ADAPTATIONS ASSOCIATED WITH AN AFTER-SCHOOL STRENGTH AND CONDITIONING PROGRAM IN MIDDLE-SCHOOL-AGED BOYS: A QUASI-EXPERIMENTAL DESIGN

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ABSTRACT

Thompson, BJ, Stock, MS, Mota, JA, Drusch, AS, DeFranco, RN, Cook, TR, and Hamm, MA. Adaptations associated with an after-school strength and conditioning program in middle-school aged boys: a quasi-experimental design. J Strength Cond Res 31(10): 2840–2851, 2017—High-intensity strength and conditioning programs aimed at improving youth performance are becoming increasingly prevalent. The purpose of this study was to investigate the effects of a 16-week after-school strength and conditioning program on performance and body composition in middle-school-aged boys. Subjects in the training group (n = 16, mean age = 11.8 years) performed 90 minutes of supervised plyometric and resistance training twice weekly for 16 weeks. A group of control subjects (n = 9, age = 12.1 years) maintained their current activity levels. Sprint speed, 5-10-5 pro agility, jump height, isometric peak torque of the leg extensors and flexors, and dual energy x-ray absorptiometry-derived body composition were examined during pretesting and posttesting. Data were analyzed by performing independent samples t-tests on the absolute change scores between groups. The primary findings were that the training intervention elicited significant improvements in 20-m sprint times (p = 0.03; mean change for training group = −0.17 seconds) and body-fat percentage (p = 0.03; 2.5% absolute improvement), the latter of which was a function of reduced fat mass (p = 0.06; −0.84 kg). Between-group differences were not noted for agility, jump height, lean mass, or strength measures; however, effect sizes generally showed greater improvements for the training group.

In contrast to findings in longitudinal studies performed in collegiate athletes, sprint speed may be particularly adaptable during adolescence. In addition to potentially improving sport performance, high-intensity plyometric and resistance training programs offer the added benefit of improved body composition. These programs appear less effective for agility and jump performance and do not elicit substantial improvements in muscle mass above maturation.

KEY WORDS resistance training, children, plyometrics, speed, body composition, lean mass

INTRODUCTION

The demand for young athletes to perform at high levels in American sports is increasing at an alarming rate. This fact is highlighted by debate concerning the appropriateness of sport and position specialization, and news reports of middle-school-aged boys being offered athletic scholarships by major Division I football programs. Not so coincidentally, strength and conditioning programs aimed at improving youth physical performance are becoming increasingly common, both in formal school settings and within the private sector. Thus, there is a need to fully understand the potential benefits and physiological implications of youth participation in strength and conditioning programs.

Although the majority of previous investigations have focused on the effects of strength development (8,10), recent studies have examined power and velocity adaptations to speed, agility, and/or plyometric training in youth. Katzmann-dis (18) examined the effects of 10 weeks of plyometric training on squat jump height and 30-m sprint speed in non-athletic boys (mean age = 11 years). The results indicated that the training group increased vertical jump height by nearly 8.0 cm. Similarly, 30-m sprint speed decreased from 5.55 ± 0.03 to 5.41 ± 0.60 seconds. Interestingly, the
plyometric training group did not show improvements for the 0–10 m split, which the author speculated may have been due to a lack of specificity for linear sprint acceleration. Faigenbaum et al. (10) compared the effects of 6 weeks of combined resistance and plyometric training versus resistance training only on fitness performance in boys (age = 12–14 years). The subjects trained twice per week, and each session was progressed in a conservative fashion. It was reported that the addition of plyometrics to the resistance training program resulted in significantly greater improvements in vertical jump height (% change = 3.4 vs. 8.1), long jump distance (1.1 vs. 6.0%), shuttle run (0.3 vs. 3.8%), and ball toss distance (5.6 vs. 14.4%). Faigenbaum et al. (10) concluded that their results were in agreement with those reported previously in adult populations, and hypothesized that plyometric training elicited specific neuromuscular adaptations that do not typically occur with conventional resistance training. Recent studies have also documented improved agility and power production after several weeks of plyometric training in youth soccer players (26,31). Interestingly, Thomas et al. (31) reported enhanced vertical jump height and agility performance, but no change in sprint ability, following 6 weeks of depth or countermovement jump training; whereas in contrast, Ingle et al. (16) found a significant but small (3%) improvement in 40-m sprint times as a result of 12 weeks of combined plyometric and resistance training in 12-year-old boys. Some specific characteristics of these previous studies include the implementation of a relatively short-term training period (6 weeks) (10,31), the absence of a resistance training component in combination with the plyometric training (18,26,31), incorporating plyometric training drills that were more focused on jumps rather than speed/agility (16,18,26,31), relatively older (17.4 years) (31) or highly trained youth (minimum of 4 years of soccer experience) (26,31), and lack of a control group design to account for the effects of natural maturation (10). Thus, research studies are lacking which simultaneously examine longer duration training programs (>12 weeks), combination plyometric and resistance training, both jump-specific and speed-specific plyometric training drills, and use a control group to account for natural maturation.

Regarding speed training in youth, it is noteworthy that investigators have documented improvements in sprint speed and agility, given that longitudinal studies in collegiate athletes have not been able to do so (13,15,17,24). Most notably, Hoffman et al. (13) examined longitudinal performance changes throughout collegiate careers in NCAA Division III football players. Two hundred eighty-nine players were studied over an 8 year period, and height, body composition, bench press and back squat strength, vertical jump height, 36.6-m sprint time, agility, and line-drill performance were assessed each season at the beginning of summer training camp. Hoffman et al. (13) reported that the improvements in bench press and back squat strength were statistically significant and meaningful (~30% change), particularly within the first 2 seasons. However, it was reported that sprint speed, agility, and vertical jump height showed minimal improvement. This result was in agreement with previous studies (15,24) and a more recent investigation by Jacobson et al. (17). The hypothesis put forward by Hoffman et al. (13) was that sprint speed and agility are genetically determined attributes that cannot be vastly improved throughout the course of a collegiate playing career. Based on the available evidence (8,13,15,17,24), it also seems reasonable to speculate that if speed, agility, power, and anaerobic conditioning levels are in fact adaptable, an optimal window of opportunity exists during childhood and adolescence when the nervous and muscular systems still exhibit substantial plasticity and there remains a high potential for improvements in motor coordination and technique-related determinants of maximal speed.

Another potentially favorable outcome of combining high-intensity plyometric and resistance training may involve improved body composition and metabolic health. Previous studies have shown beneficial changes in percent body fat and/or body composition from resistance training in children (5,28). Combining plyometric and resistance training may capitalize on the high-intensity attributes of these types of training, which may exceed the benefits of resistance training alone by inducing a greater total energy expenditure. Although previous studies confirm the health and body composition benefits of youth resistance training (5,8,28,29), the impact of combination training on these specific parameters remains under-investigated. These types of training modalities also offer the advantage of being viewed favorably by children because of the similarity with their movements during play (3,8,12), which may increase the likelihood of engagement and compliance, both of which are activity-based features necessary for the success of any performance or health promoting program. The discovery of effective training routines could have lofty implications for impacting the health of youth because of the continued high prevalence of metabolic- and obesity-related issues in this population (22). The importance of investigating this area of youth health was noted recently by experts (8) who suggested that “…additional randomized controlled trials are needed to further examine the effects of resistance training on metabolic health outcomes in youth” (pg. S66). Thus, more research is warranted examining the effects of longer duration (>12 weeks) high-intensity combination plyometric and resistance training on both performance and body composition outcomes in youth populations. The purpose of the present study was to investigate the effects of a 16-week after-school strength and conditioning program on performance measures including speed, agility, vertical jump, and lower-body strength, as well as body composition, in middle-school-aged boys.
METHODS

Experimental Approach to the Problem
This study used a quasi-experimental control design with repeated measures to investigate the effects of a 16-week combination plyometric and resistance training program on performance and health-related characteristics in middle-school-aged boys. Subjects in the training group performed 90 minutes of plyometric and resistance training, twice weekly for 16 weeks. The training program was designed and supervised by experienced strength and conditioning professionals. Outcome measures included 20-m sprint, 5-10-5 pro agility, vertical jump height, unilateral isometric strength, and body composition (body fat percent, fat mass, lean mass). We hypothesized that the high-intensity combination training program would elicit favorable effects on all measures compared with natural maturation (i.e., vs. the control group), with the exception of muscle size (lean mass) that has not been previously shown (19,25) to respond significantly to resistance training in similar youth populations.

Subjects
The training program for this study was conducted at a local business in Lubbock, TX during the fall of the 2014 and 2015 academic school years. Because of the extensive time commitment and the need for transportation to and from the training facility, a randomized-control design was not possible. Rather, an observational research design was implemented. Specifically, middle-school-aged boys were recruited at several local schools via word of mouth, flyers, and electronic messages that were distributed to the parent(s) or legal guardian(s) of each child. Each child was invited to participate in the training program. Boys that met the inclusion/exclusion criteria and wished to participate were enrolled in the training group. Those that met the inclusion/exclusion criteria but were unable to participate because of lack of transportation or an inability to commit to the program’s time demands were recruited to participate in the control group. Subjects in the training group were required to attend 75% of the training days to be included in the posttest.

Twenty-five middle-school-aged boys between the ages of 11–14 years completed the study. Sixteen boys elected to take part in the training program (mean ± SD: age = 11.8 ± 0.9 years, stature = 156.1 ± 9.2 cm, mass = 46.9 ± 11.9 kg, BMI = 19.1 ± 2.9 kg·m⁻²). The number of training subjects at each age was as follows: 11 years (eight); 12 years (five); 13 years (two); 14 years (one). Nine subjects were in the control group (age = 12.1 ± 0.93 years, stature = 153.7 ± 11.8 cm, mass = 41.9 ± 13.0 kg, BMI = 17.5 ± 3.4 kg·m⁻²). The number of control subjects at each age was as follows: 11 years (two); 12 years (five); 13 years (one); 14 years (one). The subjects had a normal mass as defined by the Centers for Disease Control and Prevention’s categorization of being within the fifth–85th percentile for their respective age (1). Individuals were not able to participate if they were affected by disease or recent musculoskeletal injury. The study procedures were approved by the Texas Tech University Human Research Protection Program (#504609). All subjects signed a child assent form before participation. In addition, a parent or legal guardian signed an informed consent form before enrollment. All subjects were engaged in their middle school’s physical education program, but none were actively participating in a structured exercise program. The subjects in the control group were asked to refrain from engaging in an organized training program designed to improve sport performance. All subjects were actively participating in at least one sport program (e.g., tennis, American football, swimming, karate, etc.) during the course of the study.

Procedures
Subjects were required to report to the laboratory on 3 separate occasions. The first session served as a familiarization trial during the school week before the pretest in which the subjects were carefully instructed on and practiced each of the performance testing procedures. The second and third sessions were the pretest and posttest, respectively. Testing was performed following an overnight fast (>8 hours) and occurred on Saturday and Sunday mornings between the hours of 8:00–10:00 AM. The subjects were asked to refrain from sports and vigorous physical activity for at least 24 hours before testing. Sixteen weeks separated the pretest and posttest during which time the training group performed the training intervention. The testing protocol consisted of the following (respective of order): dual energy x-ray absorptiometry (DXA) scans, isometric strength, vertical jump, sprints, and agility. Performance testing was performed in an indoor, temperature-controlled gymnasium. All subjects wore athletic clothing and tennis shoes during testing. Strong verbal encouragement was provided throughout testing. Technique-related instructions or tips for maximizing performance during jumping, sprinting, and agility tests were not provided during testing. The laboratory environment was carefully controlled and kept consistent for pretest and posttesting to ensure similar levels of subject arousal.

DXA
The subjects completed one total body scan using the DXA (Lunar Prodigy Primo; GE Healthcare, Madison, WI, USA) during both of the testing sessions. All scans were performed by a trained technician that had completed both university radiation training and a training session held by the device’s manufacturer. In accordance with the manufacturer’s recommendations, DXA quality assurance testing was performed within 24 hours before each scan. Each variable was analyzed with manufacturer-provided software (enCORE 2011; GE Healthcare). Variables included in this study comprised total-body fat mass (kg), lean mass (kg), and percent fat (%). Previous work from our laboratory has demonstrated high test–retest reliability for these measures (30).
In addition to total-body measures, right thigh lean mass (kg) was calculated using custom regions of interest for the sole purpose of normalizing the isometric strength data. Similar procedures have been performed previously in studies investigating the effects of aging on muscle quality (11). All regions of interest were determined by the same investigator using the software’s (enCORE 2011; GE Healthcare) polygon function. Regions of interest included only the muscle area involved in isometric strength testing. Each trace began superolateral to the greater trochanter (inferior to the anterior superior iliac spine) and moved distally toward the lateral epicondyle. Next, a line parallel to the distal femur crossed medially and connected to a subsequent line moving toward the inferior portion of the ischium. A diagonal line crossing the midline at the neck of the femur connected the quadrilateral box on the lateral side. The pelvic girdle and inferior leg were excluded from each calculation.

**Isometric Strength**
Strength assessments were performed on a Biodex System 3 dynamometer (Biodex Medical Systems, Shirley, NY, USA). Subjects were seated on the dynamometer and secured with restraining straps placed across the chest, hips, and thigh, and the lower leg was fixed to the dynamometer lever arm via a padded strap placed at 5 cm above the malleolus. Subjects performed a 10-repetition warm-up of dynamic leg extension and flexion muscle actions at 50% of maximum effort at a velocity of 90°·s⁻¹. Following a 2-minute rest period, subjects performed 3 isometric MVCs of the leg extensors and leg flexors in a randomized order. The MVCs were each separated by a 2-minute rest period. The knee joint angle was set at 60° for the leg extension and 30° for the leg flexion MVCs (7), and subjects were provided strong verbal encouragement during all MVCs, with instructions to “push” or “pull” “as hard and fast as you possibly can” for a total of 5 seconds. The torque signals were digitized at a sampling rate of 1,926 Hz (a preset commercial hardware device frequency), stored on a personal computer, and subsequently processed offline with custom written software (LabVIEW 8.5; National Instruments, Austin, TX, USA). Signals were filtered using a fourth-order, zero phase-shift, low-pass Butterworth filter with a 50-Hz cutoff frequency. Peak torque (PT, Nm) was calculated as the highest 500 milliseconds epoch across the entire torque–time curve and the highest MVC was used for further analyses. Additionally, a composite PT value was derived by summing the leg extensor and flexor PT values, as a means to collectively represent the lower-body strength values. Strength (PT) values were calculated as absolute (Nm) and normalized to thigh lean mass (Nm·kg⁻¹).

**Countermovement Vertical Jump**
The countermovement jump procedures have been described previously (32). Briefly, a Vertec (JUMPUSA.com, Sunnyvale, CA) was used for the jump tests. Before the jump testing, standing reach height was determined. Standing reach height was defined as the highest vane touched with the dominant hand and both feet remaining flat on the floor. Following standing reach height, countermovement jump testing was performed with the subject standing directly under the Vertec with the dominant shoulder aligned directly below the lateral edge of the lowest vane. Subjects were allowed to initiate the jump and performed the countermovement at a self-selected tempo, jumping as high as possible to push aside as many vanes as possible. Three trials were performed with 1 minute of recovery between the jump attempts. Maximal countermovement jump height (cm) was calculated by subtracting the standing reach height from the maximal absolute jump height.

**Sprint Speed**
Sprint speed was assessed with a 20-m maximal sprint test. The subjects performed 3 maximal effort sprints separated by 2 minutes of rest. The test began with the subjects in a 2-point crouched position. The toes of the dominant foot (based on kicking preference) were placed slightly behind the starting line and the toes of the nondominant foot were placed slightly behind the dominant heel. The subjects stood at the starting line with a modest forward lean and their knees slightly bent. Twenty-meter sprint speed was determined using an electronic timing gate system (TC-System; Brower Timing Systems, Draper, UT, USA). The best 2 trials were averaged for subsequent analyses.

**Agility**
The 5-10-5 proagility test was performed to assess agility, similar to the procedures of Vescovi et al. (33). The subjects performed 3 maximal trials separated by 2 minutes of rest. A slight modification of the test was implemented to provide a flying start to incorporate the use of the timing gates (TC-System; Brower Timing Systems). Execution of the test involved subjects sprinting maximally from the starting position to the end line (9.1 m) where they touched the gymnasium floor with their right hand, changed direction, and sprinted back to the starting line (9.1 m) where they then touched the floor with their left hand and made a final change of direction to sprint through the timing gates (4.6 m). Trials in which the subjects lost their balance or did not touch the ground were not considered suitable. The best 2 trials were averaged for the subsequent analyses.

**Training Procedures**
The subjects in the training group participated in the afterschool strength and conditioning program 2 evenings per week for 16 weeks (32 total training sessions). All training was closely supervised by coaches with undergraduate or graduate degrees in Exercise Physiology or a related field and Certified Strength and Conditioning Specialist certification through the National Strength and Conditioning Association. Training sessions were held every Monday, Tuesday, Thursday, and Saturday, but subjects were only required to attend 2 sessions and were asked to not be
present on both Monday and Tuesday to allow for adequate recovery. In the event of a missed training session, subjects were allowed to attend 3 sessions within the following 7 day period, but not on consecutive days. Each training session was held from 6:00 to 7:30 PM (90 minutes in duration). The first 45 minutes of each training session consisted of a brief active dynamic warm-up followed by high-intensity, short-duration balance training, plyometrics, speed work, and agility drills. During the second 45 minutes, the subjects completed the resistance training protocol. The primary rationale for each exercise or drill inclusion was on the basis of its potential to improve sport performance. Throughout the intervention, the subject-to-coach ratio never exceeded 4:1. Additionally, coaches demonstrated and encouraged proper technique with various visual and verbal cues. No injuries occurred as a result of the training.

Training began each day with a 5–10 minute warm-up that included dynamic stretches (e.g., walking toe touches, knee-to-chest walk) and calisthenic drills (e.g., body-weight squats, single leg calf raises). Following the warm-up, subjects engaged in a balance, plyometric, speed, and agility program that was designed to maximize sprint mechanics and linear and multidirectional speed and power. The program featured 3 groups of exercises that rotated on a weekly basis (e.g., block one was performed during weeks 1, 4, 7, etc.). Example exercises included front hurdle hops, depth jumps, long jumps, assisted/resisted sprinting, heel kicks, agility ladder work, and

Figure 1. Examples of the hang clean (top), back squat (middle), and deadlift (bottom) technique used in this study.
TABLE 1. Mean ± SD values for all variables before (pretest) and after (posttest) the 16-wk intervention period for the training and control groups.*†

<table>
<thead>
<tr>
<th>Variable</th>
<th>Training Pre</th>
<th>Post</th>
<th>Pretest–posttest change scores</th>
<th>Control Pre</th>
<th>Post</th>
<th>Pretest–posttest change scores</th>
</tr>
</thead>
<tbody>
<tr>
<td>Percent fat (%)</td>
<td>24.6 (8.2)</td>
<td>22.1 (8.7)</td>
<td>−2.5 (2.5)±</td>
<td>20.3 (8.9)</td>
<td>20.0 (7.9)</td>
<td>−0.33 (1.7)</td>
</tr>
<tr>
<td>Fat mass (kg)</td>
<td>11.6 (5.0)</td>
<td>10.7 (5.0)</td>
<td>−0.84 (1.4)§</td>
<td>9.2 (7.3)</td>
<td>9.4 (7.2)</td>
<td>0.16 (0.76)</td>
</tr>
<tr>
<td>Lean mass (kg)</td>
<td>33.4 (8.3)</td>
<td>35.9 (9.6)</td>
<td>2.5 (1.8)</td>
<td>31.1 (7.2)</td>
<td>32.7 (7.4)</td>
<td>1.5 (1.2)</td>
</tr>
<tr>
<td>20-m sprint (s)</td>
<td>4.28 (0.36)</td>
<td>4.10 (0.33)</td>
<td>−0.17 (0.15)‡</td>
<td>4.68 (4.7)</td>
<td>4.66 (4.4)</td>
<td>0.06 (0.26)</td>
</tr>
<tr>
<td>Agility (s)</td>
<td>5.63 (0.36)</td>
<td>5.51 (0.34)</td>
<td>0.12 (0.17)</td>
<td>6.52 (1.04)</td>
<td>6.28 (0.62)</td>
<td>0.27 (0.66)</td>
</tr>
<tr>
<td>Composite Peak torque (PT) (Nm)</td>
<td>147.1 (50.2)</td>
<td>173.5 (59.4)</td>
<td>26.4 (28.9)</td>
<td>143.4 (52.0)</td>
<td>151.5 (42.6)</td>
<td>8.1 (19.5)</td>
</tr>
<tr>
<td>Norm composite PT (Nm·kg⁻¹)</td>
<td>40.4 (7.2)</td>
<td>43.8 (6.1)</td>
<td>3.4 (6.8)</td>
<td>43.7 (9.0)</td>
<td>43.7 (5.2)</td>
<td>0.04 (6.3)</td>
</tr>
<tr>
<td>PT extensors (Nm)</td>
<td>100.6 (34.6)</td>
<td>116.1 (35.5)</td>
<td>15.5 (15.1)</td>
<td>98.9 (32.5)</td>
<td>104.1 (26.4)</td>
<td>5.2 (17.2)</td>
</tr>
<tr>
<td>Norm PT extensors (Nm·kg⁻¹)</td>
<td>27.7 (4.8)</td>
<td>29.6 (4.4)</td>
<td>1.9 (4.4)</td>
<td>30.6 (6.8)</td>
<td>30.3 (3.5)</td>
<td>−0.34 (5.6)</td>
</tr>
<tr>
<td>PT flexors (Nm)</td>
<td>46.5 (17.2)</td>
<td>57.4 (26.2)</td>
<td>10.9 (17.5)</td>
<td>44.6 (22.8)</td>
<td>47.5 (17.5)</td>
<td>2.9 (8.3)</td>
</tr>
<tr>
<td>Norm PT flexors (Nm·kg⁻¹)</td>
<td>12.8 (3.3)</td>
<td>14.3 (3.1)</td>
<td>1.5 (3.3)</td>
<td>13.1 (4.5)</td>
<td>13.5 (2.3)</td>
<td>0.37 (1.0)</td>
</tr>
<tr>
<td>Jump height (cm)</td>
<td>34.8 (6.3)</td>
<td>34.4 (6.8)</td>
<td>−0.32 (4.8)</td>
<td>29.3 (7.1)</td>
<td>28.3 (8.2)</td>
<td>−1.0 (7.9)</td>
</tr>
</tbody>
</table>

*Composite PT = sum of the leg extensor and flexor peak torque values; PT = peak torque; norm PT = peak torque normalized to the thigh lean mass (kg).

†Change scores = mean of individual pretest to posttest change scores.

§p = 0.06.

sled pull sprints. All drills were performed with maximal or near maximal effort and were ≤20 yards in distance. Rest periods between each attempt at a drill were generally ~60 seconds, and longer rest and hydration breaks were provided between different exercises. For many exercises, subjects worked in pairs, and one individual rested or assisted with a drill while the other was engaged in training. The performance of each drill was closely monitored, and feedback was provided to the subjects concerning methods of minimizing injury risk and maximizing performance, with one example being avoidance of knee valgus during landing. During the first several weeks of the program, coaches were conservative with respect to training advancement. Progressive overload was slowly implemented over time by adding additional repetitions or increasing training intensity when possible (e.g., increasing the height of a box jump). When possible, the intensity of each exercise was individualized to ensure an appropriate degree of training stress and progression (e.g., different sized boxes or hurdles for each subject).

The resistance training program featured 2 days with differing exercises that were alternated each visit. All exercises were performed with a 6.82 or 20.45 kg barbell. The first day included the back squat, incline bench press, Romanian deadlift, wide-grip bent row, and hang clean. The second day included the deadlift, bench press, front squat, close-grip bench row, and push press. In general, progress in
emphasis was placed on proper resistance training technique to ensure that the subjects understood how each exercise was to be performed. During these training sessions, the subjects trained with either a PVC pipe or a 6.82 kg barbell. With the exception of the hang clean and push press, the concentric and eccentric phases of each exercise were performed with a standardized 1–2 seconds cadence. For the hang clean and push press, the subjects performed each repetition as rapidly as possible. Because of the age and lack of training experience of the subjects, training loads were not based on the results of repetition-maximum testing at the beginning of the investigation. Instead, the subjects began the study using light-to-moderate external loads that allowed for proper technique, and additional weight was progressively added throughout the 16 weeks. Increases in training load were made at the coach’s discretion. In most cases, 2.273 kg increases were made, but the use of 0.113, 0.227, 0.340, and 0.430 kg fractional plates (Rogue Fitness HQ, Columbus, OH, USA) allowed for small adjustments in training load, particularly for the upper-body exercises. Decisions regarding changes in external loads were largely based on exercise technique and perceived barbell velocity. In the event that the subjects could not perform 5 repetitions for a given external load, or if exercise technique became compromised because of excessive fatigue (e.g., squats performed above parallel or lumbar flexion during the deadlift), weight was removed from the barbell for the next set. During the 20th training session, 5 repetition-maximum strength testing was performed for the back squat, deadlift, and incline bench press exercises using guidelines described previously (2), and subsequent training loads were modified based on these results. Each subject kept a handwritten training journal detailing perception of effort and fatigue, and the load used for each exercise. Training logs were carefully evaluated by coaches and study investigators during weekly meetings, and subsequent training loads were assigned based on each subject’s training technique and the ability to perform the previously assigned workout.

**Statistical Analyses**

Independent samples t-tests were used to compare baseline demographics between the groups. The use of analyses of covariance to adjust for minor baseline differences was considered, but the lack of group randomization made this impermissible (34). Thus, to examine the effects of the 16-week intervention, the absolute change scores were calculated for each variable. Independent samples t-tests were then used to compare the change score differences between the experimental and control groups. Additionally, the data were analyzed using the Cohen’s $d$ effect size statistic for pretest to posttest changes. Effect size values of 0.2, 0.5, and 0.8 corresponded to small, moderate, and large differences, respectively. An alpha level of 0.05 was used to determine statistical significance and SPSS software (version 23.0; IBM Corporation, Armonk, NY, USA) was used for statistical analyses.

**RESULTS**

There were no differences between the groups at baseline for age ($p = 0.36$), stature ($p = 0.58$), mass ($p = 0.33$), BMI ($p = 0.23$), or percent body fat ($p = 0.24$). There were also no baseline differences between the groups for leg extensor ($p = 0.90$) or flexor ($p = 0.81$) PT values.

Table 1 presents the mean ± SD values for each of the variables before and after the 16-week period for the training and control groups. For percent body fat, there were greater ($p = 0.03$) pretest to posttest changes for the training ($-2.49 \pm 2.5\%$) compared with the control ($-0.33 \pm 1.7\%$) group. There were no differences between the groups for total lean mass change scores ($p = 0.13, 2.54 \pm 1.79$ vs. $1.51 \pm 1.15$ kg for training and control, respectively) or fat mass ($p = 0.06, -0.84 \pm 1.41$ vs. $0.16 \pm 0.76$ kg).
The 20-m sprint change scores showed greater ($p = 0.03$) improvements for the training ($-0.17 \pm 0.15$ seconds) compared with the control group ($0.06 \pm 0.26$ seconds). Figure 2 shows individual change scores for the percent body fat and 20-m sprint variables.

No differences were observed between the groups for the agility ($p = 0.52,-0.12 \pm 0.17$ vs. $-0.27 \pm 0.66$ seconds for training and control groups, respectively) or jump performances ($p = 0.78,-0.32 \pm 4.79$ vs. $-1.03 \pm 7.89$ cm).

No significant group differences were revealed for absolute ($p = 0.11,26.35 \pm 28.87$ vs. $8.08 \pm 19.53$ Nm for the training and control groups, respectively) or normalized ($p = 0.24,3.39 \pm 6.81$ vs. $0.04 \pm 6.30$ Nm·kg$^{-1}$) composite PT. There were also no between group differences for either the leg extensor absolute ($p = 0.13,15.49 \pm 15.14$ vs. $5.20 \pm 17.16$ Nm) or normalized ($p = 0.27,1.93 \pm 4.42$ vs. $-0.34 \pm 5.58$ Nm·kg$^{-1}$) PT values and the leg flexor absolute ($p = 0.21,10.87 \pm 17.54$ vs. $2.88 \pm 8.33$ Nm) or normalized ($p = 0.43,1.46 \pm 3.31$ vs. $0.37 \pm 3.01$ Nm·kg$^{-1}$) PT values. The effect sizes for all variables are presented in Figure 3.

**DISCUSSION**

The present findings demonstrated that a 16-week combination plyometric and resistance training program elicited significant improvements in 20-m sprint performance and body composition in middle-school-aged boys. Although larger effect sizes were typically observed for the training group, substantial improvements above and beyond normal maturation were not noted for agility, lean mass, and lower-body isometric strength measures.

A key finding of this investigation is the improved 20-m sprint times for the training group as a result of the 16-week training program, whereas the control group exhibited a small increase in sprint times (Table 1 and Figures 2B and 3). The 4.7% sprint improvement in this study was slightly higher than the significant 3.1% improvement in 40-m sprint times reported by Ingle et al. (16) following a 12-week plyometric and resistance program in ~12-year-old boys. In contrast, Faigenbaum et al. (10) showed no change in 9.1-m sprint times following 6 weeks of either resistance training or resistance training and plyometrics. Discrepancies between these findings and Faigenbaum et al. (10) may be because of differences in the length of the training term (16 vs. 6-weeks), baseline age (11.9 vs. 13.5 years), sprint distances measured (20 vs. 9.1-m), and training program. For example, the present study likely had a heavier focus and volume on sprint technique and speed-based drills compared with their study and the greater sprint distance (20-m) in this study may have allowed for greater expression of gains at maximal speed.

Interestingly, improvements above normal maturation were not observed for the agility test. Both groups experienced modest but nonsignificant improvements in agility (effect sizes of 0.34 and 0.33 for training and control groups, Figure 3). This finding also appears to be in contrast to Faigenbaum et al. (10) who reported significant improvements of 3.8% in the proagility run for the plyometric and resistance training group. However, a similar magnitude of improvement in agility performance was found in the present control group, suggesting that in 11–14-year-old boys, agility seems to improve to a higher extent than maximal running speed simply because of the natural processes of growth and development. Although the reason for this is unknown, we can only speculate that perhaps biological growth factors (i.e., height or limb length increases) or enhanced motor development or learning effects may elicit favorable effects on agility performance over a 4-month period in middle-school-aged boys. Further work is needed to discover the potential mechanisms behind this finding.

Vertical jump performance showed no improvement in either group, which is a perplexing finding, given the jump drills that were performed in the training group. These findings are not in agreement with previous research that has reported significant increases in vertical jump between 3.4 and 34.6% (9,10,16,18) following resistance training and/or resistance training and plyometric programs ranging from 6 to 12 weeks.
Evidence suggests that for middle-school-aged boys, running performance determinants may be highly influenced by technique (6,10), balance (6), motor performance and coordination (4,20), and anthropometrics (height, limb length, mass etc.) (20,21) and that increasing maturity at this age changes sprint mechanics (20). Meyers et al. (20) recently showed that sprint speed may not increase in 11–13-year-old boys, despite increases in stride length and ground contact time and decreased stride frequency. This may shed light on the present findings showing no improvement in sprint times for the control group, whereas modest improvements were observed in agility. A slight shift during maturation toward greater contact times and higher stride lengths would likely be favorable factors for improving agility times because of the higher force requirements necessary for acceleration and change of direction inherent to the agility task. The heavy focus on speed technique in the present training program may have yielded more favorable running mechanics for the training group. Future research is needed to quantify running mechanical changes as a result of the potential interaction of maturity and similar training programs as the present study in middle-school-aged boys. Notably, the aforementioned maturation-based, running-related adaptations may not necessarily have positively influenced vertical jump given the heavy reliance on this performance to high force output relative to body weight. An increase in body mass with only modest gains in strength may have been prohibiting factors for improved vertical jump for the boys in the current study. This scenario may be specific to middle-school-aged boys, whereas maturity changes that follow (increased muscle and strength) may then permit improved vertical jump. This hypothesis may explain why Faigenbaum et al. (9) found a modest 4.5% gain in VJ following a resistance training program in slightly older boys (13.9 vs. 11.9 years for the present study). Finally, it is also possible that training volume requirements differ between performance types, such that more volume/frequency is needed to elicit meaningful changes in agility and particularly vertical jump performance, specifically in 11–14-year-old boys, whereas speed may be improved with a combination of moderate volume training and favorable anthropometric changes over the course of a several month period. More research is needed to unravel the specific effects of training volume, intensity, and exercise mode on the different performance types specifically for middle-school-aged boys.

The combination training program of the current study elicited improved body composition—resulting largely from a proportionally higher loss of fat mass compared with the control group. The training group displayed a mean relative reduction in percent body fat of ~10% compared with the negligible 1.5% decrease for the control group. This is a notable and meaningful finding given the alarming worldwide increase in the prevalence of childhood obesity. Although previous authors (5,8,28) have noted resistance training induced favorable body composition effects in children and adolescents, previous studies that have examined these effects in children have included populations categorized as obese (29,35), or in conjunction with a hypocaloric dietary intervention (28,35), unlike the present study which examined a fairly typical youth body composition demographic and which did not manipulate any aspect of the subject’s diet. Also, the previous studies have not examined the effects of a relatively high-intensity combined plyometric and resistance training program. Benson et al. (5) investigated the effects of 8 weeks of progress resistance training in ~12-year-old boys and girls with baseline body fat percent similar to the present study subjects (i.e., 20–24%) and reported a significantly greater body fat percent reduction between the training and control groups; however, one reason for their observed interaction was likely the increase in body fat percent for the control group (1.2%), whereas the training group showed only a mean relative reduction of 1.3%. Thus, the present study showed a substantially larger reduction in relative body fat vs. Benson et al. (5) and was also substantially higher than the negligible 0.2% percent body fat lost in a study conducted by Yu et al. (35) following 6 weeks of resistance training in obese children. A likely explanation for the greater body fat improvements in this study could be the combined training program, which included plyometrics in addition to resistance training and the longer (16 vs. 6–8 weeks) duration of the program. The 90-minute combination of plyometric and resistance training at relatively high intensities performed twice per week was likely responsible for inducing a sufficient energy expenditure/deficit to elicit fat loss in this population although it is also plausible that a portion of the energy deficit was attributed to increased daily spontaneous physical activity (19). Future studies are needed that examine daily physical activity patterns to help elucidate the factors contributing to body fat reductions induced by combination plyometric and resistance training in youth populations. These results show that these type of training programs may be promising interventional approaches for the effective management of body weight and composition issues highly prevalent in today’s youth, particularly as it has been suggested that youth tend to enjoy resistance-training-type exercise because of the short periods of activity separated by brief periods of rest because this is congruent with how youth move and play (3,8,12).

There were no significant differences between groups noted for any of the strength-related variables. However, some caution should be employed when examining these findings as the effect size statistics do show a tendency for higher strength gains for the training group. For example, the effect sizes for the training group showed strength changes of 0.46–0.51, which are noticeably higher than the control group (−0.07 to 0.18) for all strength variables. Previous studies (9,19,25) have reported significant strength improvements between 13 and 36% in comparable youth populations as the present study. Meinhardt and colleagues (19)
showed that 19 weeks of multijoint resistance training elicited a 36% improvement in leg press strength for ~12-year-old boys, which was substantially higher than the present strength gains ranging between 15.4 and 23.4% for the training group. Differences in testing procedures may explain some of the variance between these studies as Meinhardt et al. (19) used the multijoint leg press to assess strength, whereas the present study assessed strength using isometric knee extensions. It is likely that some of the strength gains induced by the training program may have been concealed because of lack of testing specificity (27). Because of the potential vulnerability of the present study population, we elected to use isometric tests of lower-body strength because of the advantages of this testing for safety and reliability (23).

In a study by Ramsay et al. (25), similar isometric assessments were used as the present study in which these researchers examined a 20-week circuit training program in 9–11-year-old boys and showed significant isometric knee extension strength gains of 13%. It is noteworthy that although traditional statistical outcomes differ between the present findings and those of Ramsay et al. (25), the present 15.4% mean increase in leg extensor PT is in agreement with their study. Also, a close examination of their data shows their control group improved knee extensor strength by ~7%, which was also similar to the present control group improvement of 5.3%. Collectively, we interpret these findings to reveal that 16 weeks of combined plyometric and resistance training program in middle-school-aged boys may elicit some modest gains in strength, slightly higher than that occurring from natural maturation. However, future studies are needed which examine different training program variations, such as higher frequency of training (3 vs 2 times per week) and multiple strength outcome assessments to better quantify the strength gain potential and elucidate the optimal programming needs for strength improvements in this youth population. Finally, no training-specific differences in lean mass were noted, which corroborates previous research (16,25), showing no resistance training effects on muscle mass gains in middle-school-aged children. These findings regarding the ineffectiveness of resistance training to improve muscle mass are likely explained by the inadequate levels of circulating androgens in prepubertal children (25). Thus, gains in strength at this age level are most likely exclusively owed to improved motor skill coordination, motor unit activation, and various other neurological-specific adaptations (25).

Like all research investigations, the present study had limitations. Three seem particularly important. The first and most obvious limitation was that the logistics of the training program made it impractical to perform a true randomized control trial, which is often considered the gold standard of medical research (14). As a result, the lack of group randomization may have had direct implications on the results. It could be argued, for example, that the parents that agreed to allow their child to enroll in the training group may have been more motivated to maintain a healthier lifestyle, thereby providing less calorically dense foods. Nonetheless, controlling the diets of the middle-school-aged children in this investigation seemed particularly challenging and unreasonable. A second potential limitation that should be considered is the subjects’ potential lack of motivation to perform testing. Although this is an important consideration in all human trials, it seems particularly pertinent in performance-based studies in children. Because of the need to control for time of day and difficulty scheduling the subjects’ visits for testing following an overnight fast, the decision was made to perform all testing between the hours of 8:00–10:00 AM, a time when most subjects acknowledged was difficult to make following a 5-day school week. Thus, we concede that motivation to perform each test with a consistent level of effort may have influenced this investigation’s findings. This suggestion could be supported by the fact that the body composition results showed arguably the greatest improvement in the training group, yet this test required no effort on the part of the subjects. Finally, the pragmatic nature of the study’s design did not allow for subjects to be randomly assigned to groups based on indices of biological development (e.g., Tanner stages). Although this investigation only included middle-school boys and the 2 groups had a similar mean age (each with one 14 year old), the physical maturity of the subjects varied widely. In an ideal scenario, a large group of middle-school boys with similar training backgrounds and at identical Tanner stages would be randomly assigned to various interventions. These 3 potential limitations highlight the challenges associated with performing highly controlled training studies in middle-school-aged children.

Practical Applications

A 16-week combination plyometric and resistance training program significantly improved linear maximal running speed and body composition, largely from fat loss, in middle-school-aged boys. Substantial improvements in lower-body strength, muscle mass, and agility were not found. However, a close examination of the data suggests that a moderate effect of training may be present for lower-body strength, when compared to natural maturation. Research is needed which examines variations in training programing variables, specific to combined training programs (e.g., plyometrics and resistance training), to determine the most appropriate programming features capable of inducing favorable performance and health effects in middle-school-aged children. These findings highlight that a particularly important benefit of combined high-intensity training programs at this age level appears to favor rather large improvements in body composition. Such a training approach may prove beneficial for not only performance-related gains, but in managing the unfavorable health effects associated with metabolic issues in youth, which may be effectively improved by performing plyometric and
resistance combination training as little as 2 times per week.

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This manuscript is dedicated to the memory of Jeffrey D. Law (February 14, 1990–August 10, 2015). Jeff received his MS in Exercise and Sports Sciences at Texas Tech University in December 2013. He was passionate about the Strength and Conditioning profession, and did everything he could to perfect his craft. His desire to learn, can-do attitude, and charisma were contagious. Jeff is sorely missed, but his positive spirit lives on in all of those that were so lucky to have known him.

References


