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A combined plyometric and resistance training program improves fitness performance in 12 to 14-years-old boys

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Abstract

Background Nowadays resistance and plyometric training are deemed to be a crucial component of a health promoting lifestyle in youth. Effects of resistance training and plyometric training may actually be synergistic, with their combined effects being greater than each program performed alone.

Aims This randomized controlled study aimed to compare the effects of an 8-week training period of combined plyometric and resistance training with resistance training alone on fitness performance in boys.

Methods Participants (24 boys, 12–14 years) were randomly assigned to an 8-week combined training group (CT, $n = 12$) that performed plyometric exercises (~20 min.) followed by resistance training or a resistance training group (RT, $n = 12$) that performed static stretching exercises (~20 min.) followed by the same resistance training program. Both groups performed twice weekly training sessions of 90 min. At baseline and after training all participants were tested on the 20-m sprint (time) and Squat Jump (power, velocity, force and height).

Results The CT group showed significantly ($p < 0.05$) improvement than RT in the 20-m sprint time (-0.07 vs. 0.05 s), and Squat Jump (Power: 159.0 vs. -5.0 W; velocity: 0.2 vs. -0.2 m s⁻¹; force: 41.2 vs. -57.4 N; height: 10.6 vs. -0.3 cm) following training.

Conclusions Results suggest that when seeking to induce specific acute adaptations in vertical jump and acceleration capacities in lower limbs, male adolescents may benefit more from exposure to a combination of plyometric and resistance training methods.

Keywords Adolescent · Strength training · Stretch–shortening cycle · Power

Introduction

Resistance and plyometric training are generally indicated in the literature as the best methods for improving the most powerful strength characteristics (explosive force) in adults and their combined effects seem to be greater than any program performed alone [1, 2]. However, little is known about the effectiveness of this combined effect in young people.

The scientific literature has widely demonstrated that resistance training for children and adolescents may improve selected motor performance skills (e.g., long jump, vertical jump, sprint speed, and medicine ball toss) while decreasing the severity and incidence of sport injuries [3–8]. On the other hand, studies employing plyometric training programs for youth reported improvements in vertical jump height [9–11] and running speed [9, 12].

Anyway, resistance and plyometric training are considered crucial components of a health promoting lifestyle in youth [13]. There is compelling evidence that resistance or plyometric training improves muscular fitness (i.e., muscular strength, muscular power, local muscular endurance) [14, 15], bone mineral accrual [16], body composition [17], motor performance skills [7, 8], and lipid profiles [3]. However, a recent review that compared the effects of traditional resistance training with plyometrics in youth population [14], observed an effect of specificity: greater

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improvements in jump height due to plyometrics, as well as greater improvements in strength and sprint measures due to resistance training.

Recently, some studies have reported that the combination of resistance training and plyometric training may offer the most benefit for adolescent athletes. Faigenbaum et al. [18] found the combination of strength and plyometric training to be more effective than resistance training, for the long jump, ball toss and shuttle run in around adolescent males. Santos and Janeira [19] suggested that the use of complex training (i.e. resistance and plyometric training) significantly improves the upper and lower body explosivity levels in young basketball players.

The above-mentioned studies seem to indicate that a combination of strength and plyometric training is likely to elicit the most improvements in youth. However, to our knowledge, very few randomized, prospective studies have examined the effects of combined plyometric and resistance training in children and adolescents. In our study, we also wanted to examine the effectiveness of pre-event static stretching, as it is perceived by coaches as an effective method to improve performance [20]. Since young athletes are often encouraged to perform static stretching before resistance exercise [21], it is interesting to know if plyometric training and resistance training (without pre-event static stretching) can provide combinatory effects in younger populations. Given that static stretching is commonly used in clinical and athletic environments with the specific aims of increasing joint ROM and reducing injury risk [22], it is important to ascertain the most efficacious method for enhancing fitness performance in children and adolescents. Even though initial gains in strength and power due to training are mediated by neural factors [2], we used an 8-week training program since previous investigations reported favorable changes in performance in youth [23] following at least 6 weeks of resistance and/or plyometric training.

Therefore, the purpose of the present study was to assess the effects of an 8-week training period of combined plyometric and resistance training on fitness performance in 12- to 14-year-old boys. We hypothesized that a combined plyometric and resistance training intervention should cause greater improvements in fitness performance as compared to resistance training and static stretching.

Materials and methods

Study design

To test our hypothesis, adaptations following combined plyometric and resistance training compared to resistance training and static stretching were assessed using a randomized controlled trial study design. This research was designed to

obtain baseline data of the fitness measures in participants, to evaluate whether an 8-week combined training period can produce improvements. This outcome was defined as statistically significant improvements in the lower limbs speed and explosive strength evaluation tests (i.e., a 20 m-sprint test and a squat jump test).

Participants

Twenty-four healthy boys (range 12–14 years) that participated in locally organized sports (principally soccer and basketball) volunteered to take part in this study. The subjects were recruited by a local sport association in April 2018. Participants were excluded if they had a chronic pediatric disease or had an orthopedic condition that would limit their ability to perform exercise. All volunteers were accepted for participation. The participants were randomly assigned to two groups: a resistance training group (RT, $n = 12$), or a combined training (i.e., plyometric training and resistance training) group (CT, $n = 12$). For randomization, we used the method of randomly permuted blocks using Research Randomizer, a program published on a publicly accessible official website (<http://www.randomizer.org>). This sample size was justified by a priori statistical power analysis using a medium effect size, alpha of 0.05 and power of 0.80, which determined that 16 subjects in total were required for participation [24]; the additional recruitment accounted for the possibility of dropouts. All participants and their parents received a complete explanation in advance about the purpose of the experiment and the parents provided written consent to the study. The procedures followed were in accordance with the ethical standards of the responsible institutional committee on human experimentation and with the Helsinki Declaration. The study was conducted from April to May 2018.

Study procedures

All study procedures were performed at a school sports facility. Initial and final test measurements were made at the same time of day and under the same experimental conditions. Subjects maintained their normal intake of food and fluids, but before testing, they abstained from physical exercise for 1 day, drank no caffeine-containing beverages for 4 h, and ate no food for 2 h. Verbal encouragement ensured maximal effort throughout all tests. Prior to data collection all subjects participated in one introductory session during which time proper form and technique on each physical fitness test were reviewed and practiced. During this session research assistants demonstrated proper testing procedures and participants practiced each test. A standardized battery of warm-up exercises was performed before maximal efforts. On the first test day, subjects performed the Squat Jump,

instead anthropometrical assessment and sprint running were undertaken on day 2. The same researchers tested and trained the participants. Pre-testing was performed the week before the training period and post-testing was performed the week after the training period.

Measures

20-m sprint test

After a self-paced 3 min warm-up run, participants performed two submaximal 20-m sprints from a starting line, followed by three maximal timed sprints in an indoor school sport facility. Each sprint was interspersed by a 2-min walk recovery. Upon completion, each participant's time was recorded to the nearest 0.01 s on a hand-held stopwatch [25]. The minimum time (s) recorded in the trials was taken as a dependent variable. The test–retest reliability reported a good reliability for the 20-m sprint test ($ICC = 0.86$).

Squat Jump test

The SJ test is a reliable and valid test for the estimation of the explosive power of the lower limbs [26]. The SJ was performed from a starting position in which the participants' knees were at a 90-degree knee angle, without allowing any counter movement. The participants' hands were kept on their hips, thus avoiding any arm swing. The subjects were required to jump as high as possible, without performing a countermovement (pre-stretch), and to land at the same point of take-off. They were also required to rebound with straight legs when landing to avoid knee bending and alteration of measurements. The SJ test was conducted with the Beast sensor (Beast Technologies s.r.l., Brescia, Italy) that is a small wearable device designed to be fixed to a wristband that the athlete wore during tests [27]. Mean velocity ($m s^{-1}$) of each trial was transferred in real time via Bluetooth 4.0 LE to the Beast app for iOS v.2.2.3, which was installed on an iPhone 6 with iOS 10.2.1 operative system. Data of each individual jump were recorded, and mean power (W), force (N) and height (cm) were calculated by applying physics laws. Each participant was given three trials, which were separated by 1-min intervals, to complete their highest jump. The highest jump in the trials was taken as the dependent variable and used in subsequent analyses. The test–retest reliability reported a high reliability for SJ ($ICC = 0.96$).

Training protocol

Both exercise groups trained twice per week on nonconsecutive days (Tuesday and Thursday) for 8 weeks under carefully monitored and controlled conditions. Prior to each training session, all subjects participated in a 10-min

warm-up period which included jogging at a self-selected comfortable pace followed by calisthenics. After the warm-up session, subjects in the combined training group performed plyometric exercises (~20 min.), whereas subjects in the resistance training group performed static stretching exercises (~20 min.), since no studies suggest that static stretching diminishes performance, although the potential benefits of an acute bout of static stretching have been questioned [28]. Following the completion of the individual protocols, all subjects performed the same resistance training program. Each training session ended with ~5 min of cool-down activities. The daily training duration for both study groups was purposely designed to be 90 min. Experienced instructors graduate in physical education discussed and demonstrated proper exercise technique throughout the study period. The instructors consistently encouraged the subjects to maintain proper technique performance. If a subject fatigued and could not perform an exercise correctly, the exercise was stopped.

Static stretching

Subjects in the resistance training only group performed static stretching exercises during the 8-week training period. Subjects held each stretch for 30 s at a point of mild discomfort, relaxed for 5 s, then repeated the same stretch for another 30 s before progressing to the opposite leg (when necessary). The specific stretches (in order of performance) were hip/low back stretch, chest/hamstring stretch, quadriceps stretch, calf stretch, triceps/hip stretch, adductor stretch, and v-sit hamstring stretch.

Plyometric training

The progressive plyometric training program used in this study was based on findings from previous investigations [29]. The plyometric program should use the principles of progression and overload. This can be accomplished by manipulating the volume dosage (reps, sets, weight, etc.) of many different variables. The quality of the work is more important with plyometrics than the quantity of the work. In fact, the exercises were periodized to allow a progressive adaptation of ligaments, tendons and bones for a volume of work that did not initially exceed 50/60 cumulative foot touches [30]. From weeks 1 to 4 the 5/4 level exercises were performed, that is, with a low physical impact for the bony and muscular structures (i.e., jumping rope, A-skip, medicine ball tosses, 20–40 cm double leg hurdle jumping), whereas from weeks 5 to 8 those of level 3/2, that is, to high physical impact (i.e., single leg hurdle hops, successive and alternated on short distances of 5–30 m, and 30–76 cm double leg hurdle jumping). Participants were instructed to

Table 1 Plyometric training program performed by CT group

	Weeks 1–4	Weeks 5–8
Plyometrics (20 min, 2 days week ⁻¹)	Jumping rope 1–3×30 s (basic bounce step, double basic bounce step, alternate foot step, scissor step, and double under)	Single leg hurdle hops 1–2×5–30 m
	A-skip 1–2×10 m	Alternate single leg hurdle hops 1–2×5–30 m
	Medicine ball tosses 1–2×10	Double leg hurdle jumps (30–76 cm) 1–2×6
	Double leg hurdle jumps (20–40 cm) 1–2×10	

All exercises were prescribed as sets×repetitions/distance/time. Inter-set rest duration was 60 s. for weeks 1–4 and 90 s. for weeks 5–8

perform all exercises with maximal effort. Table 1 shows the 8-week program of the plyometric training.

Resistance training

Following static stretching or plyometric training, all participants participated in the same progressive resistance training program. On Tuesdays all subjects performed three sets of 10 to 12 repetitions on the following exercises: barbell back squat, barbell lunge and standing calf raise. On Thursdays subjects performed three sets of 10 to 12 repetitions on the following exercises: barbell front squat, dumbbell step up and standing calf raise. External load was progressively increased each week by 5%. The last repetition of the third resistance training set on each exercise represented momentary muscular fatigue whereby participants were unable to perform additional repetitions. Following every resistance training session, subjects in both groups performed two sets of 12 to 25 repetitions of abdominal (e.g., abdominal curl) and lower back (e.g., kneeling trunk extension) strengthening exercises. Subjects were taught how to record their data on workout logs and did so throughout the training period. The instructors reviewed the workout logs daily and made appropriate adjustments in training weight and repetitions throughout the study period.

Statistical analysis

Descriptive data were calculated for all variables and presented as group mean values and standard deviations. Normality of all variables was tested using Shapiro–Wilk test procedure. Levene's test was used to determine homogeneity of variance. A multivariate analysis of variance (MANOVA) was used to detect differences between the study groups in all baseline variables. Training-related effects were assessed by 2-way analyses of variance with repeated measures (group×time). When 'Time×Group' interactions reached the level of significance, group-specific post hoc tests (i.e., paired t-tests) were conducted to identify the significant comparisons.

Percentage changes were calculated as [(posttraining value–pretraining value)/pretraining value]×100. The reliabilities of 20-m sprint time, vertical jump (Squat Jump) power, velocity, force and height average measurements were assessed using intraclass correlation coefficients; scores from 0.8 to 0.9 were considered as good, while values above > 0.9 were considered as high [31]. All analyses were performed using SAS Imp Statistics (v. 14.1, Cary, NC, USA) and statistical significance was set at $p < 0.05$.

Results

All participants received the treatment conditions as allocated. Twenty-four participants completed the training program, and none reported any training-related injury. The RT and CT groups did not differ significantly at baseline either in physical characteristics or fitness performance measures ($p > 0.05$). The characteristics of the study population are described in Table 2.

Significant main effects of 'Time' were observed on the vertical jump power and height, $F_{1,22} = 15.1$ and 20.2 , respectively, $p < 0.001$. Post-hoc analysis revealed that the CT group made significant improvements both in the power and height of the vertical jump ($p < 0.0001$), whereas the RT group showed no significant differences in the same measures. Significant 'Group×Time' interactions were found for the 20-m sprint and the vertical jump power, velocity, force and height, $F_{1,22} = 13.0, 17.6, 86.7, 16.9$, and 23.0 ,

Table 2 Anthropometric characteristics of the recruited subjects (mean±SD)

	RT ($n = 12$)	CT ($n = 12$)
Age (years)	13.1 (0.8)	13.3 (0.9)
Body mass (kg)	54.1 (1.7)	54.0 (4.2)
Height (m)	1.67 (0.04)	1.7 (0.04)
BMI (kg m ⁻²)	19.3 (0.7)	18.6 (1.05)

None of the group differences were significant ($p > 0.05$). *RT* Resistance training group, *CT* combined training (plyometric training and resistance training) group, *BMI* body mass index

Table 3 Fitness parameters in RT and CT groups

Variables	RT (<i>n</i> = 12)			CT (<i>n</i> = 12)		
	Baseline	Post	Δ%	Baseline	Post	Δ%
20-m sprint (s)	3.24 (0.26)	3.29 (0.23)	1.54	3.19 (0.19)	3.12 (0.22) ^{a,b}	− 2.19
Squat jump						
Power (W)	952.2 (235.8)	947.2 (202.1)	− 0.52	910.6 (180.1)	1069.6 (193.8) ^{a,b}	17.46
Velocity (m s ^{−1})	1.6 (0.19)	1.4 (0.27)	− 12.50	1.5 (0.12)	1.7 (0.13) ^{a,b}	13.33
Force (N)	605.1 (91.6)	547.7 (67.0)	− 9.49	602.2 (91.5)	643.4 (90.8) ^{a,b}	6.84
Height (cm)	34.2 (8.4)	33.9 (6.4)	− 0.88	28.5 (5.3)	39.1 (5.3) ^{a,b}	37.19

Data are presented as the mean (± SD)

RT Resistance training group, CT combined training (plyometric training and resistance training) group, Δ% individual percent change

^aSignificantly greater improvement from baseline ($p < 0.05$)

^bSignificant 'Time × Group' interaction = significant effect of the CT program ($p < 0.05$)

respectively, $p < 0.01$, with the CT group that showed significantly greater improvements in performance compared to the RT group ($p < 0.01$). Baseline and post-training fitness performance data are presented in Table 3.

Discussion

This research, through a randomized controlled trial study design, tested the hypothesis that two sessions per week of combined plyometric and resistance training performed for 8 weeks can cause a greater increase in fitness performance between 12- to 14-year-old boys than resistance training and static stretching. Results suggested that subjects that added plyometric training to resistance training program were able to achieve greater improvements in lower body speed and power as compared with subjects that participated in a conditioning program with resistance training and static stretching. From the results of this study it was observed that boys of the combined training group were able to make significant improvements in the sprint speed and vertical jump following a range of 8-week plyometric and resistance-based training programs. The current study also identified significant 'time × training group' interactions for jumping and sprinting variables, with combined training programs (i.e., Plyometric and resistance training) having a significant influence on the performance changes reported following the 8-week intervention period. Although the acute and chronic effects of static stretching on performance need to be considered, such improvements lower body power are likely due to the addition of plyometric training to the resistance training program.

These findings support previous studies where plyometric or resistance training was found to result in the greatest improvements in sprint speed and vertical jump for male adolescents [7–12, 18, 19, 32]. Although no tests on neuromuscular activation were performed in this study, plyometric

training may also prime the neuromuscular system for the demands of resistance training by activating additional neural pathways and enhancing to a greater degree the readiness of the neuromuscular system. This potential advantage may be particularly beneficial during the first few weeks of training when young participants are learning how to perform loaded exercises correctly. Besides, it is acknowledged that appropriately prescribed plyometric training enhances stretch–shortening cycle function in youth [24]. Accordingly, plyometric training appeared to stimulate the greatest gains in combined training (plyometric and resistance training) group, with significant improvements (range of %) reported for all sprinting and jumping variables. However, it was postulated that resistance training should be incorporated at an early age and prior to power/plyometric training to establish an adequate foundation of strength for power training activities [14].

In the present investigation, subjects that participated in the combined plyometric and resistance training program made significantly greater improvements in lower body power and speed than subjects that performed static stretching and resistance training. In fact, plyometric and resistance training enhanced lower body power (as measured by the squat jump) by 17.5% as compared to a − 0.5% gain by the group that performed static stretching and resistance training. Although combined plyometric and resistance training resulted in greater gains in vertical jump height performance than resistance training and static stretching (37.2% and − 0.9%, respectively), few were the gains in the 20-m sprint time (− 2.2% vs. 1.5%, respectively). This difference in the performances may be due to a specificity of the plyometric exercises which mainly involved a development in projection of the vertical component (elevation) rather than horizontal (advancement) and therefore to the choice of exercises in our plyometric training program. While lower body plyometric exercises have a vertical and horizontal component, most of the exercises focused on hopping or

jumping vertically. It appears that additional lower body plyometric exercises that focus on forward jumping may be needed to make gains in forward running performance beyond those that can be achieved from resistance training and static stretching. This suggestion is consistent with the findings from others that noted significant improvements in the running velocity performance in youth that regularly performed specific plyometric exercises [9, 12, 32–34].

It is also possible that the group that performed static stretching exercises before resistance training may have had an adverse effect on performance. Although static stretching before resistance training is a common practice for young, because regular long-term stretching may improve force production and velocity of contraction [35], evidence suggests that an acute bout of pre-event static stretching might negatively impact strength and power performance in children and adolescents [12, 28]. Therefore, we need to consider all this as we evaluate the results of this study. Clearly, further training studies are needed to assess whether the negative impact of an acute bout of static stretching will have long-term consequences on training induced gains in strength and power.

It should also be noted that performance gains were achieved without any occurrence of musculoskeletal injury. This finding provides further support to recommendations from international consensus statements that children should participate in a varied, technical competency driven, and age appropriate strength and conditioning program to facilitate athletic development [4], and to prevent the reduction of the fitness performance in sports activities caused by incorrect lifestyle habits [36]. In this regard, previous studies showed that a multilateral approach to training plays a key role in improving physical capacities and motor skills in adolescents [37]. In addition, it is always advised to be guided during the training by an expert in the sport sciences to prevent musculoskeletal injury which are very common among athletes that participate in conditioning programs [38]. Therefore, practitioners must ensure that youth of all ages are prescribed varied, periodized and developmentally appropriate training programs. Furthermore, rather than an independent entity, resistance training should be a component of an integrated approach to youth physical development, which targets multiple physical fitness qualities and aligns with the goals of long-term physical development strategies [4].

This study has some limitations that must be known. First, a resistance training only group was not included. A third group that performed only resistance training would have provided us with more information. But for organizational reasons this was not possible since it was difficult to find other available participants. However, the aim of the present randomized controlled study was on comparing the effects of 8 weeks of a combined plyometric and resistance

training with a resistance training and static stretching in male adolescents. Second, another test to evaluate the explosive strength of the lower limbs was considered, that is the squat jump with counter movement. In effect, during the introductory session to learn correct form and technique, participants were also asked to perform a fast-downward movement to approximately a 90° knee flexion immediately followed by a quick upward vertical movement, as high as possible for the subject, all in one sequence. However, the boys were unable to learn the correct technical gesture of the countermovement jump since they flexed their knees at different angles in each jump. Therefore, during the pre-testing we eliminated this test because it was not performed correctly and standardized, and also the reliability calculated with the intraclass correlation coefficient was poor. Finally, our findings were limited to 12 to 14-years-old boys. Future studies should extend these observations to school-aged girls, and to other age groups.

Conclusions

In summary, the novel findings of the study suggest that when seeking to induce specific acute adaptations in vertical jump and acceleration capacities, male adolescents may benefit more from exposure to a combination of plyometric and resistance training methods. Performance in these two methods differs in the time available in which to produce force. Plyometrics involve rapid movement speeds and high rates-of-force development, whereas resistance training allows for much longer contraction times to attain higher peak force outputs. Thus, plyometric training is necessary for tasks that require higher levels of reactive strength, whereas resistance training is required when aiming to improve tasks that place a high demand on concentric strength.

Author contributions FF designed the study, was involved in the interpretation of data, wrote and revised the manuscript. SC collected data and was involved in the interpretation of data and writing of the manuscript. GG designed the study, carried out the statistical analysis, interpreted the data, wrote and revised the manuscript. All authors contributed intellectually to the manuscript and all authors have read the manuscript and approved the submission.

Compliance with ethical standards

Conflict of interest The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Ethical approval All procedures performed in studies involving human participants were in accordance with the ethical standards of the University Institutional Review Board and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

Informed consent All participants and their parents received a complete explanation in advance about the purpose of the experiment and the parents provided written consent to the study.

References

1. Fatouros IG, Jamurtas AZ, Leontsini D et al (2000) Evaluation of plyometric exercise training, weight training, and their combination on vertical jumping performance and leg strength. *J Strength Cond Res* 14:470–476
2. Fleck SJ, Kraemer W (2014) Designing resistance training programs, 4th edn. Human Kinetics, Champaign
3. Faigenbaum AD, Kraemer WJ, Blimkie CJ, Jeffreys I, Micheli LJ, Nitka M, Rowland TW (2009) Youth resistance training: updated position statement paper from the national strength and conditioning association. *J Strength Cond Res* 23:S60–S79
4. Lloyd RS, Faigenbaum AD, Stone MH et al (2014) Position statement on youth resistance training: the 2014 international consensus. *Br J Sports Med* 48:498–505
5. Meylan CMP, Cronin JB, Oliver JL, Hopkins WG, Contreras B (2014) The effect of maturation on adaptations to strength training and detraining in 11–15-year-olds. *Scand J Med Sci Sports* 24:e156–e164
6. McNeely E, Armstrong L (2002) Strength training for children: a review and recommendations. *Phys Health Educ J* 68:1–6
7. Faigenbaum AD, Mediate P (2006) Effects of medicine ball training on fitness performance of high school physical education students. *Phys Educ* 63:160–167
8. Flanagan SP, Laubach LL, De Marco Jr GM et al (2002) Effects of two different strength training modes on motor performance in children. *Res Q Exerc Sport* 73:340–344
9. Kotzamanidis C (2006) Effect of plyometric training on running performance and vertical jumping in prepubertal boys. *J Strength Cond Res* 20:441–445
10. Matavulj D, Kukolj M, Ugarkovic D, Tihanyi J, Jaric S (2001) Effects of plyometric training on jumping performance in junior basketball players. *J Sports Med Phys Fitness* 41:159–164
11. Moran JJ, Sandercock GR, Ramírez-Campillo R, Meyla CM, Collison JA, Parry DA (2017) Age-related variation in male youth athletes' countermovement jump after plyometric training: a meta-analysis of controlled trials. *J Strength Cond Res* 31:552–565
12. Faigenbaum AD, Milliken L, Moulton L, Westcott WL (2005) Early muscular fitness adaptations in children in response to two different resistance training regimens. *Pediatr Exerc Sci* 17:237–248
13. World Health Organization (2010) Global recommendations on physical activity for health. World Health Organization, Geneva
14. Behm DG, Young JD, Whitten JH et al (2017) Effectiveness of traditional strength vs. power training on muscle strength, power and speed with youth: a systematic review and meta-analysis. *Front physiol* 8:423
15. Michaleff ZA, Kamper SJ (2011) Effects of resistance training in children and adolescents: a meta-analysis. *Br J Sports Med* 45:755. <https://doi.org/10.1136/bjsports-2011-090170>
16. Gomez-Bruton A, Matute-Llorente A, González-Agüero A, Casajús JA, Vicente-Rodríguez G (2017) Plyometric exercise and bone health in children and adolescents: a systematic review. *World J Pediatr* 13:112–121
17. Schranz N, Tomkinson G, Olds T (2013) What is the effect of resistance training on the strength, body composition and psychosocial status of overweight and obese children and adolescents? A systematic review and meta-analysis. *Sports Med* 43:893–907
18. Faigenbaum AD, McFarland JE, Keiper FB, Tevlin W, Ratamess NA, Kang J, Hoffman JR (2007) Effects of a short-term plyometric and resistance training program on fitness performance in boys age 12 to 15 years. *J Sports Sci Med* 6:519–525
19. Santos EJ, Janeira MA (2008) Effects of complex training on explosive strength in adolescent male basketball players. *J Strength Cond Res* 22:903–909
20. Shehab R, Mirabelli M, Gorenflo D, Feters MD (2006) Pre-exercise stretching and sports related injuries: knowledge, attitudes and practices. *Clin J Sport Med* 16:228–231
21. Haff G, Triplett NT (2015) Essentials of strength training and conditioning, 4th edn. Human Kinetics, Champaign
22. McHugh MP, Cosgrave CH (2010) To stretch or not to stretch: the role of stretching in injury prevention and performance. *Scand J Med Sci Sports* 20:169–181
23. Myer GD, Ford KR, Palumbo OP, Hewett TE (2005) Neuromuscular training improves performance and lower-extremity biomechanics in female athletes. *J Strength Cond Res* 19:51–60
24. Faul F, Erdfelder E, Lang AG, Buchner A (2007) G*Power 3: a flexible statistical power analysis program for the social, behavioral, and biomedical sciences. *Behav Res Methods* 39:175–191
25. Reiman M, Manske R (2009) Functional testing in human performance. Human Kinetics, Champaign
26. Markovic G, Dizdar D, Jukic I, Cardinale M (2004) Reliability and factorial validity of squat and countermovement jump tests. *J Strength Cond Res* 18:551–555
27. Balsalobre-Fernández C, Marchante D, Baz-Valle E, Alonso-Molero I, Jiménez SL, Muñoz-López M (2017) Analysis of wearable and smartphone-based technologies for the measurement of barbell velocity in different resistance training exercises. *Front Physiol* 8:649. <https://doi.org/10.3389/fphys.2017.00649>
28. Behm DG, Blazevich AJ, Kay AD, McHugh M (2016) Acute effects of muscle stretching on physical performance, range of motion, and injury incidence in healthy active individuals: a systematic review. *Appl Physiol Nutr Metab* 41:1–11
29. Chu D, Faigenbaum A, Falkel J (2006) Progressive plyometrics for kids. Healthy Learning, Monterey
30. Bompa TO, Buzzichelli CA (2018) Periodization: theory and methodology of training, 6th edn. Human Kinetics, Champaign
31. Vincent W, Weir JP (2012) Statistics in kinesiology, 4th edn. Human Kinetics, Champaign
32. Lloyd RS, Radnor JM, Croix MBDS, Cronin JB, Oliver JL (2016) Changes in sprint and jump performances after traditional, plyometric, and combined resistance training in male youth pre-and post-peak height velocity. *J Strength Cond Res* 30:1239–1247
33. Racil G, Zouhal H, Elmontassar W, Abderrahmane AB, De Sousa MV, Chamari K et al (2015) Plyometric exercise combined with high-intensity interval training improves metabolic abnormalities in young obese females more so than interval training alone. *Appl Physiol Nutr Metab* 41:103–109
34. Battaglia G, Paoli A, Bellafiore M, Bianco A, Palma A (2014) Influence of a sport-specific training background on vertical jumping and throwing performance in young female basketball and volleyball players. *J Sports Med Phys Fitness* 54:581–587
35. Hunter JP, Marshall RN (2002) Effects of power and flexibility training on vertical jump technique. *Med Sci Sports Exerc* 34:478–486
36. Greco G, Tambolini R, Ambruosi P, Fischetti F (2017) Negative effects of smartphone use on physical and technical performance of young footballers. *J Physical Educ Sports* 17:2495–2501
37. Fischetti F, Greco G (2017) Multilateral methods in physical education improve physical capacity and motor skills performance of the youth. *J Physical Educ Sports* 17:2160–2168
38. Greco G, Settimo M, Fischetti F (2018) Relationship between the correct running technique and lower back well-being perceived by the practitioner. *J Physical Educ Sports* 18:1796–1800

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