long Jump (cm); 20m Sprint - 20m Sprint Running (s); **** p < 0.001.

		Pre	Post	Difference (Pre - Post)	p
R	VO ₂ max	44.1 \pm 3.1	44.4 \pm 4.0	-0.4 \pm 1.5	0.124
	1kg Ball-Throw	347.8 \pm 59.8	368.1 \pm 63.8	-20.3 \pm 10.8	0.000****
	3kg Ball-Throw	224.0 \pm 38.9	242.2 \pm 41.6	-18.2 \pm 7.9	0.000****
	SL Jump	124.7 \pm 13.1	131.2 \pm 14.9	-6.5 \pm 3.8	0.000****
	CM Jump	21.3 \pm 4.5	22.4 \pm 5.2	-1.1 \pm 1.8	0.000****
	20m Sprint	4.4 \pm 0.2	4.3 \pm 0.2	0.1 \pm 0.1	0.000****
RA	VO ₂ max	44.4 \pm 3.3	46.1 \pm 4.1	-1.7 \pm 1.9	0.000****
	1kg Ball-Throw	358.2 \pm 62.6	378.6 \pm 63.7	-20.4 \pm 10.7	0.000****
	3kg Ball-Throw	224.4 \pm 40.8	244.0 \pm 42.3	-19.5 \pm 10.8	0.000****
	SL Jump	130.6 \pm 17.5	139.8 \pm 20.4	-9.1 \pm 6.6	0.000****
	CM Jump	22.3 \pm 4.0	23.3 \pm 4.3	-0.9 \pm 1.6	0.000****
	20m Sprint	4.4 \pm 0.3	4.3 \pm 0.3	0.1 \pm 0.1	0.000****
CT	VO ₂ max	41.1 \pm 2.2	44.2 \pm 2.8	-3.1 \pm 1.5	0.000****
	1kg Ball-Throw	336.5 \pm 72.7	357.5 \pm 70.7	-21.0 \pm 9.4	0.000****
	3kg Ball-Throw	235.1 \pm 49.6	254.0 \pm 47.9	-18.9 \pm 9.4	0.000****
	SL Jump	128.3 \pm 23.0	136.5 \pm 23.3	-8.2 \pm 5.7	0.000****
	CM Jump	23.8 \pm 6.1	26.2 \pm 7.9	-2.4 \pm 3.8	0.000****
	20m Sprint	4.4 \pm 0.4	4.3 \pm 0.4	0.1 \pm 0.1	0.000****
C	VO ₂ max	44.8 \pm 3.6	45.0 \pm 4.0	-0.2 \pm 1.6	0.386
	1kg Ball-Throw	364.3 \pm 55.9	367.5 \pm 59.4	-3.3 \pm 10.8	0.053
	3kg Ball-Throw	224.3 \pm 44.3	229.9 \pm 45.2	-5.5 \pm 18.8	0.057
	SL Jump	132.6 \pm 19.6	135.7 \pm 23.2	-3.1 \pm 11.0	0.066
	CM Jump	22.2 \pm 4.7	22.6 \pm 5.3	-0.4 \pm 1.8	0.103
	20m Sprint	4.4 \pm 0.3	4.4 \pm 0.3	0.0 \pm 0.1	0.076

Changes from pre- to post training momentum were observed with paired t-test (table 4) showed better results on CT group in VO₂max, 1kg Ball-Throw, and CM Jump tests compared to the other experimental groups; RA group presented better results than the other

experimental groups on 3kg Ball-Throw and SL Jump. On 20m sprint all experimental groups showed similar results.

The results of MANCOVA showed that only the group factor presented statistical significance with a medium effect ($\eta_p^2 = 0.293$, $p < 0.001$) on changes of explosive strength and VO_{2max} measures for the different groups, adjusted to the covariate variables. Neither the interaction nor the sex factor were significant. Moreover, medium effect sizes were found on the 1kg Ball-Throw ($\eta_p^2 = 0.357$, $F(3, 160) = 29.58$, $p < 0.001$), 20m sprint ($\eta_p^2 = 0.294$, $F(3, 160) = 22.19$, $p < 0.001$), and VO_{2max} ($\eta_p^2 = 0.374$, $F(3, 160) = 31.87$, $p < 0.001$). Small effect sizes were verified on the 3kg Ball-Throw ($\eta_p^2 = 0.222$, $F(3, 160) = 12.69$, $p < 0.001$), SL Jump ($\eta_p^2 = 0.117$, $F(3, 160) = 7.09$, $p < 0.001$), and on the CM Jump ($\eta_p^2 = 0.088$, $F(3, 160) = 5.17$, $p < 0.01$). Bonferroni test showed on the 1kg Ball-Throw (Figure 1) and 3kg (Figure 2), SL Jump (Figure 3), and 20m sprint (Figure 5) that changes were significantly higher on R, RA and CT groups than C group; increases on the CM Jump were significantly higher on CT group than RA, and C groups (Figure 4). In addition, the VO_{2max} increases more significantly on RA and CT groups than R and C groups (Figure 6).

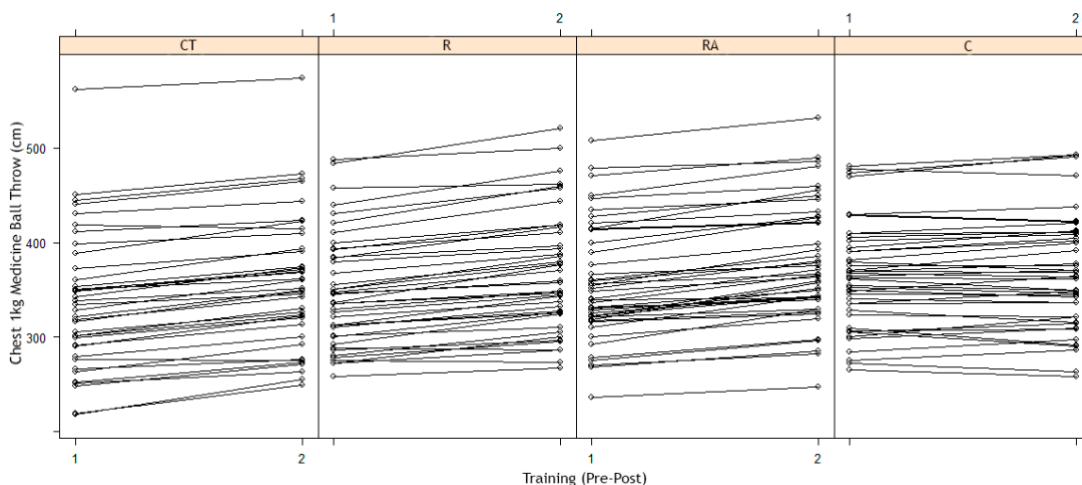


Figure 1. Spaghetti Plot. Obtained values in pre- and post-test of training in resistance training alone (R), intra-session concurrent training (RA), concurrent training performed in different sessions (CT), and control group (C) on chest 1kg medicine ball throw.

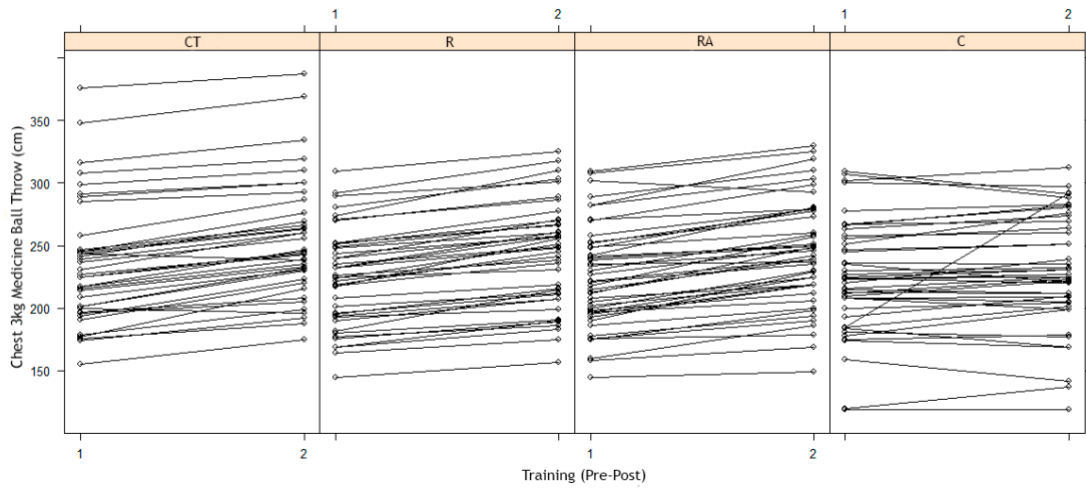


Figure 2. Spaghetti Plot. Obtained values in pre- and post-test of training in resistance training alone (R), intra-session concurrent training (RA), concurrent training performed in different sessions (CT), and control group (C) on chest 3 kg medicine ball throw.

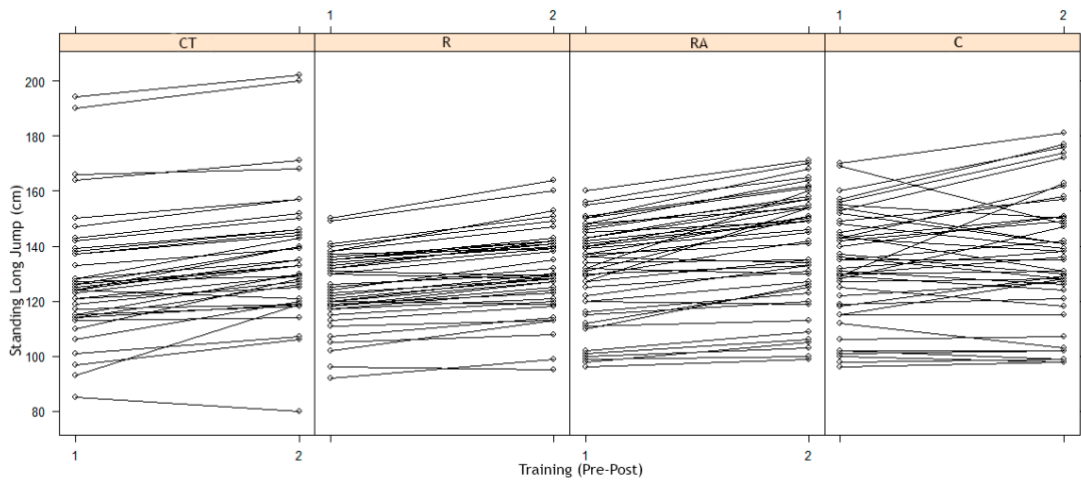


Figure 3. Spaghetti Plot. Obtained values in pre- and post-test of training in resistance training alone (R), intra-session concurrent training (RA), concurrent training performed in different sessions (CT), and control group (C) on standing long jump.

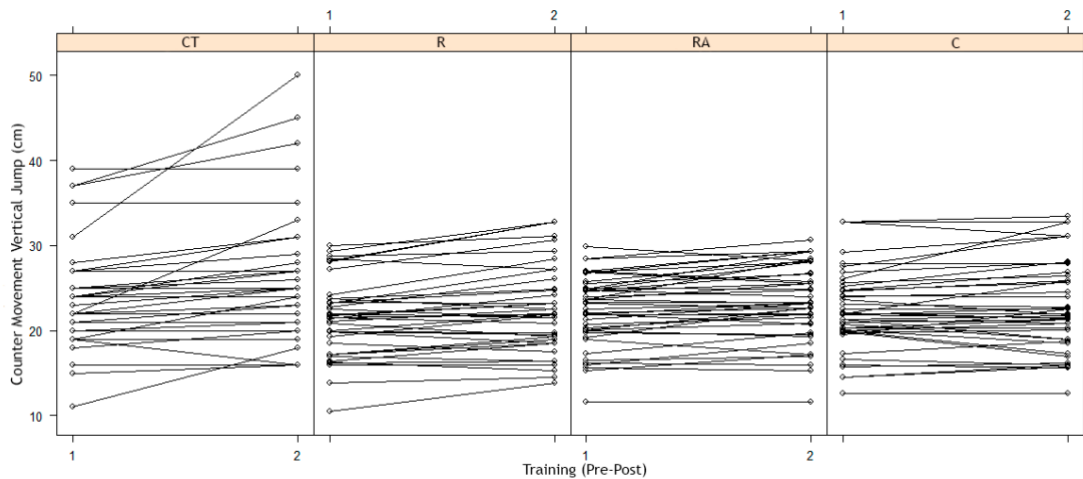


Figure 4. Spaghetti Plot. Obtained values in pre- and post-test of training in resistance training alone (R), intra-session concurrent training (RA), concurrent training performed in different sessions (CT), and control group (C) on counter movement vertical jump.

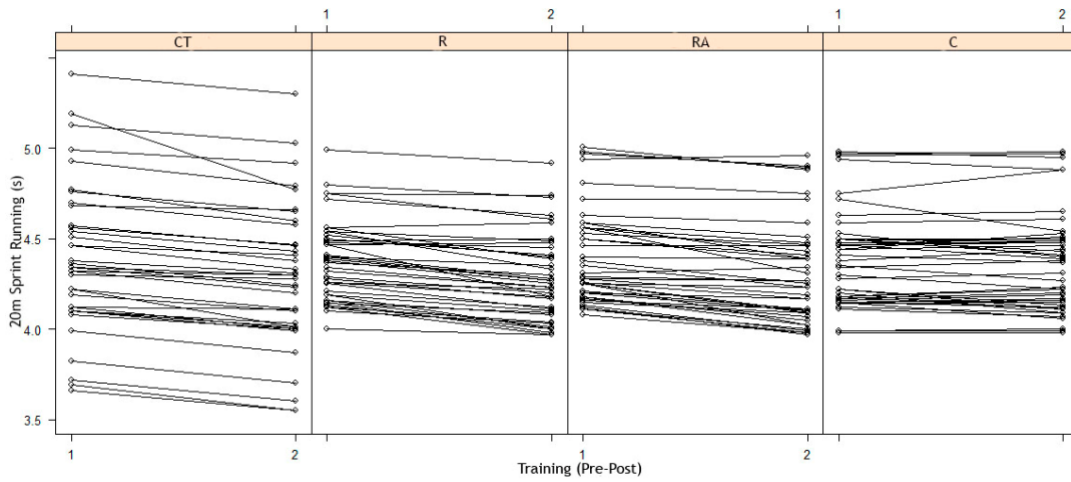


Figure 5. Spaghetti Plot. Obtained values in pre- and post-test of training in resistance training alone (R), intra-session concurrent training (RA), concurrent training performed in different sessions (CT), and control group (C) on 20m sprint running.

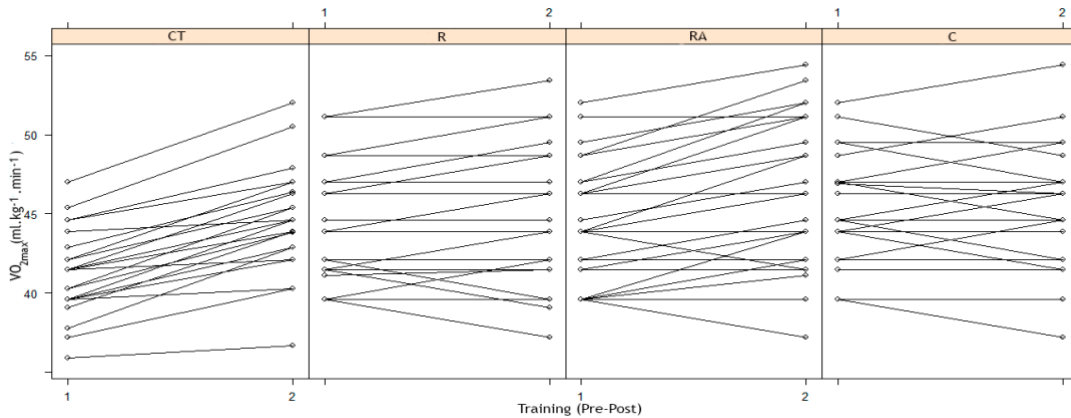


Figure 6. Spaghetti Plot. Obtained values in pre- and post-test of training in resistance training alone (R), intra-session concurrent training (RA), concurrent training performed in different sessions (CT), and control group (C) on maximal oxygen uptake (VO₂max).

With regard to the sex factor, there was found no influence on this factor, adjusted to the covariate variables. On 1kg Ball-Throw ($F(1, 160) = 0.80, p > 0.05$), and 3 kg ($F(1, 160) = 1.51, p > 0.05$) (Figure 7 and Figure 8, respectively), SL Jump ($F(1, 160) = 0.04, p > 0.05$) (Figure 9), CM Jump ($F(1, 160) = 0.80, p > 0.05$) (Figure 10), 20m Sprint ($F(1, 160) = 0.48, p > 0.05$) (Figure 11), and VO₂max ($F(1, 160) = 1.91, p > 0.05$) (Figure 12).

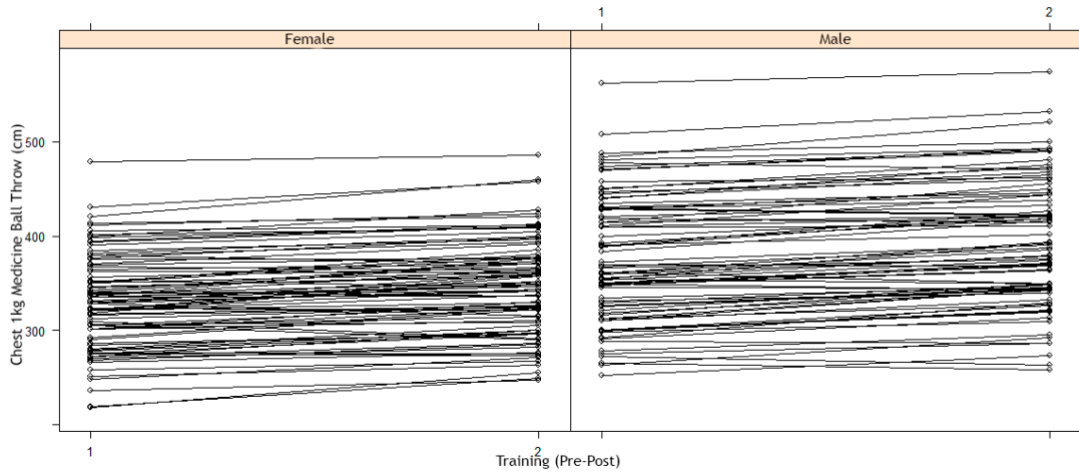


Figure 7. Spaghetti Plot. Obtained values in pre- and post-test of training in prepubertal girls and boys on chest 1kg medicine ball throw (cm).

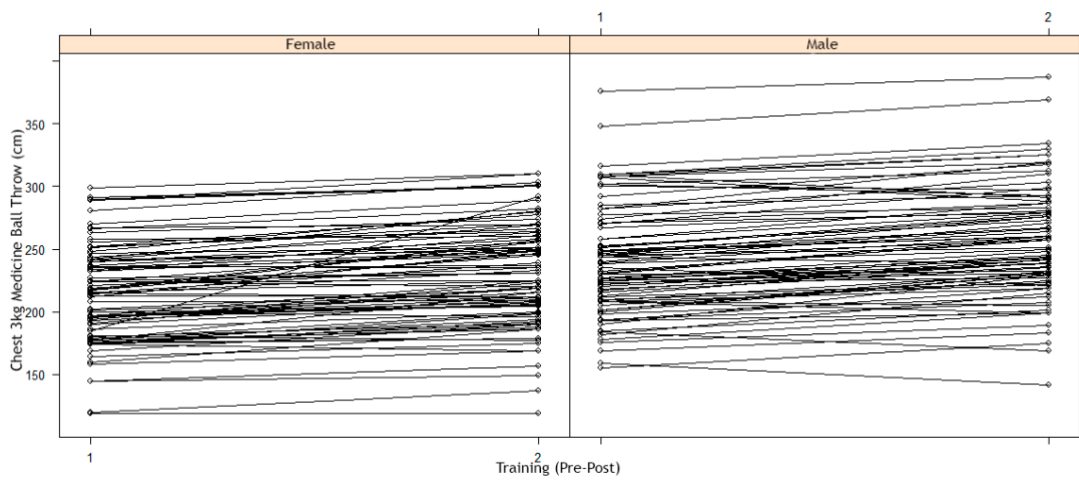


Figure 8. Spaghetti Plot. Obtained values in pre- and post-test of training in prepubertal girls and boys on chest 3kg medicine ball throw (cm).

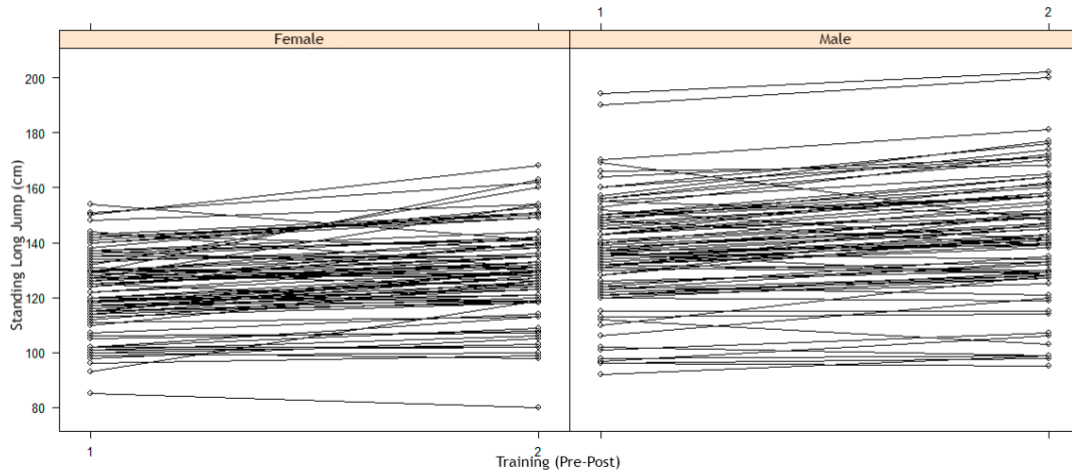


Figure 9. Spaghetti Plot. Obtained values in pre- and post-test of training in prepubertal girls and boys on standing long jump (cm).

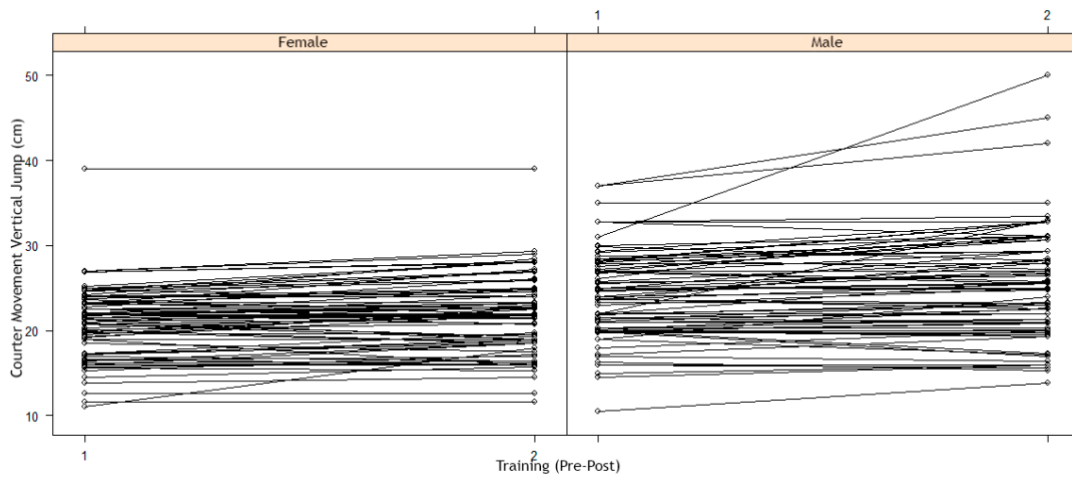


Figure 10. Spaghetti Plot. Obtained values in pre- and post-test of training in prepubertal girls and boys on counter movement vertical jump (cm).

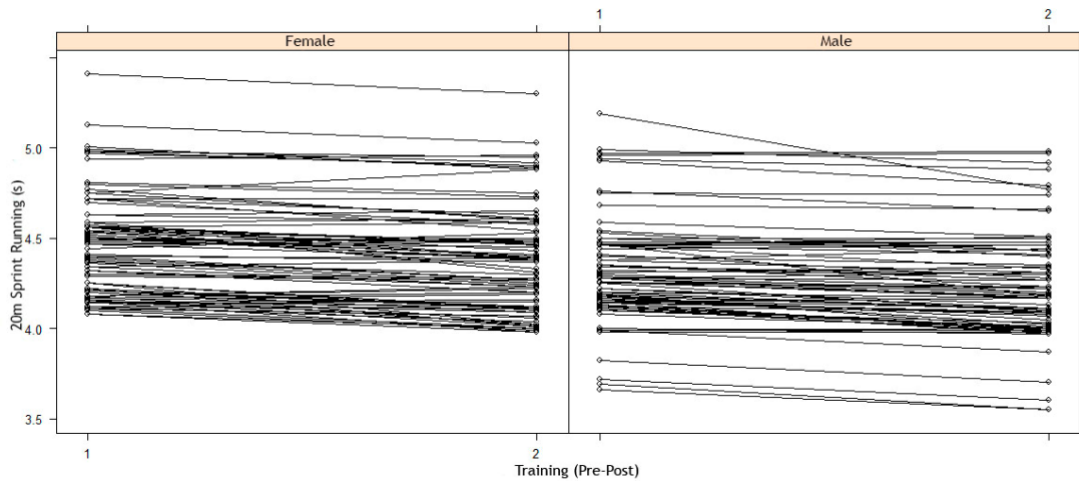


Figure 11. Spaghetti Plot. Obtained values in pre- and post-test of training in prepubertal girls and boys on 20m sprint running (s).

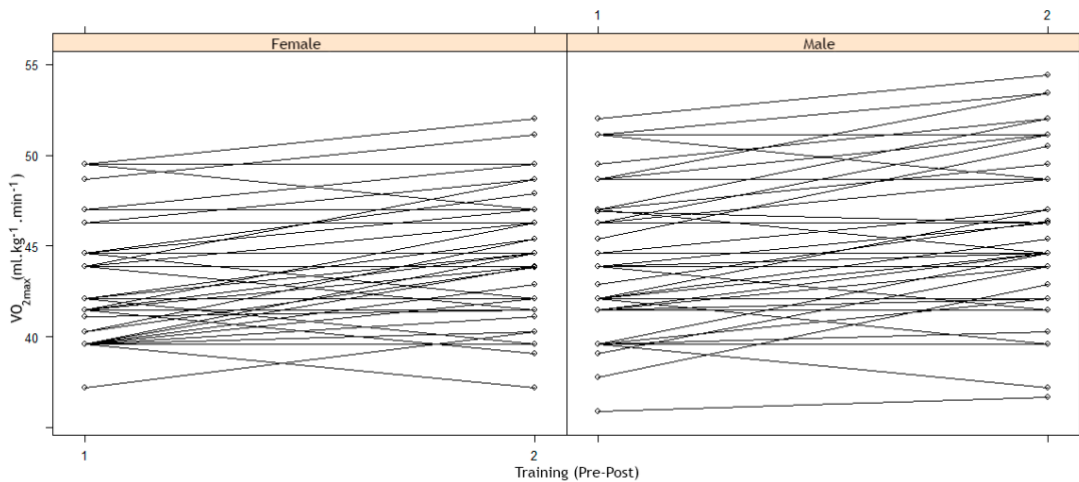


Figure 12. Spaghetti Plot. Obtained values in pre- and post-test of training in prepubertal girls and boys on VO₂max (ml.kg⁻¹.min⁻¹).

Discussion

The main purpose of concurrent training in training on explosive strength and VO₂max in a sample of prepubertal girls and boys. The main results confirmed that explosive strength was improved in all the experimental groups with better results in the concurrent training group, which performed the training in different sessions, followed by the intra-session concurrent training group that performed the training in the same session and finally by the resistance training alone group. In addition, on the VO₂max was shown that RA and CT groups were increased from pre- to post-training momentum. Thus, concurrent training in two different sessions is suggested to be an effective method to increase explosive strength and VO₂max in prepubertal children.

Several studies have suggested that concurrent training could have an interference effect on muscle strength development (García-Pallarés & Izquierdo, 2011; Sale et al., 1990; Santos et al., 2012). The main reasons for these results are deeply related to acute fatigue and with the different neuromuscular adaptations from the aerobic or resistance training (Marta, 2012). Moreover, small reductions in overload during the training period could also compromise adaptations, and no clear findings describe an inhibition in strength or aerobic adaptation by different neuromuscular adaptations (Izquierdo-Gabarren et al., 2010; Marta, 2012). Hereupon, the relevance of these mechanisms either in isolation or together in inhibiting adaptation during concurrent training must be clarified.

The increased explosive strength of the upper and lower limbs that was observed in the training groups (i.e., 1 and 3 kg Ball-Throw, SL Jump, CM Jump), in the 20m sprint and in VO_2 max demonstrate that, although the concurrent training performed in different sessions obtained better results, when performed in the same session and resistance training alone may also be a beneficial training stimuli to improve explosive strength in prepubertal children. These results may have a special significance to optimize exercise programs in prepubertal children. The current data are congruent with the results of previous study (Marta et al., 2013b) in this area that have been conducted with prepubertal children. Furthermore, no differences were found post training in the C group in any variable related to explosive strength, and in the post training VO_2 max in the R group. Our findings are consistent with the results of previous studies (Dorgo et al., 2009; Marta et al., 2013b; Santos et al., 2012), that mentioned that resistance training programs are not effective in improving aerobic fitness in prepubertal children.

Resistance and aerobic training are regularly performed concurrently at school or in extracurricular activities (Santos et al., 2012) in an attempt to obtain gains in several physiologic systems to achieve total conditioning, to meet functional demands, or to improve several health-related components simultaneously (Marta, 2012). Previous studies reported that concurrent training appears to be effective on both strength and aerobic fitness features of prepubertal children but also in adults (Marta et al., 2013b; Shumann et al., 2014). Moreover, performing concurrent training allows the benefits from both aerobic and resistance training to be acquired simultaneously (García-Pallarés & Izquierdo, 2011; Izquierdo-Gabarren et al., 2010; Marta et al., 2013b). Furthermore, introducing both aerobic and muscular fitness is fundamental to promote health and should be a suitable goal in a training program (Taanila et al., 2011).

The current study also showed better results in the groups that performed concurrent training in different sessions. The literature is far from be consensual regarding the efficacy of concurrent training performed on the same day (Craig et al., 1991) or on the alternate days each week (Glowacki et al., 2004). According to Doma & Deakin (2013), strength and aerobic

training performed on the same day appears to impair running performance the following day, and may compromise adaptation compared to alternate - day concurrent training (Dudley & Djamil, 1985; Izquierdo-Gabarren et al., 2010). In addition, Fyfe et al. (2014) reported that concurrent training performed on the same day can lead to increased energy expenditure, which consequently causes a higher saturation and residual fatigue. However, it is worth mentioning that there were no significant differences between the groups. This may be explained by the faster recovery of children when submitted to physical exercise compared with adults (Hatzikotoulas et al., 2009). Indeed, lower muscle glycolytic activity and higher muscle oxidative capacity allows the faster resynthesizing of phosphocreatine in children (Ratel et al., 2002). Regarding to the gender gap, the results seem to suggest that there is no significant effect on training - induced strength or VO_2 max adaptations. These data corroborate the results of previous studies conducted with children, reporting no significant differences in strength and aerobic response related to sex. Marta et al. (2013a) found that sex did not affect training-induced strength or aerobic fitness adaptations in prepubertal children (8- week resistance training program and aerobic training program, 2x1h week, intensity: 75% heart rate maximum). Siegel et al. (1989) also observed that following a similar training period, but using hand-held weights, stretch tubing, balls, and self-supported movements, training responses of boys and girls were similar, although significant differences in favour of boys on all initial strength evaluations have been reported.

Training-induced strength gains during and after puberty in males are associated with increases in fat-free mass, due to the effect of testosterone on muscle hypertrophy. In reverse, smaller amounts of testosterone in females (resulting from enzymatic conversion of androgenic precursors in the adrenal gland) seem to limit the magnitude of training-induced strength gains (Kraemer et al., 1989). However, during preadolescence, beyond the small muscle mass of the girls, the boys still present a reduced muscle mass, because the effects of circulating androgens, particularly testosterone, only manifest themselves at puberty (Ramsay et al., 1990). Regarding the training - induced VO_2 max adaptations in boys and girls, according to Vinet et al. (2003) during pre-adolescence there are no significant sex differences in maximal heart rate and arteriovenous oxygen, and although the stroke volume is significantly higher in boys than in girls, when expressed relative to lean body mass, the difference is no longer significant.

According to our results, concurrent training performed in different sessions is effective to improve explosive strength and VO_2 max in prepubertal children and may emerge as an innovative and support tool for teachers, coaches and researchers and may be used in clubs or YMCA's when appropriately prescribed and supervised. Although the majority of studies on physical fitness have focused on aerobic capacity and have neglected muscular fitness, there is evidence that neuromotor aptitude based on muscular force can be as important as aerobic capacity in the maintenance of health (Armstrong & Welsman, 1997), and both are essential

for promoting health (Taanila et al., 2011). The current study provides both promising results for the application of concurrent training in different sessions to evaluate explosive strength in prepubertal children and remarks for future research in this area. There are some main limitations to be considered: i) different training program design or different methods of organizing training workouts can lead to different training-induced outcomes; ii) the training period of 8 weeks is rather short; iii) different training durations between resistance training and concurrent training groups may have conditioned training-induced gains; iv) it was not possible to elucidate the mechanisms responsible for the observed effects (i.e., no electrophysiological measures); v) the sample included normal-weight, physically active prepubertal children. Thereupon, some care shall be taken when translating these findings to children with different parameters.

Practical Applications

Performing concurrent resistance and aerobic training in different sessions does not impair strength development in healthy prepubertal children, but it seems to be an effective exercise program that can be prescribed as a means to improve explosive strength and aerobic capacity. This should be considered when designing the school-based programs or in the designing of resistance training in sports clubs to improve its efficiency. Thereupon, this innovative and safe methodology provides a new path to reduce the monotony of training or classes and to prepare the individual for a healthy future. It is important to know that training in different sessions can be performed without implications on prepubertal children's growth and health.

Study 3

Does intra-session concurrent resistance and aerobic training order influence training-induced explosive strength and VO₂max in prepubertal children?

Abstract

The aim of this study was to analyse the interference of resistance and aerobic training order over an 8-week period on explosive skills and maximal oxygen uptake (VO₂max) in prepubertal children. One hundred and twenty-eight prepubertal children aged 10-11 years (10.9±0.5 years) were randomly selected and assigned to one of the three groups: intra-session concurrent aerobic prior to (AR: n=39) or after resistance training (RA: n=45) or control group (C: n=44; no training program). The C maintained their baseline level performance, and training-induced differences were found in the experimental groups. Increases were found in the 1 kg and 3 kg medicine ball throws: AR: 3%, 5.5%, p<0.05, p<0.001; RA: 5.7%, 8.7%, p<0.001, respectively; in the counter movement vertical jump and standing long jump: AR: 6.5%, 3.4%, p<0.05; RA: 7%, 4.5%, p<0.001, respectively; in the 20m shuttle run time: AR: 2.3%; RA: 4.6%, p<0.001; and, in the VO₂max: AR: 7.3%, p<0.001; RA: 3.8%, p<0.001 from pre- to post-training. All programs were effective, but RA produced better results than AR for muscle strength variables, and AR produced better results than RA for aerobic capacity variables. The present study explored an unknown issue and added useful information to the literature in this area. These training methods should be taken into consideration to optimize explosive strength and cardiorespiratory fitness training in school-based programs and sports club programs.

Key words: Youth, Power, Cardiorespiratory, Muscular Conditioning, Sequence

Introduction

Concurrent training (i.e., a combination of resistance and aerobic regimens) has become a recurrent topic for researchers due to the controversial results of different experiments (Cadore et al., 2012b, 2014; Chtara et al., 2008; García-Pallarés & Izquierdo, 2011; Izquierdo et al., 2004). Several studies have shown that concurrent training can affect the development of muscle strength and/or power (García-Pallarés & Izquierdo, 2011; Hennessy & Watson, 1994; Izquierdo-Gabarren et al., 2010; Leveritt et al., 2003). In contrast, other experiments have indicated a positive effect of concurrent training on strength (Baker, 2001; Davis et al., 2008a, 2008b; Gorostiaga et al., 1999; Gravelle & Blessing, 2000; Kraemer et al., 1995) and on maximal aerobic capacity (Glowacki et al., 2004; Kraemer et al., 2001; McCarthy et al., 1995; Silva et al., 2012).

Whereas multiple studies have investigated concurrent training in young, adult or even elderly populations (Chtara et al., 2005, Davis et al., 2008a; Holviala et al., 2010; Marta et al., 2013b; Takeshima et al., 2007), a limited number of studies have explored concurrent training in prepubertal (Marta et al., 2013b) and pubertal children (Santos et al., 2012). The majority of the pediatric research has focused on activities that enhance cardiorespiratory fitness and recent findings indicate that resistance training offer benefits to children and adolescents (Faigenbaum & Myer, 2010; Kemper et al., 2000; Santos et al., 2012). Meanwhile, improvements in muscular fitness, speed and agility, rather than cardiorespiratory fitness, seem to have a positive effect on skeletal health (Kemper et al., 2000; Santos et al., 2012). Concurrent aerobic training and resistance training have the potential to bring about gains in cardiorespiratory and muscular fitness simultaneously (Kang & Ratamess, 2014). Moreover, children and adolescents involved in physical education classes often perform resistance and aerobic training concurrently in an effort to achieve specific adaptations to both forms of training (Izquierdo-Gabarren et al., 2010; Santos et al., 2012). Furthermore, Marta et al. (2013b), showed that concurrent training is equally effective on training-induced explosive strength as resistance training alone in prepubertal children. Moreover, this experiment only compared the effects of intra-session concurrent training vs. resistance training alone. In fact, concurrent training order in prepubertal children is another important issue that still has not been investigated. According to Kang & Ratamess (2014), most studies suggest that different intra-session training order produces no significant differences in training-induced adaptations because both combinations generate similar improvements in cardiorespiratory and muscular fitness. Furthermore, those studies also found that either training order can have its own advantages that could make concurrent training more effective. For example, Chtara et al. (2005) observed that performing aerobic training prior to resistance training

could improve running performance and $VO_2\text{max}$ to a greater extent than the reverse order. Nevertheless, Cadore et al. (2012a, 2012b) suggested that for intra-session concurrent training protocols, the strength gains might be optimized with intra-session resistance prior to aerobic training order. To the best of our knowledge, no research has been conducted concerning the effects of intra-session concurrent resistance and aerobic training order on training-induced explosive strength in prepubertal populations; thus, research in this area seems useful and relevant.

Therefore, the purpose of the current study was to analyze the interference of intra-session concurrent resistance and aerobic training order over an 8-week period on explosive skills and maximal oxygen uptake ($VO_2\text{max}$) in a large sample of prepubertal children. We hypothesized that the prepubertal children would show increased explosive strength following the 8-week intra-session concurrent resistance prior to aerobic training order, and that the prepubertal children would show increases $VO_2\text{max}$ independent of the training approach.

Methods

Experimental Approach to the Problem

The aim of the current study was to analyze the interference of intra-session concurrent resistance and aerobic training order (resistance prior to aerobic training (RA) or aerobic prior to resistance training (AR)) over an 8-week period on explosive strength and maximal oxygen uptake ($VO_2\text{max}$) in prepubertal children. The study followed a repeated measures design, with each participant randomly assigned to a specific training program (concurrent resistance and aerobic training or concurrent aerobic and resistance training) or the control group (no training regimen). The 8-week period and study design were developed based in specific studies conducted in prepubertal children which performed in similar periods (Marta et al., 2013a, 2013b). Based on those studies, and the knowledge of an experienced coach and researcher, a training program composed of specific sets, repetitions and exercises was designed. The children were evaluated for changes in strength (chest 1 and 3 kg medicine ball throw, standing long jump, counter movement vertical jump, and a 20m sprint running) and cardiovascular parameters ($VO_2\text{max}$) before and after 8 weeks of training.

Subjects

The sample consisted of one hundred and twenty-eight healthy prepubertal children (aged 10.91 ± 0.51 years) from the Santa Clara school cluster (Guarda, Portugal) who were randomly

assigned to the different training programs or the control group (C). The average height and body mass of the entire sample were 1.43 ± 0.08 m and 39.12 ± 8.60 kg, respectively. The inclusion criteria were children aged 10 to 11.5 years (in 5th or 6th grade) without a chronic pediatric disease or orthopedic limitation and without regular extra-curricular physical activity (i.e., practice of a sport at an academy).

Procedures

Sample Procedures

Children were recruited from a Portuguese public high school and randomly assigned to two experimental groups (8-week training, twice a week, from January 14 to March 15, 2015) and one control group (C). The groups were intra-session concurrent resistance prior to aerobic training group (RA: n=45, 24 girls, 21 boys), intra-session concurrent aerobic prior to resistance training group (AR: n= 39, 16 girls, 23 boys), and a control group (C: n=44, 23 girls, 21 boys) with no training protocol. This last group followed the physical education class curriculum and did not undergo a specific training program. The assigned groups were determined randomly using a random number generator on a computer and could not be predicted. This procedure was established according to the “CONSORT” statement, which can be found at <http://www.consort-statement.org/>. The participants were randomly assigned to 1 of 3 intervention arms. Randomization was performed using R software version 2.14 (R Foundation for Statistical Computing, and developed by Bell Laboratories- Lucent Technologies, in Vienna, Austria). Before the start of training, all subjects attended physical education classes twice a week, with one class lasting 45 minutes and the other lasting 90 minutes. Typical physical education classes have low to moderate intensity and involve the performance of various sports (team sports, gymnastics, dance, adventure sports, etc.) with an evident pedagogical focus.

A detailed analysis of the sample, program, training and testing procedures can be found in Study 2.

Statistical Analysis

Standard statistical methods were used to calculate means and standard deviations. The normality of the data distribution was evaluated by applying the Kolmogorov-Smirnov test. The within-subject reliabilities of the aerobic and strength tests were determined by calculating ICCs and 95% confidence intervals (CIs). We performed a univariate analyse (One-way ANOVA) to compare physical performance variables, age, body mass index (BMI) and body fat percentage (BFP) at baseline between the groups. To evaluate the changes from pre-

treatment to post-treatment, we used a paired t-test for each group, and we performed a multivariate analysis of covariance (MANCOVA) with group as fixed-effect and age, BMI, BFP, and physical performances variables as covariates. The normality of the residuals was examined by the Kolmogorov-Smirnov test, and the homogeneity of the variance-covariance matrix was examined by the Box M test. This assumption was not verified, so we used Pillai's trace test statistics ($M = 81.70$, $F_{2, 125} = 1.81$, $p < 0.05$). An analysis of covariance (ANCOVA) was performed for each dependent variable, followed by the Bonferroni post-hoc comparison test. Using the ANCOVA results, it was also possible to analyze the effect size of the intervention on the physical performance variables. The data were analyzed Statistical Package for Social Sciences (SPSS) v22.0® for Windows, and statistical significance was set at $p \leq 0.05$.

Results

In pre-training, the results showed no differences in BMI, BFP, or in explosive strength variables between groups, except for age ($F_{2, 125} = 3.36$, $p > 0.05$), 1kg ball throw ($F_{2, 125} = 4.67$, $p > 0.05$), and aerobic capacity (VO_{2max}) ($F_{2, 125} = 5.44$, $p > 0.05$). Were also showed differences between the RA and AR groups, and between the AR, RA and C groups (table 1).

Table 1 - Univariate Analysis.

Mean \pm SD of age, body mass index (BMI), body fat percentage (BFP), maximal oxygen uptake (VO_{2max}), and muscle strength variables in intra-session resistance prior to aerobic training (RA), intra-session aerobic prior to resistance training (AR), and control group (C). VO_{2max} - Multistage Shuttle Run ($ml \cdot kg^{-1} \cdot min^{-1}$); 1kg Ball-Throw - Chest 1 kg Medicine Ball-Throw (cm); 3kg Ball Throw - Chest 3kg Medicine Ball Throw (cm); SL Jump - Standing Long Jump (cm); CM Jump - Counter Movement Vertical Jump (cm); 20m Sprint - 20m Sprint Running (s).

	RA	AR	C	p
Age, mean + SD	10.8 \pm 0.5	11.1 \pm 0.5	10.9 \pm 0.5	0.038***
BMI, mean + SD	19.3 \pm 3.0	18.2 \pm 3.1	19.2 \pm 3.1	0.346
BFP, mean + SD	22.6 \pm 8.3	18.6 \pm 8.8	21.6 \pm 7.0	0.290
VO_{2max}	44.4 \pm 3.3	42.5 \pm 3.1	44.8 \pm 3.6	0.000****
#1 1kg Ball-Throw	3.6 \pm 0.6	3.3 \pm 0.7	3.6 \pm 0.6	0.000****
3kg Ball-Throw	2.2 \pm 0.4	2.3 \pm 0.4	2.2 \pm 0.4	0.081
SL Jump	1.3 \pm 0.2	1.3 \pm 0.3	1.3 \pm 0.2	0.659
CM Jump	0.2 \pm 0.0	0.2 \pm 0.1	0.2 \pm 0.1	0.442
20m Sprint	4.4 \pm 0.3	4.3 \pm 0.3	4.4 \pm 0.3	0.013***

*** $p < 0.05$; **** $p < 0.001$; #1 One-way ANOVA

The explosive strength variables and the aerobic capacity variable increased significantly in the RA and AR groups from before to after the 8-week training session. The C group presented no significant increases in the explosive strength variables nor in the aerobic capacity variable (table 2). These results did not support the hypothesis that $VO_2\text{max}$ increases independently from the implemented exercise training programs.

Regarding the effects of different types of training on explosive strength, changes from pre- to post-training were observed (table 2). The RA group showed better improvement in the 1 kg Ball-Throw, 3 kg Ball-Throw, SL Jump, CM Jump and 20m sprint running tests compared with the other experimental group. The AR group showed better improvement in $VO_2\text{max}$ than RA group.

Table 2 - Mean \pm SD and Paired t-test analysis.

Mean \pm SD and paired t-test to maximal oxygen uptake ($VO_2\text{max}$) and muscle strength variables pre- and post-training in intra-session resistance prior to aerobic training (RA), intra-session aerobic prior to resistance training (AR) and control group (C). $VO_2\text{max}$ - Multistage Shuttle Run ($\text{ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$); 1kg Ball-Throw - Chest 1 kg Medicine Ball Throw (cm); 3kg Ball-Throw - Chest 3kg Medicine Ball Throw (cm); CM Jump - Counter Movement Jump (cm); SL Jump - Standing Long Jump (cm); 20m Sprint - 20m Sprint Running (s); *** $p < 0.05$; **** $p < 0.001$.

		Pre	Post	Difference (Pre - Post)	p
AR	$VO_2\text{max}$	42.5 \pm 3.1	45.6 \pm 3.2	-3.1 \pm 1.7	0.000****
	1kg Ball Throw	3.3 \pm 0.7	3.4 \pm 0.7	-0.1 \pm 0.2	0.033***
	3kg Ball Throw	2.3 \pm 0.4	2.4 \pm 0.5	-0.1 \pm 0.1	0.000****
	SL Jump	1.3 \pm 0.3	1.4 \pm 0.3	-0.1 \pm 0.2	0.025***
	CM Jump	0.2 \pm 0.1	0.2 \pm 0.1	0.0 \pm 0.0	0.001***
	20m Sprint	4.3 \pm 0.3	4.2 \pm 0.3	-0.1 \pm 0.0	0.000****
RA	$VO_2\text{max}$	44.4 \pm 3.3	46.1 \pm 4.1	-1.7 \pm 1.9	0.000****
	1kg Ball Throw	3.6 \pm 0.6	3.8 \pm 0.6	-0.2 \pm 0.1	0.000****
	3kg Ball Throw	2.2 \pm 0.4	2.4 \pm 0.4	-0.2 \pm 0.1	0.000****
	SL Jump	1.3 \pm 0.2	1.4 \pm 0.2	-0.1 \pm 0.1	0.000****
	CM Jump	0.2 \pm 0.0	0.2 \pm 0.0	0.0 \pm 0.2	0.000****
	20m Sprint	4.4 \pm 0.3	4.3 \pm 0.3	-0.1 \pm 0.1	0.000****
C	$VO_2\text{max}$	44.8 \pm 3.6	45.0 \pm 4.0	-0.2 \pm 1.6	0.386
	1kg Ball Throw	3.6 \pm 0.6	3.7 \pm 0.6	-0.1 \pm 0.1	0.053
	3kg Ball Throw	2.2 \pm 0.4	2.2 \pm 0.5	-0.1 \pm 0.2	0.057
	SL Jump	1.3 \pm 0.2	1.3 \pm 0.2	-0.1 \pm 0.1	0.066
	CM Jump	0.2 \pm 0.1	0.2 \pm 0.1	0.0 \pm 0.2	0.103
	20m Sprint	4.4 \pm 0.3	4.4 \pm 0.3	0.0 \pm 0.1	0.076

The results of MANCOVA showed a statistical significance with a medium effect of the group factor ($\eta_p^2 = 0.37$, $p < 0.001$) on changes of explosive strength and VO_{2max} measures for the different groups, adjusted to the covariate variables. Moreover, medium effect sizes of the group factor were found for VO_{2max} ($\eta_p^2 = 0.27$, $F_{2,125} = 22.10$, $p < 0.001$) and 20m sprint ($\eta_p^2 = 0.30$, $F_{2,125} = 25.18$, $p < 0.001$). Small effect sizes of the group factor were found for the 1 kg Ball-Throw ($\eta_p^2 = 0.17$, $F_{2,125} = 12.40$, $p < 0.001$), 3 kg Ball-Throw ($\eta_p^2 = 0.16$, $F_{2,125} = 11.60$, $p < 0.001$), and SL Jump ($\eta_p^2 = 0.05$, $F_{2,125} = 3.37$, $p < 0.05$). A small effect size was also found for the CM Jump ($\eta_p^2 = 0.04$, $F_{2,125} = 2.22$, $p = 0.11$), but the differences in the CM Jump results between groups were not statistically significant.

Were presented changes in the 3kg Ball-Throw (Figure 1), SL Jump (Figure 2), and CM Jump (Figure 3) results from before to after training were significantly higher in the RA and AR groups than in the C group. The increases in the 1 kg Ball-Throw (Figure 1) and 20m sprint (Figure 4) results were significantly higher in the RA group than in the AR group. In addition, VO_{2max} (Figure 5) increased more in the AR group than in the RA group.

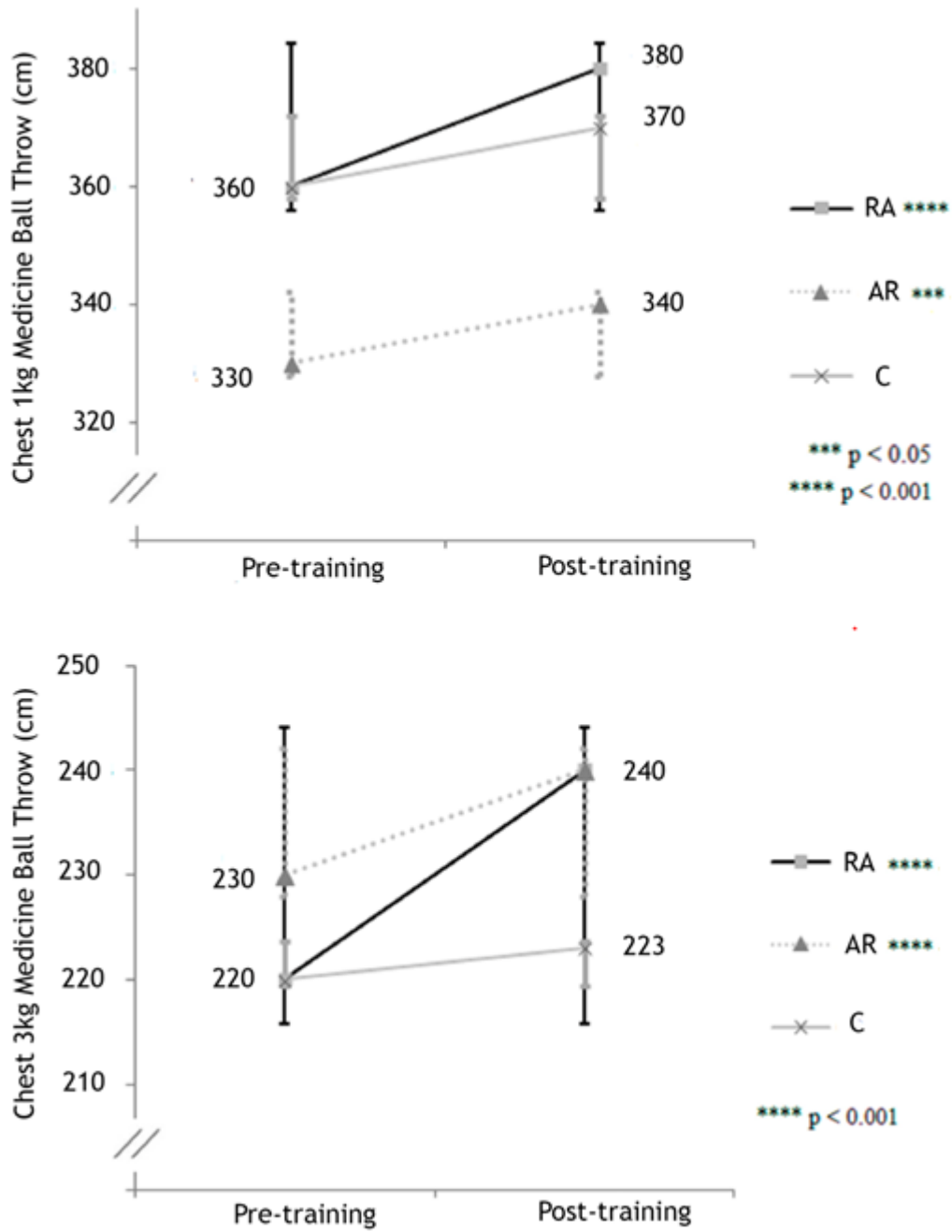


Figure 1. Obtained values in pre- and post-test of training in intra-session resistance prior to aerobic training (RA), intra-session aerobic prior to resistance training (AR), and control group (C) on chest 1 kg and 3kg medicine ball throw.

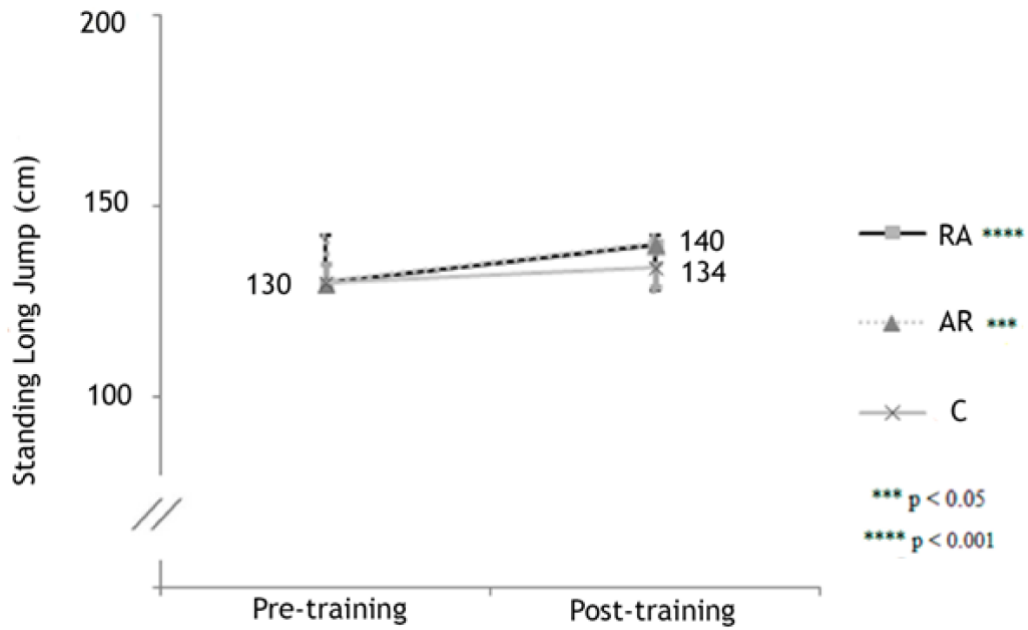


Figure 2. Obtained values in pre- and post-test of training in intra-session resistance prior to aerobic training (RA), intra-session aerobic prior to resistance training (AR), and control group (C) on standing long jump.

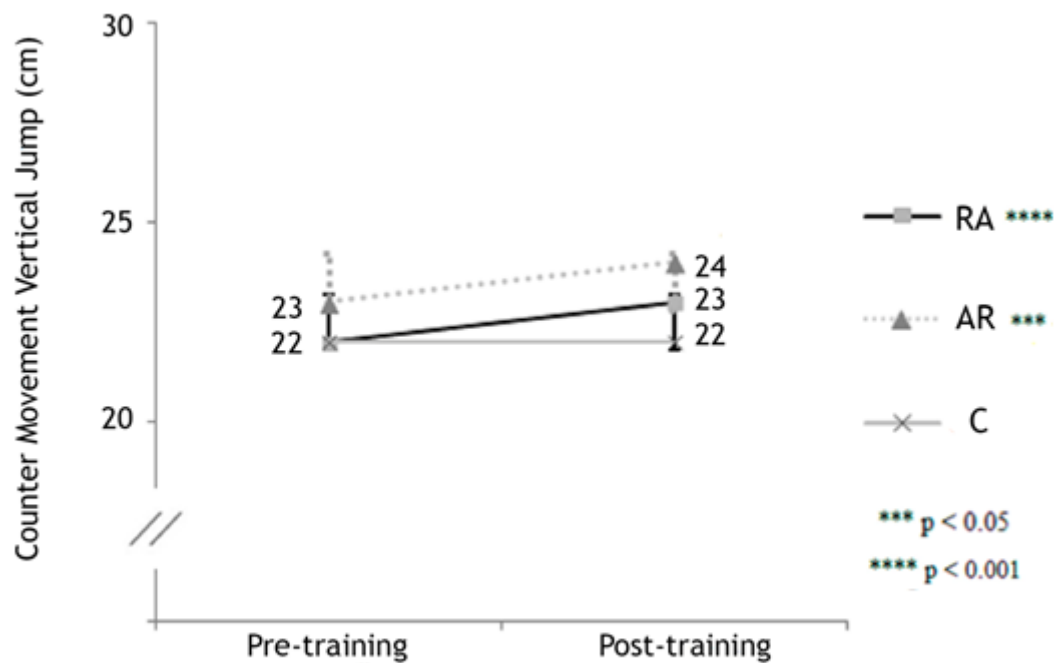


Figure 3. Obtained values in pre- and post-test of training in intra-session resistance prior to aerobic training (RA), intra-session aerobic prior to resistance training (AR), and control group (C) on counter movement vertical jump.

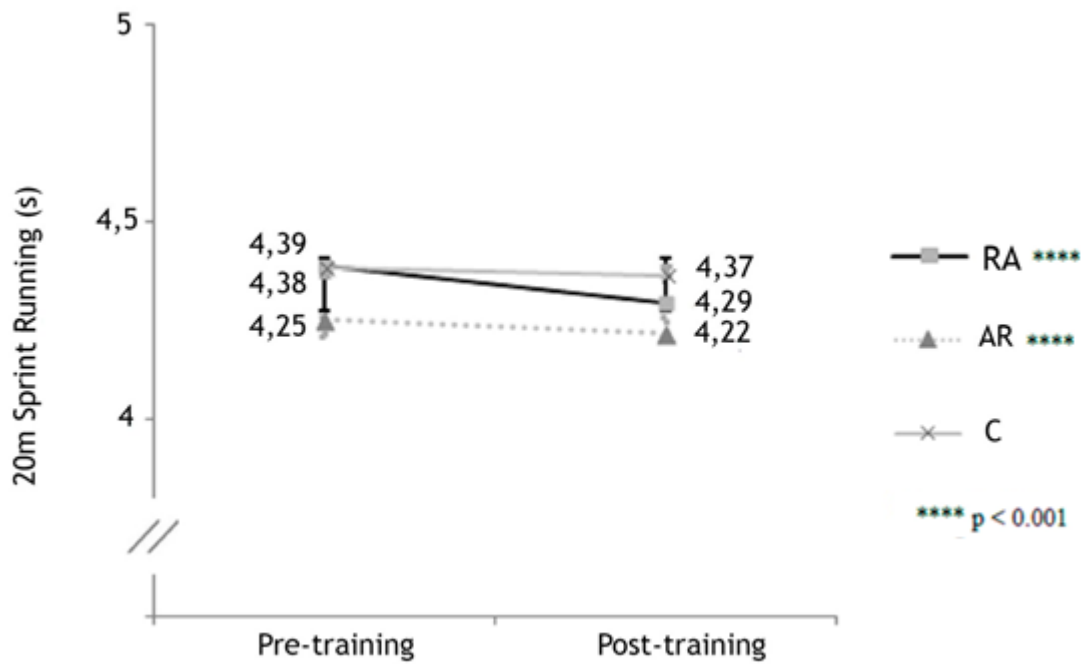


Figure 4. Obtained values in pre- and post-test of training in intra-session resistance prior to aerobic training (RA), intra-session aerobic prior to resistance training (AR), and control group (C) on 20m sprint running.

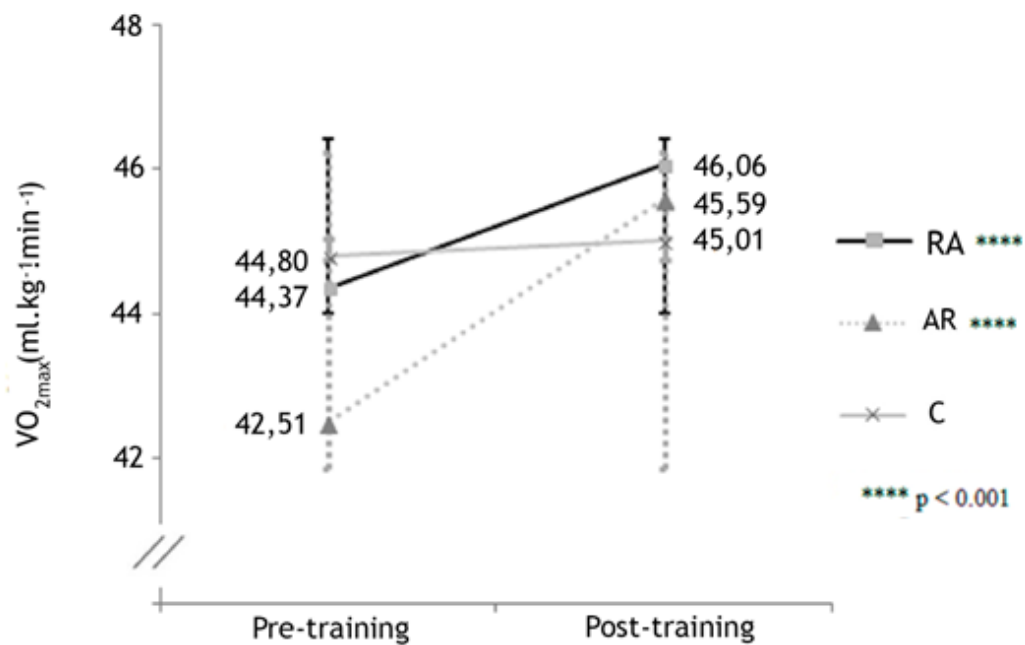


Figure 5. Obtained values in pre- and post-test of training in intra-session resistance prior to aerobic training (RA), intra-session aerobic prior to resistance training (AR), and control group (C) on maximal oxygen uptake (VO_{2max}).

Discussion

The present study is the first to investigate the order effect of concurrent resistance and aerobic training among prepubertal children. Specifically, the purpose of the current study was to compare the effects of an 8-week period of concurrent resistance and aerobic training order on explosive skills and VO_2 max training parameters in prepubertal children. The main findings indicated that the intra-session concurrent training order (resistance prior to aerobic training/aerobic prior to resistance training) programs investigated here were effective, well-rounded exercise programs that can be performed to improve explosive strength in prepubertal children. Nevertheless, the RA group produced better results than the AR group. Additionally, the AR group showed greater improvement in cardiorespiratory fitness than the other experimental group. These results are of great interest and are useful for optimizing and innovating school-based programs at sports clubs for children.

Concurrent resistance and aerobic training have the potential to improve cardiorespiratory and muscular fitness simultaneously (Cadore et al., 2012b, 2014; Silva et al., 2012). However, for concurrent training, the best order for intra-session aerobic and resistance training is unclear. For example, there are studies (Bell et al., 1988; Collins & Snow, 1993) that have reported that intra-session resistance and aerobic training, regardless of training order, can similarly improve aerobic capacity and muscular strength, and conclude that both training orders are equally effective. Yet, in the recent study, Kang & Ratamess (2014) found that each intra-session training order had its own advantages that should be considered to make concurrent training more effective. Although the order effect of intra-session concurrent resistance and aerobic training on training-induced explosive strength in prepubertal children have not yet been explored, and the present study may provide reliable and useful information in this area.

In the current study, no significant differences were found between experimental groups (RA and AR) after training on the variables related to explosive strength and aerobic capacity, except for the 1 kg Ball-Throw ($p < 0.05$). Moreover, there were overall increases in explosive strength of the upper and lower limbs for both experimental training groups, suggesting that intra-session resistance training prior to aerobic training and intra-session aerobic training prior to resistance training are both beneficial training stimuli for enhancing explosive strength and aerobic capacity in prepubertal children. The RA group showed higher improvements than the AR group in muscle strength variables: the medicine ball throws were higher (2.7% and 2.2% for the 1 kg and 3 kg ball throws, respectively; $p < 0.05$), the jumps were higher (1.1% and 0.5% for the CM and SL Jumps, respectively; $p < 0.05$), the 20m times were lower (2.3%, $p < 0.001$). These results indicated that intra-session resistance prior to aerobic training may be more effective than intra-session aerobic training prior resistance training to

improve explosive strength in young children. This is consistent with studies by Cadore et al. (2012a, 2012b) that observed greater maximal dynamic strength gains (upper and lower body) and greater force per unit of muscle mass in elderly men from a concurrent training group that performed resistance training prior to aerobic training (maximal dynamic strength of upper body: 15%, maximal dynamic strength of lower body: 35.1%, and force per unit of muscle mass: 27.5%, $p < 0.001$, $p < 0.01$, and $p < 0.001$, respectively) compared to the reverse order (maximal dynamic strength of upper body: 11.5%, maximal dynamic of lower body: 21.9%, and force per unit of muscle mass: 15.2%, $p < 0.001$, $p < 0.01$, and $p < 0.02$, respectively).

Interestingly, the $VO_2\text{max}$ was significantly greater after training in the AR group compared with the RA group (AR: 7.3%; RA: 3.8%, $p < 0.001$), suggesting that intra-session aerobic training prior resistance training may be more effective than intra-session resistance training prior aerobic training at improving aerobic capacity in prepubertal children. Nevertheless, this difference could have been due to the order of training used in the different groups or to acute neuromuscular fatigue induced by resistance training (used in the RA and AR groups). Such residual fatigue may reduce the quality of aerobic training, leading to a reduction in aerobic development over time (Robineau et al., 2014). In fact, the results of the present study are in line with the results of Chtara et al. (2005), who investigated training order of concurrent aerobic and resistance training on aerobic capacity and performance in male sports students (during 12 weeks, twice a week) and found that performing aerobic training prior to resistance training could improve running performance and $VO_2\text{max}$ to a greater extent than the reverse order (8.5% and 13.7%, $p < 0.01$ and $p < 0.01$ vs. 4.6% and 11.0%, $p < 0.05$ and $p < 0.01$, respectively).

There is no consensus on the interference of intra-session concurrent training order in performance adaptations. There are studies (Ali-Mohamadi et al., 2014; McGawley & Andersson, 2013; Taipale et al., 2015) that have reported that intra-session resistance and aerobic training, regardless of training order, does not impair physiological and performance adaptations. In contrast, other studies have provided evidence that the order of intra-session resistance and aerobic training may affect performance adaptations (Bell et al., 1988; Chtara et al., 2005; Hickson, 1980). However, our findings may clarify previous evidence. Thus, in the current study, improvements in the explosive strength and in the aerobic capacity for both experimental training groups were found, indicating that concurrent training, regardless of training order, does not affect performance in school-age children. This is consistent with recent work showing that concurrent training is equally effective on training-induced explosive strength as resistance training alone in prepubertal children (Marta et al., 2013b).

In brief, our data suggested that training order influences muscle strength and aerobic capacity improvement in prepubertal children. Therefore, these results are meaningful for the development of explosive strength and cardiorespiratory fitness training in school-based programs and sports clubs' programs, improving the specificity of training related to children characteristics, and contributing for the achievement of the results proposed. Furthermore, intra-session concurrent training order (resistance training prior to aerobic training or aerobic training prior to resistance training) seems to be effective at improving both explosive strength and aerobic capacity. Although all programs were effective, the RA group produced better improvement in muscle strength variables than the AR group, and the AR group produced better improvement in aerobic capacity variables than the RA group. Thus, it is also suggested that the effectiveness of the intra-session resistance and aerobic training order may be dependent on the programs' priorities. Nevertheless, there are some limitations of this study that should be addressed: i) field tests were only applied in the experimental training groups, and laboratory tests with higher control standards may have generated more accurate data; ii) different methods of organizing training workouts can lead to different training-induced outcomes.

Practical Applications

To increase the efficiency of physical education classes and to optimize exercise programs, intra-session resistance prior to aerobic training and intra-session aerobic prior to resistance training programs should be considered in school-based and sports clubs' programs. Furthermore, the youth strength and conditioning programs should include explosive strength and aerobic training as these are related with improvements in health, fitness, academic performance and quality of life (Brown, 2007; Moazzami & Khoshraftar, 2011). However, if the main purpose is to improve aerobic capacity, intra-session aerobic prior to resistance training should be used. To improve muscular strength, intra-session resistance prior to aerobic training would be the most suitable alternative. Therefore, the current study is innovative, and these findings can be helpful for teachers, coaches and researchers in their efforts with prepubertal children.

Study 4

Modelling fitness variables responses to training in children

Abstract

The aim of this study was to determine strength and oxygen uptake ($VO_2\max$) performances according to different training program intervention design with 8-weeks duration in prepubertal children through a multiple linear regression models. Two hundred and forty-five healthy prepubertal children (aged 10.9 ± 0.5 years) were randomly assigned to a specific training program (resistance training alone - R, aerobic training alone - A, intra-session concurrent aerobic and resistance training - AR, intra-session concurrent resistance and aerobic training - RA, or concurrent training performed in different sessions - CT) or a control group (no training regimen - C). It was possible to develop indirect predictive models for each training method, by including each variable pre-training, body fat percentage and body mass index. The models provided explained 82% of variance in the $VO_2\max$, 98% in the 1kg Ball-Throw, 96% in the 3kg Ball-Throw, 92% in the Counter-movement Jump, 93% in the Standing-long jump and 98% in the 20m sprint performances. This novel approach to training evaluation and control aims to provide a tool to allow professionals to calculate changes with a high confidence level (CI 95%), to control gains and to choose the best training methodology to apply according to the defined purposes. The results of this study could be a great support to teachers, coaches and professionals providing important tools to improve the efficacy and individualization of training.

Key words: concurrent training, resistance, aerobic, explosive, linear regression, youth.

Introduction

Several studies reported that concurrent training can be highly effective for improving strength and aerobic fitness simultaneously (Kang & Ratamess, 2014; Pugh et al., 2015; Alves et al., 2016a, 2016b) in children. Concurrent training is commonly defined as a combination of resistance (R) and aerobic (A) training, performed either in the same training session or separately on alternating days, often limiting the recovery between subsequent exercise sessions (Bell et al., 1997, 2000; Cadore et al., 2010, 2012; Reed et al., 2013). To date, physical education professionals have used this training approach as an efficient and motivational method for children to improve health-related parameters and to gain physical activity habits (Alves et al., 2016a).

More recently, our lab (Alves et al. 2016a, 2016b) contributed to this field by showing that different types of concurrent training (resistance exercise and aerobic training either in the same training session or in different sessions; and aerobic training followed by resistance exercise vs. resistance training followed by aerobic exercise) is equally effective for training-induced explosive strength, depending on the programs' priorities. However, it still difficult for practitioners not only to choose the best training design but also to predict and identify training standards for resistance and aerobic enhancement in school environment. In fact, to the best of our knowledge, no study has tried to predict the possible gains or decreases in resistance and aerobic performances in a concurrent training context. This not only could help to implement the best training "formula" in order to achieve physical fitness goals, but also to have more details on how each subject respond to the training and allows a comparison of individual progress with previously established standards goals. Therefore, the aim of the current study was to determine strength and maximal oxygen uptake (VO_2max) performances according to different training program intervention design with 8-weeks duration in prepubertal children through a multiple linear regression models. Our hypothesis was that it was possible to predict models that would have different responses based on training program interventions, explaining the relationship between strength, cardiovascular and anthropometrics variables in the prepubertal children performance.

Methods

Experimental Approach to the Problem

The study design was developed based in previous studies conducted in prepubertal children which performed in similar periods (Alves et al., 2016a, 2016b). Two hundred and forty-five healthy prepubertal children (aged 10.9 ± 0.5 years) from a school cluster (Guarda, Portugal) were randomly assigned to a specific training program (R, A, AR, RA, or CT) or a control group (C, no training regimen) during 8 weeks. The average height and body mass of the entire sample were 1.4 ± 0.1 m and 39.8 ± 9.0 kg, respectively.

The training programs consisted in a 10-minute warm-up period (low to moderate intensity exercises) followed by strength and/or aerobic training and vice versa. The A group performed 20m shuttle run exercise only. The R group performed resistance training only, comprising 1 and 3 kg medicine ball throws, jumps onto a box (from 0.3 to 0.5 m), vertical jumps above a 0.3-0.5 m hurdle and sets of 30 to 40 m of speed running. The RA group performed the same resistance training and then a 20m shuttle run exercise, while the AR group performed a 20m shuttle run exercise and then resistance training. Finally, CT performed resistance training, and in an alternate session (on the next day) performed a 20m shuttle run after the warm-up. After 4 weeks of training, A, RA, AR, and CT groups were reassessed by a 20m shuttle run test to readjust the volume and intensity of the 20m shuttle run exercise.

Children were evaluated for changes in resistance (chest 1 and 3 kg medicine ball throw, standing long jump, counter movement vertical jump, and a 20m sprint running) and cardiovascular parameters ($VO_2\max$) before and after 8 weeks of training. More detailed information about the training and evaluation procedures of this study can be found in Alves et al. (2016a, 2016b).

Statistical Analysis

Statistical analyses were performed using Statistical Package for Social Sciences (SPSS) v22.0® for Windows and statistical significance was set at $p \leq 0.05$. Standard statistical methods were used to calculate the means and standard deviations to describe the data. After check that no assumptions underlying the analysis of residues have been violated (normality, independence and homogeneity of variances) it was possible to predict indirect methods for explosive strength and maximal oxygen uptake variables after each training program chosen through the multiple linear regression model. It was considered the stepwise method. We

applied the multiple linear regression since the aim of this study was to evaluate the children performance on the post-test (in respect to explosive strength and maximal oxygen uptake variables) as a function of their baseline values, training program intervention, body fat percentage and body mass index. The normality was verified by the Kolmogorov-Smirnov test. For the homogeneity of variances, the scatterplot of standardized predicted values versus studentized residuals was performed. In order to check the independence, the Durbin-Watson Statistics was calculated. The assumption of no extreme values was also verified. The 95% confidence interval (CI 95%) was calculated for all estimated variables on the regression model.

Results

Table 1 provides descriptive statistics of the independent variables inserted in the standard model for each variable. It was only considered the data that verified all assumptions underlying the regression analysis.

Table 1 - Descriptive statistics of the independent variables in analysis.

Mean \pm SD are presented for the pre-test. n is the number of subjects included in each training, specifically: C, RA, AR, A, R, CT. C - control group, R- resistance training alone, A- aerobic training alone, RA - intra-session resistance and aerobic training, AR - intra-session aerobic and resistance training, CT- concurrent training performed in different sessions. 1kg_BT - Chest 1 kg Medicine Ball Throw (cm); 3kg_BT - Chest 3kg Medicine Ball Throw (cm); CM - Counter Movement Vertical Jump (cm); SL - Standing Long Jump (cm); SP - 20m Sprint (s); V - Multistage Shuttle Run (VO_2max , $\text{ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$), BMI - Body mass index (kg/m^2), BFP - Body fat percentage.

	V (n=243)	1kg_BT (n=244)	3kg_BT (n=244)	SL (n=237)	CM (n=238)	SP (n=241)
V	43.06 \pm 3.29	1kg_BT 345.68 \pm 65.80	3kg_BT 226.65 \pm 43.49	SL 129.34 \pm 20.14	CM 22.89 \pm 5.37	SP 4.37 \pm 0.31
BMI	19.01 \pm 3.16	BMI 19.00 \pm 3.16	BMI 19.00 \pm 3.16	BMI 18.97 \pm 3.14	BMI 18.98 \pm 3.19	BMI 19.02 \pm 3.18
BFP	21.32 \pm 8.21	BFP 21.29 \pm 8.18	BFP 21.34 \pm 8.19	BFP 21.18 \pm 8.09	BFP 21.31 \pm 8.19	BFP 21.38 \pm 8.23
C	N = 44	N =44	N =43	N =40	N =43	N =43
RA	N =44	N =45	N =45	N =45	N =45	N =45
AR	N =32	N =31	N =32	N =30	N =32	N =32
CT	N =40	N =41	N =41	N =40	N =36	N =40
A	N =42	N =42	N =42	N =41	N =41	N =41
R	N =41	N =41	N =41	N =41	N =41	N =40

To verify whether the independent variables were significantly predictive or not to obtain the results of dependent variables (post-test) a multivariate linear regression analysis was performed, considering the stepwise method. Thus, it was possible to estimate the linear regression equations to predict the gains in each variable after 8 weeks and according to the training methodology used.

In table 2 it can be observed that the null hypothesis in which the coefficient equals zero is rejected at the 95% confidence level. Therefore, we have sufficient evidences to conclude that each of these variables were significant in the post training performances. Based on this we obtained regression equations to each training program (table 3).

Table 2 - Estimated regression coefficients from linear regression models only for significant variables. Confidence intervals are presented for significant variables. * p-value - p-value of the coefficients, R_a^2 -adjusted R square of the model, **p-value- ANOVA p-value. C - control group, R- resistance training alone, A- aerobic training alone, RA - intra-session resistance and aerobic training, AR - intra-session aerobic and resistance training, CT- concurrent training performed in different sessions. 1kg_BT - Chest 1 kg Medicine Ball Throw(cm); 3kg_BT - Chest 3kg Medicine Ball Throw (cm); CM - Counter Movement Vertical Jump (cm); SL - Standing Long Jump (cm); SP - 20m Sprint (s); V - Multistage Shuttle Run (VO_{2max} , $ml \cdot kg^{-1} \cdot min^{-1}$), BMI - Body mass index (kg/m^2), BFP - Body fat percentage, $VO_{2max_{pre}}$ - VO_{2max} in the baseline, $VO_{2max_{post}}$ - VO_{2max} after 8-weeks of training. *** $p < 0.05$; **** $p < 0.001$.

Variable		Estimates	CI _{95%}	p-value*	R_a^2	ANOVA (**p-value)
V _{post}	Constant	3.859	(0.326, 7.393)	0.032***	0.822	0.000
	V _{pre}	0.954	(0.882, 1.027)	0.000****		
	RA	1.547	(1.009, 2.086)	0.000****		
	CT	2.683	(2.074, 3.291)	0.000****		
	AR	2.621	(1.995, 3.246)	0.000****		
	A	2.952	(2.336, 3.568)	0.000****		
	BFP	-0.070	(-0.096, -0.044)	0.000****		
1kg_BT _{post}	Constant	0.025	(-6.989, 7.039)	0.994	0.978	0.000
	1kg_BT _{pre}	1.009	(0.990, 1.029)	0.000****		
	RA	17.019	(13.407, 20.631)	0.000****		
	R	17.053	(13.334, 20.771)	0.000****		
	CT	16.954	(13.220, 20.688)	0.000****		
	AR	10.615	(6.510, 14.721)	0.000****		
3kg_BT _{post}	Constant	4.610	(-1.931, 11.151)	0.166	0.955	0.000
	3kg_BT _{pre}	0.993	(0.965, 1.021)	0.000****		
	RA	16.484	(13.036, 19.932)	0.000****		
	R	15.143	(11.587, 18.699)	0.000****		
	CT	15.042	(11.482, 18.602)	0.000****		
	AR	9.730	(5.844, 13.615)	0.000****		
CM _{post}	Constant	0.440	(-4.469, 1.349)	0.341	0.918	0.000
	CM _{pre}	1.015	(0.976, 1.055)	0.000****		
	A	-0.918	(-1.485, -0.351)	0.002***		
	CT	0.670	(0.080, 1.261)	0.026***		
SL _{post}	Constant	5.605	(-0.645, 11.856)	0.079	0.933	0.000
	SL _{pre}	1.013	(0.974, 1.052)	0.000****		
	RA	6.684	(4.701, 8.667)	0.000****		
	R	4.113	(2.058, 6.167)	0.000****		
	CT	4.030	(1.969, 6.091)	0.000****		
	BFP	-0.216	(-0.314, -0.119)	0.000****		
SP _{post}	Constant	-0.036	(-0.134, 0.062)	0.474	0.976	0.000
	SP _{pre}	0.998	(0.974, 1.021)	0.000****		
	AR	-0.018	(-0.039, 0.003)	0.094		
	RA	-0.083	(-0.101, -0.065)	0.000****		
	R	-0.084	(-1.103, -0.065)	0.000****		
	CT	-0.078	(-0.097, -0.059)	0.000****		
	BFP	0.002	(0.001, 0.002)	0.000****		

Table 3 - Regression equations to each training program. BFP: body fat percentage (%), 1 kg_BT_{post}: chest 1 kg medicine ball throw (cm) after 8-weeks of training, 3 kg_BT_{post}: chest 3 kg medicine ball throw (cm) after 8-weeks of training, CM_{post}: counter movement jump (cm) after 8-weeks of training, SL_{post}: standing long jump (cm) after 8-weeks of training, SP_{post}: 20m sprint running (s) after 8-weeks of training, V_{post}: Multistage Shuttle Run (VO₂max, ml.kg⁻¹.min⁻¹) after 8-weeks of training. All variables included in the equations correspond to the baseline values (BFP, 1 kg_BT, 3 kg_BT, CM, SL, SP, V).

	Control group	Intra-session resistance and aerobic training	Intra-session aerobic and resistance training	Concurrent training performed in different sessions	Aerobic training only	Resistance training only
V _{post}	3.859+0.954xV-0.070xBFP	5.406+0.954xV-0.070xBFP	6.48+0.954xV-0.070xBFP	6.542+0.954xV-0.070xBFP	6.811+0.954xV-0.070xBFP	
1kg_BT _{post}	0.025+1.009x1kg_BT	17.044+1.009x1kg_BT	10.64+1.009x1kg_BT	16.979+1.009x1kg_BT		17.078+1.009x1kg_BT
3kg_BT _{post}	4.610+0.993x3kg_BT	20.634+0.993x3kg_BT	13.192+0.993x3kg_BT	18.516+0.993x3kg_BT		18.65+0.993x3kg_BT
CM _{post}	0.440+1.015xCM			1.11+1.015xCM	-0.478+1.015xCM	
SL _{post}	5.605+1.013xSL-0.216xBFP	12.289+1.013xSL-0.216xBFP		9.635+1.013xSL-0.216xBFP		9.718+1.013xSL-0.216xBFP
SP _{post}	-0.036+0.998xSP+0.002xBFP	-0.119+0.998xSP+0.002xBFP	0.054+0.998xSP+0.002xBFP	-0.114+0.998xSP+0.002xBFP		-0.12+0.998xSP+0.002xBFP

The different training programs explained 82% of variance in the VO₂max, 98% in the 1kg Ball-Throw, 96% in the 3kg Ball-Throw, 92% in the CM Jump, 93% in the SL Jump and 98% in the 20m sprint performances.

Discussion

The aim of this study was to determine strength and VO₂max performances according to different training program intervention design with 8-weeks duration in prepubertal children through a multiple linear regression models. The resulting models explained 82% of variance in the VO₂max, 98% in the 1kg Ball-Throw, 96% in the 3kg Ball-Throw, 92% in the CM Jump, 93% in the SL Jump and 98% in the 20m sprint performances, when including each variable pre-value, BFP and BMI. With the results obtained, it was possible to develop indirect predictive models for each training method and these equations are a novel approach to training evaluation and control, providing important tools for professionals to improve the efficacy and individualization of training.

Throughout the years, several studies presented different training programs to improve physical fitness. Strength training have the potential to improve muscle strength, endurance, and power (Benson et al., 2007; Kang & Ratamess, 2014), while aerobic training is suggested to improve cardiorespiratory fitness (Kang & Ratamess, 2014). Moreover, recent research suggested that concurrent resistance and aerobic training have the feasibility to improve muscular and cardiorespiratory fitness simultaneously, especially in children (Alves et al., 2016a, 2016b; Cadore et al., 2012; Silva et al., 2012). When verifying the influence of different training programs, all the analyzed variables in this study showed to be improved after 8 weeks of aerobic, resistance or concurrent training, in prepubertal children (Alves et al., 2016a, 2016b).

It was quite clear in our previous studies that any of the experimental training programs resulted in improved cardiovascular or/and strength parameters (for further, please see Alves et al., 2016a, 2016b). Therefore, by using the data collected, it was possible to develop an indirect method to evaluate explosive strength and $VO_2\text{max}$ variables according to each training methodology applied to children. It was considered that changes in strength and aerobic variables is strongly related to the baseline values, BFP, BMI, and training methodology (Grund et al., 2000). The analysis of the relationships included the training programs as independent variables, which is a novelty in this type of study.

The different equations explained each change in 1kg Ball-Throw, 3kg Ball-Throw, SL Jump, CM Jump, and 20m sprints by more than 90%, which reveals their accuracy and reliability. The explained variance of $VO_2\text{max}$ was lower, but still enough to support the predictive model. It can be stated that qualitatively a high prediction of strength and cardiovascular variables were verified. Even so, a range between 20% ($VO_2\text{max}$) and 2% (1kg Ball-Throw and 20m sprints) cannot be explained by the included variables. Perhaps predictability would increase if more specific apparatus were used for evaluation (e.g. breath-by-breath oxygen measures) or if other scientific domains were included, such as maturation change, motor control, genetics psychology (Armstrong et al., 2015; Schutte et al., 2016; Vandendriessche et al., 2011).

One of the goals of physical activity professionals working with children should be to develop their strength and cardiovascular fitness so that they can reach the standard values for a healthy youth. Usually several assessments are performed in the beginning of school year to evaluate physical fitness. Based on those results, teachers should plan a training program to improve the weakest capacities and to maintain the higher-level ones. Moreover, it is known that different kind of training develops each strength and/or aerobic parameters differently. For instance, aerobic training program obtained better results in $VO_2\text{max}$, while AR, CT and RA groups seems to be more efficiency in explosive strength (Alves et al., 2016a, 2016b). Thus, with the prediction equations suggested and based on previous evaluations, the teacher is now able to understand which one is the best program to implement. In addition, he can adjust each training program individually to each student and according to their needs and using variables that are easy to collect and have ecological meaning to design, control and evaluate the training process.

Predictive models are not new in sports science research. However, until now most of them were developed to explain acute performances responses based on biomechanical, physiological or/and anthropometric measures (Barbosa et al., 2010; Morais et al., 2016), to predict aerobic capacity ($VO_2\text{max}$) or maximal strength (1RM) (Hoffman et al., 2003; Reynolds et al., 2006), and not to understand and predict the responses to different training programs as the present study performed. This approach aims to provide a tool for the professionals to

calculate changes, with high confidence level (CI 95% is also provided in the results if needed), to control gains and to choose the best training methodology to apply according to the purposes defined. At the end of the program, the same variable could be evaluated again and compared with expected results and thus to identify responders or even to understand the children commitment with the program.

As a conclusion, the model based on pre- values of strength and cardiovascular variables, BMI, BFP and training programs, is appropriate to explain changes in $VO_2\text{max}$, 1kg and 3kg Ball-Throw, SL Jump, CM Jump, and 20m sprint prepubertal children (aged 9-12 years old). These results were novel findings in this area, and the equations presented could be a great support to teachers, coaches, professionals to estimate and predict the physical fitness gains throughout 8-weeks of training (twice-a-week, the same as the physical education lessons). Nevertheless, further research is needed to upgrade this data for longer period duration of training or even including other physiological variables that help to explain the effects obtained.

Practical Applications

The indirect predictive models for each training method were developed, being a novel approach to training evaluation and control. These equations could be of great interest for teachers, coaches, professionals, allowing to estimate and to predict the changes in the physical fitness of children during 8-weeks of training (twice-a-week, the same as the physical education lessons). Moreover, these equations providing to abovementioned professionals pertinent information (i.e., relationship between variables and training methods, according to the measurement) to decide which program training is more effective according to the children' purposes/needs. With this novel approach, it is also possible to improve the efficacy and individualization of training.

Chapter 4. General Discussion

The purpose of this thesis was to analyze the effects of different combination approaches between resistance and aerobic training [concurrent training design (concurrent training performed simultaneously during the same session or concurrent training performed in different sessions) and intra-session training sequence (aerobic prior to resistance training or resistance prior to aerobic training)] on explosive strength and aerobic capacity in prepubertal children. Additionally, we also intended to provide multiple linear regression models to predict distinct strength variables and $VO_2\text{max}$ performances in 8-weeks training programs in children. The scarcity of research about the effects of different combination approaches between resistance and aerobic training on prepubertal children performance was the bottom line of our experimental investigation. Our results not only report the absence of impairment in strength development with concurrent training performed in different sessions, as also suggested that is an effective method for training-induced explosive strength and $VO_2\text{max}$. It is also found that performed intra-session concurrent training, performed concurrent training in different sessions or performed resistance training alone provide similar neuromuscular adaptations in prepubertal girls and boys. With concern to the intra-session concurrent training sequence effects it was report that both order seemed to be potential alternatives to improve prepubertal children performance. Ultimately, our findings also provided indirect predictive models for specific training programs during 8-weeks.

The preliminary study of this work was to present an updated review based on the state of art regarding the importance of physical fitness and the significance of different combination approaches between resistance and aerobic training, as well conditioning methods exercise alone on improvements of physical fitness, specifically explosive strength and cardiorespiratory fitness in prepubertal children (Study 1). In the last decades, the research on the effects of different approaches between resistance and aerobic training, or even the effects of aerobic or resistance training alone has been performed in young, adults and elderly populations. Yet, it was observed that the knowledge about the effects of concurrent training applied to children was limited. Nevertheless, in the literature there are some evidences about different conditioning methods performed in children. Scientific researches highlighting the efficiency of resistance training on improving bone density, muscular and endurance strength of children without compromising their normal growth. Concerning to the aerobic training, it has been proved its effectiveness on improvements of children aerobic capacity. Lastly, besides the limited studies on the effects of concurrent training in children, it has been demonstrated that the intra-session concurrent training as an effective method to improve explosive strength and $VO_2\text{max}$ in children as well.

Children should benefit of the development of strength and cardiovascular parameters (Ortega et al., 2008; Taanila et al., 2011), but the best way to accomplish those improvements remains unclear. Most of the pediatric research started to be focused on activities that enhance cardiorespiratory fitness, ignoring for a while the neuromuscular fitness conditions based on muscular strength (Cepero et al., 2011). Afterwards, recent researches report that resistance training can provide unique benefits to children when appropriately prescribed and supervised (Faigenbaum et al., 2009; Faigenbaum & Myer, 2010), demystifying the idea that resistance training would lead to injuries as well negatively influence the normal growth of children (Blimkie, 1993; Docherty et al., 1987; Faigenbaum et al., 1996). Posteriorly, emerged another method of conditioning, namely the concurrent training, which is able to produce gains in cardiorespiratory and muscular fitness simultaneously (Kang & Ratamess, 2014). Unfortunately, little is known about this topic and its effects on prepubertal children performance (Marta et al., 2013b). Therefore, it seemed important to investigate the effects of different approaches between resistance and aerobic training on explosive strength and cardiorespiratory trainability in this population (Study 2).

The first experimental study showed more effectiveness on explosive strength and $VO_2\text{max}$ in concurrent training performed in different sessions, followed by the intra-session concurrent training and then resistance training alone which was only effective on explosive strength. Our results were congruent with the results of Marta et al. (2013b), which compared intra-session concurrent training with resistance training alone. However, to the best of our knowledge, there is no study reporting the effects of concurrent training in different sessions in children. Regarding to the gender gap, it was found no significant effect on training - induced strength or $VO_2\text{max}$ adaptations between girls and boys, being consensual with results of Marta et al. (2013b). All these findings underline the effectiveness of concurrent training in different sessions on both resistance and aerobic features of prepubertal children without compromising their normal growth.

Considering the abovementioned, there is a scarcity regarding the effects of different combination approaches between resistance and aerobic training in children. Beyond the typically variables that characterize a training program (i.e., volume, intensity, frequency) which can may affect concurrent training, intra-session concurrent training sequence may also be considered as a potential one. Thus, it seemed pertinent to analyze the effects of different intra-session concurrent training order in prepubertal children (Study 3). When comparing the effects of different intra-session concurrent training order in prepubertal children, both experimental training groups demonstrated significant results not only in explosive strength, but also in $VO_2\text{max}$ performance. Additionally, through the obtained results it is suggested that intra-session aerobic training prior resistance training may be more effective than intra-session resistance training prior aerobic training at improving aerobic capacity in prepubertal children. To improve explosive strength, it is demonstrated that

intra-session resistance prior to aerobic training may be more effective than intra-session aerobic training prior resistance training. Similarly, early researches focused on the concurrent training sequence effects on performance and health (Kang & Ratamess, 2014; Chtara et al., 2005) concluded that optimum training sequence was determined by the individual purposes of the training program.

To complement the present thesis, it was developed a third experimental study with the purpose to provide multiple linear regression models for determining distinct strength parameters and VO_2 max performances according to each training program intervention design with 8-weeks duration (Study 4). With the results obtained, it was possible to develop indirect predictive models for each training method, being a novel approach to training evaluation and control.

Ultimately, the findings of this thesis allowed to understand the effects of different combination approaches between resistance and aerobic training in prepubertal children, initial considered an unknown issue where further investigations were needed. Therefore, to improve explosive strength and aerobic capacity is suggested in children as the mainly effective method the concurrent resistance and aerobic training performed in different sessions. In fact, these novel findings seem to be useful for teachers, coaches and researchers to apply in their future works. However, further investigations should be performed with an effort to support the presented evidences.

Some main limitations of this thesis should be mentioned:

- i) These studies were performed during 8 weeks, and this might be considered a short period;
- ii) Different training durations between resistance training group and concurrent training groups may have conditioned training-induced gains;
- iii) It was not possible to study the responsible mechanisms of the observed effects (i.e., no electrophysiological measures);
- iv) The measures of the studies were performed in a field test context, but laboratory tests with higher control standards may be generated accurate data;
- v) The sample included normal-weight and physically active prepubertal children. Thereupon, some care shall be taken when translating these findings to children with different parameters.

Chapter 5. Overall Conclusions

The main findings of this thesis highlight the positive effects of concurrent resistance and aerobic training on prepubertal children performance. The major conclusions of the present work were:

- i) There is a lack of research about the effects of different combination approaches between aerobic and resistance training on prepubertal children performance;
- ii) The different combinations of concurrent training applied in this work does not impair the normal growth of children;
- iii) Concurrent resistance and aerobic training performed in different sessions is considered the most effective conditioning method for training- induced explosive strength and $VO_2\text{max}$;
- iv) Intra-session concurrent training, concurrent resistance and aerobic training performed in different sessions, and resistance training alone provide similar neuromuscular adaptations in prepubertal girls and boys;
- v) Both intra-session concurrent training order are effective on explosive strength and $VO_2\text{max}$ improvements in prepubertal children, but intra-session aerobic prior to resistance training is more effective to obtain improvements on aerobic capacity.
- vi) To improve explosive strength, intra-session resistance prior to aerobic training is more effective;
- vii) Predictive equations to evaluate explosive strength and $VO_2\text{max}$ variables of children were developed.

Chapter 6. Suggestions for future research

The effects of different combinations of concurrent training in prepubertal children are far from being well known and further researches are needed to support the presented evidences. Therefore, some suggestions for future investigations are listed below:

- i) To replicate these studies but with longer training periods;
- ii) Further investigations should add information about power and velocity during resistance training measures;
- iii) Futures experiments should measure different physiologic parameters to understand the responsible mechanism of the observed effects;
- iv) To develop a study in the same line of thinking but including prepubertal children with different conditions (physical disability, chronic diseases or athletes), to reach the knowledge about concurrent training in this population;
- v) To replicate these studies but implementing a detraining period to know the influence of a training cessation on prepubertal children performance.

Chapter 7. References

Chapter 1 - General Introduction.

- ◆ Alves, A.R., Marta, C.C., Neiva, H.P., Izquierdo, M., & Marques, M.C. (2016a). Concurrent training in prepubescent children: The effects of 8 weeks of strength and aerobic training on explosive strength and VO₂max. *Journal of Strength & Conditioning Research*, 30 (7), 2019-32.
- ◆ Alves, A.R., Marta, C.C., Neiva, H.P., Izquierdo, M., & Marques, M.C. (2016b). Does intra-session concurrent strength and aerobic training order influence training-induced explosive strength and VO₂max in prepubescent children? *Journal of Strength & Conditioning Research*, 30(12), 3267-3277.
- ◆ Barbosa T.M., Costa, M., Marinho, D.A., Coelho, J., Moreira, M., & Silva, A.J. (2010). Modeling the links between young swimmers' performance: energetic and biomechanic profiles. *Pediatric Exercise Science*, 22(3), 379-391.
- ◆ Benson, A.C., Torode, M.E., & Fiatarone Singh, M.A. (2007). A rational and method for high-intensity progressive resistance training with children and adolescents. *Contemporary Clinical Trials*, 28(4), 442-450.
- ◆ Blimkie, C.J. (1993). Resistance training during preadolescence. Issues and controversies. *Sports Medicine*, 15(6), 389-407.
- ◆ Cadore E.L., Pinto, R.S., Pinto, S.S., Alberton, C.L., Correa, C.S., Tartaruga, M.P., Silva, E.M., Almeida, A.P., Trindade, G.T., & Kruel, L.F. (2011). Effects of strength, endurance, and concurrent training on aerobic power and dynamic neuromuscular economy in elderly men. *Journal of Strength & Conditioning Research*, 25(3), 758-766.
- ◆ Cadore, E.L., Izquierdo, M., dos Santos, M.G., Martins, J.B., Rodrigues Lhullier, F.L., Pinto, R.S., Silva, R.F., & Kruel, L.F. (2012). Hormonal responses to concurrent strength and endurance training with different exercise orders. *Journal of Strength & Conditioning Research*, 26(12), 3281-3288.

- ◆ Cadore, E.L., Izquierdo, M., Pinto, S.S., Alberton, C.L., Pinto, R.S., Baroni, B.M., Vaz, M.A., Lanferdini, F.J., Radaelli, R., González- Izal, M., Bottaro, M., & Kruel, L.F. (2013). Neuromuscular adaptations to concurrent training in the elderly: effects of intra-session exercise sequence. *Age (Dordr)*, 35(3), 891-903.
- ◆ Caspersen, C.J., Powell, K.E., & Christenson, G.M. (1985). Physical activity, exercise, and physical fitness: Definitions and distinctions for health-related research. *Public Health Reports*, 100(2), 126-131.
- ◆ Cepero, M.R., López, R., Suárez-Llorca, C., Andreu-Cabrera, E., & Rojas, F.J. (2011). Fitness test profiles in children aged 8-12 years old in Granada (Spain). *Journal of Human Sports Exercise*, 6(1), 135-145.
- ◆ Chtara, M., Chamari, K., Chaouachi, M., Chaouachi, A., Koubaa, D., Feki, Y., Millet, G., & Amri, M. (2005). Effects of intra-session concurrent endurance and strength training sequence on aerobic performance and capacity. *British Journal of Sports Medicine*, 39(8), 555-560.
- ◆ Craig, B.W., Lucas, J., Pohlman, R., & Stelling, H. (1991). The effects of running, weightlifting and a combination of both on growth hormone release. *Journal of Applied Sport Science Research*, 5(4), 198-203.
- ◆ Davis, W.J, Wood, D.T., Andrews, R.G., Elkind, L.M., & Davis, W.B. (2008). Concurrent training enhances athletes' strength, muscle endurance, and other measures. *Journal of Strength & Conditioning Research*, 22(5), 1487-1502.
- ◆ Docherty, D., Wenger, H.A., & Collis, M.L. (1987). The effects of resistance training on aerobic and anaerobic power of young boys. *Medicine & Science in Sports & Exercise*, 19(4), 389-392.
- ◆ Doma, K., & Deakin, G.B. (2013). The effects of strength training and endurance training order on running economy and performance. *Applied Physiology, Nutrition, and Metabolism*, 38(6), 651-656.
- ◆ Eisenmann, J.C., Wickel, E.E., Welk, G.J., & Blair, S.N. (2005). Relationship between adolescent fitness and fatness and cardiovascular disease risk factors in adulthood: The Aerobics Center Longitudinal Study (ACLS). *American Heart Journal*, 149 (1), 46-53.
- ◆ Faigenbaum, A.D., Westcott, W.L., Micheli, L.J., Outerbridge, A.R., Long, C.J., LaRosa-Loud, R., & Zaichkowsky, L.D. (1996). The effects of strength training and detraining on children. *Journal of Strength & Conditioning Research*, 10(2),109-114.

- ◆ Faigenbaum, A.D., Kraemer, W.J., Blimkie, C.J., Jeffreys, I., Micheli, L.J., Nitka, M., & Rowland, T.W. (2009). Youth resistance training: Updated position statement paper from the National Strength and Conditioning Association. *Journal of Strength & Conditioning Research*, 23(5), S60-S79.
- ◆ Faigenbaum, A.D., & Myer, G.D. (2010). Pediatric resistance training: Benefits, concerns, and program design considerations. *Current Sports Medicine Reports*, 9(3), 161-168.
- ◆ Garber, C.E., Blissmer, B., Deschenes, M.R., Franklin, B.A., Lamonte, M.J., Lee, I.M., Nieman, D.C., & Swain, D.P. (2011). American College of Sport Medicine position stand. Quantity and quality of exercise for developing and maintaining cardiorespiratory, musculoskeletal, and neuromotor fitness in apparently healthy adults: Guidance for prescribing exercise. *Medicine & Science in Sports & Exercise*, 43(7), 1334-1359.
- ◆ García-Pallarés, J., & Izquierdo, M. (2011). Strategies to optimize concurrent training of strength and aerobic fitness for rowing and canoeing. *Sports Medicine*, 41(4), 329-343.
- ◆ Glowacki, S.P., Martin, S.E., Maurer, A., Baek, W., Green, J.S., & Crouse, S.F. (2004). Effects of resistance, endurance, and concurrent exercise on training outcomes in men. *Medicine & Science in Sports & Exercise*, 36(12), 2119-2127.
- ◆ Hennessy, L.C., & Watson, A.W.S. (1994). The interference effects of training for strength and endurance simultaneously. *Journal of Strength & Conditioning Research*, 8(1), 12-19.
- ◆ Hoffman, J.R., & Kang, J. (2003). Strength changes during an in-season resistance-training program for football. *Journal of Strength & Conditioning Research*, 17(1), 109-114.
- ◆ Izquierdo, M., Häkkinen, K., Ibañez, J., Kraemer, W.J., & Gorostiaga, E.M. (2005). Effects of combined resistance and cardiovascular training on strength, power, muscle cross-sectional area, and endurance markers in middle-aged men. *European Journal of Applied Physiology*, 94(1-2), 70-75.
- ◆ Kang, Y., & Ratamess, N. (2014). Which Comes First? Resistance Before Aerobic Exercise or Vice Versa? *American College of Sports Medicine*, 18(1), 9-14.

- ◆ Kraemer, W.J., Patton, J.F., Gordon, S.E., Harman, E.A., Deschenes, M.R., Reynolds, K., Newton, R.U., Triplett, N.T., & Dziados, J.E. (1995). Compatibility of high-intensity strength and endurance training on hormonal and skeletal muscle adaptations. *Journal of Applied Physiology*, 78(3), 976-989.
- ◆ Kraemer, W.J., Keuning, M., Ratamess, N.A., Volek, J.S., McCormick, M., Bush, J.A., Nindl, B.C., Gordon, S.E., Mazzeti, S.A., Newton, R.U., Gómez, A.L., Wickham, R.B., Rubi, M.R., & Häkkinen, K. (2001). Resistance training combined with bench-step aerobics enhances women's health profile. *Medicine & Science in Sports & Exercise*, 33(2), 259-269.
- ◆ Kvaavik, E., Klepp, K.I., Tell, G.S., Meyer, H.E., & Batty, G.D. (2009). Physical fitness and physical activity at age 13 years as predictors of cardiovascular disease risk factors at ages 15, 25, 33, and 40 years: Extended follow-up of the Oslo Youth Study. *Pediatrics*, 123(1), e80-e86.
- ◆ Leveritt M., Abernethy, P.J., Barry, B.K., & Logan, P.A. (1999). Concurrent strength and endurance training. A review. *Sports Medicine*, 28(6), 413-427.
- ◆ Marta, C.C., Marinho, D.A., Barbosa, T.M., Izquierdo, M., & Marques, M.C. (2012). Physical fitness differences between prepubescent boys and girls. *Journal of Strength and Conditioning Research*, 26(7), 1756-1766.
- ◆ Marta, C.C., Marinho, D.A., Barbosa, T.M., Izquierdo, M., & Marques, M.C. (2013). Effects of concurrent training on explosive strength and VO₂max in prepubescent children. *International Journal of Sports Medicine*, 34 (10), 888-896.
- ◆ Matton, L., Duvigneaud, N., Wijndaele, K., Philippaerts, R., Duquet, W., Beunen, G., Claessens, A.L., Thomis, M., & Lefevre, J. (2007). Secular trends in anthropometric characteristics, physical fitness, physical activity and biological maturation in Flemish adolescents between 1969 and 2005. *American Journal of Human Biology*, 19(3), 345-357.
- ◆ Mondal, A. (2006). Physical and motor fitness level of Indian (Bengalee) school going girls. *International Journal of Applied Sports Sciences*, 18(2), 50-64.
- ◆ Morais, J.E., Silva, A.J., Marinho, D.A., Marques, M.C., Batalha, N., & Barbosa, T.M. (2016). Modelling the relationship between biomechanics and performance of young sprinting swimmers. *European Journal of Sport Science*, 16(6), 661-668.

- ◆ Moreno, J.A., Cervelló, E., & Moreno, R. (2007). El autoconcepto físico como predictor de la intención de ser físicamente activo. *Psicología y Salud*, 17(2), 261-267.
- ◆ Ortega, F.B., Ruiz, J.R., Castillo, M.J., & Sjöström, M. (2008). Physical fitness in childhood and adolescence: A powerful marker of health. *International Journal of Obesity*, 32(1), 1-11.
- ◆ Rahnama, N., Gaeini, A.A., & Hamedinia, M.R. (2007). Oxidative stress responses in physical education students during 8 weeks aerobic training. *Journal of Sports Medicine and Physical Fitness*, 47(1), 119-123.
- ◆ Reynolds, J.M., Gordon, T.J., & Robergs, R.A. (2006). Prediction of one repetition maximum strength from multiple repetition maximum testing and anthropometry. *Journal of Strength & Conditioning Research*, 20(3), 584-592.
- ◆ Sale, D.G., McDougall, J.D., Jacobs, I., & Garner, S. (1990). Interaction between concurrent strength and endurance training. *Journal of Applied Physiology*, 68(1), 260-270.
- ◆ Shaw, B.S., Shaw, I., & Brown, G.A. (2009). Comparison of resistance and concurrent resistance and endurance training regimes in the development of strength. *Journal of Strength & Conditioning Research*, 23(9), 2507-2514.
- ◆ Silva, R.F., Cadore, E.L., Kothe, G., Guedes, M., Alberton, C.L., Pinto, S.S., Pinto, R.S., Trindade, G., & Kruel, L.F. (2012). Concurrent training with different aerobic exercises. *International Journal of Sports Medicine*, 33(8), 627-643.
- ◆ Steele, R.M., Brage, S., Corder, K., Wareham, N.J., & Ekelund, U. (2008). Physical activity, cardiorespiratory fitness, and the metabolic syndrome in youth. *Journal of Applied Physiology*, 105(1), 342-351.
- ◆ Stratton, G., Fairclough, S.J., & Ridgers, N.D. (2008). *Youth physical activity and sedentary behavior: Challenges and solutions*. Champaign, IL: Human Kinetics Publishers. Leeds, England.
- ◆ Taanila, H., Hemminki, A.J., Suni, J.H., Pihlajamäki, H., & Parkkari, J. (2011). Low physical fitness is a strong predictor of health problems among young men: A follow-up study of 1411 male conscripts. *BMC Public Health*, 11, 590.

- ◆ Tambalis, K.D., Panagiotakos, D.B., Arnaoutis, G., & Sidossis, L.S. (2013). Endurance, explosive power and muscle strength in relation to body mass index and physical fitness in Greek children aged 7-10 years. *Pediatric Exercise Science*, 25(3), 394-406.
- ◆ Tomkinson, G.R., & Olds, T.S. (2007). Secular changes in pediatric aerobic fitness test performance: The global picture. *Medicine and Sport Science*, 50, 46-66.
- ◆ Trost, S.G., Pate, R.R., Sallis, J.F., Freedson, P.S., Taylor, W.C., Dowda, M., & Sirard, J. (2002). Age and gender differences in objectively measured physical activity in youth. *Medicine & Science in Sports & Exercise*, 34(2), 350-355.
- ◆ Viñas, B.R., Majem, L.S., Barba, L.R., Pérez-Rodrigo, C., & Bartrina, J.A. (2006). Actividad física en la población infantil y juvenil española en el tiempo libre. Estudio Enkid (1998-2000), *Apunts Medicina de l'Esport*, 41(151), 86-94.

Chapter 2 - Study 1.

- ◆ Aaron, D.J., Storti, K.L., Robertson, R.J., Kriska, A.M., & LaPorte, R.E. (2002). Longitudinal study of the number and choice of leisure time physical activities from mid to late adolescence. *Archives of Pediatrics and Adolescent Medicine*, 156(11), 1075-1080.
- ◆ Abernethy, L., & Bleakley, C. (2007). Strategies to prevent injury in adolescent sport: A systematic review. *British Journal of Sports Medicine*, 41(10), 627-638.
- ◆ Alves, J.V., Saavedra, F., Simão, R., Novaes, J., Rhea, M.R., Green, D., & Reis, V.M. (2012). Does aerobic and strength exercise sequence in the same session affect the oxygen uptake during and post-exercise? *Journal of Strength & Conditioning Research*, 26(7), 1872-1878.
- ◆ Andersen, L.B., & Haraldsdóttir, J. (1994). Changes in CHD risk factors with age: a comparison of Danish adolescents and adults. *Medicine & Science in Sports & Exercise*, 26(8), 967-972.
- ◆ Arazi, H., Faraji, H., Moghadam, M.G., & Samadi, A. (2011). Effects of concurrent exercise protocols on strength, aerobic power, flexibility and body composition. *Kinesiology*, 43(2), 155-162.
- ◆ Armstrong, N., & Welsman, J. (1997). *Young People and Physical Activity*. Oxford University Press. Michigan, USA.

- ◆ Baker, D. (2001). The effects of an in-season concurrent training on the maintenance of maximal strength and power in professional and college-aged rugby league football players. *Journal of Strength & Conditioning Research*, 15(2), 172-177.
- ◆ Baquet, G., Berthoin, S., Dupont, G., Blondel, N., Fabre, C., & van Praagh, E. (2002). Effects of high intensity intermittent training on peak VO₂ in prepubertal children. *International Journal of Sports Medicine*, 23(6), 439-444.
- ◆ Baquet, G., van Praagh, E., & Berthoin, S. (2003). Endurance training and aerobic fitness in young people. *Sports Medicine*, 33(15), 1127-1143.
- ◆ Benson, A.C., Torode, M.E., & Singh, M.A.F. (2007). A rationale and method for high-intensity progressive resistance training with children and adolescents. *Contemporary Clinical Trials*, 28(4), 442-450.
- ◆ Blair, S.N., Kohl, H.W., Paffenbarger, R.S., Clark, D.G., Cooper, K.H., & Gibbons, L.W. (1989). Physical fitness and all-cause mortality. A prospective study of healthy men and women. *JAMA*, 262(17), 2395-2401.
- ◆ Blimkie, C.J. (1993). Resistance training during preadolescence. Issues and controversies. *Sports Medicine*, 15(6), 389-407.
- ◆ Boreham, C., Twisk, J., Neville, C., Savage, M., Murray, L., & Gallagher, A. (2002). Associations between physical fitness and activity patterns during adolescence and cardiovascular risk factors in young adulthood: The Northern Ireland Young Hearts Project. *International Journal of Sports Medicine*, 23(1), S22- S26.
- ◆ Cadore, E.L., Pinto, R.S., Lhullier, F.L., Correa, C.S., Alberton, C.L., Pinto, S.S., Almeida, A.P., Tartaruga, M.P., Silva, E.M., & Kruel, L.F. (2010). Physiological effects of concurrent training in elderly men. *International Journal of Sports Medicine*, 31(10), 689-697.
- ◆ Cadore E.L., Pinto, R.S., Pinto, S.S., Alberton, C.L., Correa, C.S., Tartaruga, M.P., Silva, E.M., Almeida, A.P., Trindade, G.T., & Kruel, L.F. (2011). Effects of strength, endurance, and concurrent training on aerobic power and dynamic neuromuscular economy in elderly men. *Journal of Strength & Conditioning Research*, 25(3), 758-766.
- ◆ Cadore, E.L., Izquierdo, M., dos Santos, M.G., Martins, J.B., Rodrigues Lhullier, F.L., Pinto, R.S., Silva, R.F., & Kruel, L.F. (2012a). Hormonal responses to concurrent strength and endurance training with different exercise orders. *Journal of Strength & Conditioning Research*, 26(12), 3281-3288.

- ◆ Cadore, E.L., Izquierdo, M., Alberton, C.L., Pinto, R.S., Conceição, M., Cunha, G., Radaelli, R., Bottaro, M., Trindade, G.T, & Kruel, L.F. (2012b). Strength prior to endurance intra-session exercise sequence optimizes neuromuscular and cardiovascular gains in elderly men. *Experimental Gerontology*, 47(2),164-169.
- ◆ Cadore, E.L., Izquierdo, M., Pinto, S.S., Alberton, C.L., Pinto, R.S., Baroni, B.M., Vaz, M.A., Lanferdini, F.J., Radaelli, R., González- Izal, M., Bottaro, M., & Kruel, L.F. (2013). Neuromuscular adaptations to concurrent training in the elderly: effects of intra-session exercise sequence. *Age (Dordr)*, 35(3), 891-903.
- ◆ Cadore, E.L., Pinto, R.S., Bottaro, M., & Izquierdo, M. (2014). Strength and endurance training prescription in healthy and frail elderly. *Aging and Disease*, 5(3), 183-195.
- ◆ Carazo-Vargas, P., & Moncada-Jiménez, J. (2015). A meta-analysis on the effects of exercise training on the VO₂max in children and adolescents. *Retos*, 27, 184-187.
- ◆ Caspersen, C.J., Powell, K.E., & Christenson, G.M. (1985). Physical activity, exercise, and physical fitness: Definitions and distinctions for health-related research. *Public Health Reports*, 100(2), 126-131.
- ◆ Cepero, M., López, R., Suárez-Llorca, C., Andreu-Cabrera, E., & Rojas, F.J. (2011). Fitness test profiles in children aged 8-12 years old in Granada (Spain). *Journal of Human & Exercise*, 6(1), 135-145.
- ◆ Chtara, M., Chamari, K., Chaouachi, M., Chaouachi, A., Koubaa, D., Feki, Y., Millet, G., & Amri, M. (2005). Effects of intra-session concurrent endurance and strength training sequence on aerobic performance and capacity. *British Journal of Sports Medicine*, 39(8), 555-560.
- ◆ Chtara, M., Chaouachi, A., Levin, G.T., Chaouachi, M., Chamari, K., Amri, M., & Laursen, P.B. (2008). Effect of concurrent endurance and circuit resistance training sequence on muscular strength and power development. *Journal of Strength & Conditioning Research*, 22(4), 1037-1045.
- ◆ Collins, M.A., & Snow, T.K. (1993) Are adaptations to combined endurance and strength training affected by the sequence of training? *Journal of Sports Sciences*, 11(6), 485-491.
- ◆ Dahab, K.S., & McCambridge, T.M. (2009). Strength training in children and adolescents: Raising the bar for young athletes? *Sports Health*, 1(3), 223-226.

- ◆ Davis, W.J., Wood, D.T., Andrews, R.G., Elkind, L.M., & Davis, W.B. (2008a). Concurrent training enhances athletes' cardiovascular and cardiorespiratory measures. *Journal of Strength & Conditioning Research*, 22(5), 1503-1514.
- ◆ Davis, W.J., Wood, D.T., Andrews, R.G., Elkind, L.M., & Davis, W.B. (2008b). Concurrent training enhances athletes' strength, muscle endurance, and other measures. *Journal of Strength & Conditioning Research*, 22(5), 1487-1502.
- ◆ Docherty, D., Wenger, H.A., & Collis, M.L. (1987). The effects of resistance training on aerobic and anaerobic power of young boys. *Medicine & Science in Sports & Exercise*, 19(4), 389-392.
- ◆ Faigenbaum, A.D., Westcott, W.L., Micheli, L.J., Outerbridge, A.R., Long, C.J., LaRosa-Loud, R., & Zaichkowsky, L.D. (1996). The effects of strength training and detraining on children. *Journal of Strength & Conditioning Research*, 10(2), 109-114.
- ◆ Faigenbaum, A.D., Milliken, L.A., & Westcott, W.L. (2003). Maximal strength testing in children. *Journal of Strength & Conditioning Research*, 17(1), 162-166.
- ◆ Faigenbaum, A.D., Milliken, L.A., Cloutier, G., & Westcott, W.L. (2004). Perceived exertion during resistance exercise by children. *Perceptual and Motor Skills*, 98(2), 627-637.
- ◆ Faigenbaum, A.D., Kraemer, W.J., Blimkie, C.J., Jeffreys, I., Micheli, L.J., Nitka, M., & Rowland, T.W. (2009a). Youth resistance training: Updated position statement paper from the National Strength and Conditioning Association. *Journal of Strength & Conditioning Research*, 23(5), S60-S79.
- ◆ Faigenbaum, A.D., & Westcott, W.L. (2009). *Youth Strength Training: Programs for health, fitness and sport*. 2nd ed. Human Kinetics, USA.
- ◆ Faigenbaum, A.D., & Myer, G.D. (2010). Pediatric resistance training: Benefits, concerns, and program design considerations. *Current Sports Medicine Reports*, 9(3), 161-168.
- ◆ Falk, B., & Mor, G. (1996). The effects of resistance and martial arts training in 6- to 8-year old boys. *Pediatric Exercise Science*, 8(1), 48-56.
- ◆ Falk, B., & Tenenbaum, G. (1996). The effectiveness of resistance training in children. A meta-analysis. *Sports Medicine*, 22(3), 176-186.
- ◆ Falk, B., & Eliakim, A. (2003). Resistance training, skeletal muscle and growth. *Pediatric Endocrinology Reviews*, 1(2), 120-127.

- ◆ French, S.A., Story, M., & Jeffery, R.W. (2001). Environmental influences on eating and physical activity. *Annual Review of Public Health, 22*, 309-335.
- ◆ Fyfe, J.J., Bishop, D.J., & Stepto, N.K. (2014). Interference between concurrent resistance and endurance exercise: Molecular bases and the role of individual training variables. *Sports Medicine, 44*(6), 743-762.
- ◆ Garber, C.E., Blissmer, B., Deschenes, M.R., Franklin, B.A., Lamonte, M.J., Lee, I.M., Nieman, D.C., & Swain, D.P. (2011). American College of Sport Medicine position stand. Quantity and quality of exercise for developing and maintaining cardiorespiratory, musculoskeletal, and neuromotor fitness in apparently healthy adults: Guidance for prescribing exercise. *Medicine & Science in Sports & Exercise, 43*(7), 1334-1359.
- ◆ García-Artero, E., Ortega, F.B., Ruiz, J.R., Mesa, J.L., Delgado, M., González-Gross, M., García-Fuentes, M., Vicente-Rodríguez, G., Gutiérrez, A., & Castillo, M.J. (2007). Lipid and metabolic profiles in adolescents are affected more by physical fitness than physical activity (AVENA study). *Revista Española de Cardiología, 60*(6), 581-588.
- ◆ García-Pallarés, J., Sánchez-Medina, L., Pérez, C.E., Izquierdo-Gabarren, M., & Izquierdo, M. (2010). Physiological effects of tapering and detraining in world-class kayakers. *Medicine & Science in Sports & Exercise, 42*(6), 1209-1214.
- ◆ García-Pallarés, J., & Izquierdo, M. (2011). Strategies to optimize concurrent training of strength and aerobic fitness for rowing and canoeing. *Sports Medicine, 41*(4), 329-343.
- ◆ Gergley, J.C. (2009). Comparison of two lower-body modes of endurance training on lower-body strength development while concurrently training. *Journal of Strength & Conditioning Research, 23*(3), 979-987.
- ◆ Glowacki, S.P., Martin, S.E., Maurer, A., Baek, W., Green, J.S., & Crouse, S.F. (2004). Effects of resistance, endurance, and concurrent exercise on training outcomes in men. *Medicine & Science in Sports & Exercise, 36*(12), 2119-2127.
- ◆ Gorostiaga, E.M., Izquierdo, M., Iturralde, P., Ruesta, M., & Ibáñez, J. (1999). Effects of heavy resistance training on maximal and explosive force production, endurance and serum hormones in adolescent handball players. *European Journal of Applied Physiology and Occupational Physiology, 80*(5), 485-493.

- ◆ Gravelle, B.L., & Blessing, D.L. (2000). Physiological adaptation in women concurrently training for strength and endurance. *Journal Strength & Conditioning Research*, 14(1), 5-13.
- ◆ Greenleaf, C.A., Petrie, T.A., & Martin, S.B. (2010). Psychosocial variables associated with body composition and cardiorespiratory fitness in middle school students. *Research Quarterly for Exercise & Sport*, 81(3), S65-S74.
- ◆ Häkkinen, K., Alen, M., Kraemer, W.J., Gorostiaga, E., Izquierdo, M., Rusko, H., Mikkola, J., Hakkinen, A., Valkeinen, H., Kaarakeinen, E., Romu, S., Erola, V., Ahtiainen, K., & Paavolainen, L. (2003). Neuromuscular adaptations during concurrent strength and endurance training versus strength training. *European Journal of Applied Physiology*, 89(1), 42-52.
- ◆ Hass, C.J., Feigenbaum, M.S., & Franklin, B.A. (2001). Prescription of resistance training for healthy populations. *Sports Medicine*, 31(14), 953-964.
- ◆ Hennessy, L.C., & Watson, A.W.S. (1994). The interference effects of training for strength and endurance simultaneously. *Journal of Strength & Conditioning Research*, 8(1), 12-19.
- ◆ Hickson, R.C. (1980). Interference of strength development by simultaneously training for strength and endurance. *European Journal of Applied Physiology Occupational Physiology*, 45(2-3), 255-263.
- ◆ Hickson, R.C., Dvorak, B.A., Gorostiaga, E.M., Kurowski, T.T., & Forster, C. (1988). Potential for strength and endurance training to amplify endurance performance. *Journal of Applied Physiology*, 65(5), 2285-2290.
- ◆ Holviala, J., Häkkinen, A., Karavirta, L., Nyman, K., Izquierdo, M., Gorostiaga, E.M., Avela, J., Korhonen, J., Knuutila, V.P., Kraemer, W.J., & Häkkinen, K. (2010). Effects of combined strength and endurance training on treadmill load carrying walking performance in aging men. *Journal of Strength & Conditioning Research*, 24(6), 1584-1595.
- ◆ Izquierdo, M., Häkkinen, K., Ibañez, J., Anton, A., Garrues, M., Ruesta, M., & Gorostiaga, E.M. (2003). Effects of strength training on submaximal and maximal endurance performance capacity in middle-aged and older men. *Journal of Strength & Conditioning Research*, 17(1), 129-139.

- ◆ Izquierdo, M., Häkkinen, K., Ibañez, J., Kraemer, W.J., & Gorostiaga, E.M. (2005). Effects of combined resistance and cardiovascular training on strength, power, muscle cross-sectional area, and endurance markers in middle-aged men. *European Journal of Applied Physiology*, 94(1-2), 70-75.
- ◆ Izquierdo-Gabarrén, M., Expósito, R.G.T., García-Pallarés, J., Sánchez-Medina, L., De Villarreal, E.S., & Izquierdo, M. (2010). Concurrent endurance and strength training not to failure optimizes performance gains. *Medicine & Science in Sports & Exercise*, 42(6), 1191-1199.
- ◆ Kang, J., Rashti, S.L., Tranchina, C.P., Ratamess, N.A., Faigenbaum, A.D. & Hoffman, J.R. (2009). Effect of preceding resistance exercise on metabolism during subsequent aerobic session. *European Journal of Applied Physiology*, 107(1), 43-50.
- ◆ Kang, Y., & Ratamess, N. (2014). Which Comes First? Resistance Before Aerobic Exercise or Vice Versa? *American College of Sports Medicine*, 18(1), 9-14.
- ◆ Katch, V.L. (1983). Physical conditioning of children. *Journal of Adolescent Health Care*, 3(4), 241-246.
- ◆ Kelley, D.E., Mintun, M.A., Watkins, S.C., Simoneau, J.A., Jadali, F., Fredrickson, A., Beattie, J., & Thériault, R. (1996). The effect of non- insulin-dependent diabetes mellitus and obesity on glucose transport and phosphorylation in skeletal muscle. *Journal of Clinical Investigation*, 97(12), 2705-2713.
- ◆ Kelley, D.E., He, J., Menshikova, E.V., & Ritov, V.B. (2002). Dysfunction of mitochondria in human skeletal muscle in type 2 diabetes. *Diabetes*, 51(10), 2944-2950.
- ◆ Kemper, H.C., Twisk, J.W., van Mechelen, W., Post, G.B., Roos, J.C., & Lips, P. (2000). Fifteen- year longitudinal study in young adults on the relation of physical activity and fitness with the development of the bone mass: The Amsterdam growth and health longitudinal. *Study Bone*, 27(6), 847-853.
- ◆ Kobayashi, K., Kitamura, K., Miura, M., Sodeyama, H., Murase, Y., Miyashita, M., & Matsui, H. (1978). Aerobic power as related to body growth and training in Japanese boys: A longitudinal study. *Journal of Applied Physiology*, 44(5), 666-672.
- ◆ Kraemer, W.J., Patton, J.F., Gordon, S.E., Harman, E.A., Deschenes, M.R., Reynolds, K., Newton, R.U., Triplett, N.T, & Dziados, J.E. (1995). Compatibility of high-intensity strength and endurance training on hormonal and skeletal muscle adaptations. *Journal of Applied Physiology*, 78(3), 976-989.

- ◆ Kraemer, W.J., Keuning, M., Ratamess, N.A., Volek, J.S., McCormick, M., Bush, J.A., Nindl, B.C., Gordon, S.E., Mazzetti, S.A., Newton, R.U., Gómez, A.L., Wickham, R.B., Rubin, M.R., & Häkkinen, K. (2001). Resistance training combined with bench-step aerobics enhances women's health profile. *Medicine & Science in Sports & Exercise*, 33(2), 259-269.
- ◆ Kүүsmaa, M. (2013). *Effects of 24 weeks of single session combined strength and endurance training on body composition and fitness: Examination of order effect*. (Master's Thesis, University of Jyväskylä, Finland). Retrieved from: <https://jyx.jyu.fi/dspace/bitstream/handle/123456789/41702/URN%3aNBN%3afi%3ajyu-201306061911.pdf?sequence=1>.
- ◆ Kvaavik, E., Klepp, K.I., Tell, G.S., Meyer, H.E., & Batty, G.D. (2009). Physical fitness and physical activity at age 13 years as predictors of cardiovascular disease risk factors at ages 15, 25, 33, and 40 years: Extended follow-up of the Oslo Youth Study. *Pediatrics*, 123(1), e80-e86.
- ◆ Leveritt M., Abernethy, P.J., Barry, B.K., & Logan, P.A. (1999). Concurrent strength and endurance training. A review. *Sports Medicine*, 28(6), 413-427.
- ◆ Malina, R.M., Beunen, G.P., Classens, A.L., Lefevre, J., Eynde, B.V., Renson, R., Vanreusel, B., & Simons, J. (1995). Fatness and physical fitness of girls 7 to 17 years. *Obesity Research & Clinical Practice*, 3(3), 221-231.
- ◆ Malina, R.M. (2006). Weight training in youth-growth, maturation and safety: An evidenced-based review. *Clinical Journal of Sport Medicine*, 16(6), 478-487.
- ◆ Mandigout, S., Lecoq, A.M., Courteix, D., Guenon, P., & Obert, P. (2001). Effect of gender in response to an aerobic training programme in prepubertal children. *Acta Paediatrica*, 90(1), 9-15.
- ◆ Marta, C.C., Marinho, D.A., Barbosa, T.M., Izquierdo, M., & Marques, M.C. (2012). Physical fitness differences between prepubescent boys and girls. *Journal of Strength & Conditioning Research*, 26(7), 1756-1766.
- ◆ Marta, C.C., Marinho, D.A., Barbosa, T.M., Izquierdo, M., & Marques, M.C. (2013). Effects of concurrent training on explosive strength and VO₂max in prepubescent children. *International Journal of Sports Medicine*, 34(10), 888-896.
- ◆ Martínez-Vizcaíno, V., & Sánchez-López, M. (2008). Relationship Between Physical Activity and Physical Fitness in Children and Adolescents. *Revista Española de Cardiología*, 61(2), 108-111.

- ◆ Massicotte, D.R. & Macnab, R.B. (1974). Cardiorespiratory adaptations to training at specified intensities in children. *Medicine & Science in Sports & Exercise*, 6(4), 242-246.
- ◆ Matos, N., & Winsley, R.J. (2007). Trainability of young athletes and overtraining. *Journal of Sports Science & Medicine*, 6(3), 353-367.
- ◆ Matton, L., Duvigneaud, N., Wijndaele, K., Philippaerts, R., Duquet, W., Beunen, G., Claessens, A.L., Thomis, M., & Lefevre, J. (2007). Secular trends in anthropometric characteristics, physical fitness, physical activity and biological maturation in Flemish adolescents between 1969 and 2005. *American Journal of Human Biology*, 19(3), 345-357.
- ◆ McCarthy, J.P., Agre, J.C., Graf, B.K., Pozniak, M.A., & Vailas, A.C. (1995). Compatibility of adaptive responses with combining strength and endurance training. *Medicine & Science in Sports & Exercise*, 27(3), 429-436.
- ◆ McCarthy, J.P., Pozniak, M.A. & Agre, J.C. (2002). Neuromuscular adaptations to concurrent strength and endurance training. *Medicine & Science in Sports & Exercise*, 34(3), 511-519.
- ◆ Micheli, L.J., Glassman, R., & Klein, M. (2000). The prevention of sports injuries in children. *Clinics in Sports Medicine*, 19(4), 821-834.
- ◆ Mirwald, R.L., Bailey, D.A., Cameron, N., & Rasmussen, R.L. (1981). Longitudinal comparison of aerobic power in active and inactive boys aged 7.0 to 17.0 years. *Annals of Human Biology*, 8(5), 405-414.
- ◆ Moreno, J.A., Cervelló, E., & Moreno, R. (2007). El autoconcepto físico como predictor de la intención de ser físicamente activo. *Psicología y Salud*, 17(2), 261-267.
- ◆ Ortega, F.B., Tresaco, B., Ruiz, J.R., Moreno, L.A., Martin-Matillas, M., Mesa, J.L., Warnberg, J., Bueno, M., Tercedor, P., Gutiérrez, A., & Castillo, M.J. (2007). Cardiorespiratory fitness and sedentary activities are associated with adiposity in adolescents. *Obesity*, 15(6), 1589-1599.
- ◆ Ortega, F.B., Ruiz, J.R., Hurtig-Wennlöf, A., & Sjöström, M. (2008a). Los adolescentes físicamente activos presentan más probabilidad de una capacidad cardiovascular saludable independientemente del grado de adiposidad. The European Youth Heart Study. *Revista Española de Cardiología*, 61(2), 123-129.

- ◆ Ortega, F.B., Ruiz, J.R., Castillo, M.J., & Sjöström, M. (2008b). Physical fitness in childhood and adolescence: A powerful marker of health. *International Journal of Obesity*, 32(1), 1-11.
- ◆ Ortega, F.B., Silventoinen, K., Tynelius, P., & Rasmussen, F. (2012). Muscular strength in male adolescents and premature death: Cohort study of one million participants. *British Medical Journal*, 345, e7279.
- ◆ Ozmun, J.C., Mikesky, A.E., & Surburg, P.R. (1994). Neuromuscular adaptations following prepubescent strength training. *Medicine & Science in Sports & Exercise*, 26(4), 510-514.
- ◆ Payne, V.G., Morrow, J.R., Johnson, L., & Dalton, S.N. (1997). Resistance training in children and youth: A meta-analysis. *Research Quarterly for Exercise & Sport*, 68(1), 80-88.
- ◆ Pfeiffer, K.A., Lobelo, F., Ward, D.S., & Pate, R.R. (2008). *Endurance trainability of children and youth: The Young Athlete*. Oxford University Press. Michigan, USA.
- ◆ Pijnappels, M., van der Burg, P.J., Reeves, N.D., & van Dieën, J.H. (2008). Identification of elderly fallers by muscle strength measures. *European Journal of Applied Physiology*, 102(5), 585-592.
- ◆ Pitukcheewanont, P., Punyasavatsut, N., & Feuille, M. (2010). Physical activity and bone health in children and adolescents. *Pediatric Endocrinology Reviews*, 7(3), 275-282.
- ◆ Rahnama, N., Gaeini, A.A., & Hamedinia, M.R. (2007). Oxidative stress responses in physical education students during 8 weeks aerobic training. *Journal of Sports Medicine and Physical Fitness*, 47(1), 119-123.
- ◆ Ramsay, J.A., Blimkie, C.J., Smith, K., Garner, S., MacDougall, J.D., & Sale, D.G. (1990). Strength training effects in prepubescent boys. *Medicine & Science in Sports & Exercise*, 22(5), 605-614.
- ◆ Reeves, N.D., Narici, M.V., & Maganaris, C.N. (2004). Effect of resistance training on skeletal muscle-specific force in elderly humans. *Journal of Applied Physiology*, 96(3), 885-892.
- ◆ Roetert, E.P. (2004). The lack of childhood activity in the United States. *Strength & Conditioning Journal*, 26(2), 22-23.

- ◆ Rowland, T.W. (2007). Promoting physical activity for children's health: rationale and strategies. *Sports Medicine*, 37(11), 929-936.
- ◆ Ruiz, J.R., Castro- Piñero, J., Artero, E.G., Ortega, F.B., Sjörström, M., Suni, J., & Castillo, M.J. (2009). Predictive validity of health-related fitness in youth: A systematic review. *British Journal of Sports Medicine*, 43(12), 909-923.
- ◆ Sadres, E., Eliakim, A., Constantini, N., Lidor, R., & Falk, B. (2001). The effect of long-term resistance training on anthropometric measures, muscle strength, and self-concept in pre-pubertal boys. *Pediatric Exercise Science*, 13(4), 357-372.
- ◆ Sale, D.G., McDougall, J.D., Jacobs, I., & Garner, S. (1990). Interaction between concurrent strength and endurance training. *Journal of Applied Physiology*, 68(1), 260-270.
- ◆ Santos, A., Marinho, D.A., Costa, A.M., Izquierdo, M., & Marques, M.C. (2011). Effects of a concurrent strength and endurance training/detraining program follow a specific detraining cycle on strength and aerobic fitness in school girls. *Journal of Human Kinetics*, 29A, 93-103.
- ◆ Santos, A., Marinho, D.A., Costa, A.M., Izquierdo, M., & Marques, M.C. (2012). The effects of concurrent resistance and endurance training follow a detraining period in elementary school students. *Journal of Strength & Conditioning Research*, 26(6), 1708-1716.
- ◆ Santos, R., Mota, J., Santos, D.A., Silva, A.M., Baptista, F., & Sardinha, L.B. (2014). Physical fitness percentiles for Portuguese children and adolescents aged 10-18 years. *Journal of Sports Sciences*, 32(16), 1510-1518.
- ◆ Shaw, B.S., Shaw, I., & Brown, G.A. (2009). Comparison of resistance and concurrent resistance and endurance training regimes in the development of strength. *Journal of Strength & Conditioning Research*, 23(9), 2507-2514.
- ◆ Shephard, R.J. (1992). Effectiveness of training programmes for prepubescent children. *Sports Medicine*, 13(3), 194-213.
- ◆ Shore, S.M., Sachs, M.L., Lidicker, J.R., Brett, S.N., Wright, A.R., & Libonati, J.R., (2008). Decreased scholastic achievement in overweight middle school students. *Obesity*, 16(7), 1535-1538.

- ◆ Sillanpää, E., Häkkinen, A., Nyman, K., Mattila, M., Cheng, S., Karavirta, L., Laaksonen, D.E., Huuhka, N., Kraemer, W.J., & Häkkinen, K. (2008). Body composition and fitness during strength and/or endurance training in older men. *Medicine & Science in Sports Exercise*, 40(5), 950-958.
- ◆ Silva, R.F., Cadore, E.L., Kothe, G., Guedes, M., Alberton, C.L., Pinto, S.S., Trindade, G., & Kruel, L.F. (2012). Concurrent training with different aerobic exercises. *International Journal of Sports Medicine*, 33(8), 627-634.
- ◆ South African Sports Medicine Association (2008). Resistance training in children and adolescents. South African Sports Medicine Association (SASMA) Web site. Retrieved from: <http://www.sasma.org.za/?p=132>.
- ◆ Steele, R.M., Brage, S., Corder, K., Wareham, N.J., & Ekelund, U. (2008). Physical activity, cardiorespiratory fitness, and the metabolic syndrome in youth. *Journal of Applied Physiology*, 105(1), 342-351.
- ◆ Steinberger, J. (2003). Diagnosis of the metabolic syndrome in children. *Current Opinion in Lipidology*, 14(6), 555-559.
- ◆ Sung, R., Yu, C., Chang, S., Mo, S., Woo, K., & Lam, C. (2002). Effects of dietary intervention and strength training on blood lipid level in obese children. *Archives of Disease in Childhood*, 86(6), 407-410.
- ◆ Szymanski, D.J., Szymanski, J.M., Bradford, T.J., Schade, R.L., & Pascoe, D.D. (2007). Effect of twelve weeks of medicine ball training on high school baseball players. *Journal of Strength & Conditioning Research*, 21(3), 894-901.
- ◆ Takeshima, N., Rogers, N.L., Rogers, M.E., Islam, M.M., Koizumi, D., & Lee, S. (2007). Functional fitness gain varies in older adults depending on exercise mode. *Medicine & Science in Sports & Exercise*, 39(11), 2036-2043.
- ◆ Tambalis, K.D., Panagiotakos, D.B., Arnaoutis, G., & Sidossis, L.S. (2013). Endurance, explosive power and muscle strength in relation to body mass index and physical fitness in Greek children aged 7-10 years. *Pediatric Exercise Science*, 25(3), 394-406.
- ◆ Tomkinson, G.R., & Olds, T.S. (2007). Secular changes in pediatric aerobic fitness test performance: The global picture. *Medicine and Sport Science*, 50, 46-66.
- ◆ Trost, S.G., Pate, R.R., Sallis, J.F., Freedson, P.S., Taylor, W.C., Dowda, M., & Sirard, J. (2002). Age and gender differences in objectively measured physical activity in youth. *Medicine & Science in Sports & Exercise*, 34(2), 350-355.

- ◆ Tsolakis, C.K., Vagenas, G.K., & Dessypris, A.G. (2004). Strength adaptations and hormonal responses to resistance training and detraining in preadolescent males. *Journal of Strength & Conditioning Research*, 18(3), 625-629.
- ◆ Vaughn, J.M., & Micheli, L. (2008). Strength training recommendations for the young athlete. *Physical Medicine & Rehabilitation Clinics of North America*, 19(2), 235-245.
- ◆ Vicente-Rodriguez, G., Ara, I., Perez-Gomez, J., Serrano-Sanchez, J.A., Dorado, C., & Calbet, J.A. (2004). High femoral bone mineral density accretion in prepubertal soccer players. *Medicine & Science in Sports & Exercise*, 36(10), 1789-1795.
- ◆ Viñas, B.R., Majem, L.S., Barba, L.R., Pérez-Rodrigo, C., & Bartrina, J.A. (2006). Actividad física en la población infantil y juvenil española en el tiempo libre. Estudio Enkid (1998-2000). *Apunts Medicina de l'Esport*, 41(151), 86-94.
- ◆ Wijndaele, K., Duvigneaud, N., Matton, L., Duquet, W., Thomis, M., Beunen, G., Lefevre, J., & Philippaerts, R.M. (2007). Muscular strength, aerobic fitness, and metabolic syndrome risk in Flemish adults. *Medicine & Science in Sports & Exercise*, 39(2), 233-240.
- ◆ Wilson, J.M., Marin, P.J., Rhea, M.R., Wilson, S.M., Loenneke, J.P., & Andersen, J.C. (2012). Concurrent training: a meta-analysis examining interference of aerobic and resistance exercises. *Journal of Strength & Conditioning Research*, 26(8), 2293-2307.
- ◆ Yu, C.C., Sung, R.Y., Hau, K.T., Lam, P.K., Nelson, E.A., & So, R.C. (2008). The effect of diet and strength training on obese children's physical self-concept. *The Journal of Sports Medicine and Physical Fitness*, 48(1), 76-82.

Chapter 3 - Study 2.

- ◆ Adam, C. (1988). *Eurofit: Handbook for the Eurofit Test of Physical Fitness*. Edigraf Editoriale Grafica. Rome, Italy.
- ◆ Arazi, H., Faraji, H., Moghadam, M.G., & Samadi, A. (2011). Effects of concurrent exercise protocols on strength, aerobic power, flexibility and body composition. *Kinesiology*, 43(2), 155-162.
- ◆ Armstrong, N., & Welsman, J. (1997). *Young people and physical activity*. Oxford University Press. Michigan, USA.
- ◆ Baar, K. (2006). Training for endurance and strength: lessons from cell signalling. *Medicine & Sciences in Sports & Exercise*, 38(11), 1939-1944.

- ◆ Cadore, E.L., & Izquierdo, M. (2013). How to simultaneously optimize muscle strength, power, functional capacity, and cardiovascular gains in the elderly: an update. *Age (Dordr)*, 35(6), 2329-2344.
- ◆ Chtara, M., Chamari, K., Chaouachi, M., Chaouachi, A., Koubaa, D., Feki, Y., Millet, G., & Amri, M. (2005). Effects of intra-session concurrent endurance and strength training sequence on aerobic performance and capacity. *British Journal of Sports Medicine*, 39(8), 555-560.
- ◆ Craig, B.W., Lucas, J., Pohlman, R., & Stelling, H. (1991). The effects of running, weightlifting and a combination of both on growth hormone release. *Journal of Applied Sport Science Research*, 5(4), 198-203.
- ◆ Doma, K., & Deakin, G.B. (2013). The effects of strength training and endurance training order on running economy and performance. *Applied Physiology, Nutrition & Metabolism*, 38(6), 651-656.
- ◆ Dorgo, S., King, G.A., Candelaria, N., Bader, J.O., Brickey, G.D., & Adams, C.E. (2009). Effects of manual resistance training on fitness in adolescents. *Journal of Strength & Conditioning Research*, 23(8), 2287-2294.
- ◆ Dudley, G.A., & Djamil, R. (1985). Incompatibility of endurance- and strength-training modes of exercise. *Journal of Applied Physiology*, 59(5), 1446-1451.
- ◆ Duke, P.M., Litt, I.R., & Gross, R.T. (1980). Adolescents self-assessment of sexual maturation. *Pediatrics*, 66(6), 918-920.
- ◆ Fyfe, J.J., Bishop, D.J., & Stepto, N.K. (2014). Interference between Concurrent Resistance and Endurance Exercise: Molecular Bases and the Role of Individual Training Variables. *Sports Medicine*, 44(6), 743-762.
- ◆ García-Pallarés, J., & Izquierdo, M. (2011). Strategies to optimize concurrent training of strength and aerobic fitness for rowing and canoeing. *Sports Medicine*, 41(4), 329-343.
- ◆ Glowacki, S.P., Martin, S.E., Maurer, A., Baek, W., Green, J.S., & Crouse, S.F. (2004). Effects of resistance, endurance, and concurrent exercise on training outcomes in men. *Medicine & Science in Sports & Exercise*, 36(12), 2119-2127.
- ◆ Hatzikotoulas, K., Patikas, D., Bassa, E., Hadjileontiadis, L., Koutedakis, Y., & Kotzamanidis, C. (2009). Submaximal fatigue and recovery in boys and men. *International Journal of Sports Medicine*, 30(10), 741-746.

- ◆ Izquierdo, M., Häkkinen, K., Ibáñez, J., Kraemer, W.J., & Gorostiaga, E.M. (2005). Effects of combined resistance and cardiovascular training on strength, power, muscle cross-sectional area, and endurance markers in middle-aged men. *European Journal of Applied Physiology*, 94(1-2), 70-75.
- ◆ Izquierdo-Gabarren, M., Expósito, R.G.T., García-pallarés, J., Sánchez- Medina, L., De Villarreal, E.S., & Izquierdo, M. (2010). Concurrent endurance and strength training not to failure optimizes performance gains. *Medicine & Science in Sports Exercise*, 42(6), 1191-1199.
- ◆ Kraemer, W., Fry, A., Frykman, P., Conroy, B., & Hoffman, J. (1989). Resistance training and youth. *Pediatric Exercise Science*, 1(4), 336-350.
- ◆ Léger, L.A., Mercier, D., Gadoury, C., & Lambert, J. (1988). The multistage 20 meter shuttle run test for aerobic fitness. *Journal of Sports Sciences*, 6(2), 93-101.
- ◆ Leveritt, M., Abernethy, P.J., Barry, B.K., & Logan, P.A. (1999). Concurrent strength and endurance training. A review. *Sports Medicine*, 28(6), 413-427.
- ◆ Leveritt, M., Abernethy, P.J., Barry, B., & Logan, P.A. (2003). Concurrent strength and training: the influence of dependent variable selection. *Journal of Strength & Conditioning Research*, 17(3), 503-508.
- ◆ Linthorne, N.P. (2001). Analysis of standing vertical jumps using a force platform. *American Journal of Physics*, 69(11), 1198-1204.
- ◆ Mäkinen, T.E., Borodulin, K., Tammelin, T.H., Rahkonen, O., Laatikainen, T., & Prättälä, R. (2010). The effects of adolescence sports and exercise on adulthood leisure-time physical activity in educational groups. *International Journal of Behavioural Nutrition and Physical Activity*, 7, 27.
- ◆ Marfell-Jones M., Olds, T., Stewart, A., & Carter, L. (2006). *International Standards for Anthropometric Assessment*. International Society for the Advancement of Kinanthropometry. Potchefstroom, South Africa: ISAK.
- ◆ Marques, M.C., Zajac, A., Pereira, A., & Costa, A.M. (2011). Strength training and detraining in different populations: Case studies. *Journal of Human Kinetics*, 29A, 7-14.
- ◆ Marta, C.C. (2013a). *Determinant of physical fitness in prepubescent children and its training effects*. (Doctoral Dissertation, University of Beira Interior, Covilhã, Portugal. Retrieved from:

https://ubibliorum.ubi.pt/bitstream/10400.6/2328/1/Determinants%20of%20physical%20fitness%20in%20prepubescent%20children%20and%20its%20training%20effects_%20Covilhã%202013.pdf.

- ◆ Marta, C.C., Marinho, D.A., Barbosa, T.M., Carneiro, A.L., Izquierdo, M., & Marques, M.C. (2013b). Effects of body fat and dominant somatotype on explosive strength and aerobic capacity trainability in prepubescent children. *Journal of Strength & Conditioning Research*, 27(12), 3233-3244.
- ◆ Marta, C.C., Marinho, D.A., Barbosa, T.M., Izquierdo, M., & Marques, M.C. (2013c). Effects of concurrent training on explosive strength and VO₂max in prepubescent children. *International Journal of Sports Medicine*, 34(10), 888-896.
- ◆ Matton, L., Duvigneaud, N., Wijndaele, K., Philippaerts, R., Duquet, W., Beunen, G., Claessens, A.L., Thomis, M., & Lefevre, J. (2007). Secular trends in anthropometric characteristics, physical fitness, physical activity and biological maturation in Flemish adolescents between 1969 and 2005. *American Journal of Human Biology*, 19(3), 345-357.
- ◆ Mayhew, J.L., Ware, J.S., Johns, R.A., & Bembien, M.G. (1997). Changes in upper body power following heavy-resistance strength training in college men. *International Journal of Sports Medicine*, 18(7), 516-520.
- ◆ McCarthy, P., Pozniak, M.A., & Agre, J.C. (2002). Neuromuscular adaptations to concurrent strength and endurance training. *Medicine & Science in Sports Exercise*, 34(3), 511-519.
- ◆ McPhail, S.M., Schippers, M., & Marshall, A.L. (2014). Age, physical inactivity, obesity, health conditions, and health-related quality of life among patients receiving conservative management for musculoskeletal disorders. *Journal of Clinical Interventions in Aging*, 9, 1069-1080.
- ◆ Mikkola, J., Rusko, H., Nummela, A., Pollari, T., & Häkkinen, K. (2007). Concurrent endurance and explosive type strength training improves neuromuscular and anaerobic characteristics in young distance runners. *International Journal of Sports Medicine*, 28(7), 602-611.
- ◆ Moro, T., Bianco, A., Faigenbaum, A.D., & Paoli, A. (2014). Pediatric resistance training: current issues and concerns. *Minerva Pediatrica*, 66(3), 217-227.
- ◆ Ortega, F.B., Ruiz, J.R., Castillo, M.J., & Sjöström, M. (2008). Physical fitness in childhood and adolescence: A powerful marker of health. *International Journal of*

Obesity, 32(1), 1-11.

- ◆ Pugh, J.K., Faulkner, S.H., Jackson, A.P., King, J.A., & Nimmo, M.A. (2015). Acute molecular responses to concurrent resistance and high- intensity interval exercise in untrained skeletal muscle. *Physiological Reports*, 3(4), e12364.
- ◆ Ramsay, J., Blimkie, C., Smith, K., Garner, S., Macdougall, J., & Sale, D. (1990). Strength training effects in prepubescent boys. *Medicine & Science in Sports & Exercise*, 22(5), 605-614.
- ◆ Ratel, S., Bedu, M., Hennegrave, A., Doré, E., & Duché, P. (2002). Effects of age and recovery duration on peak power output during repeated cycling sprints. *International Journal of Sports Medicine*, 23(6), 397-402.
- ◆ Sale, D.G., McDougall, J.D., Jacobs, I., & Garner, S. (1990). Interaction between concurrent strength and endurance training. *Journal of Applied Physiology*, 68(1), 260-270.
- ◆ Santos, A.P., Marinho, D.A., Costa, A.M., Izquierdo, M., & Marques, M.C. (2012). The effects of concurrent resistance and endurance training follow a detraining period in elementary school students. *Journal of Strength & Conditioning Research*, 26(6), 1708-1716.
- ◆ Shumann, M., Kүүsma, M., Newton, R.U., Sirparanta, A.L., Syvöoja, H., Häkkinen, A., & Häkkinen, K. (2014). Fitness and lean mass increases during combined training independent of loading order. *Medicine & Science in Sports & Exercise*, 46(9), 1958-1968.
- ◆ Siegel, J.A., Camaione, D.N., & Manfredi, T.G. (1989). The effects of upper body resistance training on prepubescent children. *Pediatric Exercise Science*, 1(2), 145-154.
- ◆ Smith, J.J., Eather, N., Morgan, P.J., Plotnikoff, R.C., Faigenbaum, A.D., & Lubans, D.R. (2014). The Health Benefits of Muscular Fitness for Children and Adolescents: A Systematic Review and Meta-Analysis. *Sports Medicine*, 44(9), 1209-23.
- ◆ Taanila, H., Hemminki, A., Suni, J., Pihlajamäki, H., & Parkkari, J. (2011). Low physical fitness is a strong predictor of health problems among young men: a follow-up study of 1411 male conscripts. *BMC Public Health*, 11, 590.
- ◆ Vinet, A., Mandigout, S., Nottin, S., Nguyen, L., Lecoq, A.M., Courteix, D., & Obert, P. (2003). Influence of body composition, hemoglobin concentration, and cardiac size

and function of gender differences in maximal oxygen uptake in prepubertal children. *Chest Journal*, 124(4), 1494-1499.

Chapter 3 - Study 3.

- ◆ Adam, C. (1988). *Eurofit: Handbook for the Eurofit Test of Physical Fitness*. Edigraf Editoriale Grafica. Rome, Italy.
- ◆ Ali-Mohamadi, M., Abbaspoor, M., Rahimi, R., & Hakimi, M. (2014). The influence of order execution components of the strength and endurance in the concurrent training on lipid profile and body composition in overweight females. *World Applied Sciences Journal*, 29(7), 946-953.
- ◆ Baker, D. (2001). The effects of an in-season concurrent training on the maintenance of maximal strength and power in professional and college-aged rugby league football players. *Journal of Strength & Conditioning Research*, 15(2), 172-177.
- ◆ Bell, G.J., Petersen, S.R., Quinney, H.A., & Wenger, H.A. (1988). Sequencing of endurance and high-velocity strength training. *Canadian Journal of Sports Sciences*, 13(4), 214-219.
- ◆ Brown, L.E. (2007). *Strength Training*. Human Kinetics. Colorado, USA.
- ◆ Cadore, E.L., Izquierdo, M., Alberton, C.L., Pinto, R.S., Conceição, M., Cunha, G., Radaelli, R., Bottaro, M., Trindade, G.T., & Kruel, L.F. (2012). Strength prior to endurance intra-session exercise sequence optimizes neuromuscular and cardiovascular gains in elderly men. *Experimental Gerontology*, 47(2), 164-169.
- ◆ Cadore, E.L., Izquierdo, M., Pinto, S.S., Alberton, C.L., Pinto, R.S., Baroni, B.M., Vaz, M.A., Lanferdini, F.J., Radaelli, R., González- Izal, M., Bottaro, M., & Kruel, L.F. (2013). Neuromuscular adaptations to concurrent training in the elderly: effects of intra-session exercise sequence. *Age (Dordr)*, 35(3), 891-903.
- ◆ Cadore, E.L., Pinto, R.S., Bottaro, M., & Izquierdo, M. (2014). Strength and endurance training prescription in healthy and frail elderly. *Aging and Disease*, 5(3), 183-195.
- ◆ Chtara, M., Chamari, K., Chaouachi, M., Chaouachi, A., Koubaa, D., Feki, Y., Millet, G., & Amri, M. (2005). Effects of intra-session concurrent endurance and strength training sequence on aerobic performance and capacity. *British Journal of Sports Medicine*, 39(8), 555-560.

- ◆ Chtara, M., Chaouachi, A., Levin, G.T., Chaouachi, M., Chamari, K., Amri, M., & Laursen, P.B. (2008). Effect of concurrent endurance and circuit resistance training sequence on muscular strength and power development. *Journal of Strength & Conditioning Research*, 22(4), 1037-1045.
- ◆ Collins, M.A., & Snow, T.K. (1993). Are adaptations to combined endurance and strength training affected by the sequence of training? *Journal of Sports Sciences*, 11(6), 485-491.
- ◆ Davis, W.J., Wood, D.T., Andrews, R.G., Elkind, L.M., & Davis, W.B. (2008a). Concurrent training enhances athletes' cardiovascular and cardiorespiratory measures. *Journal of Strength & Conditioning Research*, 22(5), 1503-1514.
- ◆ Davis, W.J., Wood, D.T., Andrews, R.G., Elkind, L.M., & Davis, W.B. (2008b). Concurrent training enhances athletes' strength, muscle endurance, and other measures. *Journal of Strength & Conditioning Research*, 22(5), 1487-1502.
- ◆ Duke, P.M., Litt, I.R., & Gross, R.T. (1980). Adolescents self-assessment of sexual maturation. *Pediatrics*, 66(6), 918-920.
- ◆ Faigenbaum, A.D., & Myer, G.D. (2010). Pediatric resistance training: Benefits, concerns, and program design considerations. *Current Sports Medicine Reports*, 9(3), 161-168.
- ◆ García-Pallarés, J., & Izquierdo, M. (2011). Strategies to optimize concurrent training of strength and aerobic fitness for rowing and canoeing. *Sports Medicine*, 41(4), 329-343.
- ◆ Glowacki, S.P., Martin, S.E., Maurer, A., Baek, W., Green, J.S., & Crouse, S.F. (2004). Effects of resistance, endurance, and concurrent exercise on training outcomes in men. *Medicine & Science in Sports & Exercise*, 36(12), 2119-2127.
- ◆ Gorostiaga, E.M., Izquierdo, M., Iturralde, P., Ruesta, M., & Ibanez, J. (1999). Effects of heavy resistance training on maximal and explosive force production, endurance and serum hormones in adolescent handball players. *European Journal Applied Physiology and Occupational Physiology*, 80(5), 485-493.
- ◆ Gravelle, B.L., & Blessing, D.L. (2000). Physiological adaptation in women concurrently training for strength and endurance. *Journal of Strength & Conditioning Research*, 14(1), 5-13.

- ◆ Hennessey, L.C., & Watson, A.W.S. (1994). The interference effects of training for strength and endurance simultaneously. *Journal of Strength & Conditioning Research*, 8(1), 12-19.
- ◆ Hickson, R.C. (1980). Interference of strength development by simultaneously training for strength and endurance. *European Journal of Applied Physiology and Occupational Physiology*, 45(2-3), 255-263.
- ◆ Holviala, J., Häkkinen, A., Karavirta, L., Nyman, K., Izquierdo, M., Gorostiaga, E.M., Avela, J., Korhonen, J., Knuutila, V.P., Kraemer, W.J., & Häkkinen, K. (2010). Effects of combined strength and endurance training on treadmill load carrying walking performance in aging men. *Journal of Strength & Conditioning Research*, 24(6), 1584-1595.
- ◆ Izquierdo, M., Ibañez, J., Häkkinen, K., Kraemer, W.J., Larrión, J.L., & Gorostiaga, E.M. (2004). Once weekly combined resistance and cardiovascular training in healthy older men. *Medicine & Science in Sports & Exercise*, 36(3), 435-443.
- ◆ Izquierdo-Gabarren, M., Expósito, R.G.T., García-pallarés, J., Sánchez- Medina, L., De Villarreal, E.S., & Izquierdo, M. (2010). Concurrent endurance and strength training not to failure optimizes performance gains. *Medicine & Science in Sports Exercise*, 42(6), 1191-1199.
- ◆ Kang, Y., & Ratamess, N. (2014). Which Comes First? Resistance Before Aerobic Exercise or Vice Versa? *American College of Sports Medicine*, 18(1), 9-14.
- ◆ Kemper, H.C.G., Twisk, J.W.R., Van Mechelen, W., Post, G.B., Roos, J.C., & Lips, P. (2000). Fifteen-year longitudinal study in young adults on the relation of physical activity and fitness with the development of the bone mass: The Amsterdam growth and health longitudinal. *Bone*, 27(6), 847-853.
- ◆ Kraemer, W.J., Patton, J.F., Gordon, S.E., Harman, E.A., Deschenes, M.R., Reynolds, K., Newton, R.U., Triplett, N.T., & Dziados, J.E. (1995). Compatibility of high-intensity strength and endurance training on hormonal and skeletal muscle adaptations. *Journal of Applied Physiology*, 78(3), 976-989.
- ◆ Kraemer, W.J., Keuning, M., Ratamess, N.A., Volek, J.S., McCormick, M., Bush, J.A., Nindl, B.C., Gordon, S.E., Mazzetti, S.A., Newton, R.U., Gómez, A.L., Wickham, R.B., Rubin, M.R., & Häkkinen, K. (2001). Resistance training combined with bench-step aerobics enhances women's health profile. *Medicine & Science in Sports & Exercise*, 33(2), 259-269.

- ◆ Leveritt, M., Abernethy, P.J., Barry, B.K., & Logan, P.A. (2003). Concurrent strength and endurance training: The influence of dependent variable selection. *Journal of Strength & Conditioning Research*, 17(3), 503-508.
- ◆ Linthorne, N.P. (2001). Analysis of standing vertical jumps using a force platform. *American Journal of Physics*, 69(11), 1198-1204.
- ◆ Marfell-Jones M., Olds, T., Stewart, A., & Carter, L. (2006). *International Standards for Anthropometric Assessment*. International Society for the Advancement of Kinanthropometry. Potchefstroom, South Africa: ISAK.
- ◆ Marta, C.C., Marinho, D.A., Barbosa, T.M., Carneiro, A.L., Izquierdo, M., & Marques, M.C. (2013a). Effects of body fat and dominant somatotype on explosive strength and aerobic capacity trainability in prepubescent children. *Journal of Strength & Conditioning Research*, 27(12), 3233-3244.
- ◆ Marta, C.C., Marinho, D.A., Barbosa, T.M., Izquierdo, M., & Marques, M.C. (2013b). Effects of concurrent training on explosive strength and VO₂max in prepubescent children. *International Journal of Sports Medicine*, 34(10), 888-896.
- ◆ Mayhew, J.L., Ware, J.S., Johns, R.A., & Bemben, M.G. (1997). Changes in upper body power following heavy-resistance strength training in college men. *International Journal of Sports Medicine*, 18(7), 516-520.
- ◆ McCarthy, J.P., Agre, J.C., Graf, B.K., Pozniak, M.A., & Vailas, A.C. (1995). Compatibility of adaptive responses with combining strength and endurance training. *Medicine & Science in Sports & Exercise*, 27(3), 429-436.
- ◆ McGawley, K., & Andersson, P.I. (2013). The order of concurrent training does not affect soccer-related performance adaptations. *International Journal of Sports Medicine*, 34(11), 983-990.
- ◆ Moazzami, M., & Khoshraftar, N. (2011). The effects of a short time training program on physical fitness in female students. *Procedia Social and Behavioral Sciences*, 15, 2627-2630.
- ◆ Robineau, J., Babault, N., Piscione, J., Lacombe, M., & Bigard, A.X. (2014). The specific training effects of concurrent aerobic and strength exercises depends on recovery duration. *Journal of Strength & Conditioning Research*, 30(3), 672-683.

- ◆ Santos, A., Marinho, D.A., Costa, A.M., Izquierdo, M., & Marques, M.C. (2012). The effects of concurrent resistance and endurance training follow a detraining period in elementary school students. *Journal of Strength & Conditioning Research*, 26(6), 1708-1716.
- ◆ Silva, R.F., Cadore, E.L., Kothe, G., Guedes, M., Alberton, C.L., Pinto, S.S., Trindade, G., & Kruel, L.F. (2012). Concurrent training with different aerobic exercises. *International Journal of Sports Medicine*, 33(8), 627-634.
- ◆ Taipale, R., Mikkola, J., Nummela, A.T., Sorvisto, J., Nyman, K., Kyröläinen, H., & Häkkinen, K. (2015). Combined strength and endurance session order: differences in force production and oxygen uptake. *International Journal of Sports Physiology and Performance*, 10(4), 418-425.
- ◆ Takeshima, N., Rogers, N.L., Rogers, M.E., Islam, M.M., Koizumi, D., & Lee, S. (2007). Functional fitness gain varies in older adults depending on exercise mode. *Medicine & Science in Sports & Exercise*, 39(11), 2036-2043.

Chapter 3 - Study 4.

- ◆ Alves, A.R., Marta, C.C., Neiva, H.P., Izquierdo, M., & Marques, M.C. (2016a). Concurrent training in prepubescent children: The effects of 8 weeks of strength and aerobic training on explosive strength and VO₂max. *Journal of Strength & Conditioning Research*, 30(7), 2019-2032.
- ◆ Alves, A.R., Marta, C.C., Neiva, H.P., Izquierdo, M., & Marques, M.C. (2016b). Does intra-session concurrent strength and aerobic training order influence training-induced explosive strength and VO₂max in prepubescent children? *Journal of Strength & Conditioning Research*, 30(12), 3267-3277.
- ◆ Armstrong, N., Barker, A.R., & McManus, A.M. (2015). Muscle metabolism changes with age and maturation: How do they relate to youth sport performance? *British Journal of Sports Medicine*, 49(13), 860-864.
- ◆ Barbosa T.M., Costa, M., Marinho, D.A., Coelho, J., Moreira, M., & Silva, A.J. (2010). Modeling the links between young swimmers' performance: energetic and biomechanic profiles. *Pediatric Exercise Science*, 22(3), 379-391.

- ◆ Bell, G.J., Syrotuik, D., Socha, T., Maclean, I., & Quinney, H.A. (1997). Effect of Strength Training and Concurrent Strength and Endurance Training on Strength, Testosterone, and Cortisol. *Journal of Strength & Conditioning Research*, 11(1), 57-64.
- ◆ Bell, G.J., Syrotuik, D., Martin, T., Burnham, R., & Quinney, H. (2000). Effect of concurrent strength and endurance training on skeletal muscle properties and hormone concentrations in humans. *European Journal of Applied Physiology*, 81(5), 418-427.
- ◆ Benson, A.C., Torode, M.E., & Fiatarone Singh, M.A. (2007). A rational and method for high-intensity progressive resistance training with children and adolescents. *Contemporary Clinical Trials*, 28(4), 442-450.
- ◆ Cadore, E.L., Pinto, R., Lhullier, F., Correa, C., Alberton, C., Pinto, S., & Kruel, L. (2010). Physiological effects of concurrent training in elderly men. *International Journal of Sports Medicine*, 31(10), 689-697.
- ◆ Cadore, E.L., Izquierdo, M., dos Santos, M.G., Martins, J.B., Lhullier, F.L.R., Pinto, R.S., & Kruel, L.F.M. (2012). Hormonal responses to concurrent strength and endurance training with different exercise orders. *Journal of Strength & Conditioning Research*, 26(12), 3281-3288.
- ◆ Grund, A., Dilba, B., Forberger, K., Krause, H., Siewers, M., Rieckert, H., & Müller, M.J. (2000). Relationships between physical activity, physical fitness, muscle strength and nutritional state in 5- to 11-year-old children. *European Journal of Applied Physiology*, 82(5-6), 425-438.
- ◆ Hoffman, J.R., & Kang, J. (2003). Strength changes during an in-season resistance-training program for football. *Journal of Strength & Conditioning Research*, 17(1), 109-114.
- ◆ Kang, Y., & Ratamess, N. (2014). Which Comes First? Resistance Before Aerobic Exercise or Vice Versa? *American College of Sports Medicine*, 18(1), 9-14.
- ◆ Morais, J.E., Silva, A.J., Marinho, D.A., Marques, M.C., Batalha, N., & Barbosa, T.M. (2016). Modelling the relationship between biomechanics and performance of young sprinting swimmers. *European Journal of Sport Science*, 16(6), 661-668.

- ◆ Pugh, J.K., Faulkner, S.H., Jackson, A.P., King, J.A., & Nimmo, M.A. (2015). Acute molecular responses to concurrent resistance and high- intensity interval exercise in untrained skeletal muscle. *Physiological Reports*, 3(4), e12364.
- ◆ Reed, J.P., Schilling, B.K., & Murlasits, Z. (2013). Acute neuromuscular and metabolic responses to concurrent endurance and resistance exercise. *Journal of Strength & Conditioning Research*, 27(3), 793-801.
- ◆ Reynolds, J.M., Gordon, T.J., & Robergs, R.A. (2006). Prediction of one repetition maximum strength from multiple repetition maximum testing and anthropometry. *Journal of Strength & Conditioning Research*, 20(3), 584-592.
- ◆ Silva, R.F., Cadore, E.L., Kothe, G., Guedes, M., Alberton, C.L., Pinto, S.S., Pinto, R.S., Trindade, G., & Krueel, L.F. (2012). Concurrent training with different aerobic exercises. *International Journal of Sports Medicine*, 33(8), 627-643.
- ◆ Schutte, N.M., Nederend, I., Hudziak, J.J., de Geus, E.J., & Bartels, M. (2016). Differences in adolescent physical fitness: A multivariate approach and meta-analysis. *Behaviour Genetics*, 46(2), 217-227.
- ◆ Vandendriessche J.B., Vandorpe, B., Coelho-e-Silva, M.J., Vaeyens, R., Lenoir, M., Lefevre, J., & Philippaerts, R.M. (2011). Multivariate association among morphology, fitness, and motor coordination characteristics in boys age 7 to 11. *Pediatric Exercise Science*, 23(4), 504-520.

Chapter 4 - General Discussion.

- ◆ Blimkie, C.J. (1993). Resistance training during preadolescence. Issues and controversies. *Sports Medicine*, 15(6), 389-407.
- ◆ Cepero, M.R., López, R., Suárez-Llorca, C., Andreu-Cabrera, E., & Rojas, F.J. (2011). Fitness test profiles in children aged 8-12 years old in Granada (Spain). *Journal of Human Sports Exercise*, 6(1), 135-145.
- ◆ Chtara, M., Chamari, K., Chaouachi, M., Chaouachi, A., Koubaa, D., Feki, Y., Millet, G., & Amri, M. (2005). Effects of intra-session concurrent endurance and strength training sequence on aerobic performance and capacity. *British Journal of Sports Medicine*, 39(8), 555-560.

- ◆ Docherty, D., Wenger, H.A., & Collis, M.L. (1987). The effects of resistance training on aerobic and anaerobic power of young boys. *Medicine & Science in Sports & Exercise*, 19(4), 389-392.
- ◆ Faigenbaum, A.D., Westcott, W.L., Micheli, L.J., Outerbridge, A.R., Long, C.J., LaRosa-Loud, R., & Zaichkowsky, L.D. (1996). The effects of strength training and detraining on children. *Journal of Strength & Conditioning Research*, 10(2), 109-114.
- ◆ Faigenbaum, A.D., Kraemer, W.J., Blimkie, C.J., Jeffreys, I., Micheli, L.J., Nitka, M., & Rowland, T.W. (2009). Youth resistance training: Updated position statement paper from the National Strength and Conditioning Association. *Journal of Strength & Conditioning Research*, 23(5), S60-S79.
- ◆ Faigenbaum, A.D., & Myer, G.D. (2010). Pediatric resistance training: Benefits, concerns, and program design considerations. *Current Sports Medicine Reports*, 9(3), 161-168.
- ◆ Kang, Y., & Ratamess, N. (2014). Which Comes First? Resistance Before Aerobic Exercise or Vice Versa? *American College of Sports Medicine*, 18(1), 9-14.
- ◆ Marta, C.C., Marinho, D.A., Barbosa, T.M., Izquierdo, M., & Marques, M.C. (2013). Effects of concurrent training on explosive strength and VO₂max in prepubescent children. *International Journal of Sports Medicine*, 34(10), 888-896.
- ◆ Ortega, F.B., Ruiz, J.R., Castillo, M.J., & Sjöström, M. (2008). Physical fitness in childhood and adolescence: A powerful marker of health. *International Journal of Obesity*, 32(1), 1-11.
- ◆ Taanila, H., Hemminki, A., Suni, J., Pihlajamäki, H., & Parkkari, J. (2011). Low physical fitness is a strong predictor of health problems among young men: a follow-up study of 1411 male conscripts. *BMC Public Health*, 11, 590.

Appendix I

- ◆ Dudley, G.A., & Djamil, R. (1985). Incompatibility of endurance and strength - training modes of exercise. *Journal of Applied Physiology*, 59(5), 1446-1451.
- ◆ Duke, P.M., Litt, I.R., & Gross, R.T. (1980). Adolescents self-assessment of sexual maturation. *Journal of Pediatrics*, 66(6), 918-920.

- ◆ Garber, C. E., Blissmer, B., Deschenes, M.R., Franklin, B.A., Lamonte, M.J., Lee, I.M., Nieman, D.C., & Swain, D.P. (2011). American College of Sports Medicine position stand. Quantity and quality of exercise for developing and maintaining cardiorespiratory, musculoskeletal, and neuromotor fitness in apparently healthy adults: Guidance for prescribing exercise. *Medicine & Science in Sports & Exercise*, 43(7), 1334-1359.
- ◆ Glowacki, S.P., Martin, S.E., Maurer, A., Baek, W., Green, J.S., & Crouse, S.F. (2004). Effects of resistance, endurance and concurrent exercise on training outcomes in men. *Medicine & Science in Sports Exercise*, 36(12), 2119-2127.
- ◆ Hatzikotoulas, K., Patikas, D., Bassa, E., Hadjileontiadis, L., Koutedakis, Y., & Kotzamanidis, C. (2009). Submaximal fatigue and recovery in boys and men. *International Journal of Sports Medicine*, 30(10), 741-746.
- ◆ Leveritt, M., Abernethy, P.J., Barry, B.K., & Logan, P.A. (1999). Concurrent strength and endurance training: A review. *Sports Medicine*, 28(6), 413-427.
- ◆ Marfell-Jones M., Olds, T., Stewart, A., & Carter, L. (2006). *International Standards for Anthropometric Assessment*. International Society for the Advancement of Kinanthropometry. Potchefstroom, South Africa: ISAK.
- ◆ Marks, J., Barnett, L.M., Strugnell, C., & Allender, S. (2015). Changing from primary to secondary school highlights opportunities for school environment interventions aiming to increase physical activity and reduce sedentary behaviour: a longitudinal cohort study. *International Journal of Behavioral Nutrition and Physical Activity*, 12(1), 59.
- ◆ Marques, M.C., Zajac, A., Pereira, A., & Costa, A.M. (2011). Strength training and detraining in different populations: Case studies. *Journal of Human Kinetics*, 29A, 7-14.
- ◆ Marta, C.C., Marinho, D.A., Barbosa, T.M., Izquierdo, M., & Marques, M.C. (2012). Physical fitness differences between prepubescent boys and girls. *Journal of Strength & Conditioning Research*, 26(7), 1756-1766.
- ◆ Marta, C.C., Marinho, D.A., Barbosa, T.M., Izquierdo, M., & Marques, M.C. (2013). Effects of concurrent training on explosive strength and VO₂max in prepubescent children. *International Journal of Sports Medicine*, 34(10), 1-9.

- ◆ McCarthy, P., Pozniak, M.A., & Agre, J.C. (2002). Neuromuscular adaptations to concurrent strength and endurance training. *Medicine & Science in Sports & Exercise*, 34(3), 511-519.
- ◆ Mikkola, J., Rusko, H., Nummela, A., Pollari, T., & Häkkinen, K. (2007). Concurrent endurance and explosive type strength training improves neuromuscular and anaerobic characteristics in young distance runners. *International Journal of Sports Medicine*, 28(7), 602-611.
- ◆ Ortega, F.B., Ruiz, J.R., Castillo, M.J., & Sjöström, M. (2008). Physical fitness in childhood and adolescence: A powerful marker of health. *International Journal of Obesity*, 32(1), 1-11.
- ◆ Santos, A., Marinho, A.D., Costa, A.M., Izquierdo, M., & Marques, M. (2012). The effects of concurrent resistance and endurance training follow a detraining period in elementary school students. *Journal of Strength & Conditioning Research*, 26(6), 1708-1716.
- ◆ Smith, J.J., Eather, N., Morgan, P.J., Plotnikoff, R.C., Faigenbaum, A.D., & Lubans, D.R. (2014). The health benefits of muscular fitness for children and adolescents: A systematic review and meta-analysis. *Sports Medicine*, 44(9), 1209-1223.

Appendix II

- ◆ Akbarpour, M.B., Assarzadeh, M., & Sadeghian, H. (2011). The Effect of Combined Strength-Endurance Training on the Improvement of Cardiovascular Disease Risk Factors of Obese Middle-aged Men. *Annals of Biology Research*, 2(6), 123-129.
- ◆ Ali-Mohamadi, M., Abbaspoor, M., Rahimi, R., & Hakimi, M. (2014). The influence of order execution components of the strength and endurance in the concurrent training on lipid profile and body composition in overweight females. *World Applied Sciences Journal*, 29(7), 946-953.
- ◆ Alves, A.R., Marta, C.C., Neiva, H.P., Izquierdo, M., & Marques, M.C. (2016). Concurrent training in prepubescent children: the effects of eight weeks of strength and aerobic training on explosive strength and VO₂max. *Journal of Strength & Conditioning Research*, 30(7), 2019-2032.

- ◆ Arazi, H., Faraji, H., Moghadam, M.G., & Samadi, A. (2011). Effects of concurrent exercise protocols on strength, aerobic power, flexibility and body composition. *Kinesiology*, 43(2), 155-162.
- ◆ Antunes, B., Monteiro, P., Silveira, L., Cayres, S., Silva, C., & Júnior, I. (2013). Effect of concurrent training on risk factors and hepatic steatosis in obese adolescents. *Revista Paulista de Pediatria*, 31(3), 371-376.
- ◆ Cadore, E.L., Pinto, R.S., Lhullier, F.L., Correa, C.S., Alberton, C.L., Pinto, S.S., Almeida, A.P., Tartaruga, M.P., Silva, E.M., & Krueel, L.F. (2010). Physiological effects of concurrent training in elderly men. *International Journal of Sports Medicine*, 31(10), 689-697.
- ◆ Dobbins, M., De Corby, K., Robeson, P., Husson, H., & Tirilis, D. (2009). School-based physical activity programs for promoting physical activity and fitness in children and adolescents aged 6-18. *Cochrane Database Systematic Reviews*, 21(1), CD007651.
- ◆ Dolezal, B.A., & Potteiger, J.A. (1998). Concurrent resistance and endurance training influence on basal metabolic rate in non-dieting individuals. *Journal of Applied Physiology*, 85(2), 695-700.
- ◆ Dridi, S., & Taouis, M. (2009). Adiponectin and energy homeostasis: consensus and controversy. *The Journal of Nutritional Biochemistry*, 20(11), 831-839.
- ◆ Duke, P.M., Litt, I.R., & Gross, R.T. (1980). Adolescents self-assessment of sexual maturation. *Pediatrics*, 66(6), 918-920.
- ◆ Hendrickson, N.R., Sharp, M.A., Alemany, J.A., Walker, L.A., Harman, E.A., Spiering, B.A., Hatfield, D.L., Yamamoto, L.M., Maresh, C.M., Kraemer, W.J., & Nindl, B.C. (2010). Combined resistance and endurance training improves physical capacity and performance on tactical occupational tasks. *European Journal of Applied Physiology*, 109(6), 1197-1208.
- ◆ Kay, S.J., & Singh, M.A.F. (2006). The influence of physical activity on abdominal fat: A systematic review of the literature. *Obesity Reviews*, 7(2), 183-200.
- ◆ Kriemler S., Zahner, L., Schindler, C., Meyer, U., Hartmann, T., Hebestreit, H., Brunner-La Rocca, H.P., van Mechelen, W., & Puder, J.J. (2010). Effect of school based physical activity programme (KISS) on fitness and adiposity in primary schoolchildren: cluster randomised controlled trial. *British Medical Journal*, 340, c785.

- ◆ Kriemler, S., Meyer, U., Martin, E., van Sluijs, E.M., Andersen, L.B., & Martin, B.W. (2011). Effect of school-based interventions on physical activity and fitness in children and adolescents: A review of reviews and systematic update. *British Journal of Sports Medicine*, 45(11), 923-930.
- ◆ Kwon, H.R., Han, K.A., Ku, Y.H., Ahn, H.J., Koo, B., Kim, H.C., & Min, K.W. (2010). The effects of resistance training on muscle and body fat mass and muscle strength in type 2 diabetic women. *Korean Diabetes Journal*, 34(2), 101-110.
- ◆ Landry, B.W., & Driscoll, S.W. (2012). Physical activity in children and adolescents. *PM&R Journal*, 4(11), 826-832.
- ◆ Leite, N., Lazarotto, L., Cavzza, J.F., Lopes, M.A., Bento, P.B., Torres, R., Heyde, M.E., Cieslak F., & Milano, G.E. (2010). Effects of aquatic exercise and nutritional guidance on the body composition of obese children and adolescents. *Revista Brasileira de Cineantropometria & Desempenho Humano*, 12(4), 232-238.
- ◆ Maiorana, A., O'Driscoll, G., Goodman, C., Taylor, R., & Green, D. (2002). Combined aerobic and resistance exercise improves glycemic control and fitness in type 2 diabetes. *Diabetes Research and Clinical Practice*, 56(2), 115-123.
- ◆ Mantovani, R.M., Silva, A.C.S., Carvalho, F.F, Oliveira, J.M., Moura, L.C.R., Cunha, S.B., Viana, M.F., & Castro, J.C. (2008). Childhood and adolescent obesity. *Revista Médica de Minas Gerais*, 18(4), S107-S118.
- ◆ Marfell-Jones M., Olds, T., Stewart, A., & Carter, L. (2006). *International Standards for Anthropometric Assessment*. International Society for the Advancement of Kinanthropometry. Potchefstroom, South Africa: ISAK.
- ◆ McArdle, W.D., Katch, F.I., & Katch, V.L. (2000). *Essentials of exercise physiology*. 2nd ed. Lippincott Williams & Wilkins. Philadelphia, USA.
- ◆ Netto-Oliveira, E.R., Oliveira, A.A.B., Nakashima, A.T.A., Rosanelu, C.F., Filho, A.O., Rechenchosky, L., & Moraes, A.C.F. (2010). Overweight and obesity in children of different socioeconomic levels. *Revista Brasileira de Cineantropometria & Desempenho Humano*, 12(2), 83-89.

- ◆ Rashad, K.I., Phillips, M.A., Revels, M., & Ujamaa, D. (2010). Contribution of the school environment to physical fitness in children and youth. *Journal of Physical Activity & Health*, 7(3), 333-342.
- ◆ Sale, D.G., Jacobs, I., MacDougall, J.D., & Garner, S. (1990). Comparison of two regimens of concurrent strength and endurance training. *Medicine & Science in Sports & Exercise*, 22(3), 348-356.
- ◆ Santos, A., Marinho, D.A., Costa, A.M., Izquierdo, M., & Marques, M.C. (2012). The effects of concurrent resistance and endurance training follow a detraining period in elementary school students. *Journal of Strength & Conditioning Research*, 26(6), 1708-1716.
- ◆ Sillanpää, E., Häkkinen, A., Nyman, K., Mattila, M., Cheng, S., Karavirta, L., Laaksonen, D.E., Huuhka, N., Kraemer, W.J., & Häkkinen, K. (2008). Body composition and fitness during strength and/or endurance training in older men. *Medicine & Science in Sports & Exercise*, 40(5), 950-958.
- ◆ Slentz, C.A., Houmard, J.A., Johnson, J.L., Bateman, L.A., McCartney, J.S., Duscha, B.D., & Kraus, W.E. (2007). Inactivity, exercise training and detraining, and plasma lipoproteins STRRIDE: A randomized, controlled study of exercise intensity and amount. *Journal of Applied Physiology*, 103(2), 432-442.
- ◆ Tanner, J.M. (1962). *Growth at adolescence*. 2nd.ed. Oxford, Blackwell Scientific.
- ◆ Ucan, Y. (2013). Effects of different types of exercises on body composition in young men and women. *Life Science Journal*, 10(3), 1799-1806.
- ◆ Wilmore, J.H., & Costill, D. (1994). *Physiology of sport and exercise*. 6th ed. Champaign, IL: Human Kinetics Publications. USA.
- ◆ Wong, T., & Harber, V. (2006). Lower excess post-exercise oxygen consumption and altered growth hormone and cortisol responses to exercise in obese men. *Journal of Clinical Endocrinology & Metabolism*, 91(2), 678-686.

Appendix I

Explosive strength training in school context: effects of concurrent training sequence in prepubertal boys

Abstract

The aim of this study was to compare the effects of 8 weeks of resistance training (R), intra-session concurrent training (RA) and concurrent training performed in different sessions (CT) on explosive strength in prepubertal boys. Eighty-two healthy prepubertal boys, aged 10-11 years (10.84 ± 0.52 years) were randomly divided into three training groups, twice a week for 8 weeks: R (n = 19), RA (n = 21), CT (n = 21) and control group (C, n = 21) no training. Significant increase was perceived from pre- to the post-test in the sprint variable (20m) in all experimental groups ($p < 0.001$). However, CT obtained better results comparing to the other groups. No significant differences were found in C. CT is equally effective compared to R or RA in prepubertal boys. This is an important fact which should be considered in the improvement of school based-programmes on strength training.

Key words: Resistance, Aerobic, Power, Prepubertal, Exercise.

Introdução

Nos últimos anos a atividade física em crianças e adolescentes tem decrescido em todo o mundo (Marks et al., 2015). Neste capítulo, a escola é um meio capaz de promover e melhorar atividade física e aptidão física através da implementação de programas de treino (Marques et al., 2011). A aptidão física é referida como fator determinante no estado de saúde atual e futuro (Smith et al., 2014) e o elemento principal para a preservação e melhoria da saúde, qualidade de vida e desenvolvimento da criança (Marta et al., 2012). A aptidão física relacionada com a saúde envolve, entre outras, a resistência aeróbia e a força muscular (Ortega et al., 2008) e alguns estudos têm procurado modelos de treino que proporcionem melhores resultados nestas componentes. Recentemente, o treino concorrente, ou seja, a combinação de treino de força e de resistência aeróbia tem tido especial relevo pela literatura, já que os estudos indicam claramente que é possível associar os benefícios de ambos os treinos num treino, ao mesmo tempo que reduz os riscos de saúde associados à inatividade física e promove a realização de atividades diárias de forma confortável e segura (Garber et al., 2011). Contudo, relativamente aos potenciais benefícios do treino concorrente, a literatura não é consensual. Existem estudos que apresentam efeitos inibitórios, conhecidos por “fenómeno de interferência” (Dudley & Djamil, 1985) nas adaptações de resistência aeróbia (Glowacki et al., 2004) e atenuação do desenvolvimento muscular (Santos et al., 2012). Por outro lado, várias pesquisas demonstram inexistência de efeitos antagónicos na força (McCarthy et al., 2002) e na resistência aeróbia (Mikkola et al., 2007). A inconsistência acerca do treino concorrente, segundo Leveritt et al. (1999), pode ser explicada pelas diferenças no desenho do estudo e/ou protocolo de treino (intensidade, volume), bem como pelo tempo de recuperação pós-treino. Recentemente, Marta et al. (2013) comprovou a importância do treino concorrente em programas escolares, demonstrando que o treino concorrente na mesma sessão parece ser eficaz tanto na força muscular como na capacidade aeróbia em crianças pré-púberes. No entanto, segundo o nosso melhor conhecimento, na literatura não existem estudos disponíveis que analisem o efeito na força de crianças pré-púberes quando o treino de força e aeróbio são aplicados em sessões diferentes, e que comparem os resultados obtidos com as adaptações observadas quando o treino de força e aeróbio é aplicado numa única sessão. A hipótese estabelecida para este estudo consistiu na possibilidade do treino concorrente na mesma sessão e em sessões intercaladas ser igualmente eficaz na melhoria da força explosiva em idades pré-pubertárias.

Metodologia

Sujeitos

A amostra, randomizada aleatoriamente, foi constituída por 82 rapazes pré-púberes, que se voluntariaram para participar no estudo, com idades compreendidas entre os 10 e 11 anos (10.84 ± 0.52 anos), pertencentes a uma escola pública portuguesa.

Instrumentos

Para este estudo foram selecionadas crianças inseridas na escala de Tanner 1-2, isentas de problemas de saúde, limitações físicas ou hábitos de atividade física nos últimos 6 meses. As crianças foram cuidadosamente informadas acerca do desenho do estudo e os pais das crianças assinaram um consentimento informado antes do início do estudo. O estudo foi realizado de acordo com a declaração de Helsínquia, sendo aprovado pela Universidade da Beira Interior (UBI) e pelo Centro de Investigação em Desporto, Saúde e Desenvolvimento Humano (CIDESD), Portugal.

Procedimentos

O estudo foi realizado na escola pública Santa Clara (Guarda, Portugal). Incorporou 8 semanas de treino, onde fizeram parte 3 grupos experimentais: R, 2xsemana; RA, 2xsemana; e CT, 2xsemana força + 2xsemana resistência aeróbia, intercalados; e o grupo de controlo (C). Antes do treino as crianças realizaram exercícios de aquecimento (intensidade baixa-moderada) durante 10 minutos (ex.: corrida e exercícios de aquecimento articulares). No final do treino as crianças realizaram 5 minutos de exercícios com alongamentos estáticos. Após o período de aquecimento o R, o RA e o CT foram submetidos a um programa de treino de força composto por: lançamento de bolas medicinais de 1 e 3 kg, saltos para plataformas e saltos de obstáculos (0,3 a 0,5 m) e séries de corridas de velocidade (30 a 40 m). Após o treino de força, o RA foi submetido a um treino aeróbio desenvolvido com base no volume de treino individual, definido para cerca de 75% do volume aeróbio máximo, com reavaliação após 4 semanas para possíveis ajustes na intensidade e volume. O CT realizou treino de força intercalado com treino aeróbio em sessões diferentes. O tempo de descanso entre séries e entre exercícios foi de 1 e 2 minutos, respetivamente. (Alves et al., 2016 apresenta uma análise mais detalhada acerca dos instrumentos e procedimentos do estudo)

Análise Estatística

A análise de dados foi realizada através do *software* estatístico para Ciências Sociais (SPSS), versão 22.0® e significância estatística foi estabelecida em $p \leq 0.05$. O cálculo de médias e desvios-padrão foi feito por métodos estatísticos padronizados. O teste de normalidade foi validado pelo teste Kolmogorov- Smirnov. Foi utilizada a análise de variância (ANOVA) para comparar os grupos no pré e pós- teste e o teste-t emparelhado na avaliação das diferenças entre os dois momentos. O Eta parcial e o tamanho de efeito foram calculados pela análise de covariância (ANCOVA).

Resultados

No início do estudo não houve diferenças significativas entre grupos relativas à idade e classificação de Tanner. Pela análise de variância (ANOVA) constatou-se que no pré- e pós- teste não houve diferenças significativas entre grupos na velocidade (20m). Contudo, através do teste-t emparelhado verificou-se um aumento significativo na velocidade do pré- para o pós-teste nos grupos experimentais ($p < 0.001$). O CT obteve os melhores resultados. O C não apresentou diferenças significativas. O fator grupo teve um efeito significativo e de pequena dimensão no teste de sprint de 20m ($F(3,78) = 6.22$, $\eta_p^2 = 0.193$, $p = 0.01$) (Figura 1).

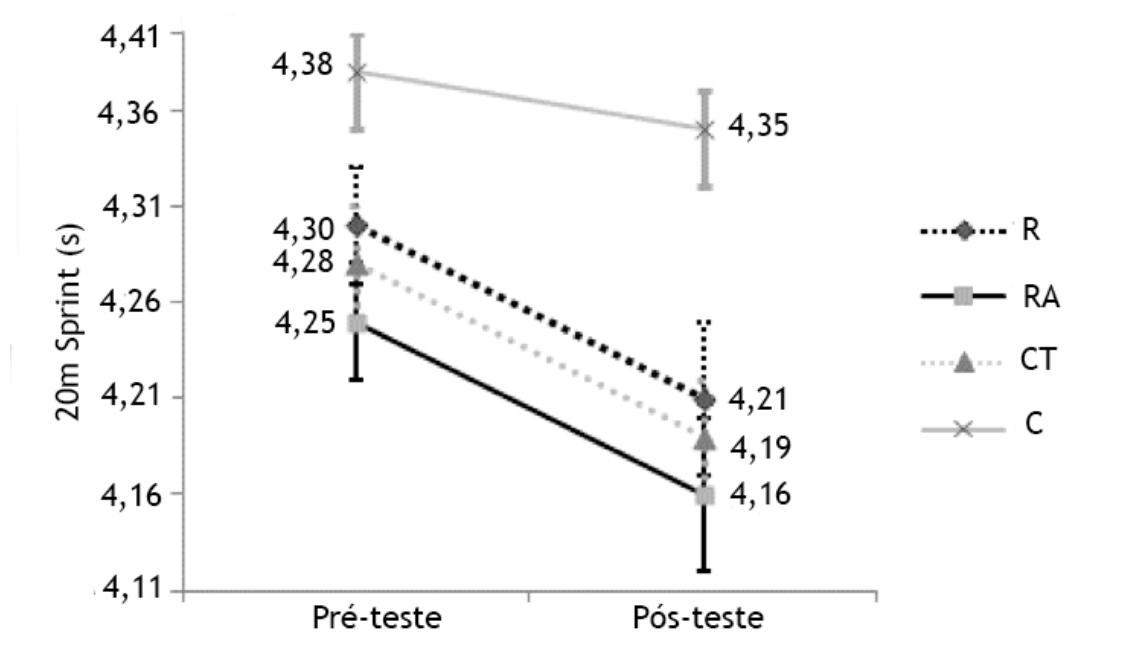


Figura 1. Dados relativos ao pré- e pós-teste do sprint (20m) no grupo de força (R), grupo concorrente na mesma sessão (RA), grupo concorrente com sessões intercaladas (CT) e grupo de controlo (C).

Discussão

O objetivo deste estudo foi comparar os efeitos de 8 semanas de treino de força (R), treino concorrente na mesma sessão (RA) e treino concorrente em sessões intercaladas (CT) na força explosiva em rapazes pré-púberes. Os resultados deste estudo parecem sugerir que o treino concorrente em sessões distintas é mais eficaz para melhorar a força explosiva em rapazes pré-púberes, no entanto as diferenças com o treino concorrente na mesma sessão não são significativas. Embora a literatura existente apenas se refira ao treino em adultos, os resultados obtidos são congruentes com o estudo de Hatzikotoulas et al. (2009) que demonstrou maior eficácia do treino concorrente em sessões distintas comparativamente a treino concorrente na mesma sessão, enquanto Dudley & Djamil (1985) sugerem que o treino concorrente realizado no mesmo dia compromete a adaptação muscular, comparativamente com treino realizado em sessões distintas. Segundo Marta et al. (2013), as crianças apresentam características neuromusculares distintas dos adultos e de acordo com Hatzikotoulas et al. (2009) as crianças têm um tempo de recuperação mais rápido comparativamente com os adultos, podendo ser um facto que explique a inexistência do ‘fenómeno de interferência’ descrito em estudos realizados em adultos. Registaram-se ainda valores estatisticamente significativos no RA, sendo consistentes com resultados de estudos anteriores na mesma área (Marta et al., 2013) realizados em crianças pré-púberes, também sujeitas a um programa de treino de 8 semanas. Contudo, a necessidade de mais informação acerca dos efeitos de treino concorrente na força explosiva é evidente, especialmente em crianças pré-púberes. A limitação a considerar neste estudo envolve a possibilidade do período de treino de 8 semanas ser curto.

Conclusão

Os resultados obtidos sugerem que o treino concorrente e o treino de força são efetivos em ganhos de força muscular explosiva em rapazes pré-púberes. Evidencia-se ainda que o treino concorrente é mais eficaz em sessões intercaladas que o treino de força e treino concorrente na mesma sessão. De forma a inovar as aulas de educação física e aumentar a sua eficácia, o treino concorrente em sessões intercaladas deverá ser considerado nos programas educativos em contexto escolar.

Appendix II

Effects of order and sequence of resistance and aerobic training on body fat in elementary school- aged girls

Abstract

The purpose of this study was to analyze the effects of order and sequence of concurrent resistance and aerobic training on body fat percentage (BFP) in a large sample of elementary school-aged girls. One hundred twenty-six healthy girls, aged 10-11 years old (10.95 ± 0.48 years) were randomly assigned into six groups to perform different training protocols per week for 8 weeks: resistance training alone (R), aerobic training alone (A), concurrent aerobic and resistance training (CT), intra-session concurrent aerobic and resistance training (AR), intra-session concurrent resistance and aerobic training (RA), and a control group (C). In R and A, the subjects performed single sessions of resistance or aerobic exercises, respectively (two days per week). In CT, resistance-aerobic training was performed on different days each week (four days per week). AR and RA performed intra-session concurrent aerobic and resistance training or concurrent resistance and aerobic training, respectively, each week (two days per week). After an 8-week training period, BFP decreased in all experimental groups (AR:13.3%, $p < 0.05$; RA:13.8%, $p < 0.001$; A: 1.9%, $p > 0.05$; R: 5.0%, $p > 0.05$; and CT: 5.6%, $p > 0.05$). However, a significant difference was found in AR and RA when compared to CT, A, and R, considering so that training sequence' may influence BFP. All programs were effective, but AR and RA obtained better results than CT, A, R on BFP. The current study explored an unknown issue and provided useful information in this area. These results have a meaningful interest to optimized school-based fat loss exercise programs in childhood.

Key words: Power, Concurrent Training, Prepubertal.

Introduction

Nowadays in the developed countries, advances in technology and changes in lifestyles led to a decrease in daily physical activity and to unsuitable diet. The incidence of diseases related with overweight has increased even among young people (Dridi & Taouis, 2009). School offers a natural environment for intervening to increase physical activity and improve the body composition among young people (Kriemler et al., 2011; Rashad et al., 2010), and a number of studies support the efficacy of school-based programs for doing so (Dobbins et al., 2009; Kriemler et al., 2010). However, many doubts arise on the best physical activity program to implement.

Aerobic training is usually used for fat mass and weight loss program (Dolezal & Potteiger, 1998; Wong & Harber, 2006). Also, resistance training can improve body composition and decrease body fat (Hendrickson et al., 2010; Kay & Singh, 2006). Furthermore, both resistance and aerobic training are often performed concurrently in most exercise programs in wellness, fitness and rehabilitative settings, in an attempt to reach different physical fitness goals (Santos et al., 2012), and there exist some studies reporting a significant decrease of subcutaneous fat and body fat percentage after performing combined resistance and aerobic training (Akbarpour et al., 2011; Maiorana et al., 2002). On the contrary, other studies have shown that the body fat percentage and total fat mass remain unchanged with concurrent resistance and aerobic training (Cadore et al., 2010; Häkkinen et al., 2010; Sillampää et al., 2008).

According to our best knowledge, there are no studies that compared the effects of concurrent training on body fat when this is done on the same day or on alternate days each week, and none studies that investigated the effects of order and sequence of concurrent training on body composition in prepubertal children have been reported. Therefore, the aim of the current study was to investigate the effect of different methods of concurrent training (intra-session vs. separate sessions concurrent resistance and aerobic training) on body fat percentage in prepubertal aged children, and compare the results achieved with those obtained when resistance or aerobic training is performed alone.

Methods

Subjects

The sample consisted of 126 prepubertal girls, aged between 10 and 11 years old, all of whom volunteered for this study. Inclusion criteria were: children aged 10 to 11.5 years (5th and 6th

graders), who were self-assessed in Tanner stages I and II, with no chronic pediatric diseases or orthopedic limitations, performing no regular oriented extra-curricular physical activity (i.e. practicing sport at a club). Subjects were carefully informed about the design of the study and subsequently the children's parents signed an informed consent document prior to the start of the study. The study was conducted according to the declaration of Helsinki, and was approved by the institutional review boards of the University of Beira Interior (UBI), Polytechnic Institute of Guarda (IPG), and Research Centre in Sports, Health and Human Development (CIDESD), Portugal.

Intervention

A randomized controlled trial was conducted in a public elementary school. Groups were determined using a random number generator and resulted in the assignment of 25 children for each group. The proportion of participants successfully completing the protocol was 88% (R: Resistance Training Alone), 96% (A: Aerobic Training Alone), 68% (CT: Concurrent Training in different sessions), 64% (AR: Intra-session Concurrent Aerobic and Resistance Training), 96% (RA: Intra-session Concurrent Resistance and Aerobic Training), and 92% (C: Control group). Thus, analysis was conducted on the remaining 126 girls (R= 22; A= 24; CT= 17; AR= 16; RA= 24; and C= 23). In R and A groups, the subjects performed single sessions of resistance or aerobic exercises, respectively (two days per week). In CT group, resistance and aerobic training were performed on different days each week (two and two days per week). AR and RA groups performed single-session concurrent aerobic and resistance training or concurrent resistance and aerobic training, respectively, each week (two days per week). The control group followed the physical education classes curriculum, without a specific training program.

Prior to training, subjects warmed up for approximately 10 minutes with low to moderate intensity exercises. At the end of the training sessions subjects performed 5 minutes of static stretching exercises. The resistance training program comprising upper body (1 and 3kg medicine ball throws) and lower body (jumps onto a box and hurdle jumps, from 0.3 m to 0.5) plyometric exercises, as well as a speed drill (sets of 20 to 40m speed runs). The subjects who performed the aerobic training program were subjected to a 20m shuttle run exercise, readjusted after 4 weeks of training (for more details of methods and procedures see Alves et al., 2015).

Statistical analysis

Statistical analyses were performed using Statistical Package for Social Sciences (SPSS) v22.0® for Windows and statistical significance was set at $p \leq 0.05$. Standard statistical methods were used to calculate the means and standard deviations. Normality of distribution was checked

by applying the Kolmogorov-Smirnov test. One-way analysis of variance (ANOVA), followed by Bonferroni's post-hoc comparison tests, was used to find the differences in the body fat percentage in the pre-test. To analyze the differences between groups in the post-test measures an analysis of covariance (ANCOVA) was estimated, followed by Bonferroni's post-hoc comparison tests. To determine the effect of group on the evolution of the body fat from pre- to the post-training an ANOVA with repeated measures was performed, with group as factor. Partial eta squared was calculated. The assumption of sphericity was validated by the Mauchly's Test of Sphericity.

Results

At baseline, there were no differences between groups for age or Tanner ratings. In addition, no differences were found between groups on the BFP ($F(5,120) = 0.581, p = 0.714$).

It was observed a significant effect of group on the BFP ($F(5,120) = 5.911, p < 0.001$) post training. It was found that the differences between groups in the post-test occurred between the control and the experimental groups that performed concurrent training in the same session (RA and AR).

There was a small-sized decrease from pre- to the post-training on the BFP ($F(5,120) = 8.930, p < 0.01$), and it was observed a medium-sized effect of the group on the evolution of this parameter ($F(5,120) = 6.011, p < 0.001$). However, the influence of the group was due to decreases from pre- to the post-training in the RA ($p < 0.001$) and AR ($p < 0.01$) groups. Inversely, there was an increase in the C group ($p < .001$). No changes on BFP from pre- to the post-training occurred for A, R and CT groups ($p = 0.788, p = 0.054, \text{ and } p = 0.372$, respectively). The mean changes on BFP in the control and experimental groups are shown in figure 1.

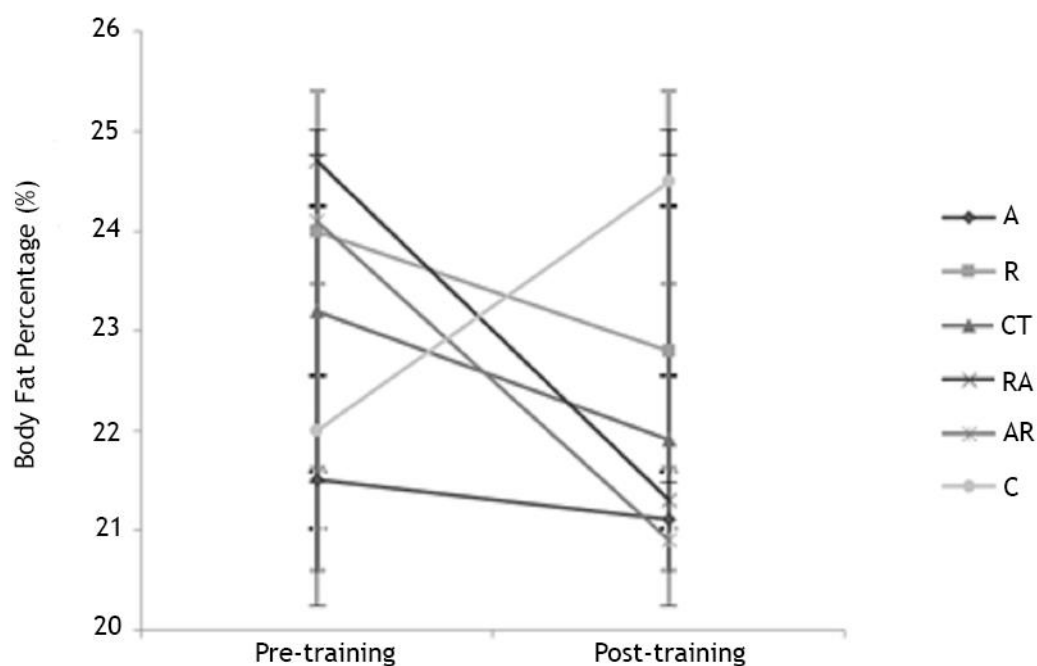


Figure 1. Differences between 8-weeks of training.

Discussion

The purpose of this study was to analyze the effects of order and sequence of concurrent resistance and aerobic training on body fat percentage in elementary school-aged girls. The main results suggested that both intra-sessions concurrent resistance and aerobic training or concurrent aerobic and resistance training were more efficient decreasing fat mass in healthy prepubertal girls, when compared with the results obtained when resistance and aerobic training was performed alone or concurrent resistance and aerobic training was performed in different sessions. These results have a meaningful interest to optimized school-based fat loss exercise programs in childhood.

The excess adiposity is one of the main risk factors for the development of several metabolic disorders (Mantovani et al., 2008; Neto-Oliveira et al., 2010). In addition, the reduction in body fat percentage with non-pharmacological interventions is the most accepted method for the majority of population, including the pediatric one (Antunes et al., 2013). These interventions are the focus of several studies that aimed to identify which training models are more effective in the prevention and treatment of excess adiposity and related diseases (Antunes et al., 2013). Resistance training increases bone and lean masses and reduces total body weight and absolute and relative fat mass (Kwon et al., 2010; Ucan, 2013; Wilmore & Costill, 1994). In parallel to this, aerobic training collaborates in the reduction and control of total body fat (Leite et al., 2010; McArdle et al., 2000) and promote beneficial changes in

individuals' lipid profile (Slentz et al., 2007). So, a combination of resistance and aerobic training could be beneficial for weight loss and body composition (Hendrickson et al., 2010).

After 8 weeks of training period, BFP decreased in all experimental groups. However, a significant difference was found in AR and RA groups when compared to CT, A, and R groups, considering so that training sequence' may influence BFP. The greater loss of body fat in AR and RA groups may be related to the basal metabolic rate (Dolezal & Potteiger, 1998). Perhaps a better recruitment of the energy reserves takes place, caused by the increased energy demands from the simultaneous training stimuli (Sale et al., 1990). Our results were in line with the results of previous studies that also reported significant decrease of BFP after performing 8 weeks of intra-session concurrent training group (AR: 17.2%; RA: 23.2%, $p < 0.001$) in obese females (Sale et al., 1990), as well as in middle-aged individuals (Maiorana et al., 2002). Similar results were also found by Arazi et al. (2011) in intra-session concurrent training group (16.5%, $p < 0.05$) and in concurrent training performed in different sessions group (CT: 19.3%, $p < 0.05$) after 12-weeks period in college students. Nevertheless, these studies did not confirm which training is more efficient to change body composition. Our outcomes showed better results in RA group when compared to AR group, which would suppose that training order may have influence on BFP. Probably, if the duration of training program was more than eight weeks, this decrease could have been more substantial.

The concurrent training can significantly increase basal metabolism and decrease body fat relative to the obtained amounts in the before-training period (Dolezal & Potteiger, 1998). The results confirmed previous evidences that have reported a decrease of subcutaneous fat and body fat percentage after performing eight weeks of concurrent resistance and aerobic training in middle-aged individuals (Akbarpour et al., 2011), as well as in pubertal children (Santos et al., 2012). These results have a meaningful interest to optimized school-based fat loss exercise programs in childhood. Concurrent training could be implemented in a school program to contribute to fat loss, regardless of the order of resistance and aerobic exertation. We should be aware that different training durations and different workouts could lead to different results. Therefore, care is needed when translating these findings to overweight/obese children programs. Children must be motivated for physical activity programs and these should focus on having fun and developing motor skills rather than on competition. As soon as a child reaches school age, fundamental sports skills must be taught, but emphasising on the fun of sport and play (Landry & Driscoll, 2012).

Conclusions

In sum, it can be stated that performing concurrent resistance and aerobic training in the same session is more helpful than aerobic or resistance training alone, or resistance and aerobic training in different sessions for reducing body fat percentage of non-athlete prepubertal girls. In addition, the order of intra-session concurrent training did not influence the body fat percentage. Thus, these evidences have a meaningful interest to optimized school-based fat loss exercise programs in childhood.