

Research article

Effects of a short-term plyometric and resistance training program on fitness performance in boys age 12 to 15 years

Avery D. Faigenbaum¹✉, James E. McFarland², Fred B. Keiper², William Tevlin¹, Nicholas A. Ratamess¹, Jie Kang¹ and Jay R. Hoffman¹

¹Department of Health and Exercise Science, The College of New Jersey, 2000 Pennington Road, Ewing, NJ 08628 USA, ²Physical Education Department, Hillsborough High School, 466 Raider Blvd. Hillsborough, NJ 08844 USA

Abstract

The purpose of this study was to compare the effects of a six week training period of combined plyometric and resistance training (PRT, n = 13) or resistance training alone (RT, n = 14) on fitness performance in boys (12-15 yr). The RT group performed static stretching exercises followed by resistance training whereas the PRT group performed plyometric exercises followed by the same resistance training program. The training duration per session for both groups was 90 min. At baseline and after training all participants were tested on the vertical jump, long jump, medicine ball toss, 9.1 m sprint, pro agility shuttle run and flexibility. The PRT group made significantly ($p < 0.05$) greater improvements than RT in long jump (10.8 cm vs. 2.2 cm), medicine ball toss (39.1 cm vs. 17.7 cm) and pro agility shuttle run time (-0.23 sec vs. -0.02 sec) following training. These findings suggest that the addition of plyometric training to a resistance training program may be more beneficial than resistance training and static stretching for enhancing selected measures of upper and lower body power in boys.

Key words: Adolescent, strength training, power, stretch-shortening cycle.

Introduction

Marked evidence indicates that regular participation in a resistance training program or a plyometric training program can improve measures of strength and power in adults (for reviews, see Chu, 1998; Fleck and Kraemer, 2004). Studies also suggest that changes in motor performance skills resulting from the performance of combined resistance training and plyometric training are greater than with either type of training alone (Adams et al., 1992; Fatouros et al., 2000; Polhemus et al. 1981). Thus, both resistance training and plyometric training are typically recommended for adults when gains in motor performance are desired.

In children and adolescents, it is well-established that training-induced gains in strength and power are indeed possible following participation in a resistance training program (Faigenbaum et al., 1996; Falk and Tenenbaum, 1996). More recent observations suggest that plyometric training may also be safe and effective for children and adolescents provided that age appropriate training guidelines are followed (Chu et al., 2006; Marginson et al., 2005). For example, Matalulj et al. (2001) found that plyometric training improved jumping performance in teenage basketball players and Kotzamanidis

(2006) reported that plyometric training enhanced jumping performance and running velocity in prepubertal boys. However, plyometric training is not intended to be a stand-alone exercise program (Bompa, 2000; Chu et al, 2006). As previously observed in adults, significantly greater gains in performance may be observed when plyometric training is combined with resistance training (Adams et al., 1992; Fatouros et al., 2000; Polhemus et al. 1981).

To our knowledge, no randomized, prospective studies have compared the effects of combined plyometric training and resistance training with resistance training and static stretching in children and adolescents. In previous reports involving youth, the effects of plyometric training were compared to a 'control' condition which consisted of sport training or physical education class (Cosser et al, 1999; Diallo et al., 2001; Kotzamanidis, 2006; Matalulj et al., 2001) or the study did not have a control group (Brown et al., 1986). Since young athletes are often encouraged to perform static stretching prior to resistance exercise (Martens, 2004), it is intriguing as to whether plyometric training and resistance training (without pre-event static stretching) can provide combinatory effects in younger populations. Given the growing popularity of youth strength and conditioning programs, and the perception among most youth coaches that pre-event static stretching is beneficial (Shehab et al., 2006), it is important to ascertain the most efficacious method for enhancing fitness performance in children and adolescents. This information would be useful to physical educators, sport coaches and health care providers.

Therefore, the purpose of the present investigation was to compare the effects of a 6-week training period of combined plyometric and resistance training with resistance training and static stretching on fitness performance in youth. Even though initial gains in strength and power due to training are mediated by neural factors (Fleck and Kraemer, 2004), we used a six week training program since previous investigations reported favorable changes in performance in youth (Martel et al, 2005; Myer et al, 2005) and adults (Adams et al., 1992; Vossen et al, 2000) following six weeks of resistance and/or plyometric training. We hypothesized that the combinatory effects of plyometric and resistance training would result in significantly greater improvements in performance as compared to resistance training and static stretching.

Methods

Participants

Twenty-seven healthy boys who participated in locally organized sports (principally baseball and American football) volunteered to take part in this study. The methods and procedures used in this study were approved by the Institutional Review Board for use of human subjects at the College, and informed written consent from the parents and assent from the children were obtained. Participants were randomly assigned to either a resistance training group ($n = 14$) or a combined resistance training and plyometric training group ($n = 13$). Baseline physical characteristics are presented by group in Table 1. Participants were excluded if they had a chronic pediatric disease or had an orthopedic condition that would limit their ability to perform exercise.

Table 1. Baseline physical characteristics. Data are means (\pm SD).

	RT ($n = 14$)	PRT ($n = 13$)
Age (years)	13.6 (.7)	13.4 (.9)
Body Mass (kg)	58.6 (14.4)	61.5 (21.8)
Height (m)	1.66 (.10)	1.64 (.10)
BMI ($\text{kg}\cdot\text{m}^{-2}$)	21.0 (3.8)	22.5 (5.9)

None of the group differences were significant. RT = resistance training group; PRT = Plyometric training and resistance training group; BMI = body mass index.

Study procedures

All study procedures took place at a school athletic facility. Even though all participants had prior experience performing the fitness tests used in this study, prior to data collection all participants participated in one introductory session during which time proper form and technique on each fitness test were reviewed and practiced. During this session research assistants demonstrated proper testing procedures and participants practiced each test. Any questions participants had were answered during this time. Participants were asked not to perform any vigorous physical activity the day before or the day of any study procedure. The same researchers tested and trained the same participants and the fitness tests were performed in the same order with identical equipment, positioning, and technique. Pre-testing was performed the week before the training period and post-testing was performed the week after the training period.

Fitness testing procedures

Power, acceleration, speed and agility were evaluated using the vertical jump, long jump, seated medicine ball toss, 9.1 m (10 yd) sprint and pro agility shuttle run. These tests are often used to assess performance in athletes (Arthur and Bailey, 1998). Lower back and hamstring flexibility were evaluated by the v-sit flexibility test in a temperature controlled environment. Standardized protocols for fitness testing were followed according to methods previously described (Harman and Pandorf, 2000; Safrit, 1995). The best score of two trials for each test was recorded to the nearest 0.5 cm. or 0.01 sec.

Briefly, the vertical jump was measured using the Vertec Jump Training System (Sports Imports, Hilliard, OH, USA). The Vertec has 49 color-coded, moveable vanes that are spaced 1.27 cm apart. Subjects were instructed to jump as high as possible and touch the highest

vane. The vertical jump was calculated by subtracting a subject's standing reach height from his maximal jump height. The standing long jump was measured on a mat which was fixed to the floor. Subjects were permitted to perform a countermovement (i.e., an active prestretch of the hip and knee extensors) prior to jumping vertically or horizontally.

The seated medicine ball toss was performed with a 3.6 kg medicine ball (about the size of a shotput). The participants sat on the floor with their back against a wall and were instructed to toss the ball as far as they could with both hands at an approximate angle of 45° (similar to a chest pass). Prior to each toss the ball was coated with magnesium carbonate (e.g., weightlifting chalk) so that when the ball landed on the floor it left a distinctive mark that allowed for a precise measurement. The distance from the wall to the near edge of the mark on the floor made by the ball was measured. The electronic Speed Trap II Timing System (Brower Timing Systems, Draper, Utah, USA) was used to time the 9.1 m sprint and pro agility shuttle run. The 9.1m sprint test was used to assess acceleration. For the pro agility shuttle run, the subjects started on a centerline facing the researcher. The subjects sprinted 4.55 m to the left, then 9.1 m to the right, and finally 4.55 m back to finish as they crossed the centerline. Scores resulting from improper technique or incorrect body positioning during any fitness test were discarded. Test-retest reliability intraclass Rs for all the dependent variables was $R \geq 0.85$. Test-retest reliability was established by testing 15 boys on two separate days. We did not assess maximal strength in this study because the variables of primary interest were upper and lower body power performance.

Training procedures

Both exercise groups trained twice per week on nonconsecutive days (Tuesday and Thursday) for six weeks under carefully monitored and controlled conditions. Prior to each training session, all subjects participated in a 10 minute warm-up period which included jogging at a self-selected comfortable pace followed by calisthenics. After the warm-up session, subjects in the resistance training group performed static stretching exercises (~25 min.). Although the potential benefits of an acute bout of static stretching have recently been questioned (Faigenbaum et al., 2005; Zakas et al., 2006), no studies suggest that regular stretching diminishes performance (Shrier, 2004). Subjects in the combined resistance training and plyometric training group performed plyometric exercises (~25 min). Following completion of the static stretching or plyometric training protocols, all subjects participated in the same resistance training program (~50 min). 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 minutes.

Throughout the study period, subjects exercised in small groups and an instructor to subject ratio of at least 1:4 was maintained. Experienced physical education teachers and certified strength and conditioning coaches discussed and demonstrated proper exercise technique throughout the study period. Teachers and coaches consistently encouraged the subjects to maintain proper tech-

nique 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 seven static stretching exercises in a slow, deliberate manner with proper body alignment during the six week training period. Subjects held each stretch for 30 seconds at a point of mild discomfort, relaxed for 5 seconds, then repeated the same stretch for another 30 seconds 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. The stretching protocol used in this study was consistent with general flexibility recommendations for school-aged children (American Alliance for Health, Physical Education, Recreation and Dance, 1999).

Plyometric training: The progressive plyometric training program used in this study was based on findings from previous investigations as well as observations from conditioning coaches and sports medicine professionals (Chu et al., 2006; Hewett et al, 1999; Myer et al, 2005). The components of this program included preparatory movement training and plyometric training. Prior to the performance of the plyometric exercises, subjects performed one or two sets of six to ten repetitions on two or three preparatory exercises (e.g., push-up, body weight squat) which prepared them for the demands of more advanced training. The inclusion of these exercises was especially important for subjects in this study who had no experience participating in a progressive plyometric program. The purpose was for these movements to become 'automatic' so the skill learned could be 'tapped' later on when subjects performed more advanced plyometric exercises.

The plyometric training program progressed from level one (weeks one and two; 1-2 sets of 10 repetitions) to level two (weeks three and four; 1-2 sets of 8 repetitions) and finally level three (weeks five and six; 1-2 sets of 6 repetitions). During weeks one, three and five, subjects performed only one set of each exercise because the plyometric training program stressed proper technique performance. During weeks two, four and six, subjects performed two sets of each exercise. Subjects performed 11 plyometric exercises during weeks one and two and 12 plyometric exercises during weeks three through six. A

summary of the plyometric exercise program is outlined in Table 2.

Subjects were encouraged to perform all plyometric exercises in an explosive manner. Level one included low intensity exercises (e.g., double leg hop) in order to safely introduce subjects to plyometric training. In addition, level one exercises provided the subjects with an opportunity to gain confidence in their abilities to perform basic plyometric movements before progressing to more advanced drills at levels two (e.g., double leg hurdle hop) and level three (e.g., single leg hurdle hop). Each exercise session included upper body plyometrics, lower body plyometrics and plyometric speed and agility drills which were specifically designed to enhance a subject's ability to accelerate, decelerate, change direction, and then accelerate again. Subjects performed each plyometric speed and agility drill once during weeks one, three and five and twice during weeks two, four and six. Subjects were provided with adequate time for recovery between exercises and sets. One abdominal exercise (e.g., medicine ball pullover sit-up) was incorporated into the plyometric training program to allow for additional recovery between upper and lower body plyometric exercises. A lightweight medicine ball (1-2 kg) was used for upper body medicine ball training.

Resistance training: Following static stretching or plyometric training, all participants participated in the same progressive resistance training program. The first 10 minutes of each resistance training session included a weightlifting progression (e.g., modified cleans and snatches) with a light load (wooden dowel or unloaded aluminum bar [~7 kg]). Subjects performed one to three sets of four repetitions on each lift. Following the weightlifting progression, subjects performed additional resistance training exercises. On Tuesdays all subjects performed three sets of 10 to 12 repetitions on the following exercises: squat, bench press, overhead press, lat pull-down, standing calf raise, and biceps curl. On Thursdays subjects performed three sets of 10 to 12 repetitions on the following exercises: front squat, incline press, lat pulldown, upright row, standing calf raise, and tricep extension. 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

Table 2. Summary of plyometric training program.

Weeks 1 and 2 1-2 sets / 10 repetitions	Weeks 3 and 4 1-2 sets / 8 repetitions	Weeks 5 and 6 1-2 sets / 6 repetitions
Double leg jump forward	Ankle jumps	Dot drill
Double leg jump backward	Hurdle hops	Single leg cone hops
Double leg "X" hop	Lateral cone hops	Long jump and sprint
MB 'stuffer flutter'	Zig-zag jump drill	Single leg zig-zag drill
Standing jump & reach	MB chest pass	MB lunge chest pass
Lateral taps on MB	Jump & turn 90°	Jump and turn 180°
MB overhead throw	High-5 drill	Tuck jumps
MB single leg dip	MB backwards throw	MB partner push pass
Arrow cone drill*	MB split squat	Split squat jump
Figure 8 drill*	Power skipping	Alternate bounding
	Clock drill*	X-drill*
	T-drill*	Shuttle drill*

MB = medicine ball; plyometric speed and agility drills were performed once during weeks 1, 3 and 5 and twice during weeks 2, 4 and 6. Details of the training program are discussed in the text.

Table 3. Fitness performance at baseline and post-training. Data are presented as the mean (\pm SD).

Variable	Group	Baseline	Post-training	$\Delta\%$
Vertical jump (cm)	RT	48.2 (10.7)	49.6 (10.1)	3.4 (5.2)
	PRT	43.1 (8.4)	46.5 (9.2) *	8.1 (7.2)
Long jump (cm)	RT	190.0 (23.1)	192.2 (25.4)	1.1 (4.3)
	PRT	181.1 (25.9)	191.9 (28.5) * †	6.0 (3.7)
9.1 m sprint (sec)	RT	2.1 (.14)	2.1 (.13)	.2 (4.0)
	PRT	2.2 (.12)	2.2 (.15)	.3 (4.6)
Shuttle run (sec)	RT	5.6 (.27)	5.6 (.25)	-.3 (3.5)
	PRT	5.6 (.18)	5.4 (.18) * †	-3.8 (5.1)
Ball Toss (cm)	RT	321.7 (58.0)	339.4 (59.1) *	5.6 (4.6)
	PRT	319.2 (96.9)	358.4 (85.2) * †	14.4 (9.8)
Flexibility (cm)	RT	20.5 (8.9)	25.6 (5.9) *	29.0 (244.9)
	PRT	18.4 (8.5)	21.2 (8.0) *	27.6 (49.2)

RT, resistance training group; PRT, plyometric training and resistance training group; $\Delta\%$, individual percent change. * Significantly greater improvement from baseline ($p < 0.05$). † Significantly greater improvement than in RT group ($p < 0.05$).

to 25 repetitions of abdominal (e.g., abdominal curl), lower back (e.g., kneeling trunk extension) and rotator cuff (e.g., external rotation) 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.

Data analysis

Descriptive data were calculated for all variables. Group differences at baseline were evaluated using independent sample t-tests. Separate two-way (group \times time) repeated measures ANOVA were performed to assess group differences for the variables of interest including vertical jump, long jump, seated medicine ball toss, 9.1 m sprint, pro agility shuttle run and flexibility. When significant main effects and interactions were observed, *post-hoc* paired t-tests corrected for alpha inflation (Bonferroni correction) were utilized for identifying the specific differences. All analyses were carried out using SPSS version 11.0 (SPSS, Inc. Chicago, IL) and statistical significance was set at $p < 0.05$.

Results

All participants attended all training sessions (100% compliance) and there were no injuries resulting from either training program. The PRT and RT groups did not differ significantly at baseline in any physical characteristics (Table 1). Likewise, there were no significant differences between groups at baseline with respect to the fitness performance measures. Significant main effects for time were observed on the vertical jump, long jump, pro agility shuttle run, medicine ball toss and flexibility, $F_{(1,25)} = 20.2, 17.9, 6.9, 80.8,$ and 19.9 , respectively, $p < .05$. Post-hoc analysis revealed that PRT made significant improvements on the vertical jump, long jump, pro agility shuttle run, medicine ball toss and flexibility whereas RT made significant improvements on the medicine ball toss and flexibility only. Significant group by time interactions were noted for the long jump, pro agility shuttle run, and medicine ball toss, $F_{(1,25)} = 7.9, 4.8,$ and 11.5 , respectively, $p < .05$, with the PRT group making significantly greater improvements in performance than RT. There

were no significant interaction effects between groups for the vertical jump, 9.1 m sprint and flexibility, $F_{(1,25)} = 3.6, 0.1,$ and 1.6 , respectively, $p > .05$. Baseline and post-training fitness performance data are presented in Table 3.

Discussion

We tested the hypothesis that six weeks of combined resistance training and plyometric training would lead to greater improvements in fitness performance in healthy boys than resistance training and static stretching. It was observed that subjects who added plyometric training to their conditioning program were able to achieve greater improvements in upper and lower body power as compared with subjects who participated in a conditioning program without plyometric training. Although the acute and chronic effects of static stretching on performance need to be considered, such improvements in upper and lower body power are likely due to the addition of plyometric training to the resistance training program.

Results from several investigations involving adults suggest that combining plyometric training with resistance training may be useful for enhancing muscular performance (Adams et al., 1992; Fatouros et al., 2000). For example, Fatouros and colleagues (2000) reported that after 12 weeks of training adult subjects who combined plyometric training with resistance training increased vertical jump performance by 15% whereas gains of 11% and 9% were reported for subjects who performed only resistance training or plyometric training, respectively. Similar findings were recently reported by Myer and colleagues (2005) who observed that a six week, multi-component training program which included resistance training, plyometric training and speed training significantly enhanced strength, jumping ability and speed in female adolescent athletes as compared to a non-exercising control group. In the aforementioned study (Myer et al, 2005), it is unknown which training component was most effective or whether the effects were combinatorial.

As previously observed in adult populations (Sale and MacDougall, 1981), it appears that training programs that include movements which are biomechanically and metabolically specific to the performance test may be more likely to induce improvements in selected perform-

ance measures. Although few if any training activities have 100% carryover to a sport or activity in terms of specificity, our findings suggest that a conditioning program which includes different types of training that are specific to the test (i.e., plyometric training and resistance training) and different loading schemes (i.e., high velocity jumps and heavy squatting) may be most effective for enhancing power performance in youth. High velocity plyometrics which consist of a rapid eccentric muscle action followed by a powerful concentric muscle action are important for enhancing the rate of force development during jumping and sprinting whereas heavy resistance training is needed to enhance muscular strength and acceleration (Fleck and Kraemer, 2004).

Thus the effects of plyometric training and resistance training may actually be synergistic, with their combined effects being greater than each program performed alone. 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. While this suggestion is consistent with the work of others (Linnamo et al., 2000), additional research is needed to explore the mechanisms responsible for these adaptations in youth.

It is also possible that the performance of static stretching exercises prior to resistance training may have had an adverse effect on performance. Although static stretching before resistance training is a common practice for young athletes (Martens, 2004; Shehab et al., 2006), recent evidence suggests that an acute bout of pre-event static stretching might negatively impact strength and power performance in children and adolescents (Faigenbaum et al., 2005; Zakas et al., 2006). Although regular long-term stretching may actually improve force production and velocity of contraction (Hortobagyi et al., 1985; Hunter and Marshall, 2002; Wilson et al., 1992), the acute effects of static stretching on strength and power performance should be considered when evaluating 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.

In the present investigation, subjects who participated in the combined plyometric and resistance training program made significantly greater improvements in upper body power, lower body power and speed and agility than subjects who performed static stretching and resistance training. Plyometric and resistance training enhanced upper body power (as measured by the seated medicine ball toss) by 14.4% as compared to a 5.6% gain by the group that performed static stretching and resistance training. While both groups performed upper body resistance training, this difference is likely due to the upper body plyometric exercises with medicine balls that were incorporated into the combined training program. These data concur with findings from Vossen and colleagues (2000) who noted that the addition of upper body

plyometrics may increase an athlete's ability to improve upper body performance.

Subjects in the plyometric and resistance training group also made significantly greater improvements in long jump performance than the static stretching and resistance training group (6.0% vs. 1.1%, respectively). Although combined plyometric and resistance training resulted in greater gains in vertical jump performance than resistance training and static stretching (8.1% and 3.4%, respectively), no significant difference between groups was observed, although a trend towards significance was noted ($p = 0.07$). These findings may be due to the choice of exercises in our plyometric training program. While lower body plyometric exercises had a vertical and horizontal component, a majority of the exercises focused on hopping or jumping forward as opposed to vertically. It appears that additional lower body plyometric exercises that focus on vertical jumping may be needed to make gains in vertical jump performance beyond those that can be achieved from resistance training and static stretching. This suggestion is consistent with the findings from others who noted significant improvements in the vertical jump performance in youth who regularly performed plyometric depth jumps which involve stepping off a box then jumping vertically as quickly and as high as possible (Diallo et al., 2001; Matalulj et al., 2001).

While some evidence suggests that plyometric training and resistance training can increase speed in adults (Delecluse et al., 1995), data on the effects of resistance training or combined plyometric training and resistance training on speed enhancement in youth are limited. Myer and colleagues (2005) demonstrated that a 6-week multi-component training program that included resistance training, plyometric training and speed training enhanced 9.1 m sprint performance in adolescent female athletes. Kotzamanidis (2006) reported that running velocity improved in prepubertal boys following 10 weeks of plyometric training. However, Kotzamanidis (2006) observed improvements in velocity for the running distances of 0 to 30 m, 10 to 20 m, and 20 to 30 m, but not for the distance of 0 to 10 m. In the present study, neither training program influenced sprint performance as measured by the 9.1 m sprint test. The short distance of 9.1 m did not permit participants to reach maximum running velocity.

Combined training significantly improved performance in the pro agility shuttle run as compared to resistance training alone (3.8% vs. 0.3%, respectively). This finding demonstrates the necessity of a multi-component conditioning program for enhancing performance in activities which involve acceleration, deceleration and a change of direction. It may be hypothesized that a comprehensive conditioning program that includes plyometric training, resistance training as well as technique oriented instruction on sprinting mechanics may be most likely to enhance running performance in youth.

The results of this investigation also demonstrate that both combined plyometric training and resistance training (without static stretching) and resistance training alone (with static stretching) can enhance flexibility in youth (as measured by the v-sit flexibility test).

Despite traditional concerns that resistance exercise may result in a loss of flexibility, results from the present investigation suggest that resistance training combined with static stretching or resistance training combined with plyometric training may enhance flexibility by about 28%. Others have reported flexibility gains in youth who participated in a resistance training program (Faigenbaum et al., 2005; Lillegard et al., 1997).

A limitation of this short-term study is that a resistance training only group was not included. However, the focus of the present study was on comparing the effects of six weeks of resistance training and plyometric training with resistance training and static stretching in boys. Also, we did not assess biological maturation before the start of the study. Although there were no baseline differences in physical or performance measures between groups, it is possible that participants in each group differed in biological maturation. Lastly, although the daily training duration for both groups was 90 minutes, the group that performed resistance training and plyometric training performed more physical conditioning than the group that performed resistance training and static stretching.

Conclusion

We have demonstrated that the addition of plyometric training to a resistance training program was more effective than resistance training and static stretching in improving upper and lower body power performance in boys. Our findings highlight the potential value of combined fitness training in a conditioning program aimed at maximizing power performance in youth, at least in the short-term. Owing to the growing popularity of youth strength and conditioning programs, additional long-term trials should be undertaken to explore the neuromuscular mechanisms responsible for training-induced adaptations in youth and investigate the effects of different types of training on diverse populations of children and adolescents.

Acknowledgements

The authors thank the administration and faculty at Hillsborough High School, Hillsborough, NJ, USA for their support of this research study. The authors also thank Jeff Schwerdtman, Kyle Newell and Mark Salandra for assistance with data collection.

References

- Adams, K., O'Shea, J.P., O'Shea, K.L. and Climstein, M. (1992) The effect of six weeks of squat, plyometric and squat-plyometric training on power production. *Journal of Strength and Conditioning Research* **6**, 36-41.
- American Alliance of Health, Physical Education, Recreation and Dance. (1999) *Physical best activity guide. Elementary Level*. Human Kinetics, Champaign, IL.
- Arthur, M. and Bailey, B. (1998) *Conditioning for football*. Human Kinetics, Champaign, IL.
- Bompa, T. (2000) *Total training for young champions*. Human Kinetics, Champaign, IL.
- Brown, M.E., Mayhew, J.L. and Boleach, L.W. (1986) Effect of plyometric training on vertical jump performance in high school basketball players. *Journal of Sports Medicine and Physical Fitness* **26**, 1-4.
- Chu, D.A. (1998) *Jumping into plyometrics*, 2nd edition. Human Kinetics, Champaign, IL.
- Chu, D., Faigenbaum, A. and Falkel, J. (2006) *Progressive plyometrics for kids*. Healthy Learning, Monterey, CA.
- Cossor, J.M., Blanksby, B.A. and Elliot, B.C. (1999) The influence of plyometric training on the freestyle tumble turn. *Journal of Science and Medicine in Sport* **2**, 106-116.
- Delecluse, C.H., Van Coppenolle, E., Willems, M., Van Leemputte, M., Diels, R. and Goris, M. (1995) Influence of high resistance and high velocity training on sprint performance. *Medicine and Science in Sports and Exercise* **27**, 1203-1209.
- Diallo, O., Dore, E., Duche, P. and Van Praagh, E. (2001) Effects of plyometric training followed by a reduced training programme on physical performance in prepubescent soccer players. *Journal of Sports Medicine and Physical Fitness* **41**, 342-348.
- Faigenbaum, A., Bellucci, M., Bernieri, A., Bakker, B. and Hoorens, K. (2005) Acute effects of different warm-up protocols on fitness performance in children. *Journal of Strength and Conditioning Research* **19**, 376-381.
- Faigenbaum, A.D., Kraemer, W.J., Cahill, B., Chandler, J., Dziados, J., Elfrink, L.D., Forman, E., Gaudiose, M., Micheli, L., Nitka, M. and Roberts, S. (1996) Youth resistance training: Position statement paper and literature review. *Strength and Conditioning Journal* **18**, 62-75.
- Faigenbaum, A.D., Milliken, L.A., Moulton, L. and Westcott, W.L. (2005) Early muscular fitness adaptations in children in response to two different resistance training regimens. *Pediatric Exercise Science* **17**, 237-248.
- Falk, B. and Tenenbaum, G. (1996) The effectiveness of resistance training in children. A meta-analysis. *Sports Medicine* **22**, 176-186.
- Fatouros, I.G., Jamurtas, A.Z., Leontsini, D., Kyriakos, T., Aggelousis, N., Kostopoulos, N. and Buckenmeyer, P. (2000) Evaluation of plyometric exercise training, weight training, and their combination on vertical jump performance and leg strength. *Journal of Strength and Conditioning Research* **14**, 470-476.
- Flanagan, S., Laubach, L., DeMarco, G., Alvarez, C., Borchers, S., Dressman, E., Gorka, C., Lauer, M., McKelvy, A., Metzler, M., Poepelman, J., Redmond, C., Rigenbach, M., Tichar, S., Wallis, K. and Weseli, D. (2002) Effects of two different strength training modes on motor performance in children. *Research Quarterly for Exercise and Sport* **73**, 340-344.
- Fleck, S.J. and Kraemer, W.J. (2004) *Designing resistance training programs*, 3rd edition. Human Kinetics, Champaign, IL.
- Harman, E. and Pandorf, C. (2000). Principles of test selection and administration. In: *Essentials of strength training and conditioning*. Eds: Baechle, T. and Earle, R. 2nd edition, Champaign, IL: Human Kinetics. 275-307.
- Hewett, T.E., Riccobene, J.V., Lindendorf, T.N. and Noyes, F.R. (1999) The effects of neuromuscular training on the incidence of knee injury in female athletes: A prospective study. *American Journal of Sports Medicine* **27**, 699-706.
- Hortobagyi, T., Faludi, J., Tihanyi, J. and Merkely, B. (1985) Effects of intense 'stretching' -flexibility training on the mechanical profile of the knee extensors and on the range of motion of the hip joint. *International Journal of Sports Medicine* **6**, 317-321.
- Hunter, J.P. and Marshall, R.N. (2002). Effects of power and flexibility training on vertical jump technique. *Medicine and Science and Sports and Exercise* **34**, 478-486.
- Kotzamanidis, C. (2006) Effect of plyometric training on running performance and vertical jumping in prepubertal boys. *Journal of Strength and Conditioning Research* **20**, 441-445.
- Lillegard, W., Brown, E., Wilson, D., Henderson, R. and Lewis, E. (1997) Efficacy of strength training in prepubescent to early postpubescent males and females: effects of gender and maturity. *Pediatric Rehabilitation* **1**, 147-157.
- Linnamo, V., Newton, R., Hakkinen, K., Komi, P., Davie, A., McGuigan, M. and Triplett-McBride, T. (2000) Neuromuscular responses to explosive and heavy resistance loading. *Journal of Electromyography and Kinesiology* **10**, 417-424.
- Marginson, V., Rowlands, A., Gleeson, N. and Eston, R. (2005) Comparison of the symptoms of exercise-induced muscle damage after and initial and repeated bout of plyometric exercise in men and boys. *Journal of Applied Physiology* **99**, 1174-1181.
- Martel, G., Harmer, M., Logan, J. and Parker, C. (2005) Aquatic plyometric training increases vertical jump in female vol-

- leyball players. *Medicine and Science in Sports and Exercise* **37**, 1814-1819.
- Martens R. (2004) *Successful coaching*. 3rd edition. Champaign, IL: Human Kinetics.
- Matavulj, D., Kukolj, M., Ugarkovic, J., Tihanyi, J. and Jaric, S. (2001) Effects of plyometric training on jumping performance in junior basketball players. *Journal of Sports Medicine and Physical Fitness* **41**, 159-164.
- Myer, G., Ford, K., Palumbo, J. and Hewitt, T. (2005) Neuromuscular training improves performance and lower extremity biomechanics in female athletes. *Journal of Strength and Conditioning Research* **19**, 51-60.
- Polhemus, R., Burkhart, E., Osina, M. and Patterson, M. (1981) The effects of plyometric training with ankle and vest weights on conventional weight training programs for men and women. *National Strength and Conditioning Association Journal* **2**, 13-15.
- Safrit, M. (1995) *Complete guide to youth fitness testing*. Human Kinetics, Champaign, IL.
- Sale, D. and MacDougall, D. (1981) Specificity in strength training: A review for the coach and athlete. *Canadian Journal of Applied Sports Science* **6**, 87-92.
- Shehab, R., Mirabelli, M., Gorenflo, D. and Fetters, M. (2006) Pre-exercise stretching and sports related injuries: Knowledge, attitudes and practices. *Clinical Journal of Sports Medicine* **16**, 228-231.
- Shrier, I. (2004) Does stretching improve performance? A systematic and critical review of the literature. *Clinical Journal of Sports Medicine* **14**, 267-273.
- Vossen, J.F., Burke, D.G. and Vossen, D.P. (2000) Comparison of dynamic push-up training and plyometric push-up training on upper-body power and strength. *Journal of Strength and Conditioning Research* **14**, 248-253.
- Wilson, G.J., Elliot, B.C. and Wood, G.A. (1992) Stretch shorten cycle performance enhancement through flexibility training. *Medicine and Science in Sports and Exercise* **24**, 116-123.
- Zakas, A., Doganis, G., Galazoulas, C. and Vamvakoudis, E. (2006) Effect of acute static stretching duration on isokinetic peak torque in prepubescent soccer players. *Pediatric Exercise Science* **18**, 252-261.

Key points

- Youth conditioning programs which include different types of training and different loading schemes (e.g., high velocity plyometrics and resistance training) may be most effective for enhancing power performance.
- The effects of resistance training and plyometric training may be synergistic in children, with their combined effects being greater than each program performed alone.

AUTHORS BIOGRAPHY

Avery D. FAIGENBAUM

Employment

Associate Professor, The College of New Jersey, Ewing, New Jersey, USA

Degrees

EdD, MS, BS

Research interests

Pediatric exercise science, resistance training

E-mail: faigenba@tcnj.edu

James E. McFARLAND

Employment

Teacher, Hillsborough High School, Hillsborough, NJ USA

Degrees

Med, BS

Fred B. KEIPER

Employment

Teacher, Amsterdam Elementary School, Hillsborough, NJ USA

Degree

BS

William TEVLIN

Employment

Student, The College of New Jersey, Ewing, New Jersey, USA

Degree

BS

Nicholas A. RATAMESS

Employment

Associate Professor, The College of New Jersey, Ewing, New Jersey, USA

Degrees

PhD, MS, BS

Research interests

Endocrinology and sports performance, resistance training.

Jie KANG

Employment

Professor, The College of New Jersey, Ewing, New Jersey, USA

Degrees

PhD, MS, BS

Research interests

Bioenergetics and body composition.

Jay R. HOFFMAN

Employment

Professor, The College of New Jersey, Ewing, New Jersey, USA

Degrees

PhD, MS, BS

Research interests

Endocrinology and sports performance, nutritional supplementation.

✉ Avery D. Faigenbaum, Ed.D.

Department of Health and Exercise Science, The College of New Jersey, 2000 Pennington Road, Ewing, NJ 08628 USA