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Effects of Combined Training on Physical Fitness and Anthropometric Measures among Boys Aged 8 to 12 Years in the Physical Education Setting

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Abstract: Some studies have shown that resistance training combined with plyometric training is more time-efficient and effective for fitness development. The degree and frequency of combined training might influence the benefit of training to maintain time. To better understand this phenomenon of the degree and frequency of combined training in pre- and early pubertal boys, we have provided a more specific recommendation for physical education teachers thus that they are able to prescribe an exercise plan for their students in the physical education setting. We aimed to investigate the effects of combined training followed by 12 weeks of a reduced/detraining period on physical fitness and anthropometric features in 8 to 12-year old boys. Forty-six healthy boys were randomly assigned to either an experimental group (EG, $n = 31$) or a control group (CG, $n = 15$). Besides regular physical education classes (PE), participants in the EG performed a combined training program (resistance and plyometric training) twice weekly for 12 weeks. In the CG, participants only underwent PE classes twice per week. Then, the trained boys were randomly assigned to either a reduced training group (RTG, n = 14) or a training cessation group (TCG, n = 17). The RTG continued a reduced combined training program once a week with PE for additional 12 weeks. In the TCG, participants only kept their PE classes twice a week for 12 weeks. We assessed physical fitness performances (biceps curl, leg power, and running speed) and anthropometric features at baseline, after 12 weeks of combined training, and after 12 weeks of reduced training/detraining. We observed a significantly greater decrease in biceps girth in the EG ($p = 0.049$, $d = 0.636$), as compared to the CG. With regard to the physical fitness measures after the 12-week combined training, the EG showed significantly greater increase on biceps curl ($p = 0.005$, $d = 0.92$) and standing long jump ($p = 0.015$, $d = 0.8$) in comparison with the CG, whereas a significantly greater improvement on 30 m sprint speed ($p = 0.031$, $d = 0.707$) was observed in the EG, as compared to the CG. With regard to detraining and reduced training, results indicated a significantly greater increase on this outcome in the RTG ($p = 0.038$, $d = 0.938$), as compared to the TCG. Resistance training combined with plyometric training can be a safe and effective way to enhance the selected aspects of physical fitness, as well as reduce muscular girth in boys aged between 8 and 12 years. The frequency of one session per week in the combined training seems to provide an additional benefit to prevent leg power of lower limb from rapid deterioration.

Keywords: resistance training; plyometric training; reduced training; combined training; physical fitness; children; anthropometric characteristics

1. Introduction

Physical fitness, the ability to efficiently perform leisure activities and advanced motor skills in sports, is widely recognized as a major component of overall physical well-being across the lifespan [1,2]. Individuals with a high physical fitness level are associated more with a reduced risk of chronic disease [3]. Physical fitness is partially genetically determined, but it can also be greatly influenced by physical exercise [4]. The World Health Organization and the U.S. Department of Health and Human Services have recommended that school-aged children should engage in at least 60 min per day of moderate-intensity physical activity [5,6]. Previous reviews indicated that resistance [7] and plyometric training [8] are safe and effective in enchanting some selected aspects of physical fitness among school-age children. Specifically, some individual studies have shown that resistance training has positive effects on muscular strength and body composition [9–14] and lower-limb power [10–12,15,16] in children. Of note, positive effects of resistance training can last regardless of detraining [15,16], and another two studies [17,18] indicated that muscular strength can revert back to primary strength level after 8 weeks of detraining. On a different note, plyometric training alone can enhance running speed and lower-limb power [19–22] and muscular strength [23,24] of adolescents. Furthermore, these improvements can be maintained after 8 or 16 weeks of reduced training or detraining [12,19]. Furthermore, researchers recently found that resistance training combined with plyometric exercises did not only improve physical fitness performance (upper- and lower-limb strength) [25], but it was also able to reduce sports-related anterior cruciate ligament injuries in school-age children [26]. Combined training (resistance and plyometric training) is possibly more time-efficient and effective for fitness development than alternating resistance and plyometric training in the same training session [27,28]. This has attracted the increasing attention of researchers to investigate the effects of combined training on physical fitness levels in adolescents and children [26,29,30]. Results of some studies indicate that combined training improved sprint capacity [26,30–32], speed [29,31,32], jump performance [26,30–32], and muscular strength [30–32] in school children aged between 12 and 15.

Furthermore, it is widely accepted that appropriate exercise programs should be arranged for children who experience normal growth and maturation because these early interventions could provide stimulation to accelerate and promote physical fitness development [33]. However, two studies investigated the influences of detraining after combined training intervention on fitness performance in children [30,34]. Faigenbaum et al. [26] found that combined training-induced gains on the curl-up and single leg hop maintained after 12 weeks of detraining, but performance on the long jump and balance test regressed in 7-year-old children. In addition, Ingle et al., [30] reported that the benefits of training on measures of upper- and lower-limb strength disappeared after 12 weeks of detraining in pre- and early pubertal boys. This mechanism responsible for the effects of detraining might be attributed to the absence of a training stimulus to reduce motor unit activation and motor coordination [30]. Likely, researchers of this study [30] pointed out that the degree and frequency of combined training might interfere with the sustainable effect of combined training on physical fitness performance, which requires further investigation.

We therefore conducted a randomized controlled trial to further investigate the effects of combined training on physical fitness among children aged 8 to 12 years in the physical education setting. Study results of the present study may provide the physical educator with a more effective exercise plan in school settings, to improve physical fitness in pre- and early pubertal children. In addition, given that studies on anthropometric characteristics of combined training have been rarely conducted, we also explored the effects of combined training on these outcome measures in the present study. More specifically, the present study has a dual purpose: (1) To investigate the effects of 12 weeks of combined training on upper and lower body fitness performance and anthropometric measures in 8– to 12–year old boys; and (2) to further explore the effects of 12 weeks of detraining and reduced training on muscular strength, lower-limb power, running speed performance, and anthropometric measures in this age group. We hypothesized that combined training would promote positive changes in the selected components of physical fitness and anthropometric measures in children. We also hypothesized that the majority of the well-established trainability in 12 weeks of combined training would be maintained in reduced training.

2. Methods

2.1. Experimental Design

We aimed to investigate the effects of 12 weeks of combined training on some components of physical fitness and anthropometric measures in schoolboys aged between 8 to 12 years old. Participants were randomly assigned to either an experimental group (EG) or a control group (CG).

Both groups attended 45 min of regular physical education (PE) classes twice per week during the 24 weeks of the intervention period. Furthermore, participants in the EG also received additional combined training twice per week on non-PE days (after 4 pm), with each training session of 60 min (detailed information of combined training will be clearly presented in Section 2.4).

We selected some components of physical fitness based on the available test equipment, including biceps curl, vertical jump, standing long jump, and 30 m sprint velocity. Anthropometric measures involved body height, body mass, body mass index (BMI), lean body mass (LBM), biceps girth, and quadriceps girth. All measurements occurred at baseline (T0) and after 12 weeks of combined training (T1). Subsequently, the participants in the EG were randomly assigned to either a training cessation group (TCG) or a reduced training group (RTG). The TCG ceased the combined training regime after 12 weeks but kept their regular PE classes. The RTG continued the combined training program but the weekly training frequency was reduced from two to one while regular PE classes remained unchanged. All the participants were asked to perform the same tests after 12 weeks of detraining and reduced training (T2). The response of each participant on all testing and training periods was closely monitored via PE teachers and experienced investigators.

2.2. Participants

Because of ethics limitations, only secondary sexual characteristics (enlargement of the larynx, deepening of the voice, and nocturnal emission) were empirically investigated at T0, T1, and T2. Three boys were excluded at T0 because of nocturnal emission. The number of possibly early puberty (only deepening of the voice) was 7 in the EG and 4 in the CG at baseline ($\chi 2 = 0.093$, $p = 0.761$), whereas 3 in the TCG, 4 in the RTG, and 4 in the CG at T1 and T2, respectively ($\chi 2 = 0.596$, $p = 0.742$). Forty-six boys (age: 10.48 ± 1.07 years) in the same school completed the present study (Figure 1). All participants were active and healthy, without a pediatric chronic disease or orthopedic limitation. None of participants had performed structured resistance training or plyometric training three months before the present study started. Informed consent was obtained from parents or guardians of the participants before the study began. All procedures in this study were approved by the Committee of University Researcher Ethics and were conducted according to the Helsinki Declaration.

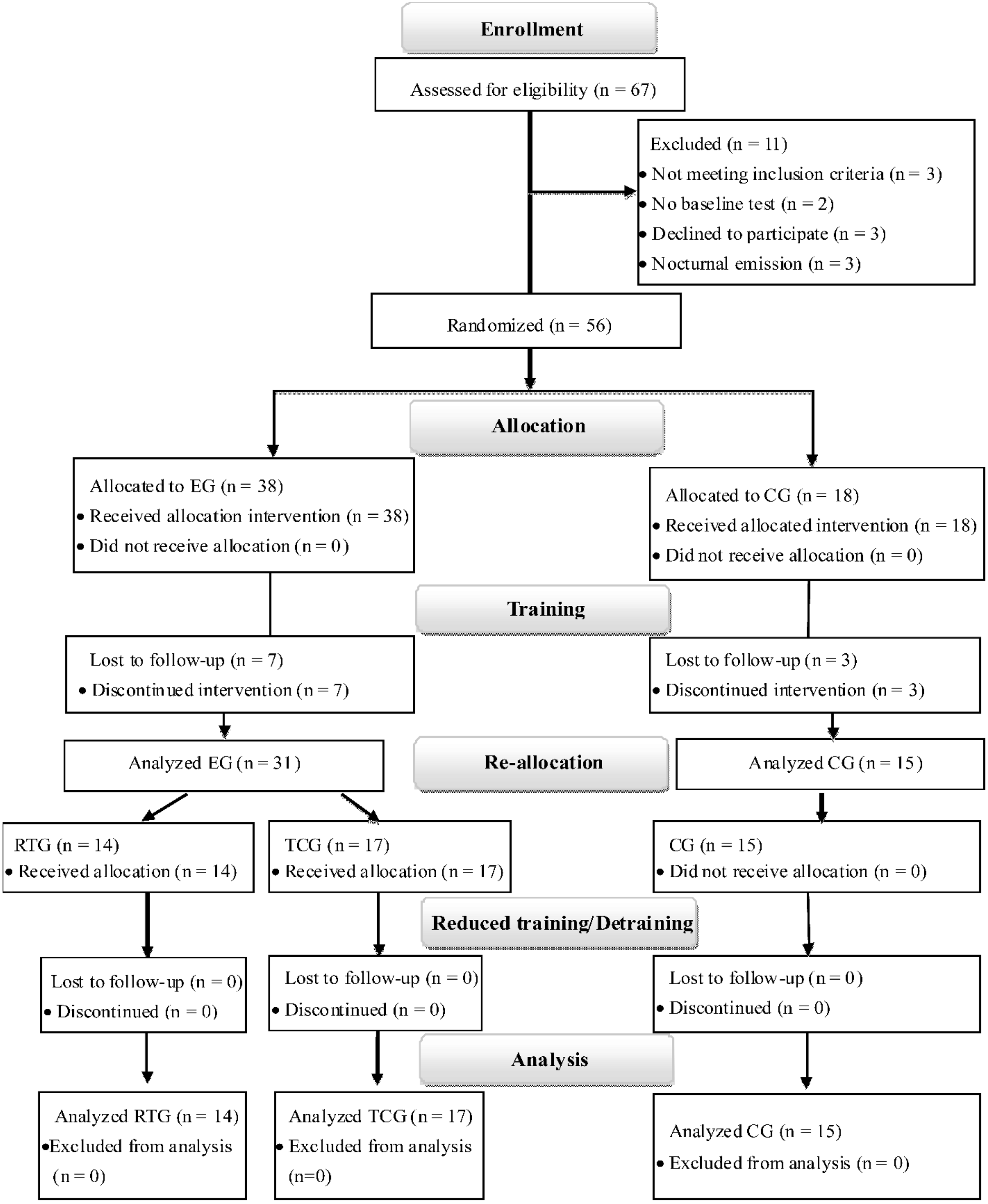

Figure 1. Flow-chart of the study design. EG = experimental group; CG = control group; RTG = reduced training group; TCG = training cessation group.

2.3. Testing Procedures

All participants were tested at baseline (T0), post-training (T1), and after 12 weeks of detraining or reduced training (T2), respectively. Before the tests started, a standardized 10 min warm-up with low-intensity exercises was performed, which included jogging and stretching. Stretching exercises involved shoulder and side stretches, back and chest stretches, quadriceps, hamstring stretches, waist, wrist, and ankle. All tests were carried out by PE teachers and specialists on the same day. The order of tests was randomly assigned to avoid any potential order influence. All participants had two trials to familiarize with testing procedures one-week before data collection, administered by the same researchers.

The anthropometric measurements of body height, body mass, biceps girth, and quadriceps girth were conducted in accordance with the international standards for anthropometric assessment [35] prior to the physical fitness tests. Percentage of body fat was measured by a multi-frequency 8-electrode body composition analyzer (Tanita MC-180, Tanita, Tokyo, Japan). Lean body mass (LBM) was estimated by the difference between body weight and the body weight multiplied by the percentage of body fat [30]. Subsequently, fitness testing (muscular strength, leg power, and running speed) was performed.

Each participant was asked to perform 6-repetition maximum (RM) in the biceps curl test, assessed 1 week before at the 1-RM test. For the 1-RM test, participants commenced with the initial 6-RM weight. If the participant was successful, 0.5 kg was added for the next trial. These steps were repeated (2 min of rest interval each time) until the identification of the 1-RM for each participant. Following a 72 h rest period, the biceps curl test was repeated to verify the initial results. The heaviest 1-RM load lifted was recorded on each test.

Lower-limb leg power was measured, as measured by the Vertical Jump test where a contact mat is linked to an electronic power timer and control box (Takei jump meter, Japan). Participants stood with feet shoulder-width apart and hands on hips. All participants should try to jump as vertically and high as possible and the highest jump in centimeter (cm) was recorded. Each participant jumped 3 times interspaced by a 1 min rest period [30]. In the standing long jump test, participants stood behind a starting line with feet slightly apart and jumped forward as far as possible. Three trials were measured, and the rest interval was 4 to 5 min between trials. The furthest distance in cm was obtained from the starting line to the shoes nearest to this line [36]. For the 30 m sprint running, participants were asked to finish a 30 meter distance on a track in the shortest time. The time was measured by the same researcher using a stopwatch (CASIO, HS-30W). Each participant repeated the same trial 3 times, separated by 5 min of rest interval [37] and the best performance was selected.

2.4. Intervention Program

One of the researchers, also as a PE teacher in the investigated school, administered all training and PE sessions with the same types of exercise during the intervention. Participants in the EG attended the combined training on non-consecutive days. Each training session lasted about 60 min and was carried out on the same days of the week [10]. A 10 min warm-up with low-intensity exercises was first led by the instructor, and it included jogging and musculoskeletal stretching. The intervention program consisted of resistance and plyometric training exercises (Table 1). The training intensity was gradually increased during the training period [30,38]. The order of workouts was alternated between a set of resistance training and a set of plyometric exercises as follows: Back squat lunges, abdomen upward jump, back squat, single-leg hop, barbell biceps curl, frog jump, push up, and 30 m sprint running. It is worth emphasizing that untrained children in the EG were asked to perform barbell biceps curl at maximal voluntary velocity with 70% (Week 1 to 6) to 80% (Week 7 to 12) of 1 RM, which is in accordance with results of a previous meta-analysis [39] indicating that muscular strength gains require a load of at least 60% to 80% of 1RM. In addition to biceps-specific training, each participant was also asked to do push-ups to exhaustion. The rest period was selected based on a study [38], which was 2 to 3 min between each two sets and 2 min between exercise programs. After the first 12 weeks of intervention, participants in the EG were randomly allocated to either an RTG or a TCG. In the TCG, participants were asked to cease combined training but to keep their regular PE classes for another 12 weeks, which is considered as the detraining period in the present study. The RTG participants still received the same combined training but the number of sessions was reduced from two to one per week (Table 1), while the regular PE classes remained unchanged. As mentioned previously [38], participants in the CG attended regular PE classes throughout the entire intervention period. Classes in PE curriculum involved a variety of low-to-moderate physical activities, including gymnastics, games, team sports, foot shuttlecock, basketball, and volleyball. Ten minutes of cool-down activity (walking and dynamic stretching) was placed at the end of each training session. Participants in the EG or RTG who were absent from the combined training were asked to make it up in another extracurricular physical activity class.

Table 1. Training program design.

Exercises	Weeks 1–2	Weeks 3–6	Weeks 7–9	Weeks 10–12	Weeks 13–24 *
Back squat lunges	2 × 10	2 × 10	3 × 12	3 × 12	3 × 12
Abdomen upward jump	2 × 20	2 × 30	3 × 30	3 × 30	3 × 30
Back squat	2 × 30	2 × 30	3 × 30	3 × 30	3 × 30
Single-leg hop	3 × 20 m	3 × 20 m	3 × 20 m	3 × 20 m	4 × 20 m
Barbell biceps curl	2 × 8/12 *	3 × 8/12 *	3 × 10/12 ⋆	3 × 10/12 ⋆	3 × 10/12 ⋆
Frog jump	2 × 20 m	2 × 20 m	3 × 20 m	3 × 20 m	3 × 20 m
Push up	exhaustion	exhaustion	exhaustion	exhaustion	exhaustion
30-m sprint running	2 × 30 m	2 × 30 m	3 × 30 m	3 × 30 m	3 × 30 m

* 70% 1 repetition maximum; ⋆ 80% 1 repetition maximum; * Reducing training session. 2–3 min rest between sets; 2 min rest between exercises program.

2.5. Statistical Analyses

Normal distribution was assessed using the Shapiro-Wilk. The independent-samples t-test was used to examine differences between the EG and CG groups in all baseline variables. One-way Analysis of Variance (ANOVA) was used to determine baseline differences among three groups (RTG, TCG, and CG). An Analysis of Covariance (ANCOVA) with groups as between-subject factors (EG, and CG; or RTG, TCG, and CG) and baseline (EG, and CG) as well as T1 (baseline; RTG, TCG, and CG) data, respectively, as a covariate were analyzed [40–42]. The ANCOVA is proposed as the appropriate statistical method to compute continuous outcomes across a range of correlations between pre- and post-intervention [43,44]. Bonferroni post-hoc test was utilized to identify the differences between each two groups. We computed effect size (Cohen's d) to determine the magnitude of the intervention effect: (1) d = 0.20 = small; (2) 0.50 = moderate; and (3) 0.8 = large. A p value of less than 0.05 was considered as significant. All data analyses were conducted using the SPSS 22.0 statistical software.

3. Results

No adverse event occurred during the 24 weeks of the intervention period. Anthropometric characteristics and physical fitness of this age group were not significantly different at baseline between EG and CG ($p > 0.05$, Table 2) and at baseline among three groups (RTG, TCG, and CG) ($p > 0.05$, Table 3). For the biceps curl test-retest assessment at the 1-RM, we observed a significantly high correlation ($r = 0.927$, $p < 0.01$), indicating that no significant difference between the two tests existed.

With regard to the anthropometric measures in Phase 1 (baseline and after 12 weeks), we only observed a significantly greater decrease on biceps girth in the EG (22.42 ± 0.77 mm) as compared to the CG (22.91 ± 0.77 mm) ($F_{1,43} = 4.11$, $p = 0.049$, $d = 0.636$). With regard to the physical fitness measures in Phase 1 (baseline and after 12 weeks), the EG showed a significantly greater increase on biceps curl ($F_{1,43} = 8.55$, $p = 0.005$, $d = 0.920$) and the standing long jump ($F_{1,43} = 6.48$, $p = 0.015$, $d = 0.801$) in comparison with the CG, whereas a significantly greater decrease on the time of the 30 m sprint was observed in the EG (5.59 ± 0.41 s), as compared to the CG (5.88 ± 0.41 s) ($F_{1,43} = 4.95$, $p = 0.031$, $d = 0.707$) (as shown in Table 2). With regard to the detraining and reduced training period of the anthropometric and physical fitness measures, the results of the ANCOVA indicated a significant difference in the standing long jump ($F_{2,42} = 3.48$, $p = 0.040$, Table 3). Post-hoc tests with the Bonferroni-adjustment further showed a significantly greater increase on this outcome in the RTG ($p = 0.038$, $d = 0.938$), as compared to the TCG. Results of all anthropometric and physical fitness measures are presented in Tables 2 and 3.

Table 2. Comparison of anthropometric characteristics and test performances before and after 12 weeks of the training program.

Variable	EG (n = 31)			CG (n = 15)			*p*	EG (n = 31)			CG (n = 15)			*p*
	Baseline (T0)							After 12 Weeks (T1)						
Anthropometrics														
Age (years)	10.55	±	1.21	10.33	±	0.72	0.457							
Height (cm)	142.88	±	10.56	141.80	±	5.63	0.654	143.93	±	0.95	144.00	±	0.95	0.822
Body mass (kg)	37.54	±	10.63	40.70	±	12.32	0.375	39.81	±	1.25	40.01	±	1.25	0.613
Body mass index (kg/m^2)	18.07	±	3.28	19.97	±	4.73	0.119	18.94	±	0.65	19.03	±	0.66	0.684
Lean body mass (kg)	30.10	±	5.67	30.50	±	4.06	0.810	31.25	±	2.20	30.39	±	2.20	0.225
Biceps girth (mm)	22.11	±	3.64	23.23	±	4.10	0.353	22.42	±	0.77	22.91	±	0.77	0.049 *
Quadriceps girth (mm)	42.62	±	5.89	44.82	±	6.12	0.246	44.02	±	1.61	44.94	±	1.62	0.078
Test performances														
Biceps curl (kg)	7.68	±	2.09	7.73	±	1.47	0.926	8.76	±	1.38	7.49	±	1.38	0.005 **
Vertical jump (cm)	37.39	±	7.36	36.93	±	6.31	0.839	39.04	±	5.28	39.06	±	5.28	0.992
Standing long jump (cm)	145.84	±	20.62	148.20	±	21.52	0.721	151.64	±	11.61	142.34	±	11.62	0.015 *
30 m sprint (s)	6.08	±	0.76	6.08	±	0.67	0.993	5.59	±	0.41	5.88	±	0.41	0.031 *

Note: In T1, results were analyzed using ANCOVA and data were expressed as baseline-adjusted means ± baseline-adjusted standard deviation. EG = experimental group, CG = control group. * denotes a significant difference between groups (* $p < 0.05$; ** $p < 0.01$).

Table 3. Comparison of anthropometric characteristics and test performances before and after 12 weeks of the detraining and reduced training program.

Variable	RTG (n = 14)	TCG (n = 17)	CG (n = 15)	*p*	RTG (n = 14)	TCG (n = 17)	CG (n = 15)	*p*
	Before 12 Weeks of Detraining and Reduced Training (T1)				**After 12 Weeks of Detraining and Reduced Training (T2)**			
Anthropometrics								
Age (years)	10.57 ± 1.45	10.82 ± 1.02	10.53 ± 0.74	0.718				
Height (cm)	144.06 ± 11.06	144.46 ± 10.52	143.27 ± 5.69	0.938	146.60 ± 1.34	146.33 ± 1.35	145.83 ± 1.35	0.304
Body mass (kg)	38.20 ± 11.10	39.28 ± 10.06	42.10 ± 12.49	0.625	40.84 ± 1.40	41.11 ± 1.40	41.01 ± 1.41	0.866
Body mass index (kg/m^2)	18.00 ± 2.72	18.62 ± 3.46	20.27 ± 4.83	0.251	18.83 ± 0.70	18.98 ± 0.69	18.98 ± 0.70	0.789
Lean body mass (kg)	31.12 ± 6.50	31.12 ± 5.74	30.65 ± 4.11	0.964	32.51 ± 1.26	32.76 ± 1.26	32.54 ± 1.26	0.824
Biceps girth (mm)	22.05 ± 3.52	22.08 ± 3.59	23.63 ± 4.07	0.421	22.11 ± 0.81	22.09 ± 0.81	23.34 ± 0.82	0.665
Quadriceps girth (mm)	43.05 ± 5.49	43.64 ± 5.48	46.29 ± 6.08	0.265	43.64 ± 1.71	43.93 ± 1.70	44.00 ± 1.73	0.840
Test performances								
Biceps curl (kg)	9.11 ± 2.88	8.44 ± 2.47	7.53 ± 2.42	0.267	9.34 ± 0.99	9.01 ± 0.98	9.31 ± 0.99	0.571
Vertical jump (cm)	39.36 ± 6.76	38.94 ± 8.24	38.87 ± 4.96	0.979	41.91 ± 5.61	42.02 ± 5.61	40.73 ± 5.61	0.782
Standing long jump (cm)	150.07 ± 20.09	151.76 ± 20.55	143.67 ± 22.75	0.536	156.79 ± 12.04	145.47 ± 12.09	152.20 ± 12.15	0.040 *
30 m sprint (s)	5.49 ± 0.43	5.68 ± 0.48	5.88 ± 0.68	0.168	5.68 ± 0.38	5.62 ± 0.37	5.66 ± 0.38	0.904

Note: Results were analyzed using ANCOVA after 12 weeks of detraining and reduced training (T2) and data were expressed as baseline-adjusted means ± baseline-adjusted standard deviation. Participants in the EG were randomly assigned to either a training cessation group (TCG) or a reduced training group (RTG) after 12 weeks of combined training. RTG = reduced training group, TCG = training cessation group, CG = control group. * denotes a significant difference between groups (* $p < 0.05$).

4. Discussion

To the best of our knowledge, this is the first study investigating changes in physical fitness performance after 12 weeks of combined training, followed by 12 weeks of reduced training in non-athletic/untrained children aged between 8 and 12 years. The results of the present study indicated that 12 weeks of combined training led to significant improvements as compared to the control group in the biceps curl test, the standing long jump, and the 30 m run test in this age group. During the detraction/reduction training period, RTC showed a significantly greater improvement in the standing long jump test as compared to TCG. More detailed information will be discussed below.

4.1. Twelve Weeks of Combined Training

In the present study, we only selected three components (muscular strength of the upper limb, leg power of lower-limb, and running speed) of physical fitness. As hypothesized, we found that the EG had significantly better performances on these three outcomes than the CG, suggesting that resistance/plyometric training combined with the regular PE curriculum is superior to the regular PE curriculum alone to enhance the selected aspects of physical fitness. Such positive results are supported by previous studies [26,28,30,45,46] investigating the effects of combined training on upper-body muscular strength [26,28,30,46], lower-limb leg power [26,28,30,45,46], and running speed [26,28,30,46]. It is worth pointing out that only one study by Ingle et al. [30] involved untrained children, with a mean age: 12.3+/−0.3 years, while the other four studies focused on children of 12–15 years, either with American football/baseball [26], soccer players [28], or basketball [45,46].

After the 12 weeks intervention period, untrained children of the EG performed better in the biceps curl test, which may be attributed to both the barbell biceps curl and push-ups that reach the sufficient intensity. In other words, an exercise regime in the present study is reasonable and effective. Biceps circumference decreased following 12 weeks of combined training; one possible explanation is that the biceps-specific exercises help untrained children to burn subcutaneous fat in the biceps, leading to a decreased thickness. Leg power of the lower limb in the present study was measured by both the standing long jump test and the vertical jump test. However, we only observed a significant improvement in the standing long jump test. Such result seems to be reasonable since the majority of the selected movements (back squat lunge, single-leg hop, and frog jump) in the combined training program involved anterior-posterior locomotion. A possible mechanism responsible for improved leg power may be attributed to two aspects. First, 12 weeks of combined training may effectively facilitate the power transfer between concentric and eccentric phases of muscle activity [47], leading the children to reach the optimal level of intermuscular synchronization like synergistic and antagonistic muscle activity [29,48]. Second, combined training might stimulate the neuromuscular system, which possibly optimizes the recruitment of muscle fibers and maximizes motoneuron firing rates and neurological adaptation [45]. It is widely accepted that there is a positive relationship between leg power and running speed. In the present study, improved lower-limb leg power was observed after the 12 weeks of combined training, which may have contributed to faster running speed (shorter time spent in the 30 m sprint test). Stronger leg power might help untrained children more efficiently to utilize the stretch shortening cycle, ultimately leading to a faster running speed [49–51].

4.2. Twelve Weeks of Reduced Training and Detraining

Following the reduced training and detraining period, RTC showed a significantly greater performance in the standing long jump test than the TCG. Results of the present study are consistent with a previous study by Ingle and co-workers [30] indicating that in pre- and early pubertal boys (12.3+/−0.3 years), benefits of combined training vanished after 12 weeks of detraining. It must be admitted that the question regarding the mechanism responsible for the effects of detraining on leg power of lower limb cannot be answered at the present stage. One possible explanation is discussed below. Participants in the TCG who stopped combined training program, but only underwent regular

PE classes, experienced substantial regression. Such phenomenon may be attributed to the exercise load in the PE class not being sufficient enough to promote the lower-limb leg power in the upward and forward direction [30], which possibly affected the sustainability and maintenance of lower-limb leg power. In addition, all anthropometric measures showed no statistically significant changes in the present study. However, there was a study [52] reporting different results. The authors showed significant decreases in body fat in all experimental groups (including concurrent training groups) in prepubescent children [52]. One possible explanation may be attributed to the children in all groups experiencing biological maturation and physical growth at the same time [9].

The 30 m sprint test was not a significant change in all groups after 12 weeks of detraining and reduced training. The lack of prominent increase in this test in the RTG indicates that one training session per week was insufficient to maintain the sprinting performance progression elicited by the combined training among boys aged between 8 and 12 years [53]. Likely, after 12 weeks of detraining and reduced training period, we did not observe significant differences among three groups in both the vertical jump test and the biceps curl test. Results of the present study are identical with the study of Ingle and colleagues [30] in pre- and early-pubertal boys, indicating that performances in the vertical jump test and the biceps curl test regressed by 4.4% and 16.3% in the experimental group after 12 weeks of detraining, respectively. The specificity principle states that only targeted exercise training could enhance specific fitness goals [54]. During the detraining and reduced training period, participants either discontinued these targeted exercises inherent in the combined training program or received one session per week. By doing this, it seems to be reasonable to observe no significant performances in these specific tests accordingly.

5. Limitations of the Study

None of the participants reported exercise-related injury throughout the intervention period, which adds further evidence that resistance training combined with plyometric exercises in children is a safe exercise intervention. However, the present study is not without limitations. First, we only used readily accessible field tests rather than the biochemistry methods or specific anthropometric methods to evaluate early pubertal development state and biological maturation. Second, no electrophysiological measurements were applied to evaluate the underlying mechanisms of performance changes. Third, given ethical issues, it was not possible to prohibit PE and habitual workout for participants, therefore we are unsure if the positive results are attributed to the synthetic effect of combined training plus PE or combined training alone. Fourth, participants were recruited from one school, therefore, results of the present study cannot be generalized to a larger school population. In addition, the present study only included healthy school boys and thus the study findings should be cautiously interpreted in girls. Fifth, the efforts during training and PE sessions had not been monitored in the present study despite the same types of exercise being implemented during the intervention.

6. Conclusions

The present study indicates that resistance training combined with plyometric training can be safe and effective to enhance the selected aspects (muscular strength, leg power, and sprinting performance) of physical fitness, as well as reduce muscular girth in boys aged between 8 and 12 years. Followed by 12 weeks of reduced training and detraining, only one previously improved performance in the standing long jump test is preserved in the reduced training group. Nonetheless, anthropometric characteristics were not affected by the detraining and reduced training. Based on resistance training combined with plyometric training, the frequency of one session per week seems to provide an additional benefit to prevent leg power of lower limb from rapid deterioration. Given that results of the present study, professionals should consider the negative consequences of detraining on physical fitness performance when they prescribe this type of fitness training. To develop and maintain fitness performance, professionals should design the goals of long-term physical development strategies and rehabilitation therapies as well as encourage school-age children and youth to participate regularly in fitness lessons and adequate time training. How to mediate the anthropometric characteristics need to be considered in rehabilitation therapies and training design.

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References

1. Zou, L. Relationship between functional movement screening and skill-related fitness in college students. *Int. J. Sports Sci.* **2016**, *6*, 11–18.
2. Zou, L.; Wang, C.; Tian, Z.; Wang, H.; Shu, Y. Effect of yang-style Tai Chi on gait parameters and musculoskeletal flexibility in healthy Chinese older women. *Sports* **2017**, *5*, 52. [CrossRef] [PubMed]
3. Kvaavik, E.; Klepp, K.I.; Tell, G.S.; Meyer, H.E.; Batty, G.D. Physical Fitness and Physical Activity at Age 13 Years as Predictors of Cardiovascular Disease Risk Factors at Ages 15, 25, 33, and 40 Years: Extended Follow-up of the Oslo Youth Study. *Pediatrics* **2009**, *123*, E80–E86. [CrossRef] [PubMed]
4. Ortega, F.B.; Ruiz, J.R.; Castillo, M.J.; Sjostrom, M. Physical fitness in childhood and adolescence: A powerful marker of health. *Int. J. Obes.* **2008**, *32*, 1–11. [CrossRef] [PubMed]
5. World Health Organization (WHO). *Global Recommendations on Physical Activity for Health*; WHO: Geneva, Switzerland, 2010.
6. Zou, L.; Xiao, Z.; Wang, H.; Wang, C.; Hu, X.; Shu, Y. Asian martial arts for children with autism spectrum disorder: A systematic review. *Arch. Budo*, **2017**, *13*, 79–92.
7. Behringer, M.; vom Heede, A.; Matthews, M.; Mester, J. Effects of Strength Training on Motor Performance Skills in Children and Adolescents: A Meta-Analysis. *Pediatr. Exerc. Sci.* **2011**, *23*, 186–206. [CrossRef] [PubMed]
8. Bedoya, A.A.; Miltenberger, M.R.; Lopez, R.M. Plyometric Training Effects on Athletic Performance in Youth Soccer Athletes: A Systematic Review. *J. Strength Cond. Res.* **2015**, *29*, 2351–2360. [CrossRef] [PubMed]
9. Cunha, G.D.; Sant'anna, M.M.; Cadore, E.L.; de Oliveira, N.L.; dos Santos, C.B.; Pinto, R.S.; Reischak-Oliveira, A. Physiological Adaptations to Resistance Training in Prepubertal Boys. *Res. Q. Exerc. Sport* **2015**, *86*, 172–181. [CrossRef] [PubMed]
10. Faigenbaum, A.D.; Milliken, L.A.; Loud, R.L.; Burak, B.T.; Doherty, C.L.; Westcott, W.L. Comparison of 1 and 2 days per week of strength training in children. *Res. Q. Exerc. Sport* **2002**, *73*, 416–424. [CrossRef] [PubMed]
11. Granacher, U.; Goesele, A.; Roggo, K.; Wischer, T.; Fischer, S.; Zuerny, C.; Gollhofer, A.; Kriemler, S. Effects and Mechanisms of Strength Training in Children. *Int. J. Sports Med.* **2011**, *32*, 357–364. [CrossRef] [PubMed]
12. Santos, E.J.; Janeira, M.A. The effects of resistance training on explosive strength indicators in adolescent basketball players. *J. Strength Cond. Res.* **2012**, *26*, 2641–2647. [CrossRef] [PubMed]
13. Velez, A.; Golem, D.L.; Arent, S.M. The impact of a 12-week resistance training program on strength, body composition, and self-concept of Hispanic adolescents. *J. Strength Cond. Res.* **2010**, *24*, 1065–1073. [CrossRef] [PubMed]
14. Mayorga-Vega, D.; Viciana, J.; Cocca, A. Effects of a circuit training program on muscular and cardiovascular endurance and their maintenance in schoolchildren. *J. Hum. Kinet.* **2013**, *37*, 153–160. [CrossRef] [PubMed]
15. Santos, A.; Marinho, D.A.; Costa, A.M.; Izquierdo, M.; Marques, M.C. The effects of concurrent resistance and endurance training follow a specific detraining cycle in young school girls. *J. Hum. Kinet.* **2011**, *29A*, 93–103. [CrossRef] [PubMed]
16. Santos, A.P.; Marinho, D.A.; Costa, A.M.; Izquierdo, M.; Marques, M.C. The effects of concurrent resistance and endurance training follow a detraining period in elementary school students. *J. Strength Cond. Res.* **2012**, *26*, 1708–1716. [CrossRef] [PubMed]

17. Faigenbaum, A.D.; Westcott, W.L.; Micheli, L.J.; Outerbridge, A.R.; Long, C.J.; LaRosa-Loud, R.; Zaichkowsky, L.D. The Effects of Strength Training and Detraining on Children. *J. Strength Cond. Res.* **1996**, *10*, 109–114. [CrossRef]
18. Tsolakis, C.K.; Vagenas, G.K.; Dessypris, A.G. Strength adaptations and hormonal responses to resistance training and detraining in preadolescent males. *J. Strength Cond. Res.* **2004**, *18*, 625–629. [PubMed]
19. Diallo, O.; Dore, E.; Duche, P.; Van Praagh, E. Effects of plyometric training followed by a reduced training programme on physical performance in prepubescent soccer players. *J. Sports Med. Phys. Fit.* **2001**, *41*, 342.
20. Fernandez-Fernandez, J.; de Villarreal, E.S.; Sanz-Rivas, D.; Moya, M. The Effects of 8-Week Plyometric Training on Physical Performance in Young Tennis Players. *Pediatr. Exerc. Sci.* **2016**, *28*, 77–86. [CrossRef] [PubMed]
21. McKay, D.; Henschke, N. Plyometric training programmes improve motor performance in prepubertal children. *Br. J. Sports Med.* **2012**, *46*, 727–728. [CrossRef] [PubMed]
22. Meylan, C.; Malatesta, D. Effects of in-season plyometric training within soccer practice on explosive actions of young players. *J. Strength Cond. Res.* **2009**, *23*, 2605–2613. [CrossRef] [PubMed]
23. Santos, E.J.; Janeira, M.A. The effects of plyometric training followed by detraining and reduced training periods on explosive strength in adolescent male basketball players. *J. Strength Cond. Res.* **2011**, *25*, 441–452. [CrossRef] [PubMed]
24. De Villarreal, E.S.-S.; Requena, B.; Newton, R.U. Does plyometric training improve strength performance? A meta-analysis. *J. Sci. Med. Sport* **2010**, *13*, 513–522. [CrossRef] [PubMed]
25. Behm, D.G.; Young, J.D.; Whitten, J.H.D.; Reid, J.C.; Quigley, P.J.; Low, J.; Li, Y.; Lima, C.D.; Hodgson, D.D.; Chaouachi, A.; et al. Effectiveness of Traditional Strength vs. Power Training on Muscle Strength, Power and Speed with Youth: A Systematic Review and Meta-Analysis. *Front. Physiol.* **2017**, *8*, 423. [CrossRef] [PubMed]
26. Faigenbaum, A.D.; McFarland, J.E.; Keiper, F.B.; Tevlin, W.; Ratamess, N.A.; Kang, J.; Hoffman, J.R. Effects of a short-term plyometric and resistance training program on fitness performance in boys age 12 to 15 years. *J. Sports Sci. Med.* **2007**, *6*, 519–525. [PubMed]
27. May, C.A.; Cipriani, D.; Lorenz, K.A. Power Development Through Complex Training for The Division I Collegiate Athlete. *Strength Cond. J.* **2010**, *32*, 30–43. [CrossRef]
28. Rodriguez-Rosell, D.; Franco-Marquez, F.; Pareja-Blanco, F.; Mora-Custodio, R.; Yanez-Garcia, J.M.; Gonzalez-Suarez, J.M.; Gonzalez-Badillo, J.J. Effects of 6 Weeks Resistance Training Combined with Plyometric and Speed Exercises on Physical Performance of Pre-Peak-Height-Velocity Soccer Players. *Int. J. Sports Physiol. Perform.* **2016**, *11*, 240–246. [CrossRef] [PubMed]
29. Cavaco, B.; Sousa, N.; Dos Reis, V.M.; Garrido, N.; Saavedra, F.; Mendes, R.; Vilaca-Alves, J. Short-term effects of complex training on agility with the ball, speed, efficiency of crossing and shooting in youth soccer players. *J. Hum. Kinet.* **2014**, *43*, 105–112. [CrossRef] [PubMed]
30. Ingle, L.; Sleap, M.; Tolfrey, K. The effect of a complex training and detraining programme on selected strength and power variables in early pubertal boys. *J. Sports Sci.* **2006**, *24*, 987–997. [CrossRef] [PubMed]
31. Alves, A.R.; Marta, C.C.; Neiva, H.P.; Izquierdo, M.; Marques, M.C. Concurrent Training in Prepubescent Children: The Effects of 8 Weeks of Strength and Aerobic Training on Explosive Strength and V[Combining Dot Above]O2max. *J. Strength Cond. Res.* **2016**, *30*, 2019–2032. [CrossRef] [PubMed]
32. Alves, A.R.; Marta, C.C.; Neiva, H.P.; Izquierdo, M.; Marques, M.C. Does Intrasession Concurrent Strength and Aerobic Training Order Influence Training-Induced Explosive Strength and V[Combining Dot Above]O2max in Prepubescent Children? *J. Strength Cond. Res.* **2016**, *30*, 3267–3277. [CrossRef] [PubMed]
33. Zou, L.; Huang, T.; Tsang, T.; Pan, Z.; Wang, C. Hard martial arts for cognitive function across the lifespan: A systematic review. *Arch Budo* **2018**, *14*, 41–58.
34. Faigenbaum, A.D.; Farrell, A.C.; Fabiano, M.; Radler, T.A.; Naclerio, F.; Ratamess, N.A.; Kang, J.; Myer, G.D. Effects of detraining on fitness performance in 7-year-old children. *J. Strength Cond. Res.* **2013**, *27*, 323–330. [CrossRef] [PubMed]
35. Stewart, A.D.; Marfell-Jones, M.; Olds, T.; De Ridder, J.H. *International Standards for Anthropometric Assessment*; Shenzhen University Press: Shenzhen, China, 2006.
36. Marta, C.; Marinho, D.A.; Barbosa, T.M.; Izquierdo, M.; Marques, M.C. Effects of Concurrent Training on Explosive Strength and VO2max in Prepubescent Children. *Int. J. Sports Med.* **2013**, *34*, 888–896. [CrossRef] [PubMed]

37. Wisløff, U.; Castagna, C.; Helgerud, J.; Jones, R.; Hoff, J. Strong correlation of maximal squat strength with sprint performance and vertical jump height in elite soccer players. *Br. J. Sports Med.* **2004**, *38*, 285–288. [CrossRef] [PubMed]
38. Faigenbaum, A.; Chu, D. *Plyometric Training for Children and Adolescents*; American College of Sports Medicine Current Comment; American College of Sports Medicine: Indianapolis, IN, USA, 2001.
39. Nunome, H.; Ikegami, Y.; Sano, S. The effect of muscle fatigue on instep kicking kinetics and kinematics in association football AU—Apriantono, Tommy. *J. Sports Sci.* **2006**, *24*, 951–960.
40. Behrens, M.; Mau-Moeller, A.; Mueller, K.; Heise, S.; Gube, M.; Beuster, N.; Herlyn, P.K.E.; Fischer, D.-C.; Bruhn, S. Plyometric training improves voluntary activation and strength during isometric, concentric and eccentric contractions. *J. Sci. Med. Sport* **2016**, *19*, 170–176. [CrossRef] [PubMed]
41. Prieske, O.; Krüger, T.; Aehle, M.; Bauer, E.; Granacher, U. Effects of Resisted Sprint Training and Traditional Power Training on Sprint, Jump, and Balance Performance in Healthy Young Adults: A Randomized Controlled Trial. *Front. Physiol.* **2018**, *9*, 156. [CrossRef] [PubMed]
42. Vickers, A.J.; Altman, D.G. Analysing controlled trials with baseline and follow up measurements. *BMJ* **2001**, *323*, 1123–1124. [CrossRef] [PubMed]
43. Egbewale, B.E.; Lewis, M.; Sim, J. Bias, precision and statistical power of analysis of covariance in the analysis of randomized trials with baseline imbalance: A simulation study. *BMC Med. Res. Methodol.* **2014**, *14*, 49. [CrossRef] [PubMed]
44. Vickers, A.J. Analysis of variance is easily misapplied in the analysis of randomized trials: A critique and discussion of alternative statistical approaches. *Psychosom. Med.* **2005**, *67*, 652–655. [CrossRef] [PubMed]
45. Santos, E.J.; Janeira, M.A. Effects of complex training on explosive strength in adolescent male basketball players. *J. Strength Cond. Res.* **2008**, *22*, 903–909. [CrossRef] [PubMed]
46. Andrejić, O. The effects of a plyometric and strength training program on the fitness performance in young basketball players. *Facta Univ. Ser. Phys. Educ. Sport* **2012**, *10*, 221–229.
47. Chu, D.A. *Explosive Power & Strength: Complex Training for Maximum Results*; Human Kinetics: Champaign, IL, USA, 1996.
48. Tian, M.Y.; Herbert, R.D.; Hoang, P.; Gandevia, S.C.; Bilston, L.E. Myofascial force transmission between the human soleus and gastrocnemius muscles during passive knee motion. *J. Appl. Physiol.* **2012**, *113*, 517–523. [CrossRef] [PubMed]
49. Nimphius, S.; Mcguigan, M.R.; Newton, R.U. Relationship between strength, power, speed, and change of direction performance of female softball players. *J. Strength Cond. Res.* **2010**, *24*, 885–895. [CrossRef] [PubMed]
50. Lockie, R.G.; Murphy, A.J.; Knight, T.J.; de Jonge, X.A.J. Factors that differentiate acceleration ability in field sport athletes. *J. Strength Cond. Res.* **2011**, *25*, 2704–2714. [CrossRef] [PubMed]
51. Lockie, R.G.; Callaghan, S.J.; Berry, S.P.; Cooke, E.R.; Jordan, C.A.; Luczo, T.M.; Jeffriess, M.D. Relationship between unilateral jumping ability and asymmetry on multidirectional speed in team-sport athletes. *J. Strength Cond. Res.* **2014**, *28*, 3557–3566. [CrossRef] [PubMed]
52. Alves, A.R.; Marta, C.C.; Neiva, H.P.; Izquierdo, M.; Marques, M.C. Effects of order and sequence of resistance and endurance training on body fat in elementary school-aged girls. *Biol. Sport* **2017**, *34*, 379–384. [CrossRef] [PubMed]
53. Blimkie, C. Resistance training during pre-and early puberty: Efficacy, trainability, mechanisms, and persistence. *Can. J. Sport Sci.* **1992**, *17*, 264–279. [PubMed]
54. Hawley, J.A. Specificity of training adaptation: Time for a rethink? *J. Physiol.* **2008**, *586*, 1–2. [CrossRef] [PubMed]