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Strength training in youth (resistance, plyometrics, complex training).

An evidence-based review.

KEY WORDS:

Strength training. Boys. Injuries. Young athletes

ABSTRACT

Objective: 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. Design: 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 invervention study; 2 are meta-analysis of resistance training; 7 relates to plyometry; and 2 concern complex training. Main results: Resistance training showed highly maximum strength improvement and enhance 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. 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.

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O treino de força com jovens (resistência, pliometria, treino complexo): Uma revisão baseada em evidências.

RESUMO

Propósito: Sumariar o estado da arte acerca dos ganhos induzidos por programas de treino resistido, pliometria e treino complexo ao nível da força, desempenho motor e ocorrência de lesões em crianças e jovens do sexo masculino dos 8 aos 17 anos de idade. Delineamento: Foram selecionados vinte e três estudos de natureza experimental (realizados entre 2000 e 2010): 11 relacionados com treino resistido; 1 acerca de adaptações fisiológicas após intervenção; 2 são meta-análises sobre treino de força; 7 referem-se a treino pliométrico; e 2 a treino complexo Resultados principais: O treino resistido induziu melhorias na força máxima, bem como na *performance* motora de jovens atletas e não atletas. Os ganhos de força estão mais relacionados com adaptações neuromusculares do que com hipertrofia. Os resultados das meta-análises sugerem magnitudes de efeito de nível moderado a elevado. O treino pliométrico melhorou os movimentos explosivos numa magnitude superior aos obtidos pelo treino resistido convencional. O treino complexo aumentou, de modo elevado, a produção de força em regime dinâmico, mas numa escala menor a potência anaeróbia e outras facetas do desempenho motor. Os ganhos de força e de desempenho motor tendem a diminuir com o destreino ou treino reduzido, qualquer que seja a modalidade de treino. Em todos os estudos revistos foi identificada somente uma lesão. Conclusões: Da revisão efetuada verificou-se que as diferentes modalidades de treino resistido são eficazes na melhoria de produção de força e na performance motora de rapazes. Melhorias mais acentuadas na produção de força estão associadas à duração dos programas. Qualquer programa de treino exige supervisão adequada para garantir a segurança dos utilizadores. Os estudos com treino complexo são ainda reduzidos.

PALAVRAS CHAVE:

Treino de força. Rapazes. Lesões. Jovens atletas.

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 [34]. Available evidences suggests, at least in adults, various positive changes in neuromuscular system, muscle function and sport performance [44, 53, 65].

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 [4, 6, 10, 13, 27, 47]. Indeed, a recent position statement paper from the National Strength and Conditioning Association [29], 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, one broad review study has clearly specified that experimental training protocols with weights and resistance machines are safe and do not negatively impact growth and maturation of youngsters [47]. More recently, the latest updated position statement paper from the National Strength and Conditioning Association [29] 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 [2, 52, 70]. Several studies, 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 [2, 40, 52]. For example, study reported decreasing of injury in adolescent soccer players after the preseason conditioning programs, which incorporated resistance training programs [39].

A growing body of data demonstrates that children and adolescent can significantly improve their strength from participating in resistance training programs [11, 28, 45, 58]. Furthermore, two meta-analyses reported overall mean effect sizes of .57 and .75, respectively, supporting the belief that resistance training programs can significantly enhance muscular strength of children and adolescents [32, 56].

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 [9]. 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 [43]. Smaller amounts of testosterone in females limit magnitude of changes in muscle hypertrophy induced by training [62, 64].

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 [12]. Adult research data show that plyometric training improves both maximal strength and local muscular endurance, power and sport performance [3, 5, 8, 22, 33, 38]. Studies in children and adolescents have also examined the effects of plyometric training programs [23, 42, 49, 52]. Recently, a study recommended that plyometric training programs are not only safe for children but can also enhance muscular strength and improve sport performances [19].

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 [18, 24, 25, 26]. 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 [33, 36]. 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-existant. 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.

MATERIAL AND 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 Discus 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 [58], eight and 20 months program length were used in 2 plyometric studies and the longest training program duration was 21 months [63]. 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 was designed for only upper extremities [75]. 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 [15, 30, 68, 73, 74, 77], one study reported significant improvement in upper body strength [75] and another one only reported significant improvement in lower body strength [63]. Significant increases in vertical jump were reported in 4 studies [14, 30, 31, 81], and significant gains in long jump were reported in 1 study [31]. Three papers demonstrated that resistance training programs significantly increased running speed in adolescent boys [15, 31, 81] and significant gains in agility were reported in 2 studies [15, 31]. Three studies used medicine ball throw for upper body explosive strength measurement and reported significant increases in distance throwing [30, 31, 73]. Aerobic endurance running, flexibility and ball shooting speed gains were reported as net results from resistance training programs [15, 30, 31, 81]. However, other studies did not find significant changes in VO2 max [68, 81], one study also reported no changes in soccer technique of young soccer players from a resistance training program [15].

One study demonstrated physiological mechanisms adaptations underlying possible training induced strength gains boys [58]. 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 [32, 56]. Both reported moderate-to-high effect sizes of strength gains. Overall mean effect size (.57) was reported from 9 studies [32] 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) [56].

Six of 7 studies reported significant increases in vertical jump after a plyometric training program in children and adolescent boys [23, 42, 46, 49, 51, 79]. Sprint performance improvements were also reported in 3 studies [23, 42, 51], in addition, significant changes in agility were noticed in 1 study [51]. One study also reported significant gains in sprint cycling after a plyometric training program [23]. Improvements in maximal voluntary force of hip extensors and rate of force development of knee extensors were also noticed in 1 study [49]. Finally, one study showed significant changes in swim block start performances of adolescent swimmers [7].

Two complex training studies showed their systematic benefits in muscular strength and motor performance. The first published study concerning complex training in youth demonstrated significant increases in both upper and lower body dynamic strength in 8 exercises [41]. Moreover, improvements in vertical jump, anaerobic power, 40-m sprint and basketball chest pass were also observed. Another complex training study 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) [67].

None of the studies reviewed so far reported injuries during training sessions. As exception, in the study reported a minor injury occurrence in one subject during a training session [63].

TABLE 1 — Experimental studies of resistance training in youth.

REFERENCE	SUBJECTS	TRAINING PROGRAM(S)	STATISTICAL ANALYSIS	OUTCOME MEASURE(S)	MAIN FINDING(S)	CONCLUSIONS
Wong et al., 2010	51 U-14 young male soccer players, E, n = 28 (13.5 ± 0.7 yrs.) C, n=23 (13.2 ± 06 yrs.)	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, plyo sit up.	Independent t-tests, MANOVA	Vertical jump, Ball-shooting, 30 m sprint, Yo-Yo intermittent endurance run level one, VO2 max test.	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%.	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.
Channell and Barfield, 2008	27 male student athletes (15.9 ± 1.2 yrs) E1 (OT), n=11 E2 (PT), n=10 C, n=6	Olympic training (OT) and traditional power lift training (PT): 60-95% of 1 RM, 3-5 sets × 3-10 reps, 3 times/wk, 8 wks; olympic training exercises: bench press, power clean, push jerk, leg press, incline, push-ups, back extensions, abdominals, lunges, decline, attacker, military press; traditional power lift exercises: bench press, squat, dead lift, leg press, incline, push-ups, back extensions, abdominals, lunges, decline, attacker, military press.	Repeated measures ANOVA	Vertical jump	E1: significant increased in vertical jump 4.5%. E2: significant increased in vertical jump 2.3%.	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.
Faigenbaum et al., 2007	22 boys (13.9 ± 0.4 yrs) only one experimental group	Resistance training program: olympic-style lift, 3 sets × 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.	Paired t-test	10 RM: bench press and squat; medicine ball toss, vertical jump, flexibility and progressive aerobic cardiovascular endurance run (PACER).	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 36%.	After-school resistance training program can improve muscular fitness and cardiovascular fitness in boys. No injuries reported.

REFERENCE	SUBJECTS	TRAINING PROGRAM(S)	STATISTICAL ANALYSIS	OUTCOME MEASURE(S)	MAIN FINDING(S)	CONCLUSIONS
Faigenbaum et al., 2007	27 boys E1 (PRT), n=13 (13.4 ± 0.9 yrs) E2 (RT), n=14 (13.6 ± 0.7 yrs)	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/low back stretch, chest/hamstring stretch, quadriceps stretch, v-sit hamstring stretch; same resistance exercise as E1.	Independent t-tests, repeated measures ANOVA	Vertical jump (countermovement jump), long jump, 9.1 m sprint, shuttle run, medicine ball toss, flexibility.	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%.	The addition of plyometric training to 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.

REFERENCE	SUBJECTS	TRAINING PROGRAM(S)	STATISTICAL ANALYSIS	OUTCOME MEASURE(S)	MAIN FINDING(S)	CONCLUSIONS
Szymanski et al., 2007	49 high school baseball school players E1, n=24 (15.3 ± 1.2 yrs) E2, n=25 (15.4 ± 1.1 yrs)	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 biceps 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.	Independent t-tests, Repeated measures ANOVA	3 RM torso rotational strength: dominant torso rotational strength, nondominant torso rotational strength; sequential hip-torso-arm rotational strength: medicine ball hitter's throw; 1 RM; parallel squat, bench press.	E2: significant increased in 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%.	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.
Christou et al., 2006	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) subjects were Tanner stage 3-5 public hair growth	Resistance training program for STR: 2 times/ wk, 16 wks, 2-3 sets × 8-15 reps, 55-80% of 1 RM; exercises: leg press, bench press, leg extension, peck-deck, leg flexion, overhead press, lag pull-downs, calf raise, sit-ups, upper-lower back extension.	Repeated measures ANOVA, ANCOVA	1 RM: bench press, leg press; vertical jump: squat jump, countermovement jump, repeated jump; 10-and 30-m sprint time, agility, flexibility soccer technique.	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 15.8%; significant improved 30-m sprint 2.5%, agility 5.4%; significant decreased in flexibility 8.2%.	Resistance training improves more maximal strength of upper and the lower boy, vertical jump height and 30-m speed; the combination of soccer and resistance training could be used for an overall development of the physical capacities of young boys. No injuries reported.

REFERENCE	SUBJECTS	TRAINING PROGRAM(S)	STATISTICAL ANALYSIS	OUTCOME MEASURE(S)	MAIN FINDING(S)	CONCLUSIONS
Shaibi et al., 2006	22 overweight Latino adolescents, E, n=11 (15.1 ± 0.5 yrs) C, n=11 (15.6 ± 0.5 yrs) all subject were Tanner stage 3 pubic hair growth	Resistance training program: 1-3 sets × 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.	Independent t-tests, paired t-tests	1 RM: bench press, leg press; VO2 peak.	E: significant changed in 1 RM bench press 26% and leg press 28%.	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.
Tsolakis et al., 2004	19 preadolescent males E, n=9 (11.8 ± 0.8 yrs) C, n=10 (12 ± 0.8 yrs) subjects were Tanner stage 1 and 2 public hair growth	Resistance training program: 3 times/ wk, 2 months, 3 sets upper body exercise × 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.	Repeated measures ANOVA, independent t-test	Elbow flexion isometric strength, 10 RM elbow flexion isotonic strength.	E: significant changed in isometric strength 17.5%; detraining (8 wks): significant decreased in isometric strength -9.5%.	The 2-months resistance training program resulted in significant increases in isometric strength of preadolescent boys. No injuries reported.

REFERENCE	SUBJECTS	TRAINING PROGRAM(S)	STATISTICAL ANALYSIS	OUTCOME MEASURE(S)	MAIN FINDING(S)	CONCLUSIONS
Szymanski et al., 2004	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)	E1 and E2: linear periodized resistance training program, 3 times/ wk, 12 wks, 2-3 sets × 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 × 8-12 reps; wrist and forearm exercises: straight bar wrist curls, straight bar reverse wrist curls, standing plate squeeze, standing radial deviation, standing ulnar deviation, seated pronation/supination.	Independent t-tests, repeated measures ANOVA	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.	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%), non-dominant 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 writst 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.	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.
Volek et al., 2003	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	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.	Independent t-tests, two-way ANOVA	Maximal strength: squat and bench press.	For all subjects combined significant increased in squat 43%, bench press 23%.	A 12-week resistance training program can significantly increase upper and lower maximal strength in boys aged 13 to 17 yrs. No injuries reported.

REFERENCE	SUBJECTS	TRAINING PROGRAM(S)	STATISTICAL ANALYSIS	OUTCOME MEASURE(S)	MAIN FINDING(S)	CONCLUSIONS
Sadres et al., 2001	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 public hair growth	Resistance training program: 2 times/ wk, 21 months, 1-4 sets × 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.	Independent t-test, repeated measures ANOVA	1 RM: knee extension, knee flexion.	E: significant change in knee extensions 83%, knee flexions 63%.	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.

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

REFERENCE	SUBJECTS	TRAINING PROGRAM(S)	STATISTICAL ANALYSIS	OUTCOME MEASURE(S)	MAIN FINDING(S)	CONCLUSIONS
Ramsay et al., 1990	26 boys (9-11 yrs) E, n=13 C, n=13 All subjects were classified as Tanner stage 1	Resistance training program: circuit training, 3,5 sets × 5-12 RM, 3 times/ wk, 20 wks; resistance exercise: arm curl, double leg extension, leg press, bench press, behind the neck pull down, sit-ups, trunk curls.	Repeated measures ANOVA	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.	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.	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.

NOTE: E = EXPERIMENTAL GROUP; C = CONTROL GROUP; RM = REPETITION MAXIMUM

TABLE 3 — Experimental studies of plyometric traning in youth

REFERENCE	SUBJECTS	TRAINING PROGRAM(S)	STATISTICAL ANALYSIS	OUTCOME MEASURE(S)	MAIN FINDING(S)	CONCLUSIONS
Meylan and Malatesta, 2009	25 young soccer players E, n=10 (13.3 ± 0.6 yrs) C, n=11 (13.1 ± 0.6 yrs)	E: plyometric drills: 2-4 sets of 6 -12 reps, 2 times/ wk, 8 wks, exercises: ankle hop, vertical jump, lateral hurdle jump, horizontal and lateral and lateral bounding, skipping, footwork.	Repeated measures ANOVA	Vertical jump: squat jump, countermovement jump; contact test, multiple 5 bounds test, 10-m sprint, agility test.	E: significant increased in countermovement jump 7.9%, contact test 10.9%; significant improved 10-m sprint 2.1%, agility 9.6%.	Plyometric training programs within regular soccer practice improved explosive actions of young players compared to conventional soccer training only. No injuries reported.
Bishop et al., 2009	22 adolescent swimmers E, n=11 (13.1 ± 1.4 yrs) C, n=11 (12.6 ± 1.9 yrs)	E: plyometric training program, 2 hrs/ wk, 8 wks, 1-5 sets × 1-5 reps; exercises: two-foot ankle hop, tuck jump, squat jump, split 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, alternate 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.	Independent t-tests, dependent t-tests	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.	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%.	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.
Weeks et al., 2008	37 adolescents boys E, n=22 (13.8 ± 0.4 yrs) C, n=15 (13.8 ± 0.4 yrs) subjects were stage 1-5 Tanner's maturation criteria	E: jump training: 2 times/ wk, 8 months, ~300 jumps; exercises: hops, tuck jumps, jump squats, star jumps, lunges, side lunges and skipping.	ANCOVA	Vertical jump	E: significant increased in vertical jump 8.9%.	8-month jump training significant increase in jumping performance in prepubertal boys. No injuries reported.

REFERENCE	SUBJECTS	TRAINING PROGRAM(S)	STATISTICAL ANALYSIS	OUTCOME MEASURE(S)	MAIN FINDING(S)	CONCLUSIONS
Kotzamanidis, 2006	30 prepubertal boys E, n=15 (11.1 ± 0.5 yrs) C, n=15 (10.9 ± 0.7 yrs) subjects were 1st stage of Tanner's maturation criteria	E: plyometric training program, 2 times/ wk, 10 wks, 10 jumps for each sets; exercises: speed bound, vertical jump; height of vertical jump = 10-30 cm; number of jumps per session = 60-100.	Repeated measures ANOVA, paired t-tests	30 m sprint test: 0-10, 10-20, 20-30 and 0-30 m; vertical jump test: squat jump.	E: significant increased in running speed by distance 10-20 m (1.71 0.11 to 1.65 0.13 s), 20-30 m (1.61 0.28 to 1.56 0.27 s), 0-30 m (5.55 0.03 to 5.41 0.6 s); significant improve in squat jump (22.99 4.49 to 30.96 4.13 cm).	The plyometric training program in prepubertal boys has a positive effect on running speed and vertical jump performance. No injuries reported.
MacKelvie et al., 2004	64 prepubertal or early pubertal boys E, n=31 (10.2 ± 0.5 yrs) C, n=33 (10.1 ± 0.5yrs) subjects were 1st stage of Tanner's maturation criteria	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	ANCOVA	Vertical jump, Long jump.	E: significant increased in vertical jump 35.4% and long jump 6.5%.	20-month plyometric training significant increase in jumping performance in prepubertal boys. No injuries reported.

REFERENCE	SUBJECTS	TRAINING PROGRAM(S)	STATISTICAL ANALYSIS	OUTCOME MEASURE(S)	MAIN FINDING(S)	CONCLUSIONS
Diallo et al., 2001	20 prepubescent soccer players (12.3 yrs) E, n=10 C, n=10 subjects were prepubertal status according to the Tanner's maturation criteria	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.	Nonparametric Wilcoxon test, Correlation coefficients	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.	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<0.01) and 20-m (p<0.05). Significant of relation between cycling power and countermovement jump (r=0.87, p<0.01), cycling power and squat jump (r=0.91, p<0.01); reduced training: decrease in countermovement jump but not significant and increase in squat jump but not significant.	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.

REFERENCE	SUBJECTS	TRAINING PROGRAM(S)	STATISTICAL ANALYSIS	OUTCOME MEASURE(S)	MAIN FINDING(S)	CONCLUSIONS
Matavulj et al., 2001	33 junior basketball players aged 15-16 yrs E1, n=11 E2, n=11 C, n=11	E1: drop jump from a 50 cm bench; E2: drop jump from a 100 cm bench; both groups performed training program 3 times/wk, 6 wks, 3 series of 10 trials.	Paired t-tests, MANCOVA, Correlation coefficients	Countermovement jump; maximal voluntary force: isometric condition of hip and knee extensors; rate of force development: isometric condition of hip and knee extensors.	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; correlation coefficient in all subject: countermovement jump and maximal voluntary force in hip extensors r=0.38; countermovement jump and maximal voluntary force in knee extensors r=0.52; countermovement jump and rate of force development of hip extensors r=0.03; countermovement jump and rate of force development of knee extensors r=0.02.	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.

NOTE: E = EXPERIMENTAL GROUP; C = CONTROL GROUP; RM = REPETITION MAXIMUM

TABLE 4 — Meta-analysis studies of resistance training in youth

REFERENCE	CRITERIA	NUMBER OF STUDIES	STATISTICAL ANALYSIS	RESULTS	CONCLUSIONS
Falk and Tenenbaum, 1996	The study design had to include resistance training programs. Maximal age of the participants were 12 and 13 for girls and boys, respectively. The data have to be available to calculate effect size (ES).	28 studies which described a resistance training program for boys and girls age-range was 10 to 14 yrs, 9 studies provided the necessary data to calculate the effect size, 4 studies provided no control group, 3 studies provided no standard deviation, 2 studies provided only percent change, 5 studies provided no data at all and 5 studies were not available.	Random effects model meta-analysis, calculate average effect size (ES) of each studies and overall mean effect size.	The majority of the studies showed gains in strength between 13 and 30% Overall mean effect size = .57 The ES of Clarke et al. study = .13 The ES of Ramsay et al. study = .51 The ES of Siegel et al. study = .35 The ES of Weltman et al. study = .56 The ES of Falk and Mor study = .83 The ES of Sailors and Berg study = 1.44	Although limited by the small number of available studies, this meta-analysis reveals that resistance training can be effective in prepubescents. No difference was found in the effect of resistance training between genders. Twice a week training frequency is sufficient to induce strength gains in children.

REFERENCE	CRITERIA	NUMBER OF STUDIES	STATISTICAL ANALYSIS	RESULTS	CONCLUSIONS
Payne et al., 1997	Studies must examine the effect of resistance training on muscular strength or muscular endurance of participants. Studies conducted on "healthy-normal" participants. Studies must report measurements of muscular strength or muscular endurance, measures of power and physical fitness indexes are not included. Studies must report mean, standard deviations and sample size for control and experimental groups. Research must included participants who were 18 years of age or less. Studies must report controls from an untreated group in an experimental-control design or as a pretest in a pretest-posttest control group design (pre-post).	28 of the reviewed studies met the criteria for inclusion.	Fixed-effect model meta-analysis, calculate effect size (ES) of each study characteristic as covariate and overall mean effect size, test of heterogeneity.	Significantly different ($p < .05$) from zero in each mean ES indicate that resistance training program was effective The mean ES of boys = .72 The overall average ES = .75	Children and youth can demonstrate considerable increases in muscular endurance and strength as a result of training. The magnitude of the effect appears to be a function of gender, training method and experimental design.

TABLE 5 — Experimental studies of complex training in youth

REFERENCE	SUBJECTS	TRAINING PROGRAM(S)	STATISTICAL ANALYSIS	OUTCOME MEASURE(S)	MAIN FINDING(S)	CONCLUSIONS
Ingle et al., 2006	54 Boys (12 ± 0.3 yrs) E, n=33 C, n=21 early pubescent ages, Tanner stage 1 or 2 pubic hair growth	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, barbell lunges, overhead press, biceps curl and triceps 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.	Repeated measures ANOVA	10 RM dynamic strength for 8 exercises: bench press, dumbbell rows, barbell calf raises, dumbbell overhead press, back squat, barbell biceps curl, back squat lunges, barbell triceps extension; anaerobic power; vertical jump; 40-m sprint; basketball chest pass; standing long jump.	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%.	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.

REFERENCE	SUBJECTS	TRAINING PROGRAM(S)	STATISTICAL ANALYSIS	OUTCOME MEASURE(S)	MAIN FINDING(S)	CONCLUSIONS
Santos and Janeira, 2008	25 young male basketball players E, n=15 (14.7 ± 0.5 yrs) C, n=10 (14.2 ± 0.4 yrs) all subjects were Tanner stage 3 or 4 pubic hair growth and genital development	Complex training: 10/ 12 RM × 2-3 sets resistance exercise + 2-3 sets × 5-15 reps plyometric exercise, 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 foot 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.	Repeated measures t-test, independent t-test	Upper and lower body explosive strength: Squat jump, countermovement jump, abalakov test, depth jump, mechanical power and seated medicine ball throw.	E: significant gains in squat jump 13%, countermovement jump 10.5%, abalakov test 10.5% and seated medicine ball throw 19.6%.	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.

NOTE: E = EXPERIMENTAL GROUP; C = CONTROL GROUP; RM = REPETITION MAXIMUM; MB = MEDICINE BALL

DISCUSSION

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 [63] and the lowest (15%) was observed in a twice a week [30], 12 weeks training program. Authors suggested that the training intensity in their study was relatively low in comparison with most previous studies among children [63]. Moreover, study supported the idea that a longer training period might have further enhanced the observed strength gains [68]. Besides, authors 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 [30]. Studies that used the same training duration and frequency (2 times per week, 16 weeks) [15, 68] reported different results in strength gains (58.8 vs. 28%), with young soccer players showing higher gains. On the other hand, 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 [73, 74]. However, another identical program showed superior results (23%) where subjects had higher age range [77]. 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 [41]. 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, the highest magnitude of changes was (34%) [42]. Nevertheless, comparable results were observed from one of the resistance training programs [15], as 31% changes in vertical jump was observed 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 [31]. 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 [14, 30, 81] as well as in plyometric studies [23, 49]. Ten-week complex training programs results in superior improvements (13%) than most of resistance training studies and similar improvement when compared to plyometric studies [67].

Significant changes in muscular strength and performances changes are most related to neural factors. Authors 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 [15]. This is in agreement with previous studies [55, 58]. The early did not observe any significant changes in muscle cross-sectional area after subjects underwent 20-week resistance training program [58]. Authors 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 [78]. Furthermore, another authors 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 [53, 74]. However, a paradoxical finding has been reported by previous study [50]. First complex training study in youth did not follow this line of reasoning [41]. They went on suggesting that another possible mechanism was postactivation potentiation (PAP). PAP is defined as an increase in muscle twitch and low-frequency tetanic force after a conditioning contractile activity [66]. 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 [60, 72]. 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 [1, 76]. However, review papers that examined the PAP explanation in order to enhance acute voluntary explosive contractions concluded that the results were equivocal [24, 37, 61]. 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. Authors 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 [15]. Besides, study reported improvements in countermovement jump but not in squat jump following plyometric training program [51]. 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, study observed increases in squat jump after plyometric training program [42] and referred that vertical jump enhancements could be the rate of force development, power, and stiffness enhancement, as already reported in adult [5, 80]. One complex training study [67] suggested that the improvements reported in their study could be explained by stimulation of the neuromuscular system [16], that is, it activates both the muscular fibers and the nervous system, so that slow-twitch fibers behave like fast-twitch fibers [17]. Running speed improvements from training programs were explained differently by authors. It is referred that a short distance sprint performance is most related to the player's ability to generate muscular power as earlier demonstrated by previous study [21, 81]. 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 [35]. Authors 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 [51]. They reported a relationship between countermovement jump and 10-m sprint as it has been observed in previous studies [20, 82] 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, authors advanced the idea of utilizing speed-bound exercises to enhance all running phases including the initial acceleration (0-10 m) [42] as these results have been previously reported in adults [59]. Changes were also observed in the intermediary acceleration (10-20 m) and steady velocity phases (20-30 m). Additionally, authors 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 [41].

Soccer drills and game have been presumed to contribute to improvements in agility because drills and games involves continuous changes of direction [15]. 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, authors 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 [51] 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 [69].

Neural adaptation factors following strength training also have been postulated to be related to anaerobic performance enhancement. Authors 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 [41, 48]. VO2 max changes were observed in young soccer players. It is 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 [81] as demonstrated by previous study [71] and as earlier proposal that aerobic performance may be affected not only by central factors related to VO2 max but also by peripheral factors such as muscle power [54]. Lastly, it has been concluded that improved swim block start performances results from plyometric training are related to increased muscular power output and force production [7]. 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 [57].

Strength and performances were observed to be decreased after detraining and reduced training period [75]. Authors 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 [41]. Strength was significantly decreased between 16.3 and 30.3%. Decreasing in vertical jumps was also remarked from plyometric and complex training study. Reduction in countermovement jump was observed after 8-week reduced training program but not significant, conversely, squat jump was increased but also not significant. Author also observed significantly decrease by 4% in vertical jump, this magnitude of changes was identical as improvement observed after 12 weeks of training period [41]. Nevertheless, one another published study 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 [67].

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. Study reported one accident, which the bar slid and fell on the thighs of the one subject while performing clean exercise [63]. 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 [6, 29, 47].

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. This aforementioned information 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 enhances explosive movements, at a greater extent than resistance training. Complex training extremely increases dynamic strength, and improves 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.

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