University of Porto
Faculty of Sport
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Biological Maturation And Response To Complex Strength Training In
Adolescent Thai Soccer Players

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**Keywords**: STRENGTH TRAINING, COMPLEX TRAINING, BIOLOGICAL MATURATION, INTERINDIVIDUAL, ADOLESCENTS, SOCCER PLAYERS
“There's nothing you can do that can't be done”
All you need is love “The Beatles”, 1967.
To my guardian angels, dad and mom
my pride is to make you proud.
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Abstract

The aims of this study were (i) to examine the effects of complex training and resistance training on muscle strength, motor performance and skills in young Thai soccer players, and (ii) to examine their inter-individual response to those two training modalities. Subjects were adolescent Thai soccer players aged 12-16 year and were divided into three groups; complex training group (CT), resistance training (RT) and control group (CON); CT and RT were submitted to 7-week strength training program along with their routine soccer training plans. Subjects’ maximum strength, motor performance and soccer skills were measure before and after the study. Skeletal maturation was also assessed. All subjects completed 21 training sessions and no any injuries were observed. Results showed significant increases in all muscle strength and motor performance of both complex and resistance training ($p<0.05$) while no changes were observed in control group ($p>0.05$). Significant changes in soccer skills were noted in all three groups ($p<0.05$). Significant differences between complex and resistance training group were observed in countermovement jump, squat jump and mean power output ($p<0.05$). The heterogeneity of responses to training showed to be significant in all variables ($p<0.05$) and no significant relationship between baseline values and responses were reported in both CT and RT ($p>0.05$). A significant association between biological maturation and response was reported only for the countermovement jump in CT ($p<0.05$). In conclusion, short-term complex and resistance training combined with routine soccer training were effective in improving muscle strength and motor performance in adolescent soccer players. Complex training was superior to resistance training in explosive strength and muscle power development. Responses to training were independent from baseline characteristics and biological maturation had influence only on complex training response in countermovement jump.

Keywords: STRENGTH TRAINING, ADOLESCENT, SOCCER, PERFORMANCE, INTER-INDIVIDUAL, MATURATION STATUS
Resumo

Os objectivos do presente estudo foram (i) analisar os efeitos do treino complexo e resistido na força muscular, performance e habilidades motoras em jovens Tailandeses jogadores de futebol e (ii) estudar a variabilidade inter-individual de resposta ao treino. A amostra compreendeu adolescentes dos 12 ao 16 anos de idade divididos em três grupos; grupo de treino complexo (CT), treino resistido (RT) e controlo (CON); Para além das suas rotinas normais de treino de futebol, os grupos CT e RT foram, adicionalmente, submetidos a um programa de treino de força com a duração de 7 semanas. A força máxima, performance motora e habilidades foram avaliadas no início e no final do programa. Foi estimada a idade óssea de cada sujeito. Todos completaram 21 sessões de treino com sucesso, sem qualquer registo de ocorrência de lesão. Os resultados mostraram um aumento significativo da força muscular e performance motora em ambos os grupos submetidos a treino complexo ou resistido ($p<0.05$), enquanto nenhuma melhoria foi observada no grupo de controlo ($p<0.05$). Todos os grupos apresentaram melhorias nas habilidades específicas do futebol ($p<0.05$). Foram também observadas diferenças significativas entre os grupos submetidos ao treino complexo ou resistido no salto com sem contramovimento ($p<0.05$). Foi observada heterogeneidade significativa em termos de resposta ao treino ($p<0.05$) e não foram registadas relações significativas entre os valores pré e pós-programa de treino nos grupos CT e RT ($p<0.05$). Foi encontrada uma associação significativa entre a maturação biológica e as adaptações ao programa apenas para o salto com contramovimento no grupo CT ($p<0.05$). O presente estudo concluiu que um programa de treino complexo ou resistido de curta duração, em combinação com as rotinas normais de treino de futebol, produziu numa melhoria da força muscular e da performance motora em jogadores de futebol adolescentes. Comparativamente ao treino resistido, o treino complexo foi mais eficaz no desenvolvimento da força explosiva. As respostas ao treino foram, na sua
generalidade, independentes das características basais e a maturação biológica.

**PALAVRAS CHAVE:** TREINO DE FORÇA, ADOLESCENTE, FUTEBOL, PERFORMANCE, INTER-INDIVIDUAL, ESTADO MATURACIONAL
CHAPTER 1: INTRODUCTION
Introduction

Strength training has become highly popular over the decades. The aims of strength training are to increase muscular strength, muscle hypertrophy, power and speed, local muscular endurance, motor performance, balance, and coordination (Kraemer & Ratamess, 2004).

For many years there was a belief that strength training, and particularly resistance training, was inappropriate for children and adolescents because it would adversely impact linear growth and physical fitness development (Pediatrics, 1983); therefore, resistance training by means of weight lifting was an unnecessary risk. Moreover, based on anecdotal reports (Vrijens, 1978), it was concluded that prepubertal children were unable to increase strength or muscle mass because they lacked circulating androgen hormones (Pediatrics, 1983). However, those ideas and beliefs have changed.

As has been shown from adequate and solid research, it is apparent that strength training programs yield positive results in children and adolescent boys and girls. Indeed, several experimental studies in adolescents have demonstrated significant training-induced changes in strength (Faigenbaum et al., 2007; Gorostiaga, Izquierdo, Iturralde, Ruesta, & Ibanez, 1999; Komi, Viitasalo, Rauramaa, & Vihko, 1978; Nichols, Sanborn, & Love, 2001; Shaibi et al., 2006). In addition, review papers and clinical observations have reported that youngsters can make significant gains in muscle strength and physical performance following properly designed and closely supervised strength training programs (Behm, Faigenbaum, Falk, & Klement, 2008; Faigenbaum et al., 2009; McCambridge & Stricker, 2008; Myer & Wall, 2006; Stratton et al., 2004).

The putative physiological mechanisms underlying training-induced gains in strength are attributed, mainly, to muscular and neural adaptations (Folland & Williams, 2007). However, the evidence of neural and muscular changes in
youth following strength training programs is indirect and limited, because of the ethical issues and limitations in the use of invasive assessment methods.

In adults, muscular changes following resistance training comprise an increase in muscle size and changes in fibre-type composition and connective tissue, as well as muscolo-tendinous stiffness and fibre pennation angle (Folland & Williams, 2007). However, the evidence regarding morphological adaptations following resistance training in children and adolescents is limited.

Studies of youth showed that resistance training improves muscle strength in children and adolescents, but, in contrast to adults, without significant increases in muscle size (Blimkie, 1989; Ozmun, Mikesky, & Surburg, 1994; Sailors & Berg, 1987). Training-induced muscle hypertrophy occurring in children is primarily due to muscle fibre hypertrophy, as a consequence of myofibrillar growth and proliferation as well as satellite cell activation (Folland & Williams, 2007). Nevertheless, these mechanisms have not been investigated in children or adolescents. Overall, only one study, conducted by (Lillegard, Brown, Wilson, Henderson, & Lewis, 1997), reported changes in muscle mass and fat using anthropometric techniques.

In addition, other possible effects of resistance training on muscular traits that can explain gains in muscle strength are changes in fibre-type composition due to alterations in the isoforms of myosin heavy-chain (Campos et al., 2002), increased tendinous stiffness (Kubo, Kanehisa, & Fukunaga, 2001, 2002; Reeves, Narici, & Maganaris, 2003) and increases in the angle of muscle pennation (Aagaard et al., 2001; Behm et al., 2008; Kanehisa et al., 2002; Reeves, Narici, & Maganaris, 2004). Nevertheless, there are no studies in children and adolescents investigating these mechanisms.

Based on the lack of evidence regarding training-induced changes in muscle size, strength gains in children have been attributed to neural adaptations. Indirect evidence of neural adaptations includes a disproportionately higher increase in muscle strength compared with the
observed increase in muscle size in adults (Folland & Williams, 2007). Neural adaptations are complicated to identify but can be observed as modifications in coordination and learning that facilitate better recruitment and activation of muscles involved in tasks demanding strength (Folland & Williams, 2007).

Several studies have attempted to investigate neural changes in children following resistance training. Collectively, these studies showed that after strength training programs, children and adolescents experienced an increase in motor unit activation (Ozmun et al., 1994; Ramsay et al., 1990), a decrease in antagonist activation, or improved inter-muscular coordination (Frost, Dowling, Dyson, & Bar-Or, 1997; Lambertz, Mora, Grosset, & Perot, 2003).

Knowledge about variation in strength and physical performance as well as response to strength training intervention among adolescents has been documented, namely based on means and controlling for confounders. For instance, biological maturity status might be associated with variation in strength and physical performance. Indeed, (Malina, Bouchard, & Bar-Or, 2004) reported that adolescent boys who mature early are stronger and perform better than those who are classified as average and late maturing. Gains in estimated muscle area are significantly related to skeletal age (SA).

The American Academy of Pediatrics (McCormick & Stricker, 2008) referred to data from the US Consumer Product Safety Commission’s National Electronic Injury Surveillance System (2007) that estimated the number of injuries related to strength training practice and equipment. Muscle strains account for 40% to 70% of all strength training injuries, with the hand, low back, and upper trunk being commonly injured areas. Most injuries occur with home equipment associated with unsafe behaviours and unsupervised settings. Injury rates in settings with strict supervision and proper technique are lower than those that occur in other sports or general recess play at school (Mazur, Yetman, & Risser, 1993; Risser, 1991).
Even though there is risk for children and adolescents who undergo strength training, the American Academy of Pediatrics and the National Strength and Conditioning Association, which is endorsed by the American College of Sports Medicine and the American Orthopaedic Society for Sports Medicine, recommend strength training for youth. Furthermore, an evidence-based review by Malina (Malina, 2006) concluded that resistance training programs do not adversely influence growth in height and weight of youth.

Strength training programs for youth can be designed with different exercise modalities. Resistance training is one of the most commonly used, and its effectiveness to achieve strength gains and to improve sport performance has been extensively studied (Faigenbaum et al., 2009).

Apart from resistance training in which children and adolescents can participate to improve strength and power, another popular training modality is plyometry. This type of training refers to the use of muscles’ cycle of lengthening and shortening, and it was shown to be especially effective to improve muscle power. Plyometric exercises start with a rapid stretch of a muscle (eccentric phase) and are followed by a rapid shortening of the same muscle (concentric phase). With plyometric training, the nervous system is conditioned to react more quickly to the stretch-shortening cycle (Faigenbaum and Chu, 2001).

Early plyometric studies of youth demonstrated the benefits of this training modality (Chu, Faigenbaum, & Falkel, 2006; Diallo, Dore, Duche, & Van Praagh, 2001; Matavulj, Kukolj, Ugarkovic, Tihanyi, & Jarić, 2001), including significant increases in maximal voluntary force, rate of force development, improvement of vertical jump and cycling performance, speed, agility, and enhancement of the efficiency of sports skills. Moreover, plyometrics is also helpful to improve bone mass, bone mineral density, and bone strength (Chu et al., 2006). In addition, there is evidence that no injuries have occurred during plyometric training sessions (Diallo et al., 2001; Matavulj et al., 2001), and it has been suggested that participation in a progressive plyometric training program
that begins with low-intensity drills is no riskier than participation in other sports and activities. Overall, data from cross-sectional studies supports the notion that supervised plyometric training is beneficial for performance and is safe for youth.

Training methodologists, coaches, athletes, and exercise scientists have referred to the idea of combining weight training and plyometric exercise in the same training session or in complex training, a series of a mixture of neuromuscular stimuli (Docherty, Robbins, & Hodgson, 2004; Ebben & Watts, 1998).

The idea of complex training has been summarized by Chu (1992: 24) (Chu, 1992) “This method of training should be used with the major weight lifts – squats, inverted leg press, split squats, bench press, power clean, snatches, and push press. As a rule of thumb, integrating two major lifts with plyometrics during a workout should yield maximum results”.

Only a few studies have attempted to investigate the effects of complex training on children and adolescents. The first published study, of prepubescent boys (Ingle, Sleap, & Tolfrey, 2006) reported that a 12-week complex training intervention induced improvements in dynamic strength, both in upper and lower body, but only slight improvements in motor performance such as vertical jump, running speed, throwing, and anaerobic power. The authors also reported no injury occurrence during the training period. Results from a study involving adolescent basketball players (Santos & Janeira, 2008), suggest the effectiveness of complex training in the enhancement of explosive strength. Indeed, the participants improved significantly their performance in countermovement jump, squat jump and medicine ball throw following a 10-week intervention program during basketball training season. Nevertheless, the above-mentioned studies did not compare the effectiveness of complex training programs with other types of strength training modalities.
The possible advantages of complex training compared to other training modalities were enounced by Chu (1996) (Chu, 1996) as likely favouring to a greater extent motor unit activation increases, recruitment of type IIb fibres, and getting type IIc fibres to act like type IIb fibres. Moreover, researchers have discussed the postactivation potentiation phenomenon, which is the basis of complex training, assuming that the explosive ability of muscle is enhanced immediately after it has been subjected to maximal or near maximal contractions (Hamada, Sale, MacDougall, & Tarnopolsky, 2000; Sale, 2002). A possible explanation for the potentiated state of muscle after maximal or near maximal stimulation is that prestimulation enhances motor-neuron pool excitability, as evidenced by a potentiated reflex response (Trimble & Harp, 1998). Therefore, the increased neural activation may occur through recruitment of more motor units, better motor unit synchronization, a decrease in presynaptic inhibition, or greater central input to the motor neuron (Aagaard, 2003; Aagaard, Simonsen, Andersen, Magnusson, & Dyhre-Poulsen, 2002). However, all these types of adaptations in response to regular complex training programs are still to be clearly elucidated, and particularly in youth.

Muscular strength and power are critical physical fitness components in soccer, and maximum strength influences power performance (Stolen, Chamari, Castagna, & Wisloff, 2005); an increase in maximum strength in usually connected with an improvement in relative strength and therefore with increased power, and these fitness components contribute considerably to soccer skills performance demanding short sprints and jumping (Schmidtbleicher, 1992; Stolen et al., 2005; Wisloff, Castagna, Helgerud, Jones, & Hoff, 2004).

Although available information about strength training in young soccer players is relatively scarce, it has been shown that maximum strength and physical performance can be improved by following intervention programs (Christou et al., 2006; Diallo et al., 2001; Maio Alves, Rebelo, Abrantes, & Sampaio, 2010; Meylan & Malatesta, 2009; Wong, Chamari, & Wisloff, 2010).
Based on these studies, different training modalities—namely resistance training, plyometric training, and complex training—have been implemented and have resulted in reported significant improvement in strength and physical capacities. Resistance training incorporated within routine soccer training over 16 weeks showed desirable results in young soccer players who did significantly improve their maximum strength in both upper and lower body, and in several performance tasks such as vertical jump, running speed, and agility (Christou et al., 2006). Another study applied a 12-week strength program combined with a power training program and reported significant increases in vertical jump and running speed as well as in ball shooting speed (Wong et al., 2010). Additionally, the same authors also observed significant changes in endurance capacity measured by the Yo-Yo intermittent endurance test. Meylan and Malatesta (2009) reported that an eight-week plyometric training program integrated into regular soccer practice resulted in greater improvements in explosive actions than conventional soccer training only; they also reported significant changes in vertical jump, 10-m sprint, and agility. Likewise, significant increases in vertical jump and short sprint speed following plyometric training were also reported by Diallo et al. (2001). In addition, we were able to identify only one study, of young Portuguese soccer players, that reported benefits of complex training (Maio Alves et al., 2010). In that study, significant improvements in vertical jump and sprint time were noted, but no changes in agility. Despite the relevance of these studies, complex training research in young soccer players is apparently scarce. Therefore, extended knowledge concerning the effects of complex training programs on overall physical performance is still needed. Furthermore, it is not yet clear whether complex training yields superior results to resistance training in equivalent time periods of training.
Introducing Thailand

Thailand (formerly known as Siam) is a country located in Southeast Asia. The country is bordered to the north by Burma and Laos, to the east by Laos and Cambodia, to the south by the Gulf of Thailand and Malaysia, and to the west by the Andaman Sea and the southern extremity of Burma (Figure 1). Thailand is the world’s 51st largest country in terms of total area, with a surface area of approximately 513,000 km² and about 66 million people. The country is divided into 76 provinces and six regions: north, east, northeast, west, central, and south (Figure 2). Bangkok is the capital as well as the largest city the country, and is the centre of political, commercial, industrial, and cultural activities. Despite the fact that Thai culture and traditions are different in each region, the main spoken language is Thai. Although Muay Thai and Sepak Takraw are national sports, soccer is, by far, the most popular.

Figure 1. Map of Thailand
Youth sport in Thailand

Looking back, many sports have been introduced in Thailand; some have became popular. In the past, there were no sports organizations, and so government authorities agreed there should be a central structure to manage and organize sports on a national level. His Majesty the King authorized the establishment of the Sports Authority of Thailand on 17 October 1985, with the main purpose of being a centre of promotion and organization of sports in Thailand. Later, on 3 October 2002, the government announced the establishment of the Ministry of Tourism and Sports of Thailand, which oversees the Sports Authority of Thailand (Figure 3).
Youth sports competitions in Thailand are typically organized on many different levels throughout the year. With continuous support from the government, youth sports games begin at kindergarten level. Each school organizes an annual meeting, and there are also competitions within regions such as in the east, northeast, and south, as well as a national kindergarten competition. Sports types encompass soccer (seven players), track and field, dancing, and tug of war. Likewise, these types of sports are also included at the elementary school competition level, where additional sports are also played.

Youth sports at high school levels are more intensively directed towards competitions. Coaches and athletes devote more time in training and team preparation for successful and honourable achievements in their school or sports organization. More types of sports are included in competitions. Apart from sports games organized in each school, there are also annual competitions among schools, cities, and regions in a variety of sports. Sports for female athletes are also included in most sport events.
There are also sports games for specific groups of schools. For instance, one of the most sensational games is “Satit Samakee Sport”. This event is organized only for schools in the established public universities. Sports games are held every year and rotated among host organizations. The competition is divided into two age levels (elementary and high school) for both males and females, and comprises 16 sports. Aiming to promote sports participation and to strengthen unity between students and staff, they provide ample opportunities for students to show their sports potential and to cheer for their teams. This type of event is very popular: it attracts spectators and also promotes cooperation among all participants. The games last one week and include wonderful opening and closing ceremonies with parades from each school. Recently, a total of 16 demonstration schools were registered around Thailand.

As there are 11 Sports Schools spread around regions of Thailand, the organization that controls and takes responsibility for these schools organizes the annual Thailand Sports School Games. This is the most important event for sports schools, as it provides them an opportunity for serious preparation for their athletes and sports teams. This competition also gives them the chance to be successful and show their outstanding achievements. Sports schools from Singapore also join in. Students participate in more than 20 different sports in this type of event.

Several important sports events are held annually, including the Thailand National Student Games, the Thailand National Youth Games, the Thailand National Games, the Thailand Sports School Games, and sports games organized by the Sports Association of Thailand.

**Khon Kaen Sports School**

Established in 1995, Khon Kaen Sports School is part of the Institute of Physical Education, Ministry of Tourism and Sports, Thailand. The school is located in Khon Kaen province, the northeast region of the country, and has approximately 48 acres of land. The aims of establishing this school are: (1) to
provide basic education for students who show relevant skills in a specific sport to be developed to a higher level, along with an adequate development in academics and socialization; (2) to develop young athletes for participating at higher competitive levels including the national and international level; (3) to study and conduct research regarding the development of young athletes and youth sports in Thailand. There are 11 Sports Schools in Thailand (see Figure 4).

Figure 4. Organizational chart of the Institute of Physical Education

Khon Kean Sports School is a residential high school. Student dormitories, staff housing, and all relevant facilities are located on the school compound. Seven sports are practiced by both male and female students at Khon Kaen Sports School: track and field, soccer, handball, weightlifting, boxing, Muay Thai, and woodball. The school covers six grades, and enrolls students ages 12 to 17 years. Admission opens annually with formal examinations in January that include (1) sports skills, (2) written tests, (3)
interview, and (4) a medical exam. At present, the total number of students, males and females, is 383 (male = 231, female = 152). The number of staff coaches varies according to sport type (see Table 1). All sports facilities are located in the school area. In the main stadium, the main soccer pitch is surrounded by a standard rubber running track; another soccer pitch is located nearby. The other sports have separate facilities. The sports science building provides fitness and exercise equipment, strength training machines, and fitness testing devices. These facilities are also open to the public.

Table 1. Number of athletes (in each sport) and coaches in the Khon Kaen Sports School

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<th>Male</th>
<th>Female</th>
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<td>Track and field</td>
<td>50</td>
<td>23</td>
<td>4</td>
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<tr>
<td>Soccer (male)</td>
<td>122</td>
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<td>Soccer (female)</td>
<td>-</td>
<td>80</td>
<td>6</td>
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<td>Handball</td>
<td>12</td>
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<td>Weightlifting</td>
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<td>Boxing</td>
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<td>Muay Thai</td>
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<td>Woodball</td>
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The daily school schedule is divided into three main periods: (1) study; (2) meal breaks; (3) sports practice. The study period is from Monday to Friday (9.00 am – 15.00 pm); two training sessions are held per day, Monday through Saturday (5.30 – 7.00 am and 16.00 – 18.00 pm); and three meal breaks are scheduled daily (7.00 – 8.00 am; 12.00 – 13.00 pm and 19.00 – 20.00 pm). All students and staff have one holiday per week (Sunday).

Students practice their specific sport and participate in youth competitions all year round. Events are organized at both the city level and the province level. To give an example of the frequency of events, 15 soccer and 10 track and field competitions are held per year. Students who show superior performance in their sport will have an opportunity to be selected for the national team.

Statement of the problem

The present thesis deals primarily with the effects of strength training programs in adolescent Thai male soccer players. Important topics that will be examined are: (1) the benefits of effective strength training programs for youngsters in muscle strength and physical performance; (2) inter-individual response to resistance training programs; and (3) risks and safety of strength training programs.

Gaps in problem solving

There is now consistent evidence supporting the fact that resistance training programs are beneficial to children and adolescents of both genders (Malina, 2006). In addition, several position statements of important medical and scientific organizations favour quality-supervised programs to enhance sports performance, injury prevention, and general health (American Academy of Pediatrics, 2008; The National Strength and Conditioning Association, 2009).
Notwithstanding the above-mentioned body of knowledge, there are still some gaps in research and available data. Among these, we identified four, which may be of further study:

1. We still do not know if complex training is as effective as resistance training regarding strength and physical performance improvements of youth.

2. It is unclear if significant positive changes induced by complex training would favour general change in fitness components as well as specific sports skills.

3. We do not know how adolescent male soccer players of different maturational status would respond to complex and resistance training loads.

4. The problem of inter-individual differences in youth strength training responses is seldom addressed.

Need for research on Thai male adolescent soccer players

Studies concerning the effects of complex training are scarce in adolescents and even more so in young soccer players during their competitive season. We were not able to find any such studies in Thailand, despite soccer’s popularity. In addition, sports schools provide their soccer players long-term preparation, where explosive strength is central to their performance. We are of the position that a study aiming at Thai adolescent soccer players may be important for the following reasons:

1. Due to lack of strength training studies of young Thai male soccer players, we do not know how they would respond to resistance and complex training programs. Besides, it is doubtful whether the available physical fitness testing batteries are appropriate for young Thai soccer players. Addressing this issue is important for youth soccer development in Thailand. Coaches and teachers would be able to apply these novel results to their soccer team.

2. It is not clear whether resistance or complex training programs yield superior results in the same training period of time in adolescent soccer players since no
information has been provided so far. Results derived from this study will also provide new data to the available literature.

3. As previously investigated, various resistance and complex training program designs led to significant improvements in several aspects of physical performance, but we do not know which program designs offer optimum benefits in a short period of time for young soccer players. It is reasonable to probe this problem; the derived information will be useful for coaches.

**Purposes of the study**

This study covers four main objectives in order to fill previous gaps in the literature and needs for research in Thailand.

1. To summarize the available results from the literature including (1) the effects of training programs on muscle strength gains and physical performance, (2) injury occurrence and available results of meta-analysis studies concerning resistance training in youth. This topic will be presented in Chapter 2.

2. To conduct a pilot study prior to the main research with an aim (1) to evaluate how adolescent Thai male athletes would respond to a given resistance and complex training program, (2) to evaluate the reliability of data gathered from muscle strength and physical performance testing batteries. This topic will be presented in Chapter 3.

3. To examine the influence of a short-term (seven weeks) complex and resistance training program in adolescent Thai male soccer players. This topic will be presented in Chapter 4.

4. To study inter-individual differences in response to both resistance and complex training programs of adolescent Thai soccer players conditional on their maturation status. This topic will be presented in Chapter 5.
Outline of the thesis

Chapter 1: Introduction.

Chapter 2: Strength training in youth (resistance, plyometrics, complex training): an evidence-based review.

Chapter 3: Importance of pilot study and data quality control in designing complex training programs for young athletes.

Chapter 4: The influence of complex training and resistance training on strength, performance, and skill in youth soccer players.

Chapter 5: Individual differences in strength changes of young soccer players and their relationship with biological maturation.

Chapter 6: General conclusions and final remarks.
References


CHAPTER 2: FIRST RESEARCH PAPER

Title: Strength Training in Youth (Resistance, Plyometrics, Complex Training) An evidence-Based Review

Authors: Rojapon Buranarugs, José Oliveira, José Maia

Journal: Portuguese Journal of Sport Sciences (accepted)
Abstract

Objectives of this study were to summarize the influence of strength training, plyometric and complex training programs on strength gains, physical performance and injury occurrence in children and adolescents boys aged 8 to 17 years. Twenty-three experimental strength training programs were selected (from 2000 to 2010): 11 were related to resistance training; 1 assesses physiological adaptations following resistance training intervention study; 2 are meta-analysis of resistance training; 7 relates to plyometry, and 2 concern complex training. Resistance training showed highly maximum strength improvement and enhances motor performance in boys, athletes or non-athletes. Strength gains are mostly related to neuromuscular adaptations than to muscle hypertrophy. Meta-analysis studies reported moderate-to-high effect sizes. Plyometric enhance explosive movement and results in superior gain than resistance training. Complex training extremely increases dynamic strength and slightly enhances anaerobic power and other motor performances. Strength and performance gains decreased after detraining and reduced training phases in all types of programs. Only one minor injury occurrence was reported from all reviewed studies. In conclusions, all reviewed types of strength training are effective in improving strength and motor performance among boys. Longer program duration, higher training intensity result in greater improvements. Carefully supervised programs are safe. Complex training studies are scarce.

Keywords: strength training, boys, injuries, young athletes
Introduction

Strength training broadly refers to a component of physical fitness conditioning by overloading the skeletal muscles through different training modalities, encompassing different types of resistances and muscle actions, which in turn can be used in isolation or in combination (Fleck and Kraemer, 2004). Available evidences suggests, at least in adults, various positive changes in neuromuscular system, muscle function and sport performance (Kraemer and Ratamess, 2000; Moritani and DeVries, 1979 and Sale, 1992).

It has been shown that strength training is effective in children and adolescent as strongly supported by a number of review papers and position statements (American Academy of Pediatrics, 2008; Behm, 2008; Blimkie, 1992; British Association of Exercise and Sport Sciences, 2004; Faigenbaum, 2000; Malina, 2006). Indeed, a recent position statement paper from the National Strength and Conditioning Association (Faigenbaum et al., 2009), have documented that children and adolescents can gain real benefits from participating in well designed and carefully supervised programs, using strength training modalities such as resistance training, plyometry and complex training. Despite the potential risk injury present in any supervised youth strength training, a broad review by Malina (2006) has clearly specified that experimental training protocols with weights and resistance machines are safe and do not negatively impact growth and maturation of youngsters. More recently, the latest updated position statement paper from the National Strength and Conditioning Association (Faigenbaum et al., 2009) strongly supports that strength training is safe for youth if the programs are properly designed and well-supervised. In addition, strength training has been demonstrated to reduce sports related injuries in youth (Abernethy and Bleakley, 2007; Micheli, 2006 and Smith et al., 1993). Several studies (Abernethy and Bleakley, 2007; Hewett et al., 1999 and Micheli, 2006), which included experimental protocols with resistance training, did not show any injury and also supported that may help to
decrease the rate of injury occurrence in youth sports. For example, Heidt et al. (2000) reported decreasing of injury in adolescent soccer players after the preseason conditioning programs, which incorporated resistance training programs.

A growing body of data demonstrates that children and adolescent can significantly improve their strength from participating in resistance training programs (Blimkie et al., 1996; Faigenbaum et al., 2001; Lillegard et al., 1997; Ramsay et. al., 1990). Furthermore, two meta-analyses by Falk and Tenenbaum (1996) and Payne et al. (1997) reported overall mean effect sizes of 0.57 and 0.75, respectively, supporting the belief that resistance training programs can significantly enhance muscular strength of children and adolescents.

A gender difference is correlated with strength performance and training induced variation. Base on number of early findings, it has been documented that boys have higher strength scores compared to girls and the difference widens with increasing age from puberty throughout adolescent and early adulthood (Blimkie, 1989). Strength gains result from training program during and after puberty in males may be related to changes in hypertrophic factors because of the influence of testosterone and other hormones (Kraemer et al., 1989). Smaller amounts of testosterone in females limit magnitude of changes in muscle hypertrophy induced by training (Rowland, 2005 and Sale, 1989).

Plyometric exercises refers to various types of exercises such as jumps, hopping, bounding and skipping, and are characterised by the mechanism of stretch-shortening cycle (SSC) movements that involve starting with a rapid and powerful eccentric action and followed immediately by concentric contraction in the same muscle group (Bosco et al., 1981). Adult research data show that plyometric training improves both maximal strength and local muscular endurance, power and sport performance (Blakey and Southard, 1987; Adam et al., 1992; Baker, 1996 and Holcomb et al., 1996; Fatouros et al., 2000; Sáez-Sáez de Villarreal et al., 2008). Studies in children and adolescents have also
examined the effects of plyometric training programs (Diallo et al., 2001; Kotzamanidis, 2006; Matavulj et al., 2001; and Meylan and Malatesta, 2009). Recently, Chu et al. (2006) recommended that plyometric training programs are not only safe for children but can also enhance muscular strength and improve sport performances.

Complex training can be described as a combination of exercises overcoming external resistances and plyometric exercises that are performed in the same set or workout (Chu, 1992; Docherty et al., 2004; Ebben, 2002; Ebben and Watts, 1998). Complex training workout begins by performing sets of concentric exercise with external resistances followed by a set of plyometric exercises recruiting the muscle group’s previously exercised concentrically with weights, and following as much as possible a similar movement pattern (anatomical plane and direction). Research on complex training in adults showed better results for vertical jump and anaerobic performance than both resistance training and plyometric training alone (Fatouros et al., 2000; Harris et al., 2000). Nevertheless, few studies are available about the effects of complex training on children and adolescents.

As aforementioned that children and adolescents can gain real benefits from strength programs as indicated by scientific evidences, a general overview about the effects of different modalities such as resistance, plyometric and complex training programs in young athletes is scarce, or non-existent. Moreover, recent researches concerning effect of training programs are mostly applied in boys or young male athletes, especially complex training programs. Therefore, the purpose of this review is to cover this gap. Its main aims are to present a summary about the influence of such training modalities (1) in strength gains and physical performance, (2) occurrence of injuries, (3) summarize the effects of strength training programs in children and adolescents boys, and (4) to summarize available results of meta-analysis resistance training studies in youth which have been conducted in the last decade.
Methods

Published papers including training programs which applied resistance training, plyometric training, complex training interventions and studies about physiological mechanisms adaptations following resistance training in boys and also resistance training meta-analysis using youths in their samples were searched. Computer databases such as Scopus, Sport Discuss FullText and PubMed were screened and keywords included (1) strength training, (2) resistance training, (3) plyometric training, (4) complex training, (5) meta-analysis, (6) youth, (7) children, (8) adolescent and (9) boys. Study inclusion were criteria as follows: (1) participants should be children or adolescent boys, (2) aged from 8 to 17 years old, (3) athletes and nonathletes of any sports, (4) the study applied a strength training intervention, and (5) should have been published in the last decade (2000 till March 2010).

Studies will be presented according to built-in summary tables concerning resistance training, physiological mechanisms adaptation following resistance training, plyometric training, complex training and meta-analysis about effect of resistance training on strength gains in boys. Additionally, comprehensive results from the effects of training programs concerning muscular strength and physical performances will be discussed as well as physiological mechanisms adaptations from training interventions in boys.
Results

One hundred and twenty two published studies were related to initial keywords, but only 23 met the criteria and will be considered for this review. From the 23 studies, 11 were related to resistance training, 1 is physiological adaptation following resistance training intervention study, 2 are meta-analysis of resistance training, 7 to plyometry, and 2 concerning complex training.

Twelve from 21 reviewed experimental studies have measured subject’s maturation status. Participants in 4 studies were classified as stages 3-5 of Tanner’s maturation criteria, stages 1-2 were reported in 7 studies and stages 1-5 were observed in 1 study. Subjects in 11 studies were non-athletes and in 10 were athletes. Fourteen studies were randomized controlled trail design.

Six to 16 week training programs duration were commonly used in reviewed studies. One study applied 20-week program (Ramsay et al., 1990), eight and 20 months program length were used in 2 plyometric studies and the longest training program duration (21 months) used by Sadres et al. (2001). Twice and 3 times per week training frequencies were mostly used. The exercises in most of resistance and complex training programs were designed for both upper and lower body, only one resistance training program by Tsolakis et al. (2004) was designed for only upper extremities. All plyometric programs were designed for only lower body.

Of the 11 resistance training studies, 6 reported significant gains in both upper and lower body muscular strength from 15 to 58.8% after subjects underwent resistance training programs (Christou et al., 2006; Faigenbaum et al., 2007; Shaibi et al., 2006; Szymanski et al., 2007; Szymanski et al., 2004 and Volek et al., 2003); one study reported significant improvement in upper body strength (Tsolakis et al., 2004) and another one only reported significant improvement in lower body strength (Sadres et al., 2001). Significant increases in vertical jump were reported in 4 studies (Channell and Barfield, 2008;
Faigenbaum et al, 2007; Faigenbaum et al., 2007 and Wong et al., 2010), and significant gains in long jump were reported in 1 study (Faigenbaum et al, 2007). Three papers demonstrated that resistance training programs significantly increased running speed in adolescent boys (Christou et al., 2006; Faigenbaum et al., 2007 and Wong et al., 2010) and significant gains in agility were reported in 2 studies (Faigenbaum et al., 2007 and Christou et al., 2006). Three studies used medicine ball throw for upper body explosive strength measurement and reported significant increases in distance throwing (Faigenbaum et al., 2007; Faigenbaum et al., 2007 and Szymanski et al., 2007). Aerobic endurance running, flexibility and ball shooting speed gains were reported as net results from resistance training programs (Christou et al., 2006; Faigenbaum et al., 2007; Faigenbaum et al., 2007; Wong et al., 2010). However, other studies did not find significant changes in VO₂ max (Shaibi et al., 2006 and Wong et al., 2010); one study also reported no changes in soccer technique of young soccer players from a resistance training program (Christou et al., 2006).

One study demonstrated physiological mechanisms adaptations underlying possible training induced strength gains boys (Ramsay et al., 1990). Significant gains in both upper and lower body maximum strength, isokinetic strength and isometric strength were observed after 20-week training program. However, in that study no significant changes in muscle cross-sectional areas were reported. An increase in percent motor unit activation of elbow flexors and knee extensors were observed, but not significant.

Two meta-analysis studies were found from study searches (Falk and Tenenbaum, 1996; Payne et al., 1997). Both reported moderate-to-high effect sizes of strength gains. Overall mean effect size (.57) was reported from 9 studies (Falk and Tenenbaum, 1996) and one another study reported an overall average effect size of .75 from a summary of 28 studies and effect size of studies in boy (.72) (Payne et al., 1997).
Six of 7 studies reported significant increases in vertical jump after a plyometric training program in children and adolescent boys (Diallo et al., 2001; Kotzamanidis, 2006; Mackelvie et al., 2004; Matavulj et al., 2001 and Meylan; Malatesta, 2009 and Weeks et al., 2008). Sprint performance improvements were also reported in 3 studies (Diallo et al., 2001; Kotzamanidis, 2006 and Meylan and Malatesta, 2009); in addition, significant changes in agility were noticed in 1 study (Meylan and Malatesta, 2009). One study also reported significant gains in sprint cycling after a plyometric training program (Diallo et al., 2001). Improvements in maximal voluntary force of hip extensors and rate of force development of knee extensors were also noticed in 1 study (Matavulj et al., 2001). Finally, one study showed significant changes in swim block start performances of adolescent swimmers (Bishop et al., 2009).

Two complex training studies showed their systematic benefits in muscular strength and motor performance. The first published study concerning complex training in youth by was conducted Ingle et al. (2006) demonstrating significant increases in both upper and lower body dynamic strength in 8 exercises. Moreover, improvements in vertical jump, anaerobic power, 40-m sprint and basketball chest pass were also observed. Santos and Janeira (2008) showed significant gains in both upper and lower explosive strength of young basketball players (vertical jump performances measured by squat jump, countermovement jump and abalakov test were found as well as seated medicine ball throw).

None of the studies reviewed so far reported injuries during training sessions. As exception, in the study of Sadres et al. (2001) a minor injury occurrence in one subject during a training session was reported.
Table 1. Experimental studies of resistance training in youth

<table>
<thead>
<tr>
<th>Reference</th>
<th>Subjects</th>
<th>Training program(s)</th>
<th>Statistical analysis</th>
<th>Outcome measure(s)</th>
<th>Main finding(s)</th>
<th>Conclusions</th>
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<tr>
<td>Wong et al., 2010</td>
<td>51 U-14 young male soccer players, E, n = 28 (13.5 ± 0.7 yrs.), C, n = 23 (13.2 ± 06 yrs.)</td>
<td>On-field combined strength and power; 3 × 6-15 reps; 2 times/wk, 12 wks; exercise: bent-over row, forward lunge, upright row, supine leg raise, push up, front half squat, sit up, biceps curl, supine leg lateral twist, front raise, back half squat, stiff-leg deadlift, weighted forward lunge, power clean, high pull, weighted squat jump, single-leg hop over hurdles, plyometric (depth) push up, double-leg lateral hop over hurdles, ployo sit up.</td>
<td>Independent Hests, MANOVA</td>
<td>Vertical jump, Ball-shooting, 30 m sprint, Yo-Yo intermittent endurance run level one, VO2 max test.</td>
<td>E: significant increases in vertical jump height 5.9%, ball shooting speed 5.2%, significant changed in 10 m sprint 4.9%, 30 m sprint 2.3%; significant improved in the Yo-Yo intermittent endurance run level one 20%.</td>
<td>On-field combined strength and power training had moderate effect on vertical jump, ball-shooting, 30 m sprint and Yo-Yo intermittent endurance run level one; small effect on 10 m sprint and maximal oxygen uptake. No injuries reported.</td>
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<td>Channell and Barfield, 2008</td>
<td>27 male student athletes (15.9 ± 1.2 yrs)</td>
<td>Olympic training (OT) and traditional power lift training (PT): 60-95% of 1 RM, 3-5 sets x 3-10 reps, 8 wks; Olympic training exercises: bench press, power clean, push jerk, leg press, incline, push-ups, back extensions, abdominals, lungen, decline, attacker, military press; Traditional power lift exercises: bench press, squat, dead lift, leg press, incline, push-ups, back extensions, abdominals, lungen, decline, attacker, military press.</td>
<td>Repeated measures ANOVA</td>
<td>Vertical jump</td>
<td>E1: significant increased in vertical jump 4.5%, E2: significant increased in vertical jump 2.3%.</td>
<td>Olympic lifts as well as power lifts provide improvement a modest advantage over power lifts for vertical jump improvement in high school athletes. No injuries reported.</td>
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<td>Faigenbaum et al., 2007</td>
<td>22 boys (13.9 ± 0.4 yrs) only one experimental group</td>
<td>Resistance training program: olympic-style lift, 3 sets x 1-4 reps, 2 times/wk, 9 wks; resistance exercise: 3 sets 8-15 RM, Olympic-style lift exercises: clean pull and the push jerk; resistance exercise: barbell squat, leg curl, bench press, front lat pull-down, seated row, biceps curl and triceps extension.</td>
<td>Paired Hest</td>
<td>10 RM: bench press and squat; medicine ball toss, vertical jump, flexibility and progressive aerobic cardiovascular endurance run (PACER).</td>
<td>Significant increases in all variables; 10 RM bench press 15%, 10 RM leg press 19%, medicine ball toss 12%, flexibility 10%, vertical jump 5%; significant changed in PACER 38%.</td>
<td>After-school resistance training program can improve muscular fitness and cardiovascular fitness in boys. No injuries reported.</td>
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<tr>
<td>Reference</td>
<td>Subjects</td>
<td>Training program(s)</td>
<td>Statistical analysis</td>
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<td>Faigenbaum et al., 2007</td>
<td>27 boys</td>
<td>E1 (PRT), n = 13 (13.4 ± 0.9 yrs)</td>
<td>Independent t-tests, repeated measures ANOVA</td>
<td>Vertical jump (counter movement jump), long jump, 9.1 m sprint, shuttle run, medicine ball toss, flexibility.</td>
<td>E1: significant improved in vertical jump 8.1%, long jump 6% shuttle run 3.8%, MB toss 14.4%, flexibility 27.6% E2: significant improved in MB toss 5.6%, flexibility 29%.</td>
<td>The addition of plyometric training to a resistance training may be more beneficial than resistance training and static stretching for enhancing selected measures of upper and lower body power in boys. No injuries reported.</td>
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<td>E2 (RT), n = 14 (13.6 ± 0.7 yrs)</td>
<td>PRT (combine plyometric training and resistance training); plyometric training program: 1-2 sets × 6-10 reps, 2 times/wk, 6 wks; plyometric exercises: standing jump and reach, lateral taps on MB, MB overhead throw, ankle jumps, hurdle hops, lateral cone hops, MB split squat, single leg cone hops, long jump and sprint, tuck jumps shuttle drill etc.; resistance training: 3 sets × 10-12 reps, 2 times/wk, 6 wks; resistance exercises: squat, bench press, overhead press, lat pull down, standing calf raise, bicep curl, front squat, incline press, upright row, tricep extension; RT (stretching + resistance training): static stretching exercises: hip/flex back stretch, chest/hamstring stretch, quadriceps stretch, v-sit hamstring stretch; same resistance exercise as E1.</td>
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<td>E1: significant improved in vertical jump 8.1%, long jump 6% shuttle run 3.8%, MB toss 14.4%, flexibility 27.6% E2: significant improved in MB toss 5.6%, flexibility 29%.</td>
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<td>Szymanski et al., 2007</td>
<td>49 high school baseball players</td>
<td>E1, n = 24 (15.3 ± 1.2 yrs)</td>
<td>Independent t-tests, Repeated measures ANOVA</td>
<td>3 RM torso rotational strength: dominant torso rotational strength 17.1%, non-dominant torso rotational strength 18.3%; significant improved in medicine ball hitter's throw 10.6%; significant changed in 1 RM bench press 16.7%, parallel squat 26.7%. E1: significant increased in dominant torso rotational strength 10.5%, non-dominant torso rotational strength 10.2%; significant improved in medicine ball hitter's throw 3%; significant changed in 1 RM bench press 17.2%, parallel squat 29.7%.</td>
<td>A 12 weeks medicine ball training program in addition to a stepwise periodized resistance training program with bat swings provided greater sport-specific training improvement in torso rotational and sequential hip-torso-arm rotational strength for high school baseball players. No injuries reported.</td>
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<td>E2, n = 25 (15.4 ± 1.1 yrs)</td>
<td>E1 and E2: periodized full-body resistance exercise program plus 100 bat swings, 3 days/wk, 12 wks, 2-3 sets × 6-10 reps of 45-75% of 1 RM; resistance exercises: parallel squats, stiff-leg deadlift, barbell bench press, dumbbell row, barbell shoulder press, lying triceps extension, barbell bicep curl; E2: additional rotational and full-body medicine ball exercises, 3 days/wk, 12 wks; medicine ball exercises: hitter’s throw, standing figure 8, speed rotations, standing side throw, granny throw, standing backwards throw, squat and throw.</td>
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<td>E1 and E2: periodized full-body resistance exercise program plus 100 bat swings, 3 days/wk, 12 wks, 2-3 sets × 6-10 reps of 45-75% of 1 RM; resistance exercises: parallel squats, stiff-leg deadlift, barbell bench press, dumbbell row, barbell shoulder press, lying triceps extension, barbell bicep curl; E2: additional rotational and full-body medicine ball exercises, 3 days/wk, 12 wks; medicine ball exercises: hitter’s throw, standing figure 8, speed rotations, standing side throw, granny throw, standing backwards throw, squat and throw.</td>
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<td>Reference</td>
<td>Subjects</td>
<td>Training program(s)</td>
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<td>Outcome measure(s)</td>
<td>Main finding(s)</td>
<td>Conclusions</td>
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<td>Christou et al., 2006</td>
<td>18 adolescent soccer players and 8 boys</td>
<td>Resistance training program for STR: 2 times/wk, 16 wks, 2-3 sets x 8-15 reps, 55-80% of 1 RM; exercises: leg press, bench press, leg flexion, overhead press, lag pull-downs, calf raise, sit-ups, upper-lower back extension.</td>
<td>Repeated measures ANOVA, ANCOVA</td>
<td>1 RM: bench press, leg press, vertical jump: squat jump, countermovement jump, repeated jump; 10-and 30-m sprint time, agility, flexibility soccer technique.</td>
<td>E1: significant changed in 1 RM bench press 52.3% and leg press 58.8%; significant increased in squat jump 31%; countermovement jump 24.6% and repeated jumps 15.6%; significant improved 30-m sprint 2.5%; agility 6.4%; significant decreased in flexibility 8.2%.</td>
<td>Resistance training program 2 times per week for 16 weeks can significantly increase both upper, lower body strength in overweight Latino adolescent male. No injuries reported.</td>
</tr>
<tr>
<td>Shaibi et al., 2006</td>
<td>22 overweight Latino adolescents</td>
<td>Resistance training program: 1-3 sets x 3-15 reps, 2 times/wk, 16 wks; exercises: leg press, dead lift, biceps curl, triceps extension, shoulder press, bench press, lat pull-down leg extensions, leg curl, calf raises.</td>
<td>Independent t-tests, paired t-tests</td>
<td>1 RM: bench press, leg press; VO2 peak.</td>
<td>E: significant changed in 1 RM bench press 26% and leg press 28%.</td>
<td>Resistance training program 2 times per week for 16 weeks can significantly increase both upper, lower body strength in overweight Latino adolescent male. No injuries reported.</td>
</tr>
<tr>
<td>Tsolakis et al., 2004</td>
<td>19 preadolescent males</td>
<td>Resistance training program: 3 times/wk, 2 months; 3 sets upper body exercise x 10 RM; readjust 10 RM every 15 days; upper body exercise: supine bench press, wide grip cable, pull-downs, biceps curl, triceps extensions, seated row and overhead press.</td>
<td>Repeated measures ANOVA, independent t-test</td>
<td>Elbow flexion isometric strength, 10 RM elbow flexion isometric strength.</td>
<td>E: significant changed in isometric strength 17.5%; detraining (8 wks): significant decreased in isometric strength -9.5%.</td>
<td>The 2-months resistance training program resulted in significant increases in isometric strength of preadolescent boys. No injuries reported.</td>
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<td>Reference</td>
<td>Subjects</td>
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<tr>
<td>Szymanski et al., 2004</td>
<td>43 male high school baseball players (15.3 ± 1.1 yrs) E1, n = 23 (15.3 ± 1.2 yrs) E2, n = 20 (15.4 ± 1.1 yrs)</td>
<td>E1 and E2: linear periodized resistance training program, 3 times/wk, 12 wks, 2-3 sets x 6-10 reps, 45-85% of 1RM; resistance exercise: parallel squats, stiff-leg deadlift, barbell bench press, bent-over row, barbell shoulder press, lying triceps extension and barbell biceps curl. E2: additional wrist and forearm exercises: 3 days/wk, 12 wks, 2 x 8-12 reps; wrist and forearm exercises: straight bar wrist curls, standing plate squeeze, standing radial deviation, standing ulnar deviation, seated pronation/supination.</td>
<td>Independent t-tests, repeated measures ANOVA</td>
<td>10 RM: wrist barbell flexion, wrist barbell extension, dominant and nondominant hand forearm, forearm supination, wrist radial deviation and wrist ulnar deviation; dominant and nondominant grip strength; 1 RM: parallel squat and bench press.</td>
<td>E1 and E2: significant increased in wrist barbell flexion (11, 27%), wrist barbell extension (16, 4, 24.4%), dominant forearm pronation (4.8, 12%), nondominant forearm pronation (7.4, 11%), dominant forearm supination (2.7, 7.5%), nondominant forearm supination (3.7, 8.5%), dominant wrist radial deviation (19.3, 26.9%), nondominant wrist radial deviation (16.1, 27.7%), dominant wrist ulnar deviation (24.8, 31.9%) and nondominant wrist ulnar deviation (22.6, 32.7%) for E1 and E2 respectively; significant improved in dominant grip strength (5.7, 5.7%) and nondominant grip strength (5.1, 3.5%) for E1 and E2 respectively; significant changed in 1 RM parallel squat (33.7, 30.7%) and 1 RM bench press (17.4, 15.9%) for E1 and E2 respectively.</td>
<td>A 12-week stepwise periodized training program can significantly increase wrist, forearm, parallel squat and bench press strength for both groups. Group 2 (E2) had further wrist and forearm strength gains. No injuries reported.</td>
</tr>
<tr>
<td>Volek et al., 2003</td>
<td>28 boy (13 to 17 yrs) E1, n = 14 E2, n = 14 maturity status was self reported (Tanner stage) by subjects with the help of their parent</td>
<td>Resistance training program, 3 days/wk, 12 wks, program consisted of varying training loads within each week of training as well as increasing intensity with concomitant decreasing volume over the 12 wks.</td>
<td>Independent t-tests, two-way ANOVA</td>
<td>Maximal strength: squat and bench press.</td>
<td>For all subjects combined significant increased in squat 43%, bench press 23%.</td>
<td>A 12-week resistance training program can significantly increase upper and lower maximal strength in boys aged 13 to 17 yrs. No injuries reported.</td>
</tr>
<tr>
<td>Reference</td>
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<td>Sadres et al., 2001</td>
<td>49 pre-pubertal boys E, n = 27 (9.2 ± 0.3 yrs) C, n = 22 (9.4 ± 0.3 yrs) subjects were Tanner stage 1, 2, except 1 stage 3 pubic hair growth</td>
<td>Resistance training program: 2 times/wk, 21 months, 1-4 sets x 5-30 reps, 30-70% of 1 RM; exercises: dead lift, clean pulls, snatch, clean, jerk, front squat, back squat, leg extension, leg flexion, arm extension, arm flexion, back extension.</td>
<td>Independent t-test, repeated measures ANOVA</td>
<td>1 RM: knee extension, knee flexion.</td>
<td>E: significant change in knee extensions 83%, knee flexions 83%.</td>
<td>Resistance training program among prepubertal boys with low to moderate; twice a week and over a period of 2 school years (21 months) can result in enhancement in muscle strength. One injury reported.</td>
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</tbody>
</table>

Note: E = experimental group; C = control group; RM = repetition maximum; MB = medicine ball
Table 2. Experimental study of physiological mechanisms adaptation following resistance training program in youth

<table>
<thead>
<tr>
<th>Reference</th>
<th>Subjects</th>
<th>Training program(s)</th>
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</tr>
</thead>
<tbody>
<tr>
<td>Ramsay et al., 1990</td>
<td>26 boys (9-11 yrs)</td>
<td>Resistance training program: circuit training, 3.5 sets × 5-12 RM, 3 times/wk, 20 sels; resistance exercise: arm curl, double leg extension, leg press, bench press, behind the neck pull down, sit-ups, trunk curls.</td>
<td>Repeated measures ANOVA</td>
<td>1 RM: bench press and leg press; isokinetic strength, isometric strength and evoked contractile properties: elbow flexors, knee extensors; computerized tomography and percent motor unit activation.</td>
<td>E: significant increases in 1 RM: bench press 34.6%, leg press 22.1%; significant gains in isokinetic strength: elbow flexors 25.8% and knee extensors 21.3%; significant gains in isometric strength: elbow flexors 37.3%, knee extensors at 90° 25.3%; no significant changes on measured muscle cross-sectional areas; 13.2, 17.4% increases in percent motor unit activation but not significant.</td>
<td>20-week progressive resistance training significant increased voluntary and evoked twitch torque in prepubescent obys. Strength increases were independent of changes in muscle cross-sectional area, and the increases in twitch torque suggest adaptations in muscle excitation-contraction coupling. Strength increases were attributed to a trend toward increased motor unit activation, and to other general and undetermined neurological adaptations to training. No injuries reported.</td>
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</table>

Note: E = experimental group; C = control group; RM = repetition maximum
Table 3. Experimental studies of plyometric training in youth

<table>
<thead>
<tr>
<th>Reference</th>
<th>Subjects</th>
<th>Training program(s)</th>
<th>Statistical analysis</th>
<th>Outcome measure(s)</th>
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<th>Conclusions</th>
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</thead>
<tbody>
<tr>
<td>Meylan and Malatesta, 2009</td>
<td>25 young soccer players, E, n = 10 (13.3 ± 0.6 yrs), C, n = 11 (13.1 ± 0.6 yrs)</td>
<td>E: plyometric drills, 2-4 sets of 8-12 reps, 2 times/wk, 8 wks; exercises: ankle hop, vertical jump, lateral hurdle jump, horizontal and lateral and lateral bounding, skipping, footwork.</td>
<td>Repeated measures ANOVA</td>
<td>Vertical jump: squat jump, countermovement jump; contact test, multiple 5 bounds test, 10-m sprint test, agility test.</td>
<td>E: significant increased in countermovement jump 7.9%, contact test 10.9%, significant improved 10-m sprint 2.1%, agility 9.6%.</td>
<td>Plyometric training programs within regular soccer practice improved explosive actions of young players compared to conventional soccer training only. No injuries reported.</td>
</tr>
<tr>
<td>Bishop et al., 2009</td>
<td>22 adolescent swimmers, E, n = 11 (13.1 ± 1.4 yrs), C, n = 11 (12.6 ± 1.9 yrs)</td>
<td>E: plyometric training program, 2 hrs/wk, 8 wks, 1-5 sets × 1-5 reps; exercises: two-foot ankle hop, tuck jump, squat jump, standing jump over barrier, front cone hops, hurdle hops, single leg bounding, single leg push-off, multiple box-to-box jumps, box skip, altitude bounding with double arm action, double leg hops depth jump, depth jump to standing long jump, jump to box, standing jump and reach, standing long jump, standing long jump with hurdle hop.</td>
<td>Independent t-tests, dependent t-tests</td>
<td>Swim block start performance: angle out of blocks, distance to head contact, swim block start velocity, time to head contact, angle of entry into water; performance time to 5.5 m.</td>
<td>E: significant improved in all variables; angle out of blocks 34.01%, distance to head contact 8.31%, swim block start velocity 15.65%, time to head contact 5.86%, angle of entry into water 15.01%; significant changed performance time to 5.5 m 15.43%.</td>
<td>The safe implementation of plyometric training in addition to habitual aquatic-based drills improved the ability of swimmers to explosively maneuver from the block start position to cover greater distances in significant faster times. No injuries reported.</td>
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<tr>
<td>Weeks et al., 2008</td>
<td>37 adolescents boys, E, n = 22 (13.8 ± 0.4 yrs), C, n = 15 (13.8 ± 0.4 yrs)</td>
<td>E: jump training; 2 times/wk, 8 months, ~300 jumps; exercises: hops, tuck jumps, jump squats, star jumps, lunges, side lunges and skipping.</td>
<td>ANCOVA</td>
<td>Vertical jump</td>
<td>E: significant increased in vertical jump 8.9%.</td>
<td>8-month jump training significant increase in jumping performance in prepubertal boys. No injuries reported.</td>
</tr>
<tr>
<td>Kotzamanidis, 2006</td>
<td>30 prepubertal boys, E, n = 15 (11.1 ± 0.5 yrs), C, n = 15 (10.9 ± 0.7 yrs)</td>
<td>E: plyometric training program, 2 times/wk, 10 wks, 10 jumps for each set; exercises: speed bound, vertical jump; height of vertical jump = 10-30 cm; number of jumps per session = 60-100.</td>
<td>Repeated measures ANOVA, paired t-tests</td>
<td>30 m sprint test: 0-10, 10-20, 20-30 and 0-30 m; vertical jump test: squat jump.</td>
<td>E: significant increased in running speed by distance 10-20 m (1.71 ± 0.11 s to 1.65 ± 0.13 s), 20-30 m (1.61 ± 0.28 s to 1.56 ± 0.27 s), 5.5-8 cm (5.55 ± 0.03 to 5.41 ± 0.6 s); significant improve in squat jump (22.95 ± 4.49 to 20.96 ± 4.13 cm).</td>
<td>The plyometric training program in prepubertal boys has a positive effect on running speed and vertical jump performance. No injuries reported.</td>
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<tr>
<td>Reference</td>
<td>Subjects</td>
<td>Training program(s)</td>
<td>Statistical analysis</td>
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<td>MacKevie et al., 2004</td>
<td>64 prepubertal or early pubertal boys</td>
<td>E: plyometric training program, 3 times/wk, 20 months, 50-120 jumps; exercises: alternating-foot jumps, 2-foot obstacle jumps, half-tuck jumps and full tuck jumps</td>
<td>ANCOVA</td>
<td>Vertical jump, Long jump.</td>
<td>E: significant increased in vertical jump 35.4% and long jump 6.5%.</td>
<td>20-month plyometric training significant increase in jumping performance in prepubertal boys. No injuries reported.</td>
</tr>
<tr>
<td>Diallo et al., 2001</td>
<td>20 prepubescent soccer players (12.3 yrs)</td>
<td>E: plyometric exercise (depth jump) and dynamic exercises, bouncing and skipping drills; number of jump = 200/session and increase to 300/session in final 5 weeks, 3 times/wk, 10 wks; 8 wks of reduced training program.</td>
<td>Nonparametric Wilcoxon test, Correlation coefficients</td>
<td>Sprint cycling performance: optimal revolution rate, optimal force, cycling power; vertical jump test: squat jump, countermovement jump, drop jump, multiple 5 bounds test, a 15-second repeated rebound jump test; sprint test: 20, 30, 40-m.</td>
<td>E: significant increased in cycling power 12%, optimal revolution rate 12%, significant improved in countermovement jump 12%, squat jump 7.3%, significant changes in multiple 5 bounds test from 10.5±0.7 to 11.1±0.8 cm, a 15-second repeated rebound jump test (p&lt;0.01) and 20-m (p&lt;0.05). Significant of relation between cycling power and countermovement jump (r=0.87, p&lt;0.01), cycling power and squat jump (r=0.91, p&lt;0.01); reduced training: decrease in countermovement jump but not significant and increased in squat jump but not significant.</td>
<td>A 10-week of specific plyometric training revealed a significant increase in jump, running and sprint-cycling performance in trained boys 12-13 years of age. No injuries reported.</td>
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<td>Matavulj et al., 2001</td>
<td>33 junior basketball players aged (15-16 yrs)</td>
<td>E1: drop jump from a 50 cm bench; E2: drop jump from a 100 cm bench; both groups performed training program 3 times/wk, 8 wks, 3 series of 10 trials.</td>
<td>Paired t-tests, MANCOVA, Correlation coefficients</td>
<td>Countermovement jump; maximal voluntary force; isometric condition of hip and knee extensors; rate of force development; isometric condition of hip and knee extensors.</td>
<td>E1: significant increased in countermovement jump (4.8 cm), rate of force development of knee extensors; E2: significant increased in countermovement jump (5.6 cm), rate of force development of knee extensors, maximal voluntary force in hip extensors, maximal voluntary force in knee extensors n=0.38; countermovement jump and maximal voluntary force in knee extensors n=0.52; countermovement jump and rate of force development of hip extensors n=0.03; countermovement jump and rate of force development of knee extensors n=0.02.</td>
<td>A limited amount of plyometric training could improve jump performance in elite junior basketball players and this improvement could be partly related with in increase in force of hip extensor. No injuries reported.</td>
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Note: E = experimental group; C = control group; RM = repetition maximum
Table 4. Meta-analysis studies of resistance training in youth

<table>
<thead>
<tr>
<th>Reference</th>
<th>Criteria</th>
<th>Number of studies</th>
<th>Statistical analysis</th>
<th>Results</th>
<th>Conclusions</th>
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<tbody>
<tr>
<td>Falk and Tenenbaum, 1996</td>
<td>1. The study design had to include resistance training programs.</td>
<td>- 28 studies</td>
<td>Random effects model meta-analysis,</td>
<td>- The majority of the studies showed gains in strength between 13 and 30%</td>
<td>1. Although limited by the small number of available studies, this meta-analysis reveals that resistance training can be effective in prepubescents.</td>
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<td>2. Maximal age of the participants were 12 and 13 for girls and boys,</td>
<td>described a</td>
<td>calculate average effect size (ES) of each</td>
<td>- Overall mean effect size = .57</td>
<td>2. No difference was found in the effect of resistance training between genders.</td>
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<td>respectively.</td>
<td>resistance training program for boys</td>
<td>study and overall mean effect size.</td>
<td>- The ES of Clarke et al. study = .13</td>
<td>3. Twice a week training frequency is sufficient to induce strength gains in children.</td>
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<td>3. The data have to be available to calculate effect size (ES).</td>
<td>6 studies</td>
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<td>- The ES of Ramsay et al. study = .51</td>
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<td>provided the</td>
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<td>- The ES of Siegel et al. study = .36</td>
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<td>necessary data</td>
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<td>- The ES of Weltman et al. study = .56</td>
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<td>to calculate the</td>
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<td>- The ES of Falk and Mor study = .83</td>
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<td>effect size, 4</td>
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<td>- The ES of Sailors and Berg study = 1.44</td>
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<td>no control group,</td>
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<td>3 studies provided</td>
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<td>5 studies were</td>
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<td>not available.</td>
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<td>Payne et al., 1997</td>
<td>1. Studies must examine the effect of resistance training on muscular</td>
<td>- 28 of the</td>
<td>Fixed-effect model meta-analysis,</td>
<td>- Significantly different (p &lt; .05) from zero in each mean ES indicate</td>
<td>1. Children and youth can demonstrate considerable increases in muscular endurance and strength as a</td>
</tr>
<tr>
<td></td>
<td>strength or muscular endurance of participants.</td>
<td>reviewed studies</td>
<td>calculate effect size (ES) of each study</td>
<td>that resistance training program was effective</td>
<td>result of training.</td>
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<td></td>
<td>2. Studies conducted on “healthy-normal” participants.</td>
<td>met the criteria</td>
<td>characteristic as covariate and overall</td>
<td>- The mean ES of boys = .72</td>
<td>2. The magnitude of the effect appears to be a function of gender, training method and experimental</td>
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<td>3. Studies must report measurements of muscular strength or muscular</td>
<td>for inclusion.</td>
<td>mean effect size, test of heterogeneity.</td>
<td>- The overall average ES = .75</td>
<td>design.</td>
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<td>endurance, measures of power and physical fitness indexes are not</td>
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<td>included.</td>
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<td>4. Studies must report mean, standard deviations and sample size for</td>
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<td>control and experimental groups.</td>
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<td>5. Research must included participants who were 18 years of age or less.</td>
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<td>6. Studies must report controls from an untreated group in an</td>
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<td>experimental-control design or as a posttest in a pretest-posttest</td>
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<td>control group design (pre-post).</td>
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Table 5. Experimental studies of complex training in youth

<table>
<thead>
<tr>
<th>Reference</th>
<th>Subjects</th>
<th>Training program(s)</th>
<th>Statistical analysis</th>
<th>Outcome measure(s)</th>
<th>Main finding(s)</th>
<th>Conclusions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ingle et al., 2006</td>
<td>54 Boys (12 ± 0.3 yrs)</td>
<td>Complex training: 70-100% of 10 RM, 1-3 sets × 7-15 reps resistance exercise + 2-3 sets × 8-10 reps plyometric exercise, 2 times/wk, 12 wks; resistance exercises: back squat, bench press, dumbbell rows, calf raises; resistance exercises: leg extension; plyometric exercises: 2 footed ankle hops, front cone hops, stand long jump, push up, standing jump and reach, tuck jump, cone hops with 180° turn; double leg hops, tuck jump with heel kick, standing jump over barrier; 12 wks of detraining.</td>
<td>Repeated measures ANOVA</td>
<td>10 RM dynamic strength for 8 exercises: bench press, dumbbell rows, barbell calf raises, dumbbell overhead press, back squat, barbell bicep curls, back squat lunges, barbell triceps extension; anaerobic power; vertical jump; 40-m sprint; basketball chest pass; standing long jump.</td>
<td>E: significant gains in 10 RM of 8 dynamic strength exercises 24.3-71.4%; significant gains in both peak and mean anaerobic power lower than or equal 5%; significant gain in vertical jump, basketball chest pass and 40-m sprint lower than or equal 4%; detraining: significant decrease in dynamic strength -16.3-30-3%; significant decrease in vertical jump, basketball chest pass and 40-m sprint -4%; significant decrease in peak anaerobic power -5.9%.</td>
<td>Complex training led to small improvements in peak and mean power, jumping, throwing and sprinting performance; large increases in dynamic strength in pre- and early pubertal boys. Complex training is a safe training modality in this age cohort. No injury reported.</td>
</tr>
<tr>
<td>Santos and Janeiro, 2008</td>
<td>25 young male basketball players</td>
<td>Complex training: 10/12 RM x 2-3 sets resistance exercise + 5-15 reps plyometric exercises, 2 times/wk, 10 wks; resistance exercises: leg extension, pull over, leg curl, decline press, leg press, lat pull down; plyometric exercises: rim jump, MB squat toss, zigzag drill, 2 footed ankle hop, MB chest pass, squat jump, tuck jump, MB overhead throw, alternate leg push off, single-arm alternate leg bound, MB backward throw, lateral jump over cone, side jump/sprint, MB seated chest pass, lateral box jump, depth jump, MB seated backward throw, hurdle hops, depth jump, 180° turn, MB pull over pass, cone hops with change of direction sprint, MB power drop and multiple box-to-box jumps.</td>
<td>Repeated measures t-test, independent t-test</td>
<td>Upper and lower body explosive strength: Squat jump, countermovement jump, abalakov test, depth jump, mechanical power and seated medicine ball throw.</td>
<td>E: significant gains in squall jump 13%, countermovement jump 10.5%, abalakov test 10.5% and seated medicine ball throw 19.6%.</td>
<td>Complex training improves the upper and lower body explosivity levels (vertical jump, medicine ball throw) in young basketball players. Complex training is a useful working tool for coaches, innovative in this strength training domain, equally contributing to a better time-efficient training. No injury reported.</td>
</tr>
</tbody>
</table>

Note: E = experimental group; C = control group; RM = repetition maximum; MB = medicine ball
Discussion and Conclusion

All reviewed studies reported that children and adolescent boys significantly improved their strength and motor performance from participating in strength training programs. Studies reported different results in strength and performance gains following training programs. Results from the longest training program (21 months) showed the highest magnitude of changes (83%) in muscle strength (Sadres et al., 2001) and the lowest (15%) was observed by Faigenbaum et al. (2007) in a twice a week, 12 weeks training program. Sadres et al (2001) suggested that the training intensity in their study was relatively low in comparison with most previous studies among children. Moreover, Shaibi et al. (2006) supported the idea that a longer training period might have further enhanced the observed strength gains. Besides, Faigenbaum et al. (2007) also proposed that differences in the training level as well as training intensity, volume and duration could explain the variance between findings in each studies. Studies that used the same training duration and frequency (2 times per week, 16 weeks) by Christou et al. (2006) and Shaibi et al. (2006) reported different results in strength gains (58.8 vs. 28%), with young soccer players showing higher gains. On the other hand, Szymanski et al. (2004) and Szymanski et al. (2007) used identical programs (3 times per week, 12 weeks) that involved the same age (13 years) subjects from the same sport and showed similar strength gains (17.4 and 17.2%), respectively. However, another identical program showed superior results (23%) where subjects had higher age range (Volek et al., 2003). Thus, it could be concluded that longer program duration and higher frequency and intensity seem to have a greater influence on the magnitude of changes of strength. One complex training study that measured strength demonstrated superior results to all of resistance training studies (Ingle et al., 2006). Magnitudes of changes were observed by up to 71.4% despite duration and frequency of the programs were similar to those of resistance training studies. To our knowledge, there is no published study that
investigated if complex training program results were superior to resistance training program alone. Various results of vertical jump increases were reported from all types of training programs. Plyometric training showed higher results when compared to other two training programs. Kotzamanidis (2006) reported the highest magnitude of changes (34%). Nevertheless, comparable results were observed from one of the resistance training programs, as Christou et al. (2006) demonstrated changes in vertical jump (31%) in a training program that last longer (16 weeks). Six-week combination programs between plyometric and resistance training showed greater magnitude of changes in vertical jump than static stretching and resistance training (Faigenbaum et al., 2007). The authors presumed that additional lower body plyometric exercises that focus on vertical jump may be needed to make gains in vertical jump performance beyond that can be achieved from resistance training and static stretching. Other resistance training studies observed similar changes in vertical jump despite unequal training program periods (Channell and Barfield, 2008; Faigenbaum et al., 2007; Wong et al., 2010) as well as in plyometric studies (Diallo et al., 2001; Matavulj et al., 2001). Ten-week complex training programs results in superior improvements (13%) than most of resistance training studies and similar improvement when compared to plyometric studies (Santos and Janeira, 2008).

Significant changes in muscular strength and performances changes are most related to neural factors. Christou et al. (2006) pointed out that neural adaptation such as increased motor unit recruitment and coordination, as well as improved coordination of involved muscle groups were the main factors that could explain the positive training response. This is in agreement with Ozmun et al. (1994) and Ramsay et al. (1990). Ramsay et al. (1990) who did not observe any significant changes in muscle cross-sectional area after subjects underwent 20-week resistance training program. They postulated that significant strength gains can be made by children independent of changes in muscle size and perhaps training induced muscle hypertrophy is contingent on adequate levels of circulating androgens (Vrijens, 1978). Furthermore, Szymanski et al. (2004)
stated, similarly, that significant strength gains occurring during the first 4-8 weeks of training are primarily attributed to neural adaptations marked by an increase in integrated electromyographic (IEMG) activity, an increase rate of motor unit activity as well as increased motor unit synchronization (Moritani and DeVries, 1979). However, a paradoxical finding has been reported by previous study (Mersch and Stoboy, 1989). Ingle et al. (2006) who first demonstrated gains in complex training in youth did not follow this line of reasoning. They went on suggesting that another possible mechanism was postactivation potentiation (PAP). Sale (2002) defined PAP as an increase in muscle twitch and low-frequency tetanic force after a conditioning contractile activity. The principal mechanism of PAP is considered to be the phosphorylation of myosin regulatory light chains, which renders actin-myosin interaction more sensitive to Ca\(^{++}\) released from the sarcoplasmic reticulum (Rassier and McIntosh, 2000 and Sweeney et al., 1993). Increased sensitivity to Ca\(^{++}\) has its greatest effect at low myoplasmic levels of Ca\(^{++}\), as occurs in twitch and low-frequency tetanic contraction; in contrast, increased sensitivity to Ca\(^{++}\) has little or no effect at saturating Ca\(^{++}\) levels, as in high-frequency tetanic contractions. Thus, PAP raises the low but not high frequency portion of the force-frequency relation (Abbate et al., 2000 and Vandenboom et al., 1993). However, review papers that examined the PAP explanation in order to enhance acute voluntary explosive contractions concluded that the results were equivocal (Docherty et al., 2004; Hodgson et al., 2005; Robbins, 2005). Thus, more research is needed in order to investigate the roles of PAP to improve strength and power performance from complex training in children.

Vertical jump improvements were reported from all types of training programs. Christou et al. (2006) explained that the increases in the maximal muscle force, as a result of strength training, also improves muscular power, despite the absence of specific jumping exercises. Besides, Meylan and Malatesta (2009) reported improvements in countermovement jump but not in squat jump following plyometric training program. The authors explained that
the plyometric training exclusively stressed the stretch-shortening cycle (SSC) of the muscle; consequently, pure concentric contraction, assessed by the squat jump, was not stimulated during training. In contrast, Kotzamanidis (2006) observed increases in squat jump after plyometric training program and referred that vertical jump enhancements could be the rate of force development, power, and stiffness enhancement, as already reported in adult (Baker, 1996; Wilson et al., 1993). Santos and Janeira (2008) suggested that the improvements reported in their complex training study could be explained by stimulation of the neuromuscular system (Chu, 1998), that is, it activates both the muscular fibers and the nervous system, so that slow-twitch fibers behave like fast-twitch fibers (Chu, 1996). Running speed improvements from training programs were explained differently by authors. Wong et al. (2010) referred that a short distance sprint performance is most related to the player’s ability to generate muscular power as earlier demonstrated by Delecluse et al. (1995). Besides, they pointed out that the exercises proposed in their study were supposed to have provided the greatest effect in sprint performance because they consisted of simultaneous triple-extension of the ankle, knee, and hip joints and also a possible transfer from the gain in the leg muscular power into the sprint performance as reported by Gorostiaga et al. (2004). Meylan and Malatesta (2009) support the idea of the efficiency of plyometry to improve specific explosive actions of young soccer players as they found a significant decrease in 10-m sprint time. They reported a relationship between countermovement jump and 10-m sprint as it has been observed in previous studies (Cronin and Hansen, 2005; Young et al., 1995) and this relationship was also observed in their study. These results can be explained by the specificity of the acceleration phase where the center of mass is lower and ground contact time is longer when compared to the maximal velocity phase, resulting in a slow stretch-shortening cycle of the muscle in similar motion to countermovement jump. This relationship verified the validity of an acyclic vertical jump to predict field performance and the role of vertical velocity and forces during initial acceleration. Furthermore, Kotzamanidis (2006) advanced the idea of utilizing
speed-bound exercises to enhance all running phases including the initial acceleration (0-10 m) as these results have been previously reported in adults (Rimmer and Sleivert, 2000). Changes were also observed in the intermediary acceleration (10-20 m) and steady velocity phases (20-30 m). Additionally, Ingle et al. (2006) explained running speed improvement in their study because the test involves shuttle sprints, requires an element of motor coordination, and therefore it is possible that a learning effect may have elicited improvements in motor skill, ultimately improving performance.

Soccer drills and game have been presumed to contribute to improvements in agility because drills and games involves continuous changes of direction (Christou et al., 2006). Furthermore, the same authors proposed that strength training has a minor effect on agility of young people, being its enhancement probably explained by a minor transfer of the strength gain to agility, which probably involves a motor control pattern. In addition, Meylan and Malatesta (2009) also explained the findings in their study using plyometric drills and encompassing many powerful lateral movements, which had an impact on the ability to change direction faster and they referred that the plyometric training program may have improved the eccentric strength of the lower limb, a prevalent component in changes of direction during the deceleration phase (Sheppard and Young, 2006).

Neural adaptation factors following strength training also have been postulated to be related to anaerobic performance enhancement. Ingle et al. (2006) agree that mechanisms responsible for peak anaerobic power enhancement following strength training may relate to increased force generation and neural adaptation such as increased motor neuron firing rate and improved muscular coordination (Mahon, 2000). VO₂ max changes were observed in young soccer players. Wong et al. (2010) explained that significantly decreases in running cost could be attributed to the improved mechanical efficiency after the combined effect of strength and power training programs as demonstrated previously by Storen et al. (2008) and as earlier
proposed by Noakes (1988) that aerobic performance may be affected not only by central factors related to VO_{2} max but also by peripheral factors such as muscle power. Lastly, Bishop et al. (2009) concluded that improved swim block start performances results from plyometric training are related to increased muscular power output and force production. They argue that the optimization of eccentric force production significantly develops elastic muscular components and explosive power production through enhanced motor unit firing rates and development of contraction intensity involved in neurophysical potentiation (Pire, 2006).

Strength and performances were observed to be decreased after detraining and reduced training period. Tsolakis et al. (2004) reported isometric strength was reduced 9.5% significantly after 2 months of detraining phase. Indeed, a 12-week detraining period after a complex training program, results in dynamic strength reductions (Ingle et al., 2006). Strength was significantly decreased between 16.3 and 30.3%. Decreasing in vertical jumps was also remarked from plyometric and complex training study. Diallo et al. (2001) observed reduction in countermovement jump after 8-week reduced training program but not significant, conversely, squat jump was increased but also not significant. Ingle et al. (2006) also observed significantly decrease by 4% in vertical jump, this magnitude of changes was identical as improvement observed after 12 weeks of training period. Nevertheless, one another published study by Santos and Janeira (2009) did not observe any changes in both upper and lower body explosive strength in adolescent basketball players after neither reduced complex training program nor detraining.

Reviewed studies indicated a relative low risk of injury in children and adolescents boys. Only one minor injury occurrence was reported from resistance training program. Sadres et al. (2001) reported one accident, which the bar slid and fell on the thighs of the one subject while performing clean exercise. The child complained of transient non-specific pain in the anterior thigh and sat out for 5 minutes then he return back to train within the same
session when the pain was resolved and had no further complains. Therefore, authors felt that no additional medical evaluation was required. Recent studies reported absence of injury occurrence. Moreover, all types of programs were effective in improving muscular strength physical performances. These evidences are in agreement with review study and position statement papers that strength training is safe for youth if the programs are properly designed and well-supervised (Behm et al., 2008; Faigenbaum et al., 2009; Malina, 2006; Small et al., 2008).

Based on evidences from current reviewed studies, it is clear that youth can profit from participating strength training programs. However, knowledge concerning effect of complex training in youth is still scarce particularly muscular strength gains and performances improvement consequence training program in young athletes. Moreover, more studies are need to address information about complex training description such as training load, intensity, frequency, exercises and training program duration in order to yield the maximum results in young athletes as well as persistence of strength and performances after detraining or reduced training period. Therefore, we still do not know if complex training results superior than resistance training in strength and performances. These aforementioned informations will be important and useful for coaches to design strength training program and schedule annual training plan in their individual and team sports.

In conclusion, resistance training programs highly improve maximum strength as well as motor performance. Magnitudes of strength and performance changes vary, depending the characteristics of the program design. Longer program duration and higher training intensity seems to result in greater improvements. More mature boys showed greater strength gains. Strength gains following training programs are mostly related to neuromuscular adaptations than to muscle hypertrophy. Plyometric training highly enhance explosive movements, at a greater extent than resistance training. Complex training extremely increases dynamic strength, and improve explosive strength
in comparable magnitude of changes to those reported by resistance and
plyometric training programs, and slightly enhances anaerobic power and other
performances. However, no comparison study on maximum strength and
performance gains between effects from resistance and complex training are
available. Strength and performance gains decreased after detraining and
reduced training phases in all types of programs. All reviewed training programs
are safe in youth and there are no reported injuries. Complex training data in
youth is still scarce.
References


Blimkie CJR (1989). Age- and sex- associated variation in strength during childhood: Anthropometric, morphologic, neurologic, biomechanical,


CHAPTER 3: SECOND RESEARCH PAPER

Title: Importance of pilot study and data quality control in designing complex training programs for young athletes

Authors: Rojapon Buranarugs, José Oliveira, José Maia

Journal: The Open Sports Sciences Journal (accepted)
ABSTRACT

The aims of this pilot study were to use various muscular strength and performance evaluation procedures to assess the preliminary responses from young Thai male athletes to strength training programs, and to apply data quality control to assess data reliability. Sixteen young Thai male athletes aged 13-17 years from the Khon Kaen Sport School were sampled: eight were soccer players and eight were track and field athletes. Subjects were divided into two groups: a complex training group (n = 8) and a resistance training group (n = 8). The pilot intervention program was applied twice a week during two weeks. Maximum strength, anaerobic power, vertical jumps, 40-yard sprints, agility and sports skills were measured before and after the two-week training programs. As expected no significant changes were observed in all measured variables from pre- to post-testing in both groups (p>0.05); mean differences (Δ) between pre- and post-testing of all variables were close to zero, and high reliability values were observed. All subjects handled well the training programs and assessments. No injuries occurred during all training and testing sessions. The training programs and testing procedures were suitable and safe for young male Thai athletes. Results from statistical analysis showed the achievement of high quality data. Further research in this cohort can be done under a well-designed training program and close supervision by researchers.

KEY WORDS: Complex training, data quality control, physical performance, resistance training, strength, young, athletes.
Introduction

Youth strength training is becoming popular as a suitable way, among others, to enhance performance in sports and reduce potential injury, and has been incorporated in many sports-oriented annual plans. Although musculoskeletal injury risk and growth disturbance from growth plate injury are major concerns in youth strength training, recent evidence has supported the idea that a strength-training program can be safe for young people if that program is properly designed and participants are closely supervised. A review study clearly indicated that resistance training has no negative influence on the growth and maturation of youngsters [1]. Moreover, there are now several position statements from important medical and scientific organizations favouring quality supervised strength training programs to enhance sports performance, prevent injury and improve the general health of children and youth involved in sports [2, 3].

Strength training programs for youth can be designed in several forms, the most effective and widely used in youth strength training researches are resistance and plyometric training [2]. Available data showed the benefits of resistance training programs when combined with sport-specific training in youth [4-6]. For example, significant strength and physical performance improvements of adolescent soccer players were reported when combined with specific soccer and resistance training programs [4]. Plyometric training studies in youth reported changes in various types of performance such as in vertical jump, sprint, agility, and sprint cycling tests following training programs [7, 8]. Recently, a position statement paper recommended that, when designing strength training programs for youth, coaches should use training loads in the range of 50-85% of 1RM for each exercise, using 1-3 sets × 6-15 repetitions 2-3 days a week [2].

Another effective strength training modality, which is becoming popular is complex training. Complex training is best described as a strength and power training method that combines resistance and plyometric training in the same training session [9, 10]. Available information demonstrates the positive effect of complex training on strength and physical performance in prepubertal boys [11] and explosive strength and sprint performance when combined with routine training in young athletes [12, 13].
Although there is evidence supporting the idea that children and adolescents can obtain real benefits from participating in complex training programs, there are gaps in the literature, namely regarding the effects of complex training methods on strength in young athletes and including topics such as program design, physical performance assessment and responses to complex training programs from young athletes engaged in different types of sports. Furthermore, and contrary to what happens in USA and some Europeans countries, there is no research tradition in Thailand for investigating the effects of complex training or resistance training programs, or a combination of both, in young athletes. In addition, available research concerning the design, implementation, data quality control and interpretation of complex training in youth is scarce. Thus, before implementing any experimental strength training study, it would be of importance to provide suitable information regarding these issues. In addition there is not much information, if any, about methodological sound strength training programs evidence-based, nor a consistent tradition in data quality control prior to the implementation of such programs in young Thai athletes.

This report deals primarily with a pilot study centred on the designing of the strength training programs, data quality control and adequate statistical analysis. These primarily results will provide enough information about the validity of short to medium term intervention programs, and this information may be useful to coaches and athletes if they are highly interested in successful training methodologies aiming a high level performance. With these ideas in mind, a study was designed aiming to evaluate how young Thai male athletes respond to complex and resistance exercises in its pilot phase (two weeks), namely to examine the suitability of training programs and to assess data reliability when using diverse testing procedures. It can also provide a suitable template for future research using experimental training programs with young athletes. The linking hypothesis of this pilot study is that high reliable information can be achieved within highly designed (i.e., supervised and monitored) strength training programs. Furthermore, we wanted to subjectively assess from athletes and coaches the suitability of the programs and the testing procedures since this was the first time that such a training program took place. We are of the position that without systematic pilot studies about distinct short-duration training programs, persuasive data and equipment controls, no sound and relevant results will be provided to coaches and athletes when implementing such programs in their annual plans.
Methods

Subjects

Subjects in this study were 16 young Thai male athletes aged 13-17 years from the Khon Kaen Sport School in Khon Kaen. Of the boys, eight were soccer players (SOC) from several soccer field positions (defender, midfielder, winger and striker) and eight were track and field athletes (TF) from several events (sprinter, hurdle, long jump, shot put and javelin throw. The subjects were further divided into two groups: a complex training group (CT: n = 8; 14.4 ± 1.5 years) and a resistance training group (RT: n = 8; 14.4 ± 1.1 years). The groups consisted of an equal number of both sport types (SOC: n = 4, TF: n = 4). Soccer players were trained by the same coach but track and field athletes were trained by different coaches according to their specialty. All subjects were involved in the training routine program for six days each week and participated in their regular school classes five days a week.

Prior to the study, all subjects and coaches were informed about the purposes of the study. Written informed consent was obtained from the parents. The study was conducted according to the declaration of Khon Kaen University, Khon Kaen, Thailand and was approved by the Ethics Committee of the Faculty of Sport, University of Porto, Porto, Portugal.

Research procedure

Training program

As study was set to evaluate the feasibility of the complex and resistance training programs, no significant changes were expected in any physical performance variables. Thus, both complex and resistance training programs were designed to last only two weeks with two sessions per week. Training programs were part of normal daily training routines of all athletes, as follows:

1. A complex training program consisting of a combination of resistance training and plyometrics. Resistance and plyometric exercises as well as training intensity and volume used in training programs have been recommended for practicability, effective and safety with youth [2, 14, 15]. Throughout the study training intensity and volumes for resistance training were constant (70% of 1RM; 2x 12) as well as for plyometric training (2 x 10 reps.). All subjects were evaluated for 1RM in all six
resistance exercises before training in order to define target training load (70% of 1RM). The order of the resistance exercises was as follows: bench press, arm curl, lat pull down, leg press, knee curl, and leg extension. Plyometric exercises, which were performed after the resistance exercises, consisted of medicine ball chest pass, medicine ball overhead throw, medicine ball backward throw, rim jump and tuck jump. This program is presented in Table 1.

2. A resistance-training program consisting of only normal resistance exercises as used in the complex training program. Training intensity and volume were also equal to the complex training group. This program is presented in Table 1.

Table 1. Complex and resistance training programs

<table>
<thead>
<tr>
<th>Week</th>
<th>Session</th>
<th>Resistance exercises</th>
<th>Set x repetitions</th>
<th>Intensity (%1RM)</th>
<th>Plyometric exercises</th>
<th>Set x repetitions</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>Leg press</td>
<td>2 x 12</td>
<td>70</td>
<td>Rim jump</td>
<td>2 x 10</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Bench press</td>
<td></td>
<td></td>
<td>Medicine ball chest pass</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Knee extension</td>
<td></td>
<td></td>
<td>Tuck jump</td>
<td></td>
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<tr>
<td></td>
<td>2</td>
<td>Arm curl</td>
<td>2 x 12</td>
<td>70</td>
<td>Medicine ball overhead throw</td>
<td>2 x 10</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Knee curl</td>
<td></td>
<td></td>
<td>Tuck jump</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Lat pull down</td>
<td></td>
<td></td>
<td>Medicine ball backward throw</td>
<td></td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>Leg press</td>
<td>3 x 12</td>
<td>70</td>
<td>Rim jump</td>
<td>3 x 10</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Bench press</td>
<td></td>
<td></td>
<td>Medicine ball chest pass</td>
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<tr>
<td></td>
<td></td>
<td>Knee extension</td>
<td></td>
<td></td>
<td>Tuck jump</td>
<td></td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>Arm curl</td>
<td>3 x 12</td>
<td>70</td>
<td>Medicine ball overhead throw</td>
<td>3 x 10</td>
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<tr>
<td></td>
<td></td>
<td>Knee curl</td>
<td></td>
<td></td>
<td>Tuck jump</td>
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<tr>
<td></td>
<td></td>
<td>Lat pull down</td>
<td></td>
<td></td>
<td>Medicine ball backward throw</td>
<td></td>
</tr>
</tbody>
</table>

Both the complex and the resistance training programs were performed before the routine training programs of the school in the afternoon during a pilot program consisting of two sessions per week for two weeks on non-consecutive days. The duration of each training session was between 45 to 60 minutes.

Testing procedures

All subjects performed all tests in one session during the morning for both pre and post-tests, ordering to the following sequence: 40-yard sprint, T-test, countermovement jump, squat jump, sport skills, 1RM bench press, 1RM leg press, and Wingate test. Subjects performed skill tests according to their sport specific type, passing and shooting skills for soccer player and medicine ball throw and
standing long jump for track and field. Three technician specialists of the Sports Authority of Thailand, Sports Sciences Center Section 3 operated all pre and post-test tests and the same coach always administered the soccer and track and field skill tests.

Maximum strength: 1RM; the maximum load that can be lifted in one repetition [16, 17]. All subjects were evaluated for 1RM in the bench press and leg press exercises by using Strive resistance training machine (Strive Enterprises, Inc., USA). The target load was obtained within 6 trials. The 1RM load was recorded in kilograms. Both exercises were performed using the same resistance equipment.

Wingate anaerobic test: A modified set devised for the Wingate anaerobic test (Monark Ergomedic 828E, AB, Sweden) of the Sports Authority of Thailand was used to evaluate anaerobic peak power and anaerobic capacity throughout the experiments. Peak anaerobic power represents the highest power output (watts/kg) generated during first 5 seconds of test and anaerobic capacity is the total amount of work (watts/kg) accomplished over a 30 seconds. The set was composed of an adapter, in the middle of which its input was connected to the Ergomedic 828E Monark Exercise AB, Sweden and its output to a CPU. The CPU was equipped with an on-line Version 2.0/1993 of the Sports Authority of Thailand. The breaking force applied was 0.068 kp per kg bodyweight and the force was equivalent to mechanical work of 4.02 J per pedal revolution per kg bodyweight. The values of the force and the mechanical work were the average values used for 13- to14-year-old boys and for 13- to 14-year-old girls [18]. These values were supposed to be used for boys and girls in Thailand. Testing procedures were according to previous suggestion [19]. After a 10-minute warm-up, a subject began pedalling as fast as possible without any resistance or breaking force. Within three seconds, a previously calculated fixed breaking force was applied to the flywheel of the Ergometer and the subject continued to pedal “all out” for 30 seconds. The testing devices were run by the technician specialist of the Sports Authority of Thailand, Sports Sciences Center Section 3.

40 yard sprint time: The 40 yard sprint test [20] was used to measure the 40 yard sprint time of subjects by using the Fusion Sport Smart Speed (Fusion Sport, Pty, Ltd, Australia). The device was operated by the technician specialist of the Sports Authority of Thailand, Sports Sciences Center Section 3. All subjects were instructed to sprint on the running track at maximum speed for a distance of 40 yards.
Fusion Sport Smart Speed recording devices were placed at the start and finish points to record the time. Subjects performed two sprints, resting for five minutes between trials.

Agility (T-test): The agility of all subjects was evaluated using a T-test [21] on an outdoor court. The Fusion Sport Smart Speed (Fusion Sport, Pty, Ltd, Australia) was used to record the time of each performance. The devices were placed at the start and finish points to record the time. Subjects started behind the recording device and ran as fast as possible, following the T figure and passing the finish point. After one practice trial, two agility tests were performed. The Fusion Sport Smart Speed device was operated by the technician specialist of the Sports Authority of Thailand, Sports Sciences Center Section 3.

Vertical jump: Vertical jump performance was measured for two types of jumps, a countermovement jump (CMJ) and a squat jump (SJ) [22]. The Fusion Sport Smart Jump (Fusion Sport, Pty, Ltd, Australia) was used to record the height of each jump. Jumps were performed on the rubber plate of the Fusion device. Subjects performed each jump twice. The Fusion Sport Smart Jump was operated by the technician specialist of the Sports Authority of Thailand, Sports Sciences Center Section 3.

Soccer skills test: Two types of soccer skill tests were used: shooting and passing. These soccer skill tests are normally used at the school to evaluate student skill.

Passing skill test: Subjects stood with a ball behind a line ten feet from a wall. They passed the ball to hit the wall, and continued passing whenever the ball returned to them. Subjects were told to pass the ball as fast as possible for 30 seconds. A score was registered only when the ball was kicked and hit the wall from behind the 10-foot-distance line. Subject performed the test twice, and the best score was recorded.

Shooting skill test: Subjects shot 10 balls toward the goal without a goalkeeper from the 18 yard range. Ten balls were placed one foot apart along the 18 yard line. The goal space was divided into 6 sections, with each section giving a different score: Three points if the subject shot a ball into the upper right or left sections, two points for the upper middle or lower right or left and one point for the lower
middle. A score was not counted if the subject shot a ball out of the target area. Subjects performed the test twice, and the best score was recorded.

Track and field tests: Two types of track and field tests were used: the standing long jump and the medicine ball throw. These track and field skill tests are used at the school to evaluate student skill.

Standing long jump: Subjects stood behind a line, facing the sandbox, with feet slightly apart. They jumped forward using a two foot take-off, landing with a swinging of the arms, and bending of the knees. Subjects attempted to jump as far as possible and land on both feet without falling backwards. The standing long jump distance was measured in meters. Subjects performed the test twice and the best score was recorded.

Medicine ball throw: Subjects stood at a line with the feet side by side and slightly apart, facing the sandbox toward which the ball was to be thrown. The three-kilogram medicine ball was held with the dominant hand at the shoulder then the subject threw the ball vigorously forward as far as possible. The subject was not permitted to step over the line after the ball was released. The distance from the starting line to the dropped point of the medicine ball in the sandbox was measured in meters. Subjects performed the test twice, and the best score was recorded.

Data analysis

Data analysis consisted of several parts: (1) main descriptive statistics to show group behavior in all tests; (2) graphs with different data configurations at pre- and posttest; (3) an intraclass correlation coefficient (ICC) to assess data reliability; (4) repeatability using the Bland-Altman technique. Since we will have 24 Bland-Altman plots we will only present 6 for illustrative purposes. For example, in the Wingate anaerobic test, it was expected that the coefficient of repeatability of peak anaerobic power would not be more than 1 watts/kg. Mean differences (Δ) were also computed to show the magnitude of changes from pre- to posttest for each variable. In addition, dependent t-tests were used to determine whether there were significant differences between pre- and posttests in all athletic tests. All analyses were done in SPSS 18.0.
Results

Table 2 shows important statistical results that are of great help in understanding the relevance of the pilot study. Mean (±standard deviation) values of the pre- and posttests of the complex and resistance training groups are reported. Mean differences (Δ) are included, indicating the amount of change from pre- to posttest. Also, t and p values from the dependent t-test are given.

Mean and standard deviations of all variables are similar from pre- to posttest in both the complex training and the resistance training group. Mean differences (Δ) are very small, showing evidence of a high interindividual consistency of performance. The dependent t-test showed no statistically significant differences (p>0.05) in all variables. The range of ICC values of all measures was (0.67 to 0.99).

Figure 1 shows only 6 of the 24 possible Bland-Altman graphs for repeatability indicating the high precision of subjects performance. For example, in the peak anaerobic performance mean differences from both complex and resistance training groups are close to 0 (0.06 watts/kg) with a precision interval that goes from 1 and -0.88 watts/kg); in 1RM bench press, mean differences are 1.1 kg, and the interval goes from -2.91 to 1.49 kg. For the rest of the variables, mean differences are 0.56 sec, -0.02 sec, 0.40 cm and -0.03 watts/kg for 40 yard speed, agility, countermovement jump and mean anaerobic power, respectively.
Table 2. Mean ± standard deviation, mean differences (Δ) between pre- and posttest, and t and p values from t-tests of all variables in the complex training and resistance training groups

<table>
<thead>
<tr>
<th>Complex training group</th>
<th>Pre</th>
<th>Post</th>
<th>Δ</th>
<th>t</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>1RM bench press (kg)</td>
<td>52.40 ± 8.18</td>
<td>52.69 ± 7.54</td>
<td>-0.29</td>
<td>-1</td>
<td>0.35</td>
</tr>
<tr>
<td>1RM leg press (kg)</td>
<td>144.25 ± 26.79</td>
<td>145.11 ± 26.06</td>
<td>-0.86</td>
<td>-2.65</td>
<td>0.08</td>
</tr>
<tr>
<td>Peak anaerobic power (watts/kg)</td>
<td>9.34 ± 1.61</td>
<td>9.53 ± 1.40</td>
<td>-0.19</td>
<td>-1.36</td>
<td>0.21</td>
</tr>
<tr>
<td>Anaerobic capacity (watts/kg)</td>
<td>7.38 ± 1.10</td>
<td>7.39 ± 1.02</td>
<td>-0.02</td>
<td>-0.21</td>
<td>0.84</td>
</tr>
<tr>
<td>40 yard speed (sec)</td>
<td>5.07 ± 0.31</td>
<td>5.09 ± 0.34</td>
<td>-0.02</td>
<td>-0.88</td>
<td>0.41</td>
</tr>
<tr>
<td>Agility (sec)</td>
<td>9.52 ± 0.54</td>
<td>9.54 ± 0.51</td>
<td>-0.02</td>
<td>-1.36</td>
<td>0.22</td>
</tr>
<tr>
<td>Countermovement jump (cm)</td>
<td>34.50 ± 6.38</td>
<td>34.24 ± 6.29</td>
<td>0.26</td>
<td>1.38</td>
<td>0.21</td>
</tr>
<tr>
<td>Squat jump (cm)</td>
<td>32.68 ± 6.20</td>
<td>32.37 ± 6.05</td>
<td>0.31</td>
<td>1.29</td>
<td>0.24</td>
</tr>
<tr>
<td>Shooting skill (pts)</td>
<td>14.25 ± 1.26</td>
<td>14.00 ± 1.15</td>
<td>0.25</td>
<td>0.52</td>
<td>0.64</td>
</tr>
<tr>
<td>Passing skill (pts)</td>
<td>14.75 ± 2.36</td>
<td>14.25 ± 1.50</td>
<td>0.5</td>
<td>1</td>
<td>0.39</td>
</tr>
<tr>
<td>Standing long jump (m)</td>
<td>2.48 ± 0.09</td>
<td>2.46 ± 0.06</td>
<td>0.03</td>
<td>1.92</td>
<td>0.15</td>
</tr>
<tr>
<td>Medicine ball throw (m)</td>
<td>9.41 ± 0.21</td>
<td>9.41 ± 0.16</td>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Resistance training group</th>
<th>Pre</th>
<th>Post</th>
<th>Δ</th>
<th>t</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>1RM bench press (kg)</td>
<td>51.83 ± 7.78</td>
<td>52.69 ± 7.42</td>
<td>-0.86</td>
<td>-2.65</td>
<td>0.08</td>
</tr>
<tr>
<td>1RM leg press (kg)</td>
<td>142.56 ± 8.17</td>
<td>142.58 ± 7.70</td>
<td>-0.01</td>
<td>-0.02</td>
<td>0.99</td>
</tr>
<tr>
<td>Peak anaerobic power (watts/kg)</td>
<td>9.95 ± 2.02</td>
<td>9.65 ± 1.93</td>
<td>0.3</td>
<td>2.05</td>
<td>0.08</td>
</tr>
<tr>
<td>Anaerobic capacity (watts/kg)</td>
<td>7.86 ± 1.24</td>
<td>7.86 ± 1.12</td>
<td>0</td>
<td>0.01</td>
<td>0.99</td>
</tr>
<tr>
<td>40 yard speed (sec)</td>
<td>5.27 ± 0.59</td>
<td>5.29 ± 0.56</td>
<td>-0.02</td>
<td>-1.67</td>
<td>0.12</td>
</tr>
<tr>
<td>Agility (sec)</td>
<td>9.71 ± 0.50</td>
<td>9.72 ± 0.50</td>
<td>-0.02</td>
<td>-0.78</td>
<td>0.46</td>
</tr>
<tr>
<td>Countermovement jump (cm)</td>
<td>31.31 ± 9.12</td>
<td>30.77 ± 8.93</td>
<td>0.54</td>
<td>1.96</td>
<td>0.09</td>
</tr>
<tr>
<td>Squat jump (cm)</td>
<td>29.70 ± 8.12</td>
<td>29.47 ± 7.84</td>
<td>0.24</td>
<td>1.28</td>
<td>0.24</td>
</tr>
<tr>
<td>Shooting skill (pts)</td>
<td>14.75 ± 0.50</td>
<td>14.25 ± 1.71</td>
<td>0.5</td>
<td>0.78</td>
<td>0.5</td>
</tr>
<tr>
<td>Passing skill (pts)</td>
<td>15.00 ± 1.41</td>
<td>15.00 ± 1.83</td>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Standing long jump (m)</td>
<td>2.41 ± 0.10</td>
<td>2.41 ± 0.11</td>
<td>0</td>
<td>0.33</td>
<td>0.76</td>
</tr>
<tr>
<td>Medicine ball throw (m)</td>
<td>9.11 ± 0.40</td>
<td>9.10 ± 0.37</td>
<td>0</td>
<td>0.14</td>
<td>0.9</td>
</tr>
</tbody>
</table>
Figure 1. Examples of six Bland-Altman plots of both complex and resistance training group (1RM bench press, countermovement jump, 40 yard speed, agility, peak anaerobic power and mean anaerobic power): Mean (dashed line) is average of difference in measured variable (pre-posttest). Mean − 2SD and Mean + 2SD (dark lines) are most of the difference from Mean which derived from the average of differences in measured variable (Δ) ± 2 × Standard deviation of the Mean difference. For example in peak anaerobic power, mean = 0.06 watts/kg and SD = 0.47 watts/kg. Mean − 2SD = -0.88 watts/kg and Mean + 2SD = 1 watts/kg.
**Discussion**

The current study applied a two-week pilot strength training program and used suitable testing protocols to evaluate the program’s feasibility for young Thai male athletes. Subjects’ responses to different strength training protocols and varied testing procedures targeted to measure muscular strength and power, physical performance and sport skills were observed. Different approaches to estimate data reliability were presented. To our knowledge, this is the first study on young Thai male athletes.

The training programs for this study were based on available data sources [4, 11, 13, 24, 25] that used both children and adolescents who were either non-athletes or athletes. As our resistance training programs were predominantly designed to evaluate how young Thai male athletes respond to the program, subjective information revealed that young Thai male athletes were highly capable of performing all exercise routines throughout the two weeks of study. During the study, all resistance exercises in each session were well tolerated by subjects. All of subjects were closely supervised by researcher and after each set of exercise, comments and suggestions were given to subjects in order to perform a proper resistance exercises technique. They were also instructed to perform in each exercise at moderate repetition velocity, which is suggested for youth resistance training program by the National Strength and Conditioning Association [2]. Performance discomfort or injuries were not observed in all resistance training sessions. No subjects dropped out during the resistance training.

The same order of exercises in the resistance training group such as training intensity, volume, and repetition velocity were applied to complex training group in order to perform exercise during resistance exercise phase. We allowed them 4 minutes rest between resistance exercise and plyometric exercise in each set as well as between exercise set. As suggested by previously study [26], this length of rest period may be optimum to enhance subsequent plyometric exercises. As plyometric exercises are characterized by stretch-shortening cycle that start with a rapid stretch of muscle (eccentric phase) and followed by a rapid shortening of the same muscle (concentric phase) [27], subjects were motivated and instructed to perform each repetition rapidly. We also focused on their quality of movements as well as instructed them to perform every repetition with proper form [14]. Comments and suggestions were given to subjects throughout every plyometric exercise phase and we also observed their improvement in performing
exercises. Most of subjects were capable of performing plyometric exercises. Moreover, they were 
enthusiastic about participating in the training program as they come to training early and intended to 
perform exercises in all sessions. Additionally, according to the subjective information from coaches, 
subjects and researchers, no any discomfort in performing all exercises were observed. Moreover, no 
ocurrence of injury as well as subject drop-out were observed during complex training program. Based 
on our findings and observations, it can be suggested that complex training program is handled well by 
young Thai male athletes and program seems to be useful for coaches to apply this training protocol to be 
one part of their sport training program.

Another aim of this study was to assess how reliable data can be obtained from various tests by 
available testing devices. As our training programs were designed for 2 weeks, we did not expect any 
changes in all variables because of insufficient training duration for improving strength and 
performances. As we expected, descriptive statistics (mean ± SD) reported in Table 2 shows similar 
magnitude in all variables of both complex and resistance training groups from pre- to posttests. 
Moreover, mean differences (Δ) are of small magnitude (lower than 1) in all variables of both groups. 
Therefore, dependent t-tests reported no significantly differences between pre- and posttests in all 
performances of both groups (p>0.05). These results clearly identified no changes from neither resistance 
nor complex training programs on all subject’s measured performances after two-weeks training 
programs. High reliabilities were observed from all tests in both training groups. Results reported that 
intracllass correlation coefficient (ICC) in most of the tests were close to 1.00 (0.82 – 0.99). Only shooting 
skill test in resistance training group showed low reliability (0.67). These results could be interpreted that 
subjects showed high consistency in performances and also testing protocols and devices were reliable. 
Lastly, repeatability using Bland-Altman plots showed good repeatabilities between pre- and posttest in 
all variables. As the Bland and Altman plot is a technique for examining precision between two 
measurements, it is expected that 95% of differences should be less than two standard deviations (this 
definition of a repeatability coefficient is adopted, for example, by the British Standards Institution) [28]. 
It is also expected that the mean differences should close to zero since the same method was used [23]. As 
shown in Figure 1, precise measurements were observed in peak anaerobic power, IRM bench press, 40 
yard speed, agility, countermovement jump and mean anaerobic power for both complex and resistance 
training group. Furthermore, the mean differences between pre- and posttest training were close to 0 (-
0.06 watts/kg for anaerobic power, 1.71 kg for 1RM bench press, -0.02 sec for 40 yard speed, 0.40 cm for countermovement jump and -0.03 watts/kg for mean anaerobic power). These results clearly indicate a high consistency of subject’s performance as well as accurate measurements.

Although subjects in our study had no experience in all tests, we found that all tests were well tolerated by all subjects. We allowed subjects 10 minutes warm up prior to the testing session. During all testing sessions, subjects were asked by researcher and coaches to perform their best. Some tests which are considered challenging task for subjects such as 1RM test and the Wingate anaerobic test were found to be feasible for young male Thai athletes. The Wingate anaerobic test has also been used to measure anaerobic power from effect of complex training program on early pubescent boys [11]. Likewise, 1RM protocol was also used to measure maximum strength in adolescent soccer players before and after 16 weeks of resistance training program [4]. In recent study, we observed no injuries occurred and no subjects dropped out during all testing sessions. Additionally, we also observed no feeling of discomfort from subjects during testing.

Conclusions

This study showed that closely supervised pilot complex and resistance training programs with a very short duration are well tolerated by young athletes. Physical performance measurements operated by qualified staff provide high quality data. Young athletes showed high consistency performance in all testing procedures. These pilot training programs were feasible and harmless.

Limitations and practical applications

The major limitation of this study, considering its purposes, is related to sample diversity, meaning that greater generalizability would be achieved if we sampled athletes from other sports. Nevertheless, its practical applications are of importance. Firstly, the design of this pilot study can be applied as a primary template in other schools when planning strength training programs. Secondly, it shows a number of steps aiming at collecting high quality data to monitor strength and performance changes that are to be highly useful for coaches and athletes.
References


CHAPTER 4: THIRD RESEARCH PAPER

Title: Effect of complex versus resistance training on strength, performance and skill in young soccer players

Authors: Rojapon Buranarugsa, José Oliveira, Robert M. Malina, José Maia

Journal: Journal of Sports Sciences (under review)
Abstract

The study compared the effects of short-term complex training and resistance training programmes on the muscular strength, physical fitness, and skill of male Thai soccer players 12–14 years of age. Equal numbers of subjects (18) were randomly assigned to one of three groups at the start of the study. Six did not complete the protocol resulting in the following numbers per group: complex training (CT: n = 16), resistance training (RT: n = 18), and control (CON: n = 14). The CT and RT groups were exposed to an intervention programme 3 times per week for 7 weeks. Maximum strength, muscular power output, vertical jump, 40-yard sprint, agility, and soccer-specific skills were measured before and after the 7-week training programmes. Both CT and RT significantly improved in maximum strength and physical fitness ($p<0.01$), whereas no changes were observed in the control group. All groups showed significant gains in soccer skills. CT showed better performance in the vertical jump and mean power output than RT ($p<0.05$). In conclusion, the seven-week strength training programmes incorporated into routine soccer training contributed to improvement in the strength and physical fitness of youth players.

Keywords: physical fitness, maturation, power output, youth sports, adolescence
Introduction

Given the importance of explosive movements in soccer (Stolen, Chamari, Castagna, & Wisloff, 2005), the effectiveness of different training modalities in improving underlying physical fitness capacities in youth is often a topic of discussion (Faigenbaum et al., 2009b; Myer & Wall, 2006). Resistance training combined with routine soccer training significantly improved strength, vertical jump, sprint acceleration and maximal speed, agility, and ball-shooting speed in youth soccer players 13–14 years old (Bangsbo, 1994; Christou et al., 2006; Gorostiaga et al., 2004; Wong, Chamari, & Wisloff, 2010), while a short-term plyometric training programme was also effective in improving fitness in the vertical jump, sprint and agility among youth soccer players (Meylan & Malatesta, 2009).

Within ancillary strength training regimens not involving any type of sport specific skills, resistance training may be combined with plyometric exercises in a periodized manner, but not in the same set or workout. More recently, complex training, which combines both resistance and plyometric exercises in the same set or workout, has been advocated as a new type of strength training regimen (Docherty, Robbins, & Hodgson, 2004). Complex training workouts begin with a set of concentric exercises with external loads followed by a set of plyometric exercises recruiting muscle groups previously exercised concentrically and adhering as much as possible to similar movement patterns. Complex training in adults has shown better results for the vertical jump and muscle power output than either resistance training or plyometric training alone (Fatouros et al., 2000; Harris, Stone, O'Bryant, Proulx, & Johnson, 2000). Studies considering the influence of complex training on strength and physical fitness in youth
are limited (Ingle, Sleap, & Tolfrey, 2006; Maio Alves, Rebelo, Abrantes, & Sampaio, 2010; Santos & Janeira, 2008). A short-term complex training protocol with 17-year-old Portuguese soccer players resulted in improvements in the vertical jump and sprint time, but not in agility (Maio Alves et al., 2010).

It is not clear whether complex training or resistance training would optimize important components of physical fitness in young soccer players in a short period of time. Moreover, randomized and controlled studies comparing the influence of short-term resistance and complex training on muscular strength, fitness and sport-specific skills in youth athletes are, to our knowledge, apparently not available. In order to test the hypothesis that complex training offers superior results to resistance training, the aim of this randomized and controlled study is to compare the effect of short-term (7-week) complex and resistance training programmes on the strength, vertical jump, speed, agility, muscle power output, and sport-specific skills of young soccer players.

Methods

Subjects

Fifty-four players volunteered to participate in the study. Subjects were randomly assigned to one three groups of 18 each: complex training (CT), resistance training (RT) and control (CON). Participants were recruited at the Khon Kaen Sports School in Khon Kaen, a province in the northeast of Thailand. All players were of Thai ancestry. Subjects, parents, and coaches were informed about the purpose and procedures of the study. Written informed consent was obtained from the parents, and each player provided assent. The study was conducted according to the ethical
declaration of Khon Kaen University, Khon Kaen, Thailand.

None of the players had any previous experience with resistance or plyometric training programmes, but all were participating in soccer training since 12 years of age. All subjects also participated in soccer competitions, approximately two matches per month on weekends.

Chronological age (CA) of each athlete was calculated as the difference between birth date (based on birth certificates) and date of a hand-wrist radiograph for the assessment of skeletal age (SA). Height and weight were measured according to procedures outlined by Lohman, Roche, and Marterell (Lohman, Roche, & Martorell, 1988). Test-retest reliability (intraclass correlation coefficients) was 0.99 for both measurements. SA was assessed with the Tanner-Whitehouse 3 [TW3 RUS, (Tanner, Healy, Goldstein, & Cameron, 2001)] which utilizes only the radius, ulna, metacarpals, and phalanges of the first, third, and fifth digits. Radiographs were taken at Srinakarin Hospital one week prior to the start of the study. An experienced assessor rated all radiographs, and two weeks later re-assessed a random sample of 10 films. Intra-observer agreement was 84%.

At the conclusion of the training programmes, 48 players remained: CT: \( n = 16 \), RT: \( n = 18 \) and CON: \( n = 14 \). Six subjects dropped-out of the study due to injuries in soccer competitions (3 subjects in CON), and illness (1 in CON, 2 in CT). The injuries did not occur during the training programmes. Baseline characteristics for CA, SA, height, weight and years of training for players who completed the study are presented
by group in Table 1.

Table 1. Baseline descriptive statistics (mean ± SD) for the three groups, $F$ statistic and $p$-values.

<table>
<thead>
<tr>
<th>Groups</th>
<th>$n$</th>
<th>Chronological Age (y)</th>
<th>Skeletal age (y)</th>
<th>Height (cm)</th>
<th>Weight (kg)</th>
<th>Training years (y)</th>
<th>$F$</th>
<th>$p$-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>CON</td>
<td>14</td>
<td>13.3 ± 0.7</td>
<td>14.1 ± 1.5</td>
<td>162.1 ± 7.1</td>
<td>48.4 ± 6.9</td>
<td>1.3 ± 0.7</td>
<td>1.179</td>
<td>0.317</td>
</tr>
<tr>
<td>RT</td>
<td>18</td>
<td>13.6 ± 0.6</td>
<td>14.7 ± 1.1</td>
<td>166.3 ± 4.7</td>
<td>52.6 ± 6.0</td>
<td>1.6 ± 0.6</td>
<td>1.901</td>
<td>0.161</td>
</tr>
<tr>
<td>CT</td>
<td>16</td>
<td>13.6 ± 0.7</td>
<td>14.9 ± 1.1</td>
<td>166.1 ± 8.7</td>
<td>54.9 ± 9.9</td>
<td>1.4 ± 0.7</td>
<td>1.678</td>
<td>0.198</td>
</tr>
<tr>
<td>$P$-value</td>
<td></td>
<td>0.317</td>
<td>0.161</td>
<td>0.198</td>
<td>0.079</td>
<td>0.413</td>
<td>2.693</td>
<td>0.079</td>
</tr>
</tbody>
</table>

**Training programmes**

The duration of the CT and RT programmes was 7 weeks. Prior to the programmes, subjects were instructed on and familiarized with proper techniques for the resistance and plyometric exercises. Each CT and RT session was conducted prior to routine soccer training in the afternoon. All CT and RT activities were done under the supervision of a coach experienced in the respective training protocols. Players performed a 10–15 minute warm-up, which included submaximal running and stretching exercises, and then moved into the specific training protocol. The durations of each RT and CT session were approximately 45 and 60 minutes, respectively. CT and RT sessions took place 3 times per week on non-consecutive days for 7 weeks (total of 21 sessions). CON performed only regular soccer training according to the sports school (team) schedule and did not participate in either CT or RT.

Details of the training programmes are summarized in Table 2. CT consisted of resistance followed by plyometric exercises in the same workout. All subjects started with three sets of 12 repetitions for resistance exercises, whereby 2 repetitions were decreased in weeks 3-4 and weeks 5-7. The resistance component included 3 exercises
for both the upper body (bench press, lateral pull-downs and arm curls) and lower body (leg press, knee extensions and knee curls). Subjects performed a single resistance exercise for one set and then shifted to perform a single plyometric exercise for one set, resulting in one complete set of complex training. Subjects were evaluated for one maximum repetition (1RM) in the selected resistance exercises prior to the training programmes. Subjects began each resistance exercise with 70% 1RM in the first and second weeks and the load was then increased by 5% for the next 2 weeks. The highest load was 80% 1RM for the last 3 weeks of the training programme. Rest intervals between sets were 4 minutes; it has been suggested that this duration may optimize plyometric performance following resistance exercise (Jensen & Ebben, 2003).
Resistance exercises were performed in the resistance training room of the sports school using a Strive resistance training machine (Strive Enterprises, Inc., PA, USA), after which the participants moved to plyometric exercises on the grass field adjacent to the building. Subjects performed three sets of 10 repetitions of plyometric exercises for the lower body including a variety of jumping activities, such as tuck jump, rim jump and squat jump with maximum effort, lateral cone jump and single leg cone hop over
cone (28 cm in height), and long jump, and a 20-meter sprint at maximum speed (3 sets of 4 repetitions). A figure 8 drill was also performed by all subjects. Players ran around several cones placed in the shape of a figure 8; cones were placed 15 meters apart (3 sets of 4 repetitions). Plyometric exercises for the upper body were performed with a medicine ball (3 kg) and included chest passes, backward throws and overhead throws. (Chu, Faigenbaum, & Falkel, 2006). The intensity and volume of resistance exercises for RT were identical to those for CT with the exception that the rest interval between sets was 3 minutes (Faigenbaum et al., 2009b).

Routine soccer training consisted of sport-specific drills aimed at enhancing game-related skills, and small-sided and full team games aimed at improving individual and team tactical behaviours.

**Testing procedures**

All subjects were tested for muscular strength, physical fitness, and two soccer skills prior to and after the 7-week programme. Before testing, subjects performed a coach-supervised 10–20 minute warm-up session consisting of submaximal aerobic exercises and stretching. All tests were done on one day in the morning and afternoon. The order of the testing was as follows: 40-yard sprint, T-test, countermovement jump, squat jump, passing skill, shooting skill, 1RM bench press, 1RM leg press, and Wingate test. Each of three administrators carried out a pre-defined set of both pre- and post-tests; the same coach always administered the soccer skill tests.
Physical fitness

*Maximum strength.* Subjects were assessed for 1RM (Ramsay et al., 1990) consisting of a bench press and a leg press. The 1RM target load was obtained within 6 trials. All subjects were closely supervised and encouraged by coaches and other players to give a maximal effort. The instructor-subject ratio was 1:1. All 1RM tests were administered by the same individual using a Strive resistance training machine.

*Muscular power.* The vertical jump was used to assess muscular power (Komi & Bosco, 1978). The countermovement jump without arms swing (CMJ) and squat jump (SJ) were assessed using the Fusion Sport Smart Jump device (Fusion Sport Pty Ltd., Australia). Subjects stood on the rubber plate of the Fusion device and performed the respective jumps at maximum force when the device was ready. Subjects performed each jump twice and the better trial (cm) was retained for analysis.

*Running speed.* Running speed was measured with a 40-yard sprint test (36.6 m) on a running track. Two sets of photocells were placed 40 yards apart to record the elapsed time. A Fusion Sport Smart Speed device was used. Subjects stood behind starting line in a standing start and were instructed to sprint at maximum speed through the distance. Two sprint trials were performed, separated by a 5-minute rest interval between trials. The better time (0.01 second) was retained for analysis.

*Agility.* Agility was assessed with the T-test protocol (Semenick, 1990) on an outdoor court. A Fusion Sport Smart Speed device placed at the start and finish points was used to record the elapsed time for each of two trials with a 5-minute interval
between trials. Subjects started behind the start line and ran as fast as possible following the T figure through the finish line. Subjects were permitted one practice trial. The better time (0.01 second) was retained for analysis.

Muscle power output. Muscle power output was assessed with the Wingate protocol (Bar-Or, 1987) using a cyclo-ergometer (Monark Ergomedic 828E, AB, Sweden) linked to a CPU with an on-line software programme by the Sports Authority of Thailand (Version 2.0/1993). Peak (W) and mean power (W) output were the main outcome variables. The breaking force was 0.070 kp per kg body weight as recommended for boys (Dotan & Bar-Or, 1983). Seat height was adjusted to a comfortable position for the pedalling movement for each subject. The feet were locked into the pedals in order to avoid slippage. On a signal from the administrator, the subject began pedalling as fast as possible without any resistance or breaking force. Within three seconds, a previously calculated fixed breaking force was applied to the flywheel of the ergometer and the subject continued to pedal for 30 seconds.

Soccer skills. Shooting and passing skill tests, which were routinely used at the sports school, were used. Passing was measured with a wall test. The subject stood with a ball behind a line 10 feet (~3 m) apart from a wall 6 m high and 10 m wide. At the signal, the player started by passing the ball to the wall and retrieving the rebound, and continued passing and retrieving as fast as possible for 30 seconds. A point was registered only when the ball was kicked and returned to the subject behind the 10-foot line. The test was performed twice and the better score was retained for analysis.
Shooting skill was tested by shots at a regulation-size goal (height 8 ft/2.44 m; width 24 ft/7.32 m) divided into 6 sections, each with a different score: three points for the upper right or left corners, two points for the upper middle section or lower right or left corners, and one point for the lower middle section. Ten balls were placed along the 18-yard line (16.5 m) about 0.3 m apart. The subject started shooting the balls toward the goal after a signal from the test administrator. No score was if the ball landed outside the target area. The scores for the 10 shots were summed. The test was performed twice, and the better score was retained for analysis.

**Reliability.** Prior to the study, a two-week pilot study was conducted in order to evaluate the reliability of all testing procedures. Sixteen young Thai male athletes from two sports (soccer and athletics) were recruited. Intra-class correlations were calculated from pre-test (before study) and post-test (after study) figures: bench press: R = .99; leg press: R = .99; countermovement jump: R = .99; squat jump: R = .99; 40-yard speed: R = .98; agility: R = .99; peak power output: R = .98; mean power output: R = .97; passing skill: R = .66; shooting skill: R = .46.

**Statistical analysis**

Descriptive statistics were calculated for all variables in the three groups. A dependent t-test was used for within-group analysis between the 7 weeks pre-test and post-test in each variable. Mixed-ANOVA models were used [groups (3) by time (2)] to test for differential effects of training programmes. Muscle power output was adjusted for body weight for the analysis. All analyses were done with SPSS version 17. The significance level was set at 5%.
Results

Descriptive statistics for strength, physical fitness and soccer skills at the start and after completion of the training programmes are presented in Table 3, while results of specific comparisons are given in Table 4. The three groups did not differ \((p>0.05)\) in CA, SA, body size, or training experience at baseline (see Table 1). Height and weight increased significantly over the course of the study \((p<0.05)\).

Maximum strength

Both the 1RM bench press and 1 RM leg press improved significantly with RT and CT. No significant changes were noted in CON. The significant group by time effects indicated that both RT and CT had greater improvements for the 1RM bench and 1RM leg press than CON, but did not differ from each other (bench, \(p=0.494\); leg, \(p=0.568\)).

Vertical Jump

Both the CMJ and SJ improved significantly in CT and RT, but did not change in CON after 7 weeks. The group by time effects were significant. CT significantly improved in both jumping tests to a greater extent than RT, while the differences between RT and CON in the two jumps were not significant \((p=0.974\) and \(p=0.915\), respectively).

Running speed and agility

The two running tests improved significantly in RT and CT, while no changes were noted in CON. The significant group by time effects indicated improvement with
RT and CT compared to CON in the 40-yard sprint, but no differences between RT and CT ($p=0.310$). RT also showed greater improvement in agility than CON and CT ($p<0.05$), but agility did not differ between CT and CON ($p=0.712$).

Muscle power output

Peak and mean power output improved significantly in RT and CT, while no changes occurred in CON. The group by time effects were significant but no significant difference between CT and RT ($p=0.332$), CT and CON ($p=0.077$) and RT and CON ($p=0.329$) were noted in peak power output. Mean power output improved in CT to a greater extent compared to RT and CON ($p<0.05$).

Soccer skills

In contrast to the functional tests, the two soccer skill tests improved significantly over the duration of the training programs in CT, RT, and CON. The group by time effects for the shooting and passing tests were not significant (post-hoc power analysis results were 0.109 and 0.418 for shooting and passing, respectively).
Table 3. Descriptive statistics (mean ± SD) for muscular strength, physical fitness and soccer skills in each group at baseline and after seven weeks, for changes (Δ) over the interval and associated p-values for differences between baseline and seven weeks.

<table>
<thead>
<tr>
<th>Variables</th>
<th>Group</th>
<th>Baseline Mean ± SD</th>
<th>After 7 weeks Mean ± SD</th>
<th>Δ Mean ± SD</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Mean ± SD</td>
<td>Mean ± SD</td>
<td>Mean ± SD</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1RM bench press (kg)</td>
<td>CON</td>
<td>46.8 ± 7.6</td>
<td>47.1 ± 7.9</td>
<td>0.3 ± 1.2</td>
<td>0.319</td>
</tr>
<tr>
<td></td>
<td>RT</td>
<td>49.4 ± 6.0</td>
<td>60.8 ± 5.7</td>
<td>11.5 ± 2.6</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td></td>
<td>CT</td>
<td>46.5 ± 10.8</td>
<td>58.4 ± 11.3</td>
<td>12.4 ± 2.7</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>1RM leg press (kg)</td>
<td>CON</td>
<td>140.7 ± 13.4</td>
<td>141.2 ± 13.7</td>
<td>0.5 ± 1.0</td>
<td>0.082</td>
</tr>
<tr>
<td></td>
<td>RT</td>
<td>137.7 ± 15.2</td>
<td>165.8 ± 13.8</td>
<td>28.1 ± 6.4</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td></td>
<td>CT</td>
<td>136.9 ± 19.6</td>
<td>169.1 ± 20.9</td>
<td>32.2 ± 7.0</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>Countermovement jump (cm)</td>
<td>CON</td>
<td>25.3 ± 3.0</td>
<td>25.3 ± 3.0</td>
<td>-0.0 ± 0.2</td>
<td>0.623</td>
</tr>
<tr>
<td></td>
<td>RT</td>
<td>24.5 ± 2.4</td>
<td>25.3 ± 2.3</td>
<td>0.8 ± 0.3</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td></td>
<td>CT</td>
<td>25.7 ± 3.3</td>
<td>27.5 ± 3.4</td>
<td>1.7 ± 0.5</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>Squat jump (cm)</td>
<td>CON</td>
<td>23.8 ± 2.5</td>
<td>23.7 ± 2.5</td>
<td>-0.1 ± 0.1</td>
<td>0.164</td>
</tr>
<tr>
<td></td>
<td>RT</td>
<td>22.8 ± 2.2</td>
<td>23.6 ± 2.2</td>
<td>0.9 ± 0.3</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td></td>
<td>CT</td>
<td>24.4 ± 2.8</td>
<td>26.0 ± 3.0</td>
<td>1.6 ± 0.6</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>40-yard speed (s)</td>
<td>CON</td>
<td>5.4 ± 0.3</td>
<td>5.4 ± 0.3</td>
<td>-0.00 ± 0.0</td>
<td>0.671</td>
</tr>
<tr>
<td></td>
<td>RT</td>
<td>5.2 ± 0.3</td>
<td>5.0 ± 0.3</td>
<td>-0.1 ± 0.1</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td></td>
<td>CT</td>
<td>5.3 ± 0.3</td>
<td>5.1 ± 0.3</td>
<td>-0.2 ± 0.1</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>Agility (s)</td>
<td>CON</td>
<td>9.7 ± 0.4</td>
<td>9.7 ± 0.4</td>
<td>-0.0 ± 0.1</td>
<td>0.553</td>
</tr>
<tr>
<td></td>
<td>RT</td>
<td>9.5 ± 0.3</td>
<td>9.3 ± 0.3</td>
<td>-0.2 ± 0.1</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td></td>
<td>CT</td>
<td>9.8 ± 0.4</td>
<td>9.6 ± 0.4</td>
<td>-0.2 ± 0.1</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>Peak power output (W)</td>
<td>CON</td>
<td>429.1 ± 104.4</td>
<td>445.8 ± 89.9</td>
<td>16.7 ± 33.2</td>
<td>0.083</td>
</tr>
<tr>
<td></td>
<td>RT</td>
<td>473.1 ± 101.1</td>
<td>530.3 ± 100.1</td>
<td>57.3 ± 20.8</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td></td>
<td>CT</td>
<td>501.4 ± 158.4</td>
<td>584.8 ± 177</td>
<td>83.4 ± 38.2</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>Mean power output (W)</td>
<td>CON</td>
<td>344.5 ± 76.1</td>
<td>350.9 ± 75.8</td>
<td>6.4 ± 11.9</td>
<td>0.06</td>
</tr>
<tr>
<td></td>
<td>RT</td>
<td>358.3 ± 62.6</td>
<td>424.7 ± 69.9</td>
<td>66.4 ± 25.2</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td></td>
<td>CT</td>
<td>405.1 ± 130.4</td>
<td>482.9 ± 140</td>
<td>77.8 ± 22.8</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>Shooting (points)</td>
<td>CON</td>
<td>15.4 ± 2.1</td>
<td>16.3 ± 1.4</td>
<td>0.9 ± 1.2</td>
<td>0.022</td>
</tr>
<tr>
<td></td>
<td>RT</td>
<td>13.3 ± 3.1</td>
<td>14.2 ± 2.6</td>
<td>0.8 ± 1.3</td>
<td>0.012</td>
</tr>
<tr>
<td></td>
<td>CT</td>
<td>13.7 ± 3.7</td>
<td>14.9 ± 3.0</td>
<td>1.2 ± 1.3</td>
<td>0.003</td>
</tr>
<tr>
<td>Passing (points)</td>
<td>CON</td>
<td>15.6 ± 1.9</td>
<td>16.4 ± 1.5</td>
<td>0.7 ± 0.7</td>
<td>0.003</td>
</tr>
<tr>
<td></td>
<td>RT</td>
<td>16.2 ± 1.2</td>
<td>16.7 ± 1.1</td>
<td>0.5 ± 0.5</td>
<td>0.001</td>
</tr>
<tr>
<td></td>
<td>CT</td>
<td>15.2 ± 2.0</td>
<td>16.3 ± 1.4</td>
<td>1.1 ± 1.1</td>
<td>0.001</td>
</tr>
</tbody>
</table>
Table 4. $F$ statistic for group x time effects, $p$-values and significant pairwise comparisons among the three groups

<table>
<thead>
<tr>
<th>Variables</th>
<th>Group x time effects</th>
<th>Pairwise comparison (significant differences)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1RM bench press (kg)</td>
<td>$F(2,45) = 119.76, p &lt; 0.001$</td>
<td>RT (diff = 13.74) and CT (diff = 11.71) &gt; CON</td>
</tr>
<tr>
<td>1RM leg press (kg)</td>
<td>$F(2,45) = 138.26, p &lt; 0.001$</td>
<td>RT (diff = 24.57) and CT (diff = 27.83) &gt; CON</td>
</tr>
<tr>
<td>Countermovement jump (cm)</td>
<td>$F(2,45) = 97.96, p &lt; 0.001$</td>
<td>CT &gt; CON (diff = 2.17) and RT (diff = 2.21)</td>
</tr>
<tr>
<td>Squat jump (cm)</td>
<td>$F(2,45) = 68.09, p &lt; 0.001$</td>
<td>CT &gt; CON (diff = 2.26) and RT (diff = 2.35)</td>
</tr>
<tr>
<td>40-yard speed (s)</td>
<td>$F(2,45) = 61.26, p &lt; 0.001$</td>
<td>RT (diff = 0.37) and CT (diff = 0.26) &gt; CON</td>
</tr>
<tr>
<td>Agility (s)</td>
<td>$F(2,45) = 52.74, p &lt; 0.001$</td>
<td>RT &gt; CON (diff = 0.31) and CT (diff = 0.26)</td>
</tr>
<tr>
<td>Peak power output (W)</td>
<td>$F(2,45) = 14.67, p &lt; 0.001$</td>
<td>-</td>
</tr>
<tr>
<td>Mean power output (W)</td>
<td>$F(2,45) = 39.77, p &lt; 0.001$</td>
<td>CT &gt; RT (diff = 32.05) and CON (diff = 56.80)</td>
</tr>
<tr>
<td>Shooting (points)</td>
<td>$F(2,45) = 0.39, p = 0.678$</td>
<td>-</td>
</tr>
<tr>
<td>Passing (points)</td>
<td>$F(2,45) = 2.15, p = 0.128$</td>
<td>-</td>
</tr>
</tbody>
</table>
Discussion

Seven weeks of CT and RT incorporated into routine soccer training significantly improved the functional capacities of youth players 12–14 years of age to a greater extent than that associated with regular soccer training alone. CT had somewhat greater effectiveness for vertical jumping (CMJ and SJ) compared to RT. Further, changes in functional capacities associated with CT and RT were independent of biological maturation, as SA did not differ among the three groups at the start of the programme. It is likely that changes in SA over seven weeks would be within the range of measurement variation associated with assessment protocols (Malina, 2011).

Observed improvements in functional capacities or physical fitness with CT and RT, specifically the respective strength training components, may be related to the specificity of training-associated responses in muscle tissue and in turn function. The majority of exercises and drills comprising routine soccer training were primarily oriented towards the acquisition and refinement of sport-specific skills, e.g., passing, dribbling, shooting and ball control, and/or tactics. Routine soccer training exercises and drills have primary instructional and repetitive components and focus on correction of movement or action patterns, with an emphasis on performance in game situations.

Short-term strength training studies with youth soccer players are limited. Significant improvements in several functional capacities were observed in under 13 soccer players after 12 weeks of strength and power training combined with soccer training (experimental group), but not in a group engaged in only routine soccer training (Wong et al., 2010). Youth soccer players 12-15 years of age (comparable in age to the
present study) also demonstrated significant changes in maximum strength and physical fitness with a combination of resistance training and routine soccer training (Christou et al., 2006). Significant improvements in vertical jumping were noted after 11 weeks of explosive strength training incorporated with soccer training in soccer players aged 17 years of age, but were not observed with routine soccer training (Gorostiaga et al., 2004).

The significant changes in muscle strength and physical fitness observed in recent studies were generally consistent with studies of complex training in youth. For example, a 12-week complex training programme resulted in large increases in upper and lower body dynamic strength but small improvements in muscle power output and jumping, throwing, and sprinting performances in prepubescent boys 12 years of age (Ingle et al., 2006). No injuries were noted among the prepubescent boys during the training protocol. Significant improvements in both upper and lower body explosive strength were also observed after a 10-week complex training programme in basketball players 14-15 years of age (Santos & Janeira, 2008).

It is still not clear which programme design would optimize changes in such a short period of time in youth. Compared to the present results (see Table 5), it is likely that a longer strength training programme would induce greater (Christou et al., 2006; Ingle et al., 2006; Santos & Janeira, 2008) or comparable (Shaibi et al., 2006) gains in strength and the vertical jump. A minor improvement in the vertical jump was reported in one complex training study (Ingle et al., 2006), but similar results were observed with various training duration (Channell & Barfield, 2008; Faigenbaum et al., 2007a; Ingle et
Differences in changes associated with strength training programmes are apparently related to various factors such as training duration, frequency, selected intensity and specific exercises. Nevertheless, desirable results were noted over a relatively short duration among the adolescent boys in the present study.
Table 5. Examples of strength training studies in young male soccer players and other males (E = experimental; C = control group; RM = repetition maximum; MB = medicine ball; ↑ = increases; PH = pubic hair; G = genital)

<table>
<thead>
<tr>
<th>Reference</th>
<th>Subjects</th>
<th>Exercises and intensity</th>
<th>Duration and frequency</th>
<th>Results (% changes; effect size)</th>
<th>ANOVAs interaction, group x time</th>
</tr>
</thead>
<tbody>
<tr>
<td>Present study</td>
<td>48 young male soccer players E1 (CT), n = 16 (13.6 ± 0.7 yrs) E2 (RT), n = 18 (13.6 ± 0.6 yrs) CON, n = 14 (13.2 ± 0.7 yrs)</td>
<td>CT (complex training program): 70-80 RM, 3 × 8-12 reps for resistance exercise, 3 × 4, 3 × 10 reps for plyometric exercises RT (resistance training program): same resistance exercises as CT</td>
<td>7 wks, 3 times/wk</td>
<td>E1: 1RM bench press ↑ (26.6%, 0.49), 1RM leg press ↑ (23.5%, 0.62), countermovement jump ↑ (6.8%, 0.26), squat jump ↑ (6.7%, 0.27), 40-yard speed ↑ (3.9%, 0.32), agility ↑ (2.4%, 0.24), peak power output ↑ (18.1%, 0.2), mean power output ↑ (20.8%, 0.28) E2: 1RM bench press ↑ (23.2%, 0.7), 1RM leg press ↑ (20.4%, 0.7), countermovement jump ↑ (3.2%, 0.17), squat jump ↑ (3.8%, 0.18), 40-yard speed ↑ (2.7%, 0.32), agility ↑ (1.7%, 0.32), peak power output ↑ (12.8%, 0.27), mean power output ↑ (18.9%, 0.45)</td>
<td>1RM bench press, 1RM leg press, countermovement jump, squat jump, 40-yard speed, agility, peak power output and mean power output (p&lt;0.05) Shooting and passing skill (p=0.05)</td>
</tr>
<tr>
<td>Wong et al., 2010</td>
<td>51 U-14 young male soccer players, E, n = 28 (13.5 ± 0.7 yrs.) C, n = 23 (13.2 ± 06 yrs.)</td>
<td>On-field combined strength and power: 3 × 6-15 reps</td>
<td>12 wks, 2 times/wk</td>
<td>- Vertical jump ↑ (5.9%, 0.70) - 10 m sprint ↑ (4.9%, 0.94) - 30 m sprint ↑ (2.3%, 0.89) - Yo-Yo intermittent endurance run level one: ↑ (20%, 0.86)</td>
<td>Vertical jump, ball shooting speed and 30 m sprint (p&lt;0.05)</td>
</tr>
<tr>
<td>Channell and Barfield, 2008</td>
<td>27 male student athletes (15.9 ± 1.2 yrs) E1 (OT), n = 11 E2 (PT), n = 10 C, n = 6</td>
<td>Olympic training (OT) and traditional power lift training (PT): 60-95% of 1RM, 3-5 sets × 3-10 reps</td>
<td>8 wks, 3 times/wk</td>
<td>E1: Vertical jump ↑ (4.5%, 0.22) E2: Vertical jump ↑ (2.3%, 0.06)</td>
<td>Vertical jump (p&lt;0.05)</td>
</tr>
<tr>
<td>Santos and Janeira, 2008</td>
<td>25 young male basketball players E, n = 15 (14.7 ± 0.5 yrs) C, n = 10 (14.2 ± 0.4 yrs) all subjects were PH3 or PH4 and G3 and G4</td>
<td>Complex training: 10/12RM × 2-3 sets resistance exercise + 2-3 sets × 5-15 reps plyometric exercise</td>
<td>10 wks, 2 times/wk</td>
<td>- Squat jump ↑ (13%, 0.34) - Countermovement jump ↑ (10.5%, 0.25) - Abalakov test ↑ (10.5%, 0.26) - Seated medicine ball throw ↑ (19.6%, 0.52)</td>
<td>Not reported</td>
</tr>
<tr>
<td>Reference</td>
<td>Subjects</td>
<td>Exercises and intensity</td>
<td>Duration and frequency</td>
<td>Results (% changes)</td>
<td>ANOVAs interaction, group x time</td>
</tr>
<tr>
<td>--------------------</td>
<td>-----------------------------------------------</td>
<td>-----------------------------------------------------------------------------------------</td>
<td>------------------------</td>
<td>----------------------------------------------------------</td>
<td>------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Faigenbaum et al., 2007</td>
<td>27 boys E1 (PRT), n = 13 (13.4 ± 0.9 yrs) E2 (RT), n = 14 (13.6 ± 0.7 yrs)</td>
<td>PRT (combine plyometric training and resistance training): plyometric training program: 1-2 sets × 6-10 reps. resistance training: 3 sets × 10-12 reps RT (stretching + resistance training, same resistance exercise as PRT)</td>
<td>6 wks, 2 times/wk</td>
<td>E1: Vertical jump ↑ (8.1%, 0.19), long jump ↑ (6%, 0.19), shuttle run ↑ (3.8%, 0.49), MB toss ↑ (14.4%, 0.21), ↑ flexibility (27.6%, 0.17) E2: MB toss ↑ (5.6%, 0.15), flexibility ↑ (29%, 0.32)</td>
<td>Long jump, shuttle run and MB toss (p&lt;0.05)</td>
</tr>
<tr>
<td>Christou et al., 2006</td>
<td>18 adolescent soccer players and 8 boys E1 (STR), n = 9 (13.8 ± 0.4 yrs) E2 (SOC) n = 9 (13.5 ± 0.9 yrs) C, n = 8 (13.3 ± 0.7 yrs)</td>
<td>Resistance training program for STR: 2-3 sets × 8-15 reps, 55-80% of 1RM</td>
<td>16 wks, 2 times/wk</td>
<td>- 1RM bench press ↑ (52.3%, 0.97) - 1RM leg press ↑ (58.8, 0.98) - Squat jump ↑ (31%, 0.93) - Countermovement jump ↑ (24.6%, 0.91) - Repeated jumps ↑ (5.8%, 0.75) - 30-m sprint ↑ (2.5%, 0.42) - Agility ↑ (5.4%, 0.94)</td>
<td>1RM bench press, 1RM leg press, squat jump and agility (p&lt;0.05)</td>
</tr>
<tr>
<td>Ingle et al., 2006</td>
<td>54 Boys (12 ± 0.3 yrs) E, n = 33 C, n = 21 subjects were PH1 and PH2</td>
<td>Complex training: 70-100% of 10RM, 1-3 sets × 7-15 reps resistance exercise + 2-3 sets × 8-10 reps plyometric exercise</td>
<td>12 wks, 2 times/wk</td>
<td>- 10RM of 8 dynamic strength exercises ↑ (24.3-71.4%, 0.48-0.83) - Both peak and mean power output lower ↑ (5%, 0.14) - Vertical ↑ (4%, 0.11) - Basketball chest pass and 40-m sprint ↑ (4%, 0.06)</td>
<td>10RM of 8 dynamic strength exercises (p&lt;0.01) Peak and mean anaerobic power (p&lt;0.05) Vertical jump, basketball chest pass and 40-m sprint (p&lt;0.01)</td>
</tr>
<tr>
<td>Shaibi et al., 2006</td>
<td>22 overweight Latino adolescents, E, n = 11 (15.1 ± 0.5 yrs) C, n = 11 (15.6 ± 0.5 yrs) all subjects were ≥ PH3</td>
<td>Resistance training program: 1-3 sets × 3-15 reps</td>
<td>16 wks, 2 times/wk</td>
<td>- 1RM bench press ↑ (26%, 0.87) - 1RM leg press ↑ (28%, 0.88)</td>
<td>Not reported</td>
</tr>
</tbody>
</table>
Changes in muscular strength observed with resistance training programmes in youth are largely related to neural factors. Resistance training is associated with enhanced motor unit activation and motor unit firing and increased muscle force production in youth (Ozmun, Mikesky, & Surburg, 1994; Ramsay et al., 1990). A study in young soccer players also suggested neural adaptation to training as evident in increased motor unit recruitment and improved coordination of the muscle groups involved (Christou et al., 2006). The improved performance and coordination of the involved muscle groups following resistance training programmes may also contribute to increased muscle strength (Ozmun et al., 1994; Ramsay et al., 1990).

Greater relative improvements in jumping performance observed with CT compared to RT may be related to neuromuscular adaptations and resistance exercises, and the effects of additional plyometric exercises. Resistance training studies in adults have indicated increases in motor unit recruitment as underlying the significant improvement in maximal force output (Cormie, McGuigan & Newton, 2010; Hakkinen et al., 1990). Changes in muscle architecture, such as muscle thickness and muscle cross-sectional area, induced by resistance training are also important factors that may contribute to improvements in maximum force production and maximum muscular power (Cormie et al., 2010; MacIntosh & Holash, 2000; Shoepe et al., 2003). Plyometric exercises also alter motor unit activation as suggested by a rise in the rate of EMG activity during a jump squat (Cormie et al., 2010). An increase in myosin heavy chain (MHC) isoforms IIa induced by resistance combined with plyometric exercises may also contribute to altered muscle force production (Perez-Gomez et al., 2008). Nevertheless, data for youth suggesting that complex training was more effective than, or at least as effective as, resistance training protocols in the
development of vertical jumping performance are limited. Positive effects of complex training on jumping performance in youth have been reported (Ingle et al., 2006; Santos & Janeira, 2008). The greater changes in the vertical jump observed with CT in the present study were likely induced by the plyometric exercises. CT experienced significantly greater increases in the vertical jump than RT, while no significant changes were noted in CON (Table 3, 4).

Although the results are generally consistent with the available literature, the study has several limitations. First, the number of volunteers in the Khon Kaen Sport School who met all criteria for the study was limited (n=54) and only 48 subjects completed the study. A post-hoc power analysis showed values ranging from .99 to 1.00, and the explained variance (partial $\eta^2$, or eta squared) attributable to the present design ranged from 92.5% to 93.2% for time effect and 86.0% to 81.3% for the time × group effect. Second, although the duration of routine soccer training for all groups was equivalent, the CT group performed more physical exercises than RT and CON groups. Third, the soccer skill tests were routinely used at the school for monitoring improvement over each academic year. It is possible that the emphasis on these two skills may have limited the responsiveness of youth to the training protocols considered.
Conclusions

Seven-week complex and resistance training programmes combined with routine soccer training were effective in developing the maximal strength and physical fitness of adolescent soccer players. The complex training protocol resulted in better results for muscle power compared to the resistance training protocol. On the other hand, the two experimental groups and the control group improved in the two soccer-specific skills.
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CHAPTER 5: FOURT RESEARCH PAPER

Title: Individual differences in response to strength training in youth soccer players

Authors: Rojapon Buranarugsa, José Oliveira, Robert M. Malina, José Maia

Journal: (submitted)
Abstract

**Objective:** To examine inter-individual responses to strength training programs among young soccer players.

**Design:** Experimental.

**Participants:** Forty-three adolescent Thai male soccer players aged 12 to 16 years.

**Interventions:** Subjects were divided into two groups: complex training (CT: n = 21) and resistance training (RT: n = 22). Both CT and RT participated in supervised training programs of 7-week duration.

**Main Outcome Measurements:** Maximum strength and motor performance were measured before and after the training programs. Height, weight, and skeletal maturity status (Tanner-Whitehouse skeletal age) were assessed prior to the start of the training programs.

**Results:** CT and RT significantly improved in maximum strength and performances (p<0.05). Changes observed in both groups ranged from 1.5% to 27.7%, but significant variances in the heterogeneity of responses were apparent for all variables (p<0.05). No significant relationship between baseline values and training response were noted in both groups (p>0.05). A significant association between skeletal maturity status at baseline and response to training was noted only or the countermovement jump in the CT (p<0.05).

**Conclusions:** Responses of adolescent soccer players to short term resistance and complex training programs showed high heterogeneity. Training responses were not associated with baseline characteristics, including skeletal maturity.
status. By inference, skeletal maturity status did not influence the responsiveness of youth soccer players to the short term resistance and complex training protocols.

**Key Words:** inter-individual variability, youth sport, adolescents, skeletal age, trainability
Introduction

Responses of youth to strength training programs (weights, resistance) are reasonably well documented in samples from the general population and among young athletes in a variety of sports.\textsuperscript{1–3} However, the main focus of analysis in the studies is group data, specifically differences between means; few estimates of effect sizes are reported.\textsuperscript{4,5} Inter-individual differences in responses to training, although considerable, are not ordinarily considered.\textsuperscript{2} Examination of means and variances in absolute or relative changes highlights broad variation in individual response to specific strength training programs.\textsuperscript{6}

Inter-individual variability in responses to endurance (aerobic) training has been described among youth.\textsuperscript{7} Mean relative change (ml·kg\textsuperscript{-1}·min\textsuperscript{-1}) among 35 boys and girls aged 11 and 12 years was 6.5±5.1%; however, relative changes varied from -3 to 0% (6 subjects) to 18-21% (1 subject). Similar variation in responses to aerobic and strength training was noted among young adults.\textsuperscript{8–10} The situation among youth is a bit more complicated as muscular strength and motor performance are influenced by growth and maturity status, especially among adolescent boys.\textsuperscript{11} Data for a 12 week isometric training program suggested that younger children gained less in absolute strength than older children and that skeletal age was significantly related to gains in estimated muscle cross-sectional area (ultrasound) associated with the training protocol.\textsuperscript{12} Of interest, strength per unit muscle cross-sectional area did not change with the isometric training protocol.
Studies of experimental training programs in youth have seemingly paid less attention to inter-individual differences in responses and have not considered factors such as variation in body size and biological maturity status at the start of a program (baseline). In this context, this study has three purposes: (1) to describe the inter-individual variability in responses to two strength training protocols, resistance and complex training, (2) to evaluate the relationship between responses and baseline values, and (3) to examine the association of skeletal maturity status at baseline with inter-individual responses to the respective training programs.

Methods

Subjects

Forty-three male soccer players aged 12 to 16 years were recruited from the Khon Kaen Sports School, Khon Kaen in the northeastern of Thailand. All were of Thai ancestry. Subjects were enrolled in the school since the first year of secondary studies. They were chosen by school teachers/coaches on the basis of sport skills, written tests and interview during the annual admission examination period. Parents, subjects and coaches were informed of the purposes and procedures of the study and written informed consent and assent were obtained. The study was approved and conducted according to the ethical guidelines of Khon Kaen University, Khon Kaen, Thailand.

Skeletal age (SA) was assessed with the Tanner-Whitehouse 3 radius-ulna-short bone protocol (TW3 RUS). Radiographs were taken in Srinakarin
Hospital one week prior to the start of the study. Chronological age (CA) was based on birth certificates and the difference between birth date and day of the radiograph. CA was subtracted from SA to provide an estimate of relative skeletal maturity (SA-CA). Height and weight were measured.

The 43 players were randomly assigned to 2 groups: complex training (CT, n=21) and resistance training (RT, n=22). CA, SA, SA-CA, height, weight and training years did not differ, on average, between the two groups at baseline (Table 1).

Table 1. Baseline characteristics (mean±SD) of players in the two groups and associated t statistics and p-values

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>RT (n=22)</th>
<th>CT (n=21)</th>
<th>t</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>CA, yrs</td>
<td>14.2 ± 1</td>
<td>14.1 ± 1.1</td>
<td>0.14</td>
<td>0.889</td>
</tr>
<tr>
<td>SA, yrs</td>
<td>14.8 ± 1.1</td>
<td>15.2 ± 1.1</td>
<td>-1.085</td>
<td>0.284</td>
</tr>
<tr>
<td>SA-CA, yrs</td>
<td>0.68 ± 0.83</td>
<td>1.08 ± 0.85</td>
<td>-1.581</td>
<td>0.122</td>
</tr>
<tr>
<td>Height, cm</td>
<td>167.4 ± 5.7</td>
<td>166.9 ± 8.4</td>
<td>0.253</td>
<td>0.801</td>
</tr>
<tr>
<td>Weight, kg</td>
<td>53.9 ± 6.4</td>
<td>55.5 ± 9.2</td>
<td>-0.671</td>
<td>0.506</td>
</tr>
<tr>
<td>Training years, yrs</td>
<td>1.9 ± 0.8</td>
<td>1.8 ± 0.9</td>
<td>0.208</td>
<td>0.836</td>
</tr>
</tbody>
</table>

**Training protocols**

Subjects were submitted to either a complex or resistance training program for 7 weeks. Subjects trained 3 times per week on non-consecutive days. All training sessions were supervised by an adult. Both training programs consisted of 6 resistance exercises for both upper and lower body: bench press,
lat-pull down, arm curl, leg press, knee extension and knee curl. Each session of CT began with 1 set of resistance exercise and followed by 1 set of plyometric exercises while RT group performing only resistance exercises. Plyometric exercises for upper body part used medicine balls (medicine ball chest pass, medicine ball backward throw and medicine ball overhead throw), while exercises for lower body part mainly involved jumping and hopping (i.e. tuck jump, rim jump, lateral cone jump, single leg cone hop). Resistance training loads were identical for both CT and RT; load began from 70% of 1RM and increased up to 80% by 5% increasing every 3 weeks with 3 sets and 8-12 repetitions. The resting duration for complex training was 4 minutes and 3 minutes for resistance training. Both training interventions were executed before routine soccer training in each day and lasted 45-60 minutes.

**Outcome measures**

Muscle strength and motor performance testing were done before and after the 7-week training programs. Testing comprised 1RM (bench press and leg press) for maximum strength, vertical jump (countermovement jump and squat jump, power), 40-yard (36.6 m) dash, running speed, T-test for agility, and the Wingate test, anaerobic power.

The 1RM protocol\textsuperscript{14,15} was assessed with a Strive resistance training machine (same as used in training exercises) under the supervision of an adult administrator. The vertical jump tests,\textsuperscript{16} were measured using the Fusion Sport Smart Jump device (Fusion Sport, Pty, Ltd, Australia). Subjects jumped with
maximal force in two trials; the better trial (cm) was retained for analysis. Running speed was measured as a 40-yard sprint on a running track. Two pairs of photocells (Fusion Sport Smart Speed device, Fusion Sport, Pty, Ltd, Australia) were placed 40 yards apart. Subjects were instructed to run at maximum speed through the distance. The better time (0.01 sec) of two trials was retained for analysis. The T-test\textsuperscript{17} of agility was done on an outdoor court using the same timing devices as the test of running speed. Subjects were allowed a practical trial and then performed twice the test. The better time (0.01 sec) was retained for analysis. The Wingate test for peak and mean power (watts/Kg)\textsuperscript{18} was performed on a cycle-ergometer (Monark Ergomedic 828E, AB, Sweden). A breaking force of 0.068 Kp per kg body mass was applied; this value was recommended for Thailand youth. Subjects began pedalling as fast as possible without any resistance or breaking force. Within three seconds, the previously calculated fixed breaking force was applied to the flywheel of the ergometer and the subject continued to pedal through 30 seconds.

Prior to the training study, the reliability of all testing procedures was evaluated two weeks apart. Sixteen male youth soccer and track and field athletes (all of Thai ancestry) were recruited as subjects. ANOVA-based intra-class correlation coefficients (R) were as follows for each test: bench press: R = .99; leg press: R = .99; countermovement jump: R = .99; squat jump: R = .99; 40-yard speed: R = .98; agility: R = .99; peak anaerobic power: R = .98; mean anaerobic power: R = .97.
Statistical analysis

Descriptive statistics, absolute (Δ) and relative (%) changes were calculated for all variables in the two groups. A dependent t-tested was used for within-group analysis of pre- and post-tests for each variable. Chi square was used to test that individual differences i.e., the variance in each group was not zero. Pearson correlation coefficients were computed between changes in each variable and corresponding baseline values in CT and RT. Correlations were also calculated between skeletal maturity status at baseline (skeletal age minus chronological age, SA-CA) and observed changes in all variables in the two groups. SPSS version 17 was used for the analyses; significance level was set at 5%.

Results

Descriptive statistics for strength and performance variables at baseline and after 7 weeks are summarized in Table 2. Maximum strength improved significantly in RT and CT (p<0.05). Results were similar for all performance variables, i.e., significant improvements (p<0.05) in RT and CT for the vertical jumps, 40-yard sprint, agility test, and Wingate anaerobic performance.
Table 2. Means (±SD), absolute changes (Δ, ±SD), and p-values from paired t-tests for performances in the two experimental training groups

<table>
<thead>
<tr>
<th>Variables</th>
<th>Group</th>
<th>Pre-training</th>
<th>Post-training</th>
<th>Δ</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1RM bench press (kg)</td>
<td>RT</td>
<td>49.8 ± 5.8</td>
<td>61.4 ± 5.4</td>
<td>11.7 ± 2.7</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td></td>
<td>CT</td>
<td>48.4 ± 10.8</td>
<td>61.4 ± 11.8</td>
<td>13.0 ± 3.5</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>1RM leg press (kg)</td>
<td>RT</td>
<td>138.2 ± 14.5</td>
<td>166.6 ± 13.8</td>
<td>28.4 ± 6.6</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td></td>
<td>CT</td>
<td>140.6 ± 18.6</td>
<td>173.0 ± 20.3</td>
<td>32.4 ± 6.7</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>Countermovement jump (cm)</td>
<td>RT</td>
<td>25.3 ± 2.9</td>
<td>26.3 ± 3.1</td>
<td>0.9 ± 0.4</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td></td>
<td>CT</td>
<td>26.8 ± 3.9</td>
<td>28.4 ± 4.0</td>
<td>1.8 ± 0.4</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>Squat jump (cm)</td>
<td>RT</td>
<td>23.8 ± 3.0</td>
<td>24.7 ± 3.0</td>
<td>0.9 ± 0.3</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td></td>
<td>CT</td>
<td>25.3 ± 3.5</td>
<td>27.0 ± 3.7</td>
<td>1.7 ± 0.6</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>40-yard speed (s)</td>
<td>RT</td>
<td>5.2 ± 0.3</td>
<td>5.0 ± 0.3</td>
<td>-0.1 ± 0.1</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td></td>
<td>CT</td>
<td>5.2 ± 0.4</td>
<td>5.0 ± 0.3</td>
<td>-0.2 ± 0.1</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>Agility (s)</td>
<td>RT</td>
<td>9.5 ± 0.3</td>
<td>9.4 ± 0.3</td>
<td>-0.1 ± 0.1</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td></td>
<td>CT</td>
<td>9.8 ± 0.4</td>
<td>9.6 ± 0.4</td>
<td>-0.2 ± 0.1</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>Peak anaerobic power (watts·kg⁻¹)</td>
<td>RT</td>
<td>9.1 ± 1.3</td>
<td>9.8 ± 1.2</td>
<td>0.8 ± 0.3</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td></td>
<td>CT</td>
<td>9.2 ± 1.5</td>
<td>10.4 ± 1.6</td>
<td>1.2 ± 0.7</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>Mean anaerobic power (watts·kg⁻¹)</td>
<td>RT</td>
<td>6.9 ± 0.8</td>
<td>7.9 ± 0.8</td>
<td>1.0 ± 0.4</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td></td>
<td>CT</td>
<td>7.3 ± 1.1</td>
<td>8.6 ± 1.1</td>
<td>1.2 ± 0.4</td>
<td>&lt; 0.001</td>
</tr>
</tbody>
</table>

Relative changes in strength and performance variables among individual subjects within RT and CT groups ranked by skeletal maturity status at baseline (SA-CA) are shown in Figures 1-4. Relative changes ranged from 1.5% to 27.7%. Correlations between changes and baseline values ranged from −0.37 to +0.25 and were not statistically significant (p>0.05).
Figure 1. Relative gains 1RM bench press (1RMBP) and 1RM leg press (1RMLP) in individual subjects within RT and CT groups. Subjects are ranked according to relative skeletal maturity status at baseline (SA-CA). Correlations between maturation and response and baseline values and response are also shown.
Figure 2. Relative gains countermovement jump (CMJ) and squat jump (SJ) in individual subjects within RT and CT groups. Subjects are ranked according to relative skeletal maturity status at baseline (SA-CA). Correlations between maturation and response and baseline values and response are also shown.
Figure 3. Relative gains 40-yard speed (SPRINT) and agility (AGILITY) in individual subjects within RT and CT groups. Subjects are ranked according to relative skeletal maturity status at baseline (SA-CA). Correlations between maturation and response and baseline values and response are also shown.
Figure 4. Relative gains peak (APPK) and mean anaerobic power (APMN) in individual subjects within RT and CT groups. Subjects are ranked according to relative skeletal maturity status at baseline (SA-CA). Correlations between maturation and response and baseline values and response are also shown.
The heterogeneity of responses to training showed significant variances in all variables in CT and RT groups; chi-square tests were significant (<0.05). These results (not shown) indicated that inter-individual differences were significantly greater than zero.

Figure 5 shows individual differences in relative skeletal maturity status (SA-CA) within RT and CT groups. The distributions of skeletal maturity status between groups were similar and showed only small differences.

Figure 5. Relative skeletal maturity status at baseline (SA-CA) of individual subjects within RT and CT groups. Subjects are ranked from least to most mature within each group.

Correlations between relative skeletal maturity status and individual changes in strength and motor performance tests in the CT and RT groups after 7 weeks varied from −0.39 to +0.48 and were not significant (p>0.05) with the exception of the countermovement jump in the CT group (p<0.05).
Discussion

The present findings show considerable variation among Thai adolescent soccer players in muscular strength and motor performance responses to a short-term CT and RT programs. Individual change scores indicated that most of subjects improved in all strength and performance variables. CT and RT groups showed similar mean relative changes in the 1RM bench press (24% and 28%, respectively) and the 1RM leg press (21% and 23%, respectively). However, wide ranges in relative gains were noted among subjects in each group. Responses among players in CT ranged from 14.4% to 45.0% for 1RM bench press and from 16.1% to 45.4% for 1RM leg press. Corresponding ranges in RT were 16.6% to 45.0% for 1RM bench press and 13.2% to 42% for 1RM leg press. The similarity of ranges in relative changes in the two groups suggested that each training protocol was equally effective. Of interest, higher mean changes after a 12-week complex training program (71.4%) was reported in prepubertal boys, and also after a 16-weeks resistance training program in adolescent soccer players (58.8%). The previous studies indicated large variation in responses to the respective strength training programs in the two diverse age groups of youth as the standard deviations were greater than the respective mean changes.

Inter-individual differences in age, height, weight, body composition and sports training experience may explain some of the variation training responses among individuals. These individual characteristics are significantly related to strength and motor performance among adolescent boys. Age and body size
are positively related to strength and performance: older and/or taller boys are, on average, absolutely stronger than younger and/or shorter boys, respectively. Fat free mass may be a significant factor in the trainability of adolescent boys a skeletal muscle is its major component and also contributes to muscular force production. Unfortunately, the relationship between changes in fat-free mass and strength associated with training in youth has not been systematically addressed. Fat-free mass is highly correlated with height in boys and also has a growth spurt during the interval of the adolescent spurt in height. The role of neuromuscular maturation and previous experience in performance are also important factors that need consideration in studies of adolescents. Large individual variations in the strength responses of adult subjects to training programs were also previously reported, and the range of variation in responses was quite large in some samples, e.g., changes ranged from –12% to 87% following a 21 weeks of training.

The present study showed no significant associations between baseline CA, SA, relative skeletal maturity status (SA-CA), height, weight and experience and training responses in either CT or RT groups (Table 1), suggesting that the individual differences in characteristics of subjects at baseline did not explain inter-individual variation observed in strength changes. Similar observations were noted with aerobic training in a mixed sample of adolescent boys and girls. Baseline VO₂max did not explain Δ VO₂max after 12-weeks of endurance training. Similarly, baseline strength values did not explain strength changes after a strength training program in adults. It has also been suggested that
genotypic factors may condition the responsiveness of individuals to strength training programs and in turn contribute to inter-individual differences in training responses as noted in adult males with endurance\textsuperscript{23,24} and strength\textsuperscript{25} training.

The apparent lack of dependency of baseline values on the aerobic trainability of youth has been attributed to higher levels of aerobic fitness at baseline and also to habitual physical activity.\textsuperscript{7} This was also suggested in adults; the magnitude of changes in aerobic performance with endurance training was greater in sedentary individuals compared to competitive athletes.\textsuperscript{7}

The absence of significant correlation between baseline characteristics and responses to the CT and RT programs among youth soccer athletes in the present study may potentially be related to the selectivity of the sample, similarity of training background and experience in soccer as well as generally higher levels of physical fitness levels of both groups at the beginning of the study.

Skeletal maturity status and physical fitness are significantly correlated in adolescent boys.\textsuperscript{11,26} Indicators of strength and fitness are also influenced by the timing of the adolescent growth spurt in boys.\textsuperscript{27,28} Static strength in an arm pull and the vertical jump, for example, attain peak velocity after peak height velocity in boys, while performance in an agility shuttle run attains peak velocity, on average, prior to peak height velocity.\textsuperscript{28} Clearly, measures of strength, power, agility and other components of performance increase with age during male adolescence and performances are influences by maturity status and the timing of the growth spurt. Variability in performance occurring during the
growth spurt in height should also be noted. For example, 6 of 444 boys (1%) in
the Leuven Growth Study of Belgian Boys declined in static strength of the arm
pull during the interval of peak height velocity. Corresponding numbers and
percentages of boys whose performance declined on the vertical jump (power)
were 31 of 446 (7%) and on the shuttle run (agility) were 149 of 445 (33%).

The issue of individual differences in maturity status affecting responses
to short-term experimental training programs has not been systematically
addressed in youth soccer players and among youth athletes in general. With
subjects ranked by relative skeletal maturity status (SA-CA) at baseline, there
were no consistent associations favouring players advanced in skeletal maturity
status in responses to the specific training programs (Figures 1–4). In other
words, training responses were not conditioned by individual differences in
skeletal maturity status at baseline. Only one other study, to our knowledge, has
addressed the relationship between SA and responsiveness to training in youth.
Among boys and girls in three age groups, 7.0±0.3, 9.0±0.3 and 11.0±0.3 years,
children with older SAs improved somewhat more in muscle cross-sectional
areas in response to an isometric training protocol. Unfortunately, the
difference between SA and CA, an indicator of relative skeletal maturity status,
was not considered. Other than this study of isometric training, other studies
which considered skeletal maturation in the context of individual differences in
response to strength training could not be located.

It is possible that individual differences in muscle mass contributed to
variation in strength gains to the CT and RT protocols in the sample of Thais
youth soccer players. An estimate of muscle mass, however, was not available. Nevertheless, biological maturity status at baseline apparently had little if any influence of the responses of Thai youth soccer players to the respective training protocols. The association noted for the CMJ in the CT group was likely a random occurrence. The training programs, however, were of relatively short duration (7 weeks); it is possible that individual differences in maturity status at baseline may influence responses to longer and more intensive training protocols. This remains to be addressed. Changes in hormone concentrations, specifically testosterone during male puberty are also important in the growth of muscle mass and in turn muscular strength during sexual maturation and the growth spurt in adolescent boys. Changes in steroidal hormonal concentrations associated with strength training in adolescent boys have also not been systematically addressed.

Although results of the study of the Thai youth soccer players show no relationship between skeletal maturity status and changes with CT and RT, the study has several limitations. First, the study was based on a sample of young athletes who were selected for the soccer school. Second, sample sizes were relatively small, but in the range of previous studies of strength training in youth. Moreover, based on a post-hoc power analysis with the following conditions: repeated measures t-test, one tail, effect size=0.6, $\alpha=0.05$ and power=0.80, the estimated number of subjects in each sample would be 19. Third, the training protocols were limited to 7 weeks, but durations of most training studies with youth fall within the range of 6 to 12 weeks.
In summary, inter-individual differences in response to complex and resistance strength training programs were variable and not random among adolescent Thais soccer players. Responses in muscular strength and motor performance were similar with both training protocols. Trainability of individual boys was not related to initial performance levels which may have been influenced by other factors such as age and body size. Skeletal maturity status (SA minus CA) at baseline was not related to the magnitude of improvements in strength and motor performances following the respective 7 week strength training programs.
References


CHAPTER 6: GENERAL CONCLUSIONS AND FINAL REMARKS
General conclusions and final remarks

Strength training is an important asset in the annual training plans and periodization cycles of young athletes’ careers towards high-level performance. Its effectiveness is well established in a growing body of experimental evidence as shown in the first paper of the present thesis.

The present thesis cycled around an experimental program in a Thai Sports School having as a primary sample young soccer players. Main conclusions will be now addressed as well as some of their implications to Thai coaches and young athletes. Furthermore, some new ideas for future research will be presented.

This work starts with a review of the evidence resulting from previous published experimental studies regarding the influence of strength training, plyometric and complex training programs on strength gains, physical performance and injury occurrence. It was possible to conclude that (1) Strength training programs are effective in boys; (2) Resistance training improves maximal strength and the overall motor performance, while plyometrics is more effective to enhance explosive strength, (3) Complex training offers various physical fitness improvements in boys, but a precise knowledge concerning the effects of this training modality on physiological mechanisms of adaptation is still limited; (4) Training programs, namely their duration, have an impact on the response magnitude, i.e., the longer program the greater the gains; (5) Older boys tend to profit more from strength training than younger ones, and (6) Strength training programs, if well designed and supervised, are safe for youngsters.

Based on the reviewed accumulated evidence, it is obvious that strength training is a worthwhile venture in the annual training plans and periodization cycles of young athletes independently of their gender. Although there is still a belief, in some groups of Thai coaches and sports administrators, that strength training might not be appropriate for youngsters, the conclusions raised from the
review showed that there is firm ground to suggest their use in the annual plans of young athletes. As youth sport is growing in participation and becoming very popular with increasing demands in response to training and competition, there is a need to spread the “good news” from evidence based research. Furthermore, it is anticipated that as young athletes use better training means and methods, carefully accommodated within their annual training plans, the greater the chances for higher responses as adult athletes.

Strength training programs for youth sports can be designed in several ways. However, in order to yield the expectations associated to their designs, some factors should be carefully considered by coaches, because the quality of training stimuli, their frequency and duration are the key elements of success. For example, any program should have at least a duration of 6 weeks, the training load should be based on 1RM and increased every week, the training frequency should have a minimum of 2-3 session per week, the choice of exercises are sport, age and biological maturation dependent, and of course a thoughtful consideration of rest among sets and series. Another very important aspect concerns the supervision of all training sessions by experienced coaches or specialized trainers. Furthermore, young athletes must be closely supervised during all training sessions in order to ensure that they perform all exercises with proper technique so as to avoid injury occurrence.

Although there are a large body of evidence regarding the effectiveness of strength training in young athletes, particularly using the resistance training and plyometric modalities, the amount of information and the strength of the evidence for the feasibility and safety of complex training, and the effectiveness for performance improvement were still low. Furthermore, a gap in the knowledge regarding the inter-individual differences in response to strength training programs was also identified.

The experimental studies embodying this work, tried to uncover, at least partly, the above-mentioned gaps. From the studies that composed this thesis, several major conclusions can be outlined.
Results from the pilot study clearly showed the feasibility of conducting well designed and supervised strength training in young Thai male athletes, and also provided guidelines for future training applications. Indeed, young Thai male athletes tolerated well the complex and resistance training programs. Moreover, well-designed and supervised complex and resistance training programs and physical fitness testing protocols are safe for young athletes. In addition, qualified assessment by experts provided high quality data and consistent performance of youth athletes. Thus, training programs and testing protocols used in this study can be further specifically applied if seriously investigated.

Further pilot studies are still needed in order to examine the response of young athletes of other sports to strength training programs, because we do not know if the protocols used in this study can be generalized for other young athletes. We propose that future pilot studies should be specifically designed for other type of training modalities including different training exercises as well as testing protocols. Likewise, of greater concern should be the adaptation of training programs to other athlete age groups and gender. The accumulated knowledge will eventually be suitable for the establishing of strength training guidelines for young Thai athletes.

This work has shown that short-term strength training programs (complex and resistance training) incorporated with routine soccer training are effective in improving maximal strength and motor performance of adolescent soccer players, although had no influence on soccer skills (passing and shooting). Additionally, complex training was superior to resistance training to improve explosive strength. Therefore, we can suggest that coaches should incorporate ancillary strength training programs along with soccer specific training routines in their annual training plans. However, its efficacy may depend on their objectives as well as other available facilities. For example, if the goal is to develop muscle strength, particularly maximal strength, resistance training will be a good choice and young athletes can also improve their motor performance.
Our results showed that only a 7-week period was sufficient enough to increase strength, but it is also possible that coaches plan longer training programs. This requires precise purposes when designing programs in order to achieve success. Complex training is also highly useful to develop overall physical fitness for young soccer players, and may possibly yield superior results for explosive strength compared to resistance training, but there is a need for further research about its long-term effects. In addition, complex training is more time consuming than resistance training. Therefore, the most appropriate training cycling of this two different strength training modalities should also be investigated.

Recording and proper analysis of training programs is highly useful for coaches since they will gather a wealth of information that may be shared to other coaches and Sports Federations. It will also prompt them to re-adjust loads accordingly. For example, when dealing with resistance training, we suggest a weekly increase of 5% of 1RM but we do not know if greater increases would be more efficient and/or may induce harm.

We do not suggest coaches to perform strength training in consecutive day, unless specific purposes may be linked to their annual periodization according to Verkhosansky block training suggestions for short periods. As it has been recommended in our review (1st paper), we should allow adequate recover periods after each training session of at least 48 hours.

The information provided in the last experimental study may be helpful for coaches so that they may clearly understand the presence of inter-individual differences in response to strength training programs. It is well known that in youth, muscular strength and physical performance are impacted by a myriad of factors, namely growth and maturation. For instance, biological maturation is considered as one of the most important predictors for strength, and may moderate the magnitude of individual responses to regular training.

Based on our results, we concluded that there is a variation in individual
responses to strength training programs among adolescent soccer players, and that the magnitude of changes following the training programs were not associated with the baseline characteristics of participants neither their biological maturation status. Therefore, this study showed seemingly paradoxical results when considering the relationship between variation in skeletal age and training responses.

These results should be prudently interpreted because of the sample size used in each experimental group. In any case we are of the position that: (1) coaches and researchers should judiciously analyse and interpret responses to training beyond interpretation provided by mean values; (2) variation in response to training is pervasive and should be interpreted also within the context of its dependency to body size (or lean body mass); biological maturation status may not have a significant effect in strength changes; (4) and that training responses, within, short term programs, may not depend on starting values, and (4) finally a concentrated effect should forms on individualized training and response. Caution must be taken to understand that as young athletes respond differently, some may be slower in responding and other may be high responder.