

Effects of Concurrent Training on Explosive Strength and VO_{2max} in Prepubescent Children

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Key words

- youth
- exercise school-based programs
- power
- endurance

Abstract

▼ The purpose of this study was to compare the effects of an 8-weeks training period of resistance training alone (GR), combined resistance and endurance training (GCON) and a control group (GC) on explosive strength and VO_{2max} in a large sample of prepubescent boys and girls. 125 healthy children (58 boys, 67 girls), aged 10–11 years old (10.8 ± 0.4 years) were assigned into 2 training groups to train twice a week for 8 weeks: GR (19 boys, 22 girls), GCON (21 boys, 24 girls) and a control group (GC: 18 boys, 21 girls; no training program). A significant but medium-sized increase from pre- to the post-training in the vertical jump (Effect size=0.22, $F=34.44$, $p<0.01$) and VO_{2max} (Effect size=0.19, $F=32.89$,

$p<0.01$) was observed. A significant large increase in the 1 kg (Effect size=0.53, $F=202.17$, $p<0.01$) and 3 kg (Effect size=0.48, $F=132.1$, $p<0.01$) ball throwing, standing long jump (Effect size=0.53, $F=72.93$, $p<0.01$) and running speed (Effect size=0.45, $F=122.21$, $p<0.01$) was also observed. The training group (GR and GCON) and sex factors did not significantly influence the evolution of strength variables from pre- to the post-training. The VO_{2max} increased significantly only in GCON. Concurrent training is equally effective on training-induced explosive strength, and more efficient than resistance training only for VO_{2max} in prepubescent boys and girls. This should be taken into consideration in order to optimize strength training school-based programs.

accepted after revision
December 20, 2012

Bibliography

DOI <http://dx.doi.org/10.1055/s-0033-1333695>
Published online:
April 2, 2013
Int J Sports Med 2013; 34:
888–896 © Georg Thieme
Verlag KG Stuttgart · New York
ISSN 0172-4622

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Introduction

▼ Nowadays, the efforts to promote levels of physical fitness and physical activity in youth should be a priority. Physical fitness and physical activity are considered to be important supportive elements for the maintenance and enhancement of health and quality of life, and hence for the improvement of the holistic development of a child [26,36]. Unfortunately, evidence exists suggesting that physical fitness and physical activity have declined worldwide in the last decades among children and adolescents [33]. Many children and adolescents are only exposed to vigorous physical activity during school-based physical education classes [7]. Therefore, it is important to ensure that during these classes students are exposed to physical activities that promote health-related physical fitness development and an active lifestyle [9]. School seems to provide an excellent setting to enhance and promote physical activity and physical fitness levels, by implementing training programs [32,44].

Because of the low aerobic capacity in children is associated with risk factors of cardiovascular disease [4], the majority of the research has focused on activities that enhance cardiorespiratory fitness disregarding, for instance, neuromuscular fitness conditions based on muscular strength [5]. However, it is recognized that youth strength training can be a safe and effective method of conditioning and should be an important component of youth fitness programs, health promotion objectives, and injury prevention [12]. Increasing both aerobic and muscular fitness is essential to promote health [2] and should be a desirable goal in a training program [45]. Due to various school constraints (i.e., reduced practice time per session, number of weekly sessions or lack of material resources and facilities), children and adolescents involved in physical education classes often concurrently perform strength and endurance training [42] in an attempt to reach different physical fitness goals [3] at the same time. However, over several decades many studies have reported an interference

effect on muscle strength development when strength and endurance were trained concurrently [10,21]. The majority of these studies found that the magnitude of increase in strength was higher in the group that performed only strength training compared with the concurrent training group. This is commonly referred to as the “interference phenomenon” [16]. A small body of evidences exists about the effect of concurrent resistance and endurance training implemented in school environment [22]. Recent studies showed that performing resistance and endurance training in the same workout does not impair strength development in adolescent school boys [42] and girls [41]. However, the effects of concurrent resistance and endurance training in prepubescent students, according to our best knowledge, have yet to be investigated.

On the other hand, physical education classes or extracurricular activities commonly include children of both sexes, and therefore it is important to verify the applicability of a concurrent training program in school-age boys and girls. Although at prepubertal ages the boys still present a reduced muscle mass, because the effects of circulating androgens, particularly testosterone, only manifest themselves at puberty, the muscle mass which is statistically higher in boys allows a better muscular strength [30]. Furthermore, boys are superior to girls in aerobic fitness because they have higher levels of physical activity, lower fat mass, and other advantages mainly linked to the cardiac size and oxygen-carrying capacity (i.e., left ventricular inner diastolic diameter, maximal heart rate and maximal stroke volume) [8]. If there is evidence in the literature that strength/endurance development is different between prepubescent boys and girls then a different trainability could be expected.

The purpose of the present study was to analyze the effects of power strength training alone and combined power strength and endurance training in the selected sample. It was hypothesized that performing resistance and endurance training in the same workout does not impair strength development in prepubescent children, just as described in the literature with pubescent children.

Material and Methods

Subjects

The sample consisted of 125 prepubescent children, aged between 10 and 11 years, all of whom volunteered for this study. Before data collection and the start of the training, each participant reported any health problems, physical limitations, physical activity habits, and training experience for the last 6 months. The selected children were in the Tanner stages 1–2 (boys: GC,

stage 1, 77.8% and stage 2, 22.2%; GR, stage 1, 73.7% and stage 2, 26.3%; GCON, stage 1, 90.5% and stage 2, 9.5%; girls: GC, stage 1, 47.6% and stage 2, 52.4%; GR, stage 1, 50% and stage 2, 50%; GCON, stage 1, 62.5% and stage 2, 37.5%). No subject had regularly participated in any form of strength training program prior to this experiment. Subjects were carefully informed about the design of the study and subsequently the children’s parents signed an informed consent document prior to the start of the study. The study was conducted according to the ethical standards of the International Journal of Sports Medicine [19] and to the declaration of Helsinki, and was approved by the institutional review boards of the University of Beira Interior (UBI) and Research Centre in Sports, Health and Human Development (CIDESD), Portugal. Parameters of body dimensions and physical performance measures were evaluated for all subjects in a pre-test (Table 1).

Experimental design and training program

This was a randomized controlled trial conducted at the Santa Clara School (Guarda, Portugal). Inclusion criteria were children aged between 10 and 11.5 years (from 5th and 6th grade), without a chronic pediatric disease or orthopedic limitation and without regular oriented extra-curricular physical activity (e.g. practice of some sport in a club). Subsequently, to minimize the effects of growth, only children who were self-assessed in Tanner stages 1–2 were selected for the sample. From the initial sample of 151 students, who volunteered to take part in this study and had the necessary requirements to join the study, and following a random distribution of the subjects in the investigation groups, only 134 applied (GR=44, GCON=51 and GC=39). The assigned groups were determined by a chance process (a random number generator on a computer) and could not be predicted. This procedure was established according to the “CONSORT” statement, which can be found at: <http://www.consort-statement.org/>. Participants were randomly assigned into 1 of 3 intervention arms. Randomization was done using R software version 2.14 (R Foundation for Statistical Computing). The rate of students who completed the training program was 93% and 88% (GR and GCON, respectively). In the control group the number remained unchanged. Thus, 125 children comprised the real sample of the study, divided into 2 training groups (8 weeks training program, twice a week) and one control group as follows: one group performing power training only (GR: 19 boys, 22 girls); another group performing combined power strength and endurance training (GCON: 21 boys, 24 girls); and the third was the control group (GC: 18 boys, 21 girls; that followed the physical education classes curriculum, without a specific training program).

Table 1 Descriptive data of the control (GC), resistance (GR) and concurrent (GCON) groups in pre-test condition: Boys and girls (Mean ± SD).

	Boys			Girls		
	GC	GR	GCON	GC	GR	GCON
decimal age (years)	10.8±0.5	10.7±0.4	10.7±0.5	10.9±0.4	10.8±0.4	10.75±0.4
body height (cm)	139.5±7.0	141.6±5.9	146.7±8.3	140.8±6.3	144.8±8.0	142.7±7.2
body mass (Kg)	37.8±7.6	38.9±10.7	42.0±9.0	37.4±6.9	41.3±9.8	39.7±9.4
counter mov. jump (cm/kg)	0.65±0.2	0.62±0.2	0.61±0.1	0.57±0.1	0.51±0.1	0.54±0.1
standing l. jump (cm/kg)	3.87±1.0	3.58±1.0	3.50±0.8	3.48±0.5	3.08±0.8	3.22±0.8
1 Kg M. ball throw (cm/kg)	10.07±1.7	9.73±1.6	9.44±1.3	9.62±1.4	8.21±1.1	8.55±1.4
3 Kg M. Ball Throw (cm/kg)	6.28±1.1	6.15±1.1	5.89±0.8	6.03±1.2	5.36±0.7	5.37±0.9
20m Sprint Running (sec/kg)	0.11±0.02	0.11±0.02	0.10±0.01	0.12±0.02	0.11±0.02	0.11±0.02
VO _{2max} (ml.kg ⁻¹ .min ⁻¹)	45.2±3.9	45.8±3.4	45.9±3.3	44.1±2.8	42.4±1.7	43.0±2.6

Prior to training, subjects warmed up for approximately 10 min with low to moderate intensity exercises (e.g., running, stretching and joint specific warm-up). Joint-rotations included slow circular movements, both clockwise and counter-clockwise, until the entire joint seemed to move smoothly. Stretching exercises included back and chest, shoulders and side stretch, as well as quadriceps, calf, groin, and hamstring stretches. At the end of the training sessions, subjects performed 5 min of static stretching exercises. After the warm-up period, both GR and GCON groups were submitted to a strength training program composed of: 1 and 3 kg medicine ball throws; jumps onto a box (from 0.3 m to 0.5 m); plyometric jumps over a hurdle of 0.3–0.5 m in height and sets of 30–40 m speed running. After finishing strength training for both GR and GCON groups, the GCON group was further subjected to a 20 m shuttle run exercise. This endurance task, which occurred immediately after the strength training session, was developed based on an individual training volume – set to about 75% of the established maximum aerobic volume achieved on a previous test. After 4 weeks of training, GCON subjects were reassessed using 20 m shuttle run tests in order to readjust the volume and intensity of the 20 m shuttle run exercise. Each training session lasted approximately between 45 min (resistance training) to 60 min (concurrent training). The rest period between sets was 1 min and between exercises 2 min. Before the start of the training, subjects completed 2 familiarization sessions to practice the drill and routines they would

further perform during the training period (i.e., power training exercises and 20 m shuttle run test). During this time, the children were taught about the proper technique for each training exercise, and any of their questions were properly answered to clarify any doubts. In the course of training there was a constant concern to ensure safety and maintain sufficient hydration levels, as well as to encourage all children to do their best to achieve the best results. Clear instructions about the importance of adequate nutrition were also provided. The same researcher conducted the training program and the anthropometric and physical fitness assessments. The instructor-to-child ratio was 1–11, slightly above the limit recommended by Faigenbaum et al. [13] (1:10). However, free weights or weight/hydraulic machines were not used in the training, but only medicine balls and body weight exercises, which facilitated the supervision process. The instructions for each exercise were given in accordance with the description of each test presented below. For the 20-m shuttle run, the instructions were given with the aid of a multi-stage fitness test audio CD, of the FITNESSGRAM® test battery. Throughout pre- and experimental periods, the subjects reported their non-involvement in additional regular exercise programs for developing or maintaining strength and endurance performance. There were no injuries resulting from the implementation of the training programs. A more detailed analysis of the program can be found in [Table 2](#).

Table 2 Training program design.

Exercises	Sessions					
	1	2	3	4	5	6
chest 1 Kg Medicine Ball Throw ^{1,2}	2×8	2×8	2×8	2×8	6×8	6×8
chest 3 Kg Medicine Ball Throw ^{1,2}	2×8	2×8	2×8	2×8		
overhead 1 Kg Medicine Ball Throw ^{1,2}	2×8	2×8	2×8	2×8	6×8	6×8
overhead 3 Kg Medicine Ball Throw ^{1,2}	2×8	2×8	2×8	2×8		
counter Movement Jump onto a box ^{1,2}	1×5	1×5	3×5	3×5	3×5	4×5
plyometric Jumps above 3 hurdling ^{1,2}	5×4	5×4	5×4	5×4	2×3	2×3
Sprint Running (m) ^{1,2}	4×20 m	4×20 m	3×20 m	3×20 m	3×20 m	3×20 m
20 m Shuttle Run (MAV) ²	75%	75%	75%	75%	75%	75%
Exercises	Sessions					
	7	8	9	10	11	12
chest 1 Kg Medicine Ball Throw ^{1,2}						
chest 3 Kg Medicine Ball Throw ^{1,2}	2×5	2×5	3×5	3×5	3×5	2×5
overhead 1 Kg Medicine Ball Throw ^{1,2}						
overhead 3 Kg Medicine Ball Throw ^{1,2}	2×8	2×8	3×8	3×8	3×8	
counter Movement Jump onto a box ^{1,2}	4×5	5×5	5×5	5×5	5×5	4×5
plyometric Jumps above 3 hurdling ^{1,2}	3×3	4×3	4×3	4×3	4×3	
sprint Running (m) ^{1,2}	4×30 m	4×30 m	4×30 m	4×30 m	4×30 m	3×40 m
20 m Shuttle Run (MAV) ²	75%	TestM	75%	75%	75%	75%
Exercises	Sessions					
	13	14	15	16		
chest 1 Kg Medicine Ball Throw ^{1,2}						
chest 3 Kg Medicine Ball Throw ^{1,2}	2×5	1×5				
overhead 1 Kg Medicine Ball Throw ^{1,2}		3×8	2×8	2×8		
overhead 3 Kg Medicine Ball Throw ^{1,2}	3×8					
counter Movement Jump onto a box ^{1,2}	4×5	2×5	2×4	2×4		
plyometric Jumps above 3 hurdling ^{1,2}	4×3	3×3				
sprint Running (m) ^{1,2}	3×40 m	4×40 m	2×30 m	2×30 m		
20 m Shuttle Run (MAV) ²	75%	75%	75%	75%		

For the Medicine Ball Throwing and Jump onto box the 1st no. corresponds to sets and 2nd corresponds to repetitions. For Sprint Running 1st number corresponds to sets and 2nd corresponds to the distance to run. For 20 m Shuttle Run training each children ran each session (until testM) 75% of maximum individual aerobic volume performed on pre-test and after this testM moment until program end, ran 75% of maximum individual aerobic volume performed on testM. MAV – maximum individual aerobic volume. 1 = power strength training protocol (GR). 2 = concurrent resistance and endurance training (GCON)

Anthropometric measurements

All anthropometric measurements were assessed according to international standards for anthropometric assessment [31] and were carried out prior to any physical performance test. The participants were barefoot and wore only underwear. Body mass (in kg) was measured to the nearest 0.1 kg using a standard digital floor scale (Seca, model 841, Germany). To evaluate body height (in cm) a precision stadiometer with a range scale of 0.10 cm was used (Seca, model 214, Germany). Maturity level based on Tanner stages was self-assessed [11].

Testing procedures

Sample groups were assessed for upper and lower body explosive strength (medicine ball throwing and standing long jump and vertical jump, respectively), running speed (20-m sprint run) and VO_{2max} (20-m multistage shuttle run test) before and after 8-weeks of training. Each subject was familiarized with all tests. All data collection was performed by the same researcher.

Counter movement vertical jump

This test was conducted on a contact mat connected to an electronic power timer, control box and handset (Globus Ergojump, Italy). From a standing position, with the feet shoulder-width apart and the hands placed on the pelvic girth, the subjects performed a counter movement with the legs before jumping. Such movement makes use of the stretch-shorten cycle, where the muscles are pre-stretched before shortening in the desired direction [29]. They were informed that they should try to jump vertically as high as possible. Each participant performed 3 jumps with a 1-min recovery between attempts. The highest jump (in cm) was recorded. The counter movement vertical jump has shown an Intraclass Correlation Coefficient (ICC) of 0.94.

Standing long jump

This test was assessed using the EUROFIT test battery [1]. The participants stood with feet slightly apart (toes behind a starting line) and jumped as far forwards as possible. 3 trials were given and the furthest distance was measured (in cm) from the starting line to the heel of the foot nearest to this line. The standing long jump has shown an ICC of 0.94.

Medicine-ball throwing

This test was performed according to the protocol described by Mayhew et al. [34]. Subjects were seated with the backside of the trunk touching a wall. They were required to hold a medicine ball (Bhalla International – Vinex Sports, Meerut – India) weighing 1 kg (Vinex, model VMB-001R, perimeter 0.72 m) or 3 kg (Vinex, model VMB-003R, perimeter 0.78 m) with their hands (abreast of chest) and throw it forward over the maximum distance possible. Hip inflection was not allowed nor withdrawal of the trunk away from the wall. 3 trials were given and the furthest throw was measured (in cm) from the wall to the first point at which the ball made contact with floor. 1-min of rest among 3 trials was given. The ICC of data for 1 kg and 3 kg medicine ball throwing was 0.94 and 0.97, respectively.

20-meter sprint running

Subjects were required to cover a 20 m distance on a track in the shortest possible time. Time (in sec) to run 20 m was obtained using photocells (Brower Timing System, Fairlee, Vermont, USA).

3 trials were performed and the best time scored (seconds and hundredth) was registered. The sprint running (time) has shown an ICC of 0.97.

20-meter multistage shuttle run

This test involved continuous running between 2 lines 20 m apart in time to recorded beeps. The subjects ran between the 2 lines, turning when signalled by the recorded beeps. After about 1 min, a sound indicates an increase in speed, and the beeps will be closer together. This continues each minute (level). The common version with an initial running velocity of 8.5 km/h, and increments of 0.5 km/h each minute [27] was used. When the participants failed to reach the line on 2 consecutive occasions, they were stopped and the number of completed 20 m laps was recorded. Estimated VO_{2max} ($ml.kg^{-1}.min^{-1}$) was calculated by Léger's equation [27], which is based on the level reached before boys were unable to keep up with the audio recording. The 20 m Shuttle Run test has shown an ICC of 0.97.

Statistical analyses

Standard statistical methods were used for the calculation of the means and standard deviations. The within-subject reliability of endurance and power tests was determined by the Intraclass Correlation Coefficient (ICC). 2-way analysis of variance (ANOVA), followed by Bonferroni's post-hoc comparison tests, was used to find the differences in the explosive strength and VO_{2max} measures in the pre-test (group and sex). To analyze the differences between groups and sex in the post-test measures an analysis of covariance (ANCOVA) was estimated for each dependent variable, followed by Bonferroni's post-hoc comparison tests, having as factors sex and group, and the measures of pre-test as a covariate. To determine the effect of sex and group on the evolution of strength/aerobic capacity from pre- to the post-training an ANOVA with repeated measures was performed for each dependent variable, with group as factor and sex as covariate. Partial eta squared as well as effect size was calculated. The normality of the residuals was validated by the Kolmogorov-Smirnov test. The assumption of sphericity was validated by the Mauchly's Test of Sphericity. Data was analyzed using SPSS 15.0. The statistical significance was set at $p \leq 0.05$.

Results



At baseline, there were no significant differences between groups for age or Tanner ratings. There were statistically significant differences between groups only in the 1 kg medicine ball throwing ($F(2, 122) = 4.45, p < 0.05$). Through the post-hoc tests, it was found that the control group had significantly higher values than GR and GCON. There were no significant differences between GR and GCON. Regarding sex differences in the pre-test, statistically significant differences were found between boys and girls in the counter movement jump ($F = 6.25, p < 0.05$), standing long jump ($F = 5.97, p < 0.05$), and 1 kg ($F = 12.25, p < 0.01$) and 3 kg ($F = 7.69, p < 0.01$) medicine ball throwing. Boys performed better than girls.

In the post-training (baseline performance as a covariate), a statistically significant effect of group on the performance of the standing long jump ($F(2, 118) = 7.20, p < 0.05$), 1 kg ($F(2, 118) = 27.41, p < 0.05$) and 3 kg medicine ball throwing ($F(2, 118) = 10.65, p < 0.05$), time-at-20 m ($F(2, 118) = 33.33, p < 0.05$) and VO_{2max}

Table 3 Evolution of the explosive strength and VO_{2max} from pre- to the post-training: ANOVA with repeated measures.

		F	df	p	Partial Eta Squared	Effect size	IC95 %
CM jump	main effect of time	34.44	1	0.000**	0.224	0.221	0.096–0.346
	interaction effect time by group	0.54	2	0.586	0.009	0.007	0–0.035
	interaction effect time by sex	0.81	1	0.37	0.007	0.005	0–0.029
SL jump	main effect of time	72.93	1	0.000**	0.376	0.535	0.419–0.651
	interaction effect time by group	3.16	2	0.046*	0.040	0.037	0–0.1
	interaction effect time by sex	0.2	1	0.659	0.002	0.001	0–0.012
1K ball throw	main effect of time	202.17	1	0.000**	0.626	0.530	0.413–0.647
	interaction effect time by group	28.21	2	0.000**	0.318	0.148	0.036–0.26
	interaction effect time by sex	1.78	1	0.185	0.014	0.005	0–0.029
3K ball throw	main effect of time	132.1	1	0.000**	0.522	0.480	0.357–0.603
	interaction effect time by group	11.14	2	0.000**	0.156	0.081	0–0.17
	interaction effect time by sex	0.06	1	0.801	0.001	0.000	0–0
20m sprint	main effect of time	122.21	1	0.000**	0.502	0.452	0.326–0.578
	interaction effect time by group	13.65	2	0.000**	0.184	0.101	0.004–0.198
	interaction effect time by sex	0.01	1	0.938	0.000	0.000	0–0
VO_{2max}	main effect of time	32.89	1	0.000**	0.214	0.195	0.074–0.316
	interaction effect time by group	6.22	2	0.003**	0.093	0.074	0–0.16
	interaction effect time by sex	2.73	1	0.101	0.022	0.016	0–0.058

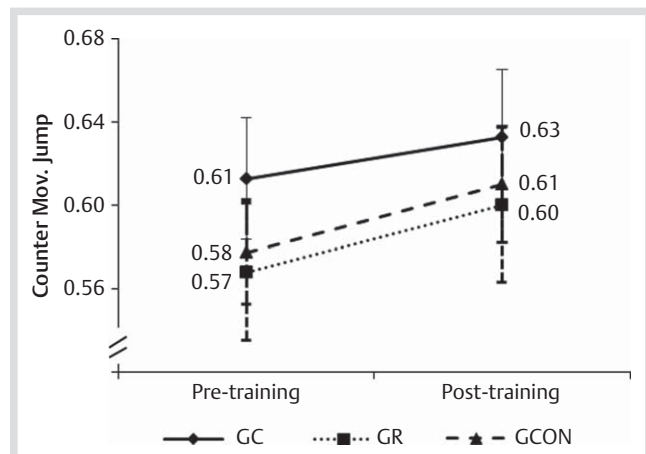
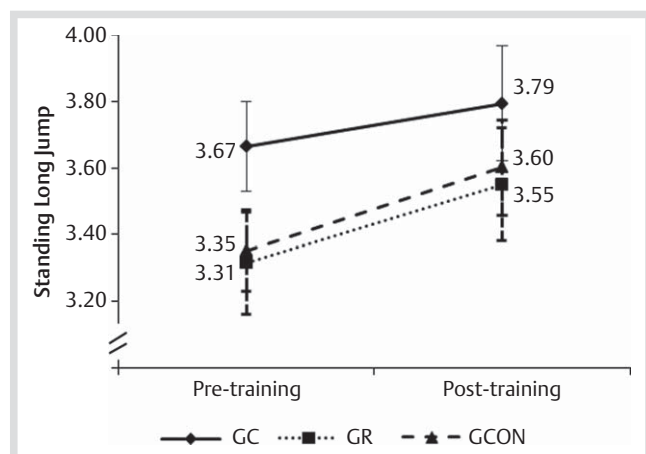
CM jump – counter movement jump; SL jump – standing long jump; 1K ball throw – 1 Kg medicine ball throwing; 3K ball throw – 3 Kg medicine ball throwing; 20m sprint – 20 m sprint running; VO_{2max} – 20 m multistage shuttle run ($ml.kg^{-1}.min^{-1}$); ** $p < 0.01$

($F(2, 118) = 10.66, p < 0.05$) was observed. Through the post-hoc tests, it was found that the differences between groups in the post-test occurred between the control and experimental groups. There were no statistically significant differences between GR and GCON. Regarding the VO_{2max} , the GCON group presented significantly higher values in the post-test than GC and GR. There were no statistically significant differences between GC and GR. The variable sex had no statistically significant influence on the post-test measures.

ANOVA with repeated measures showed a significant, but medium-sized increase from pre- to the post-training in the counter movement vertical jump ($F(1, 121) = 34.44, p < 0.01$) and VO_{2max} ($F(1, 121) = 32.89, p < 0.01$). There was a significant and high-sized increase in the 1 kg ($F(1, 121) = 202.17, p < 0.01$) and 3 kg ($F(1, 121) = 132.10, p < 0.01$) medicine ball throwing and standing long jump ($F(1, 121) = 72.93, p < 0.01$). Plus, there was a significant and large decrease in time for the 20 m distance from pre- to post-training ($F(1, 121) = 122.21, p < 0.01$) (Table 3).

Regarding the effect of the group factor on the evolution of strength and aerobic capacity from pre- to the post-training, there was no statistically significant influence of this factor on the evolution of the vertical jump ($F(2, 121) = 0.54, p \geq 0.05$). A significant, but small-sized effect, of the group on the evolution of the standing long jump ($F(2, 121) = 3.16, p < 0.05$), 3 kg medicine-ball throwing ($F(2, 121) = 11.14, p < 0.01$) and VO_{2max} ($F(2, 121) = 6.22, p < 0.01$) was observed. There was a significant and medium-sized effect of the group on the evolution of the 1 kg medicine ball throwing ($F(2, 121) = 28.21, p < 0.01$) and running velocity ($F(2, 121) = 13.65, p < 0.01$). However, the ANOVA with repeated measures for each group showed that the positive influence of the group on the standing long jump, 1 kg and 3 kg medicine-ball throwing and running speed was due to significant increases from pre- to the post-training in GR and GCON. The VO_{2max} increased significantly only in GCON. (Fig. 1–6).

Regarding sex factor, it did not significantly influence the evolution from pre- to the post-training of the vertical jump ($F(1, 121) = 0.81, p \geq 0.05$), standing long jump ($F(1, 121) = 0.20,$

**Fig. 1** Counter movement jump (cm/kg) by group.**Fig. 2** Standing long jump (cm/kg) by group.

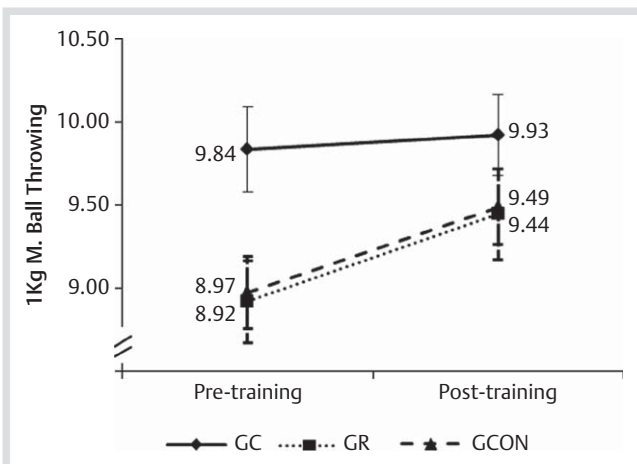


Fig. 3 1 Kg medicine ball throwing (cm/kg) by group.

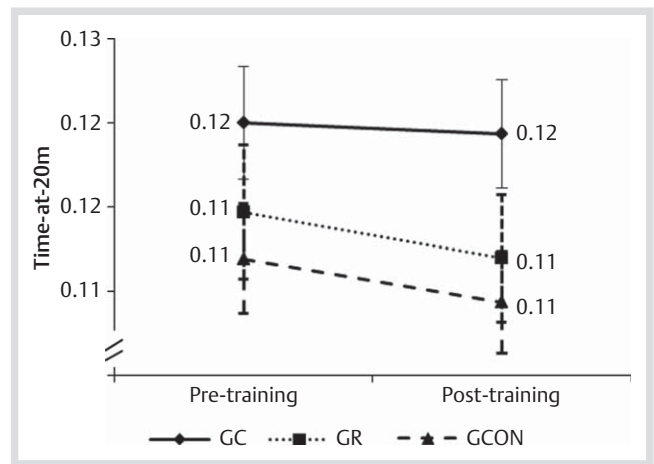


Fig. 5 Time-at-20m (sec/kg) by group.

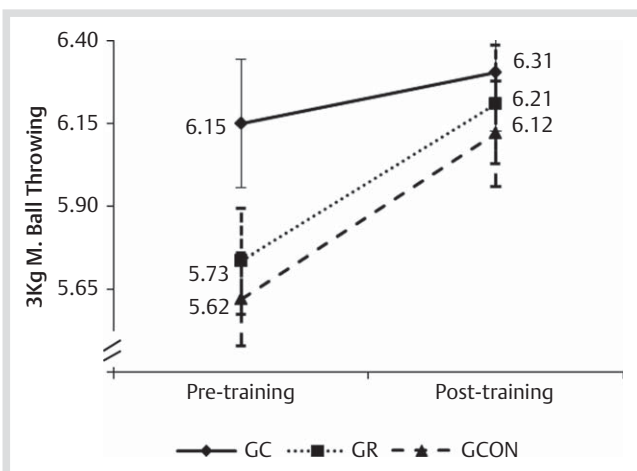


Fig. 4 3 Kg medicine ball throwing (cm/kg) by group.

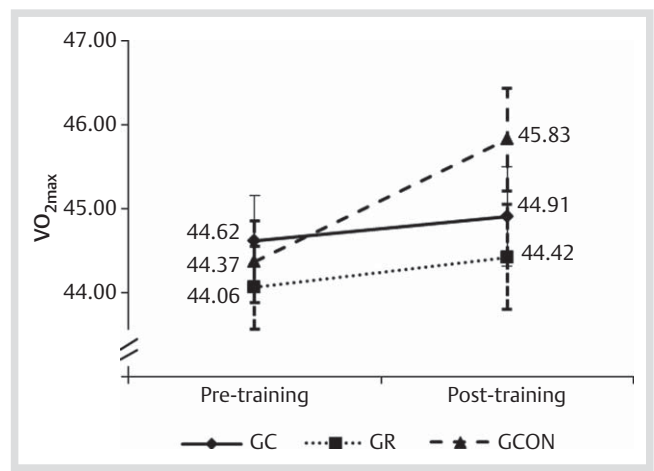


Fig. 6 VO_{2max} (ml.kg⁻¹.min⁻¹) by group.

$p \geq 0.05$), 1 kg ($F(1, 121) = 1.78, p \geq 0.05$) and 3 kg ($F(1, 121) = 0.06, p \geq 0.05$) medicine-ball throwing, running speed ($F(1, 121) = 0.01, p \geq 0.05$), and VO_{2max} ($F(1, 121) = 2.73, p \geq 0.05$). (○ Fig. 7–12).

Discussion

The purpose of the study was to analyze the effect of power strength training alone and combined power strength and endurance training in a large sample of prepubescent boys and girls. The main results suggested that concurrent training is an effective, well-rounded exercise program that can be performed to improve initial and/or general strength in healthy prepubescent boys and girls. Additionally, data suggest that sex does not have a significant effect on training-induced explosive strength and VO_{2max} of prepubescent children. These results are of a high interest to optimize all-round exercise programs in childhood.

The significant increase observed in both training groups for explosive strength of upper and lower limbs (e.g. throwing of 1 kg and 3 kg medicine balls, standing long jump and counter movement vertical jump) as well as in 20-m sprint running indicates that both concurrent resistance and endurance training and resistance training alone may be a positive training stimulus to enhance explosive strength in healthy prepubescent children. These findings are consistent with the results of previous studies

in this area conducted with young people [14,40], who were also subjected to training programs using medicine balls and jumps (6 and 10 weeks training programs, respectively, twice per week on nonconsecutive days). Similar results were reported by Faigenbaum et al. [15], using child-size exercise machines twice weekly over an 8-weeks period, while Dorgo et al. [9] conducted 9 and 18 weeks of manual resistance training, respectively. Additionally, no significant differences were found in the post training between GR and GCON groups in any variable related to the explosive strength selected. This fact seems to suggest that endurance training does not positively affect strength development in school-age children, but also does not seem to impair strength development. There is a relative paucity of published reports focusing on the implementation of concurrent resistance and endurance training in school children [22]. The studies conducted by Santos et al. [41,42] are an exception, however they relate exclusively to the implementation of concurrent training programs in pubertal school girls and boys, respectively. Using a very similar training program design (i.e., resistance training using medicine balls, endurance training using the 20-m multistage shuttle-run test, twice weekly for 8 weeks), the authors found significant training-induced gains in ball throw, running speed and height-and-length of the jumps, in both strength training alone, and combined strength and aer-

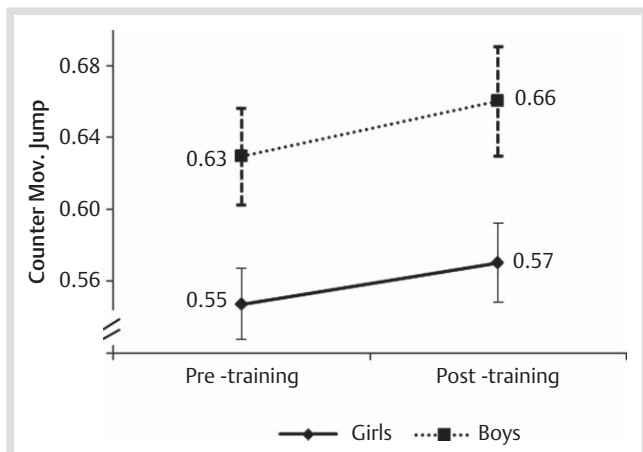


Fig. 7 Counter movement jump (cm/kg) by sex.

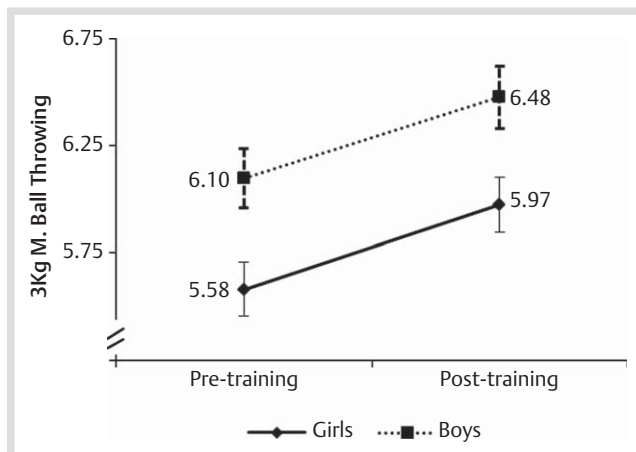


Fig. 10 3Kg medicine ball throwing (cm/kg) by sex.

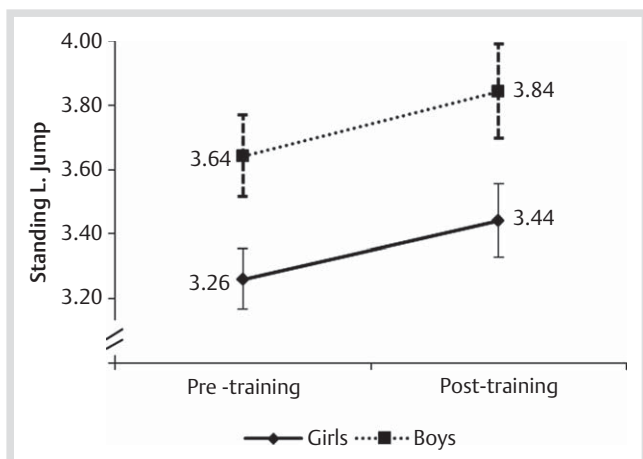


Fig. 8 Standing long jump (cm/kg) by sex.

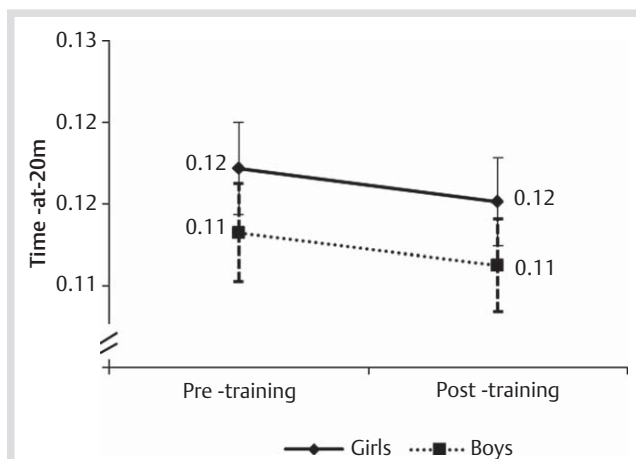


Fig. 11 Time-at-20m (sec/kg) by sex.

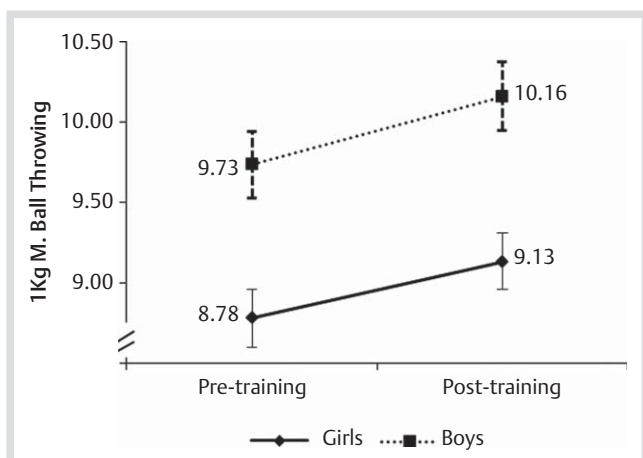


Fig. 9 1Kg medicine ball throwing (cm/kg) by sex.

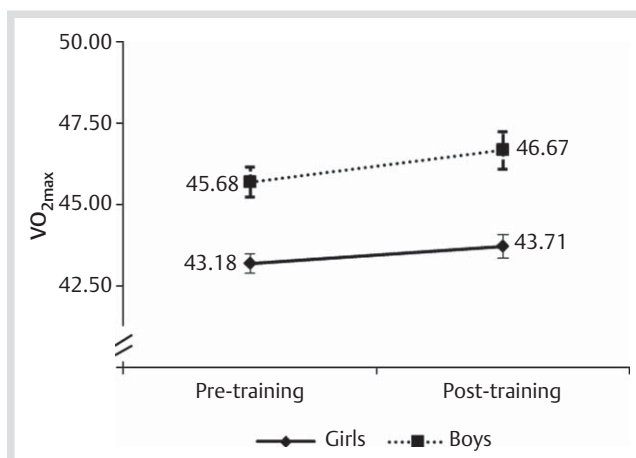


Fig. 12 VO_{2max} (ml.kg⁻¹.min⁻¹) by sex.

obic training. No significant differences were found in the post training between these experimental training groups. However, a training program design different to that in this particular study, or different methods of organizing training workouts, can lead to different results, due to several factors that can influence the level or degree of interference generated by con-

current training [16]. These factors include the initial training status of the subjects [25], exercise mode, volume, intensity and frequency of training [17,18,23]. For example, Sale et al. [39] observed that concurrent resistance and endurance training applied on separate days produced higher gains than those produced by concurrent training on the same day. Strength and

endurance training elicit distinct and often divergent adaptive physiological mechanisms. The concurrent development of both fitness components in the same training regimen can lead to conflicting neuromuscular adaptations, such as reductions in the motor unit recruitment, decreases of rapid voluntary neural activations, chronic depletion of muscle glycogen stores, skeletal muscle fibre type transformation, decreases in the cross-sectional area of muscle fibres and in the rate of muscle force production due to the reduction in total protein synthesis [6,20]. Children have neuromuscular and endurance characteristics that distinguish them from adults. Those characteristics may help to explain the absence of the “interference phenomenon”, described in related studies done with adults. In the present study, with prepubescent children, as well as in studies conducted by Santos et al. [41,42], with adolescents, no electrophysiological measures were included. Therefore, future investigations should include those measures when analyzing the effects of the implementation of the concurrent resistance and endurance training programs in the considered age groups. The current results also showed a significant enhancement in VO_{2max} only for GCON. In agreement with previous studies [9,41,42], these finding seems to indicate that the resistance training program component was not effective in improving aerobic fitness in prepubescent school children. After 18-weeks of manual resistance training, Dorgo et al. [9] observed that only the subjects who were exposed to additional cardiovascular endurance training achieved significant improvements for the 1-mile run performance. The subjects who performed only manual resistance training showed some improvement from pre- to midterm- and pre- to post-test. But these changes were not statistically significant. Similarly, Santos et al. [41,42] found that VO_{2max} increased significantly only in the endurance training group, after 8 weeks. However, it is important to note that the greater efficiency of the concurrent training in the VO_{2max} gains may have been conditioned by the different duration of training sessions between the 2 intervention groups (approximately 45' and 60' per session for GR and GCON, respectively). Regarding the gender gap, the results seem to suggest that there is no significant effect on training-induced strength and VO_{2max} adaptations. These data corroborate the results of previous studies conducted with children, reporting no significant differences in aerobic training response related to sex. Rowland and Boyajian [38] observed no significant differences relative to sex in maximal oxygen uptake after an endurance training program (three 30-min sessions of aerobic activity weekly for 12 weeks at an intensity producing a mean heart rate of 166 beats per minute). Similarly, Obert et al. [35] found that sex did not affect training-induced cardiovascular response in prepubescent children (13-week endurance training program, $3 \times 1 \text{ h week}^{-1}$, intensity: $>80\%$ heart rate maximum). Aerobic training increased VO_{2max} in children, regardless of sex, mediated by an improvement in maximum stroke volume [35]. Similar mechanisms, including loading conditions and cardiac morphology, appear to be involved in both boys and girls in order to explain such an improvement [35]. According to Vinet et al. [46] during pre-adolescence there are no significant sex differences in maximal heart rate and arteriovenous oxygen, and although the stroke volume is significantly higher in boys than in girls, when expressed relative to lean body mass, the difference is no longer significant.

The observed similarity between boys and girls in training-induced strength is also consistent with findings of previous studies conducted with prepubescent children. After applying a 12-week progressive resistance program Lillegard et al. [28] found significant main effects favouring strength gains in males, only in lat pull and leg extension (3 sets of ten repetitions of 10RM on barbell curl, triceps extension, bench press, lat pull, leg extension and leg curl exercises, three 1-h session per week). There were no significant post training sex differences in jumping and running speed. Siegel et al. [43] also observed that following a similar training period, but using hand-held weights, stretch tubing, balls, and self-supported movements, training responses of boys and girls were similar, although significant differences in favour of boys on all initial strength evaluations have been reported. Training-induced strength gains during and after puberty in males are associated with increases in fat-free mass, due to the effect of testosterone on muscle hypertrophy. In reverse, smaller amounts of testosterone in females (resulting from enzymatic conversion of androgenic precursors in the adrenal gland) seem to limit the magnitude of training-induced strength gains [24]. However, during preadolescence, beyond the small muscle mass of the girls, the boys still present a reduced muscle mass, because the effects of circulating androgens, particularly testosterone, only manifest themselves at puberty [37].

In brief, our data suggest that a concurrent resistance and endurance school-based training program seems to be effective on both strength and endurance fitness for school-age children. The results also indicate that sex does not affect explosive strength improvement, either in the resistance training alone, or combined resistance and endurance training. In this sense, and assuming various school constraints (i.e., reduced practice time per session, number of weekly sessions or lack of material resources and facilities) in order to increase the physical education classes efficiency, combined training programs of resistance and endurance should be considered in school-based programs. There are some main limitations to be considered: i) the training period of 8 weeks is quite short; ii) different training program design or different methods of organizing training workouts can lead to different training-induced outcomes; iii) different methods of evaluating pre- and post-training muscular strength and aerobic capacity may also lead to data bias; iv) different training durations between strength training and concurrent training groups may have conditioned training-induced gains; v) due to the methodological approach (i.e., no electrophysiological measures) it was not possible to clarify the underlying mechanisms responsible for the observed effects; (vi) the study population included normal-weight, physically active children. Therefore, care is needed when translating these findings to overweight/obese and/or less/more physically active children.

Acknowledgements

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The authors would like to thank all the pupils who participated in this research and their parents that allowed them to engage in it, and gratefully acknowledge Adalberto Carvalho (the school principal of the School Cluster Santa Clara) and the management team for allowing the use of the training equipment used in this study and school facilities.

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