Concurrent Training in Prepubescent Children: The Effects of 8 Weeks of Strength and Aerobic Training on Explosive Strength and $\dot{V}O_2max$

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Abstract

Alves, AR, Marta, CC, Neiva, HP, Izquierdo, M, and Marques, MC. Concurrent training in prepubescent children: the effects of 8 weeks of strength and aerobic training on explosive strength and $\dot{V}O_2$max. *J Strength Cond Res* 30(7): 2019–2032, 2016–The purpose of this study was to compare the effects of 8-week training periods of strength training alone (GS), combined strength and aerobic training in the same session (GCOM1), or in 2 different sessions (GCOM2) on explosive strength and maximal oxygen uptake ($\dot{V}O_2$max) in prepubescent children. Of note, 168 healthy children, aged 10–11 years (10.9 ± 0.5), were randomly selected and assigned to 3 training groups to train twice a week for 8 weeks: GS ($n = 41$), GCOM1 ($n = 45$), GCOM2 ($n = 38$) groups, and a control group (GC) ($n = 44$; no training program). The GC maintained the baseline level, and trained-induced differences were found in the experimental groups. Differences were observed in the 1 and 3-kg medicine ball throws (GS: +5.8 and +8.1%, respectively; GCOM1: +5.7 and +8.7%, respectively; GCOM2: +6.2 and +8%, respectively, $p < 0.001$) and in the countermovement jump height and in the standing long jump length (GS: +5.1 and +5.2%, respectively; GCOM1: +4.2 and +7%, respectively; GCOM2: +10.2 and +6.4%, respectively, $p < 0.001$). In addition, the training period induced gains in the 20-m time (GS: +2.1%; GCOM1: +2.1%; GCOM2: +2.3%, $p < 0.001$). It was shown that the experimental groups (GCOM1, GCOM2, and GS) increased $\dot{V}O_2$max, muscular strength, and explosive strength from pretraining to posttraining. The higher gains were observed for concurrent training when it was performed in different sessions. These results suggest that concurrent training in 2 different sessions seems to be an effective and useful method for training-induced explosive strength and $\dot{V}O_2$max in prepubescent children. This could be considered as an alternative way to optimize explosive strength training and cardiorespiratory fitness in school-based programs.

Key Words sequence, exercise, youth, power

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Introduction

Physical fitness has declined worldwide in recent decades among children and adolescents (28). The effect of a sedentary lifestyle has become a major public health threat (33) that is highly associated with cardiovascular, cardiorespiratory, and musculoskeletal diseases (31). Nowadays, physical fitness has emerged as a determinant factor of current and future health status (34,42) and as a main element for the preservation and enhancement of health, quality of life, and holistic development during childhood (27). Moreover, it is often assumed that physical activity during childhood and adolescence has a positive influence on adult health (22). Here, schools could provide an excellent setting to enhance and promote physical activity by implementing safe training programs (24,26).

The children should benefit from the development of strength and cardiovascular parameters and from these 2 important health-related physical fitness components (34,43). The concurrent training, by combining aerobic and strength regimens, would allow children to associate the benefits of both activities into a single training session (5,35). However, Glowacki et al. (14) reported that it could hinder aerobic adaptations and attenuation of strength development because of an inhibitory effect on muscle (13,16). This effect is known as the "interference phenomenon" (10,13). Afterward, it was reported that concurrent

TABLE 1. Training program design (sets × repetitions/distances).*

Exercise	1-kg ball throw	3-kg ball throw	SL jump	CM jump	20-m sprint	20-m shuttle run (MAV) (%)
Sessions						
1	2 × 8	2 × 8	2 × 4	1 × 5	2 × 20 m	70
2	2 × 8	2 × 8	2 × 4	1 × 5	2 × 20 m	70
3	2 × 8	2 × 8	2 × 4	1 × 5	2 × 20 m	70
4	2 × 8	2 × 8	2 × 4	1 × 5	2 × 20 m	70
5	2 × 8	2 × 8	2 × 4	2 × 5	3 × 20 m	75
6	2 × 8	2 × 8	2 × 4	2 × 5	3 × 20 m	75
7	2 × 8	2 × 8	2 × 4	2 × 5	3 × 20 m	75
8	2 × 8	2 × 8	2 × 4	2 × 5	3 × 20 m	75
9	3 × 8	2 × 8	3 × 4	2 × 5	3 × 20 m	75
10	3 × 8	2 × 8	3 × 4	2 × 5	3 × 20 m	75
11	3 × 8	3 × 6	3 × 4	3 × 5	3 × 30 m	80
12	3 × 8	3 × 6	3 × 4	3 × 5	3 × 30 m	80
13	3 × 8	3 × 6	4 × 4	3 × 5	3 × 30 m	80
14	3 × 8	3 × 6	4 × 4	3 × 5	3 × 30 m	80
15	3 × 8	3 × 6	4 × 4	3 × 5	3 × 30 m	80
16	3 × 8	3 × 6	4 × 4	3 × 5	3 × 30 m	80

*1-kg ball throw = chest 1-kg medicine ball throwing (centimeter); 3-kg ball throw = chest 3-kg medicine ball throwing (centimeter); SL jump = standing long jump (centimeter); CM jump = countermovement jump onto a box (centimeter); 20-m sprint = 20-m sprint running (seconds); MAV = maximal individual aerobic volume.

training impairs the development of strength and muscular power but did not affect the development of aerobic capacity compared with both forms of stand-alone training (17,39). Nevertheless, some studies have shown no antagonistic effects on strength (30) or aerobic performance (32) after concurrent training. It seemed that the physiological adaptations that followed concurrent training are dependent on the type and degree of the stimulus applied during the training session (4) and the incorporation of recovery posttraining (20). These could result in beneficial effects of concurrent training and

TABLE 2. Univariate analysis.*†

	GS	GCOM1	GCOM2	GC	*p*
Sex					
Female, *n* (%)	22 (53.7)	24 (53.3)	17 (44.7)	23 (52.3)	0.841
Male, *n* (%)	19 (46.3)	21 (46.7)	21 (55.3)	21 (47.7)	
Age, mean + *SD*	10.8 ± 0.4	10.8 ± 0.5	11.0 ± 0.5	10.9 ± 0.5	0.062
BMI, mean + *SD*	19.3 ± 3.4	19.3 ± 3.0	19.2 ± 2.9	19.2 ± 3.1	0.997
FAT, mean + *SD*	22.5 ± 7.7	22.6 ± 8.2	21.4 ± 8.6	21.6 ± 7.0	0.845
$\dot{V}O_2$max	44.1 ± 3.1	44.4 ± 3.3	41.1 ± 2.2	44.8 ± 3.6	0.000‡
1-kg ball throw	347.8 ± 59.8	358.2 ± 62.6	336.5 ± 72.7	364.3 ± 55.9	0.205
3-kg ball throw	224.0 ± 38.9	224.4 ± 40.8	235.1 ± 49.6	224.3 ± 44.3	0.608
SL jump (cm)	124.7 ± 13.1	130.6 ± 17.5	128.3 ± 23	132.6 ± 19.6	0.240
CM jump	21.3 ± 4.5	22.3 ± 4.0	23.8 ± 6.1	22.2 ± 4.7	0.154
20-m sprint (s)	4.4 ± 0.2	4.4 ± 0.3	4.4 ± 0.4	4.4 ± 0.3	0.997

*$\dot{V}O_2$max = multistage shuttle run (ml·kg^{-1}·min^{-1}); 1-kg ball throw = chest 1-kg medicine ball throwing (centimeter); 3-kg ball throw = chest 3-kg medicine ball throwing (centimeter); SL jump = standing long jump (centimeter); CM jump = countermovement jump onto a box (centimeter); 20-m sprint = 20-m sprint running (seconds).

†Percentage (%) of sex, mean ± *SD* of age, body mass index (BMI), % fat mass (FAT), maximal oxygen uptake ($\dot{V}O_2$max), and muscle strength variables in strength training alone (GS), combined strength and aerobic training in the same session (GCOM1), combined strength and aerobic training in 2 different sessions (GCOM2), and control group (GC).

‡significant difference $p < 0.001$.

§$p < 0.01$.

TABLE 3. Intraclass correlation (95% confidence interval for intraclass correlation coefficient) of maximal oxygen uptake ($\dot{V}O_2max$) and muscle strength variables in strength training alone (GS), combined strength and aerobic training in the same session (GCOM1), combined strength and aerobic training in 2 different sessions (GCOM2), and control group (GC).*

	Overall	GS	GCOM1	GCOM2	GC
$\dot{V}O_2max$	0.850 (0.802–0.887)	0.915 (0.847–0.954)	0.873 (0.781–0.928)	0.808 (0.660–0.895)	0.914 (0.848–0.952)
1-kg ball throw	0.979 (0.972–0.985)	0.985 (0.972–0.992)	0.986 (0.974–0.992)	0.991 (0.983–0.995)	0.982 (0.968–0.990)
3-kg ball throw	0.951 (0.934–0.963)	0.981 (0.964–0.990)	0.967 (0.940–0.981)	0.981 (0.964–0.990)	0.912 (0.844–0.951)
SL jump	0.925 (0.899–0.944)	0.963 (0.932–0.980)	0.940 (0.894–0.967)	0.969 (0.942–0.984)	0.870 (0.773–0.927)
CM jump	0.898 (0.864–0.924)	0.931 (0.875–0.963)	0.929 (0.874–0.960)	0.855 (0.739–0.922)	0.938 (0.888–0.965)
20-m sprint	0.970 (0.959–0.978)	0.963 (0.931–0.980)	0.973 (0.951–0.985)	0.986 (0.974–0.993)	0.973 (0.952–0.985)

*$\dot{V}O_2max$ = multistage shuttle run (ml·kg^{-1}·min^{-1}); 1-kg ball throw = chest 1-kg medicine ball throwing (centimeter); 3-kg ball throw = chest 3-kg medicine ball throwing (centimeter); SL jump = standing long jump (centimeter); CM jump = countermovement jump onto a box (centimeter); 20-m sprint = 20-m sprint running (seconds).

recent studies tried to clarify it, namely, in child population (25,26,39).

Other main issue about this methodology is the sequential order for better results. Two decades ago, Sale et al. (38) reported that concurrent strength in the same day instead of different days might inhibit the strength development but not maximal oxygen uptake ($\dot{V}O_2max$). Recently, Chtara et al. (6) confirmed that aerobic training followed by strength training produced greater improvements in aerobic performance than the reverse order or the separating the training methods, thus highlighting the relevance of concurrent training. On this, it is important to note that this study was conducted in adults. The inconsistencies across these findings may be explained by the studies designs and training protocols (19). These included the mode of aerobic exercise, variations in the intensity and volume of the strength and aerobic training, different sequences of the strength and aerobic training sessions, distinct recovery periods between the strength and aerobic sessions, and variations in the frequency of training sessions per week (2,12). Nevertheless, the effects of concurrent strength and aerobic training and its consequences in prepuberty are yet to be investigated.

Along with the scarce results regarding the effects of strength training and aerobic combinations, to the authors' best knowledge, there are no data regarding the effect of intrasession concurrent endurance and strength training or separately components in prepubescent population. Such data would give insight into the influence of concurrent training in explosive strength adaptation and aerobic capacity. Therefore, this study aimed to compare the effects of an 8-week training period with different training activities performed during the same training session or during different training sessions on explosive strength and $\dot{V}O_2max$ parameters in prepubescent children. The established hypothesis submitted in this article is that prepubescent children can increase their explosive strength performances by concurrent training sessions conducted separately over a consecutive 8-week period. We also hypothesize that $\dot{V}O_2max$ increases independently from the different combination approaches.

METHODS

Experimental Approach to the Problem

The aim of this study was to compare the effects of 8-week training periods of strength training alone (GS), combined strength and aerobic training in the same session (GCOM1), or in 2 different sessions (GCOM2) on explosive strength and maximal oxygen uptake ($\dot{V}O_2max$) in prepubescent children. The study followed a repeated measures design with each participant being randomly assigned a specific program or a control group (GC) (no training program), and evaluated in pretest and posttest momentum. Concerning the training protocol applied, it was verified in previous studies (26,39), strength and cardiovascular improvements in

TABLE 4. Mean ± *SD* and paired *t*-test to maximal oxygen uptake ($\dot{V}O_2max$) and muscle strength variables pretraining and posttraining momentum in strength training alone (GS), combined strength and aerobic training in the same session (GCOM1), combined strength and aerobic training in 2 different sessions (GCOM2), and control group (GC).*

	Pre	Post	Difference (pre–post)	*p*
GS				
$\dot{V}O_2max$	44.1 ± 3.1	44.4 ± 4	−0.4 ± 1.5	0.124
1-kg ball throw	347.8 ± 59.8	368.1 ± 63.8	−20.3 ± 10.8	0.000†
3-kg ball throw	224 ± 38.9	242.2 ± 41.6	−18.2 ± 7.9	0.000†
SL jump	124.7 ± 13.1	131.2 ± 14.9	−6.5 ± 3.8	0.000†
CM jump	21.3 ± 4.5	22.4 ± 5.2	−1.1 ± 1.8	0.000†
20-m sprint	4.4 ± 0.2	4.3 ± 0.2	0.1 ± 0.1	0.000†
GCOM1				
$\dot{V}O_2max$	44.4 ± 3.3	46.1 ± 4.1	−1.7 ± 1.9	0.000†
1-kg ball throw	358.2 ± 62.6	378.6 ± 63.7	−20.4 ± 10.7	0.000†
3-kg ball throw	224.4 ± 40.8	244 ± 42.3	−19.5 ± 10.8	0.000†
SL jump	130.6 ± 17.5	139.8 ± 20.4	−9.1 ± 6.6	0.000†
CM jump	22.3 ± 4	23.3 ± 4.3	−0.9 ± 1.6	0.000†
20-m sprint	4.4 ± 0.3	4.3 ± 0.3	0.1 ± 0.1	0.000†
GCOM2				
$\dot{V}O_2max$	41.1 ± 2.2	44.2 ± 2.8	−3.1 ± 1.5	0.000†
1-kg ball throw	336.5 ± 72.7	357.5 ± 70.7	−21.0 ± 9.4	0.000†
3-kg ball throw	235.1 ± 49.6	254 ± 47.9	−18.9 ± 9.4	0.000†
SL jump	128.3 ± 23	136.5 ± 23.3	−8.2 ± 5.7	0.000†
CM jump	23.8 ± 6.1	26.2 ± 7.9	−2.4 ± 3.8	0.000†
20-m sprint	4.4 ± 0.4	4.3 ± 0.4	0.1 ± 0.1	0.000†
GC				
$\dot{V}O_2max$	44.8 ± 3.6	45.0 ± 4	−0.2 ± 1.6	0.386
1-kg ball throw	364.3 ± 55.9	367.5 ± 59.4	−3.3 ± 10.8	0.053
3-kg ball throw	224.3 ± 44.3	229.9 ± 45.2	−5.5 ± 18.8	0.057
SL jump	132.6 ± 19.6	135.7 ± 23.2	−3.1 ± 11.0	0.066
CM jump	22.2 ± 4.7	22.6 ± 5.3	−0.4 ± 1.8	0.103
20-m sprint	4.4 ± 0.3	4.4 ± 0.3	0.0 ± 0.1	0.076

*$\dot{V}O_2max$ = multistage shuttle run ($ml \cdot kg^{-1} \cdot min^{-1}$); 1-kg ball throw = chest 1-kg medicine ball throwing (centimeter); 3-kg ball throw = chest 3-kg medicine ball throwing (centimeter); CM jump = countermovement jump onto a box (centimeter); SL jump = standing long jump (centimeter); 20-m sprint = 20-m sprint running (seconds).
†significant difference $p < 0.001$.
‡significance difference $p < 0.01$.

children using the same training protocol. Based on those studies and in the knowledge of an experienced coach and researcher, it was structured as a training program (Table 1), comprising specific sets, repetitions, and drills. Moreover, combined strength and aerobic training in different sessions was chosen because there were no reports about its effects in prepubescent children.

Subjects

The sample consisted of 168 prepubescent children (aged 10.9 ± 0.5 years) from the school cluster Santa Clara (Guarda, Portugal), that were randomly assigned different training programs. The height and body mass of the entire sample was as follows: 1.43 ± 7.74 m, and 40.0 ± 8.8 kg, respectively.

The inclusion criteria were children aged between 10 and 11.5 years (from fifth and sixth grade), without a chronic pediatric disease or orthopedic limitation and without a regular oriented extracurricular physical activity (i.e., practice of some sport in an academy). For the entire sample, participation in a minimum of 22 of the 24 training sessions was required to be included in the analysis.

Before data collection and the beginning of the training, each participant reported any health problems, physical limitations, physical activity habits, and training experiences for the last 6 months. Thereafter, maturity levels based on Tanner stages (11) were self-assessed, and to minimize the effects of growth, only children that were self-assessed in Tanner stages I-II were selected. No subject had regularly participated in any form of training program before this experiment. Efforts were made to collect a sample for making comparable groups. After approval from the local ethics board of University of Beira Interior, Covilhã, Portugal, ensuring compliance with the declaration of Helsinki, the

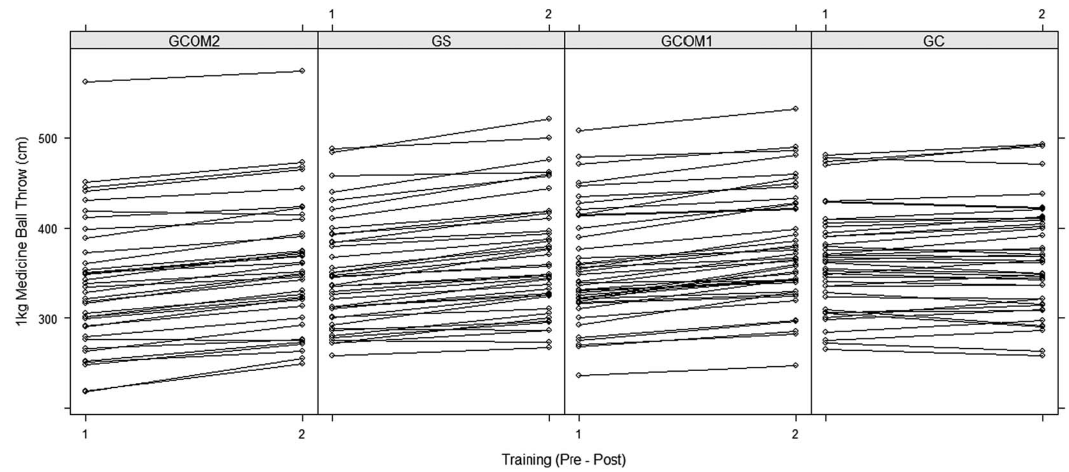

Figure 1. Spaghetti plot. Obtained values in pretest and posttest of training in strength training alone (GS), combined strength and aerobic training in the same session (GCOM1), or in 2 different sessions (GCOM2), and control group (GC) on 1-kg medicine ball throw.

participants (prepubescent children) were informed about the study procedures, risks, and benefits, and a written informed consent was signed by the parent/guardian of the subjects.

Procedures

Sample Procedures. One hundred sixty-eight healthy children recruited from a Portuguese public high school were randomly assigned to 3 experimental groups (8-week training, twice a week, from January 14 to March 15, 2013) and 1 GC as follows: 1 group performing GS ($n = 41$, 22 girls, 19 boys); another group performing GCOM1 ($n = 45$, 24 girls, 21 boys); the third performing GCOM2 ($n = 38$, 17 girls, 21 boys); and the GC ($n = 44$, 23 girls, 21 boys)–no training program. This last group followed the physical education class curriculum and did not have a specific training program. 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. The participants were randomly assigned 1 of 4 intervention arms. Randomization was performed using R software version 2.14 (R Foundation for Statistical Computing). Before the start of

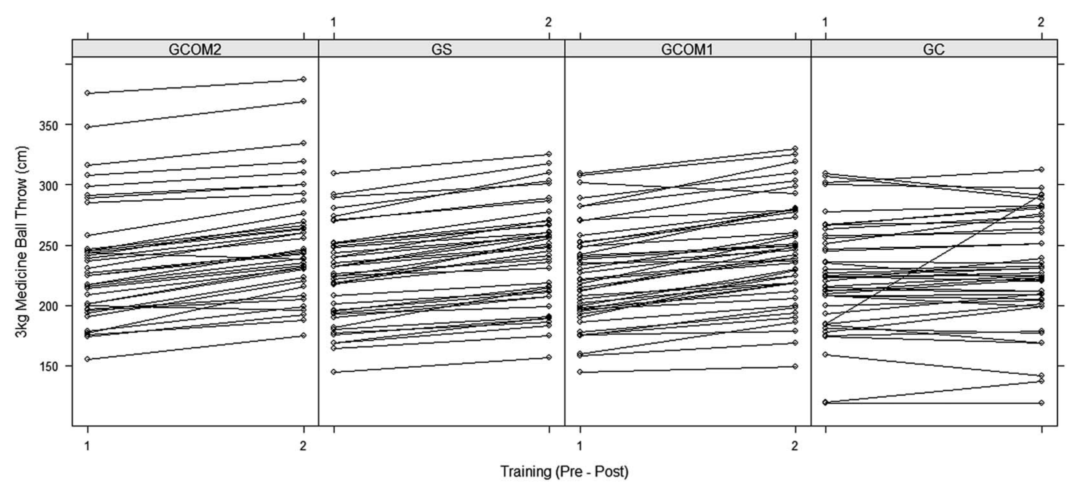

Figure 2. Spaghetti plot. Obtained values in pretest and posttest of training in strength training alone (GS), combined strength and aerobic training in the same session (GCOM1), or in 2 different sessions (GCOM2), and control group (GC) on 3-kg medicine ball throw.

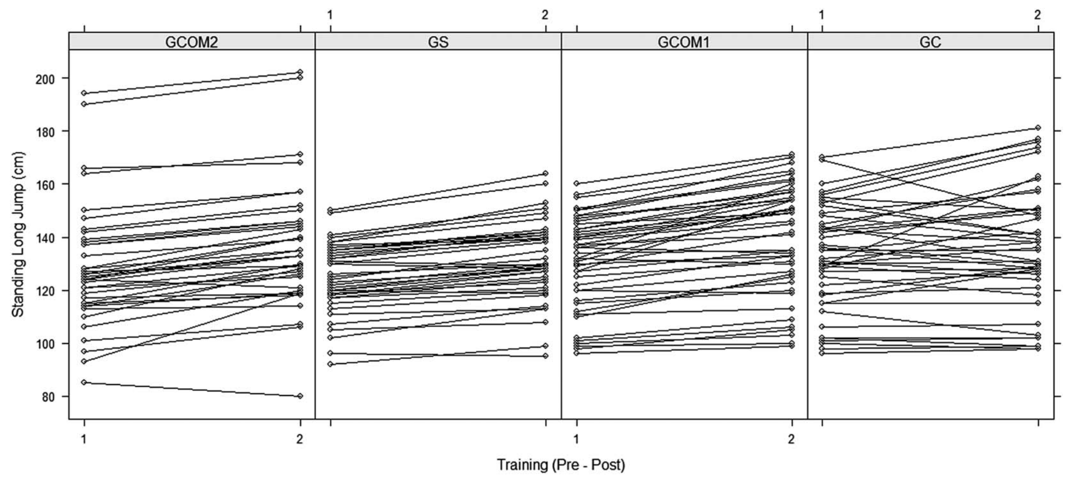

Figure 3. Spaghetti plot. Obtained values in pretest and posttest of training in strength training alone (GS), combined strength and aerobic training in the same session (GCOM1), or in 2 different sessions (GCOM2), and control group (GC) on standing long jump.

the training, all the sample subjects attended physical education classes twice a week, with duration of 45 and 90 minutes each class, respectively. Typical physical education classes with an intensity low to moderate included various sports (team sports, gymnastics, dance, adventure sports, among others) with an evident pedagogical focus.

Training Procedures. The training program was implemented additionally to physical education classes. Before the training, the subjects warmed up for approximately 10 minutes with low to moderate-intensity exercises (e.g., running, sprints, stretching, and joint specific warm-up). Joint rotations included slow circular movements, both clockwise and counterclockwise, until the entire joint moved smoothly. Stretching exercises included back and chest stretches, shoulder and side stretches, wrist, waist, quadriceps, groin, and hamstring stretches. At the end of the training sessions, all subjects performed 5 minutes of static stretching exercises such as kneeling lunges, ankle over knee, rotation, and hamstrings. After the warm-up period, all the training groups were submitted to a strength training program composed of 1 and 3-kg medicine ball throws, jumps onto a box (from 0.3

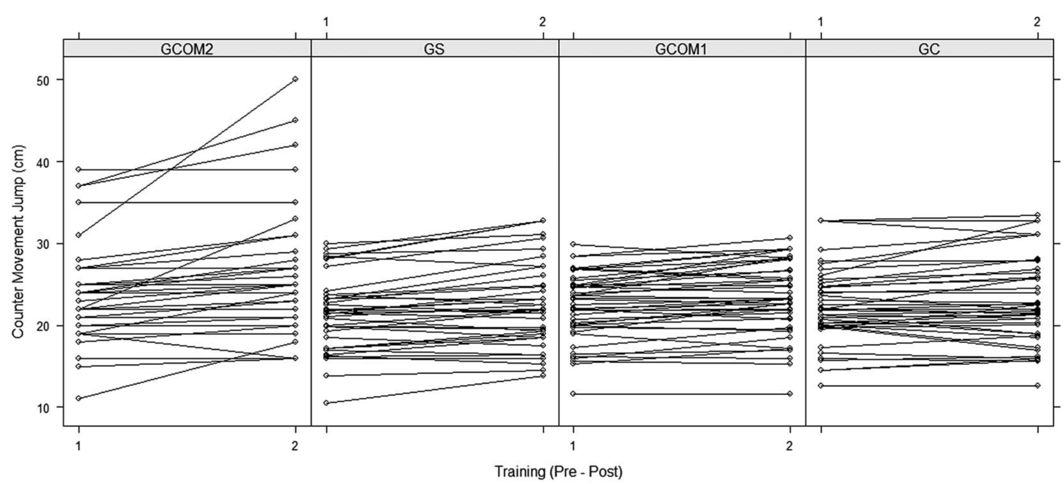

Figure 4. Spaghetti plot. Obtained values in pretest and posttest of training in strength training alone (GS), combined strength and aerobic training in the same session (GCOM1), or in 2 different sessions (GCOM2), and control group (GC) on countermovement jump.

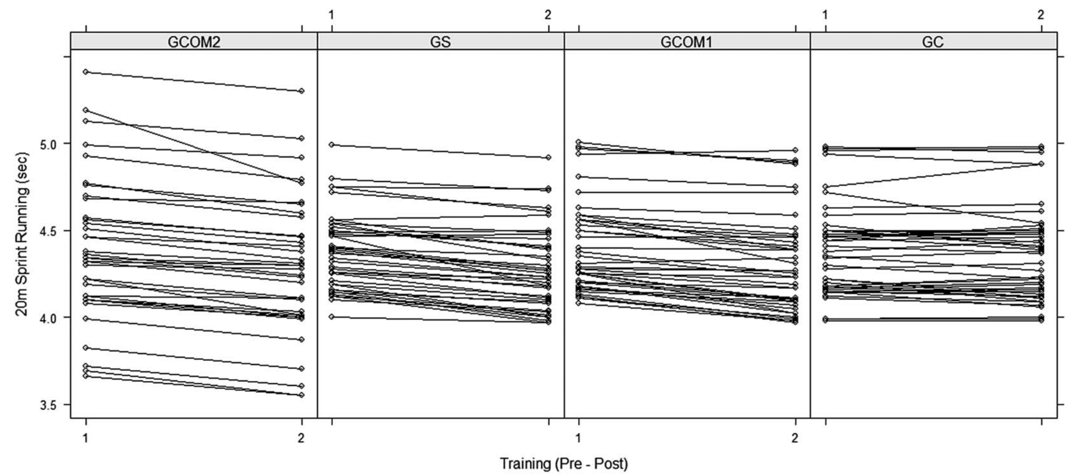

Figure 5. Spaghetti plot. Obtained values in pretest and posttest of training in strength training alone (GS), combined strength and aerobic training in the same session (GCOM1), or in 2 different sessions (GCOM2), and control group (GC) on 20-m sprint running.

to 0.5 m), vertical jumps above a 0.3–0.5 m hurdle and sets of 30–40 m of speed running.

After completion of the strength training for the GCOM1, GCOM2, and GS groups, the GCOM1 group performed a 20-m shuttle run exercise, whereas the GCOM2 group performed a 20-m shuttle run exercise in an alternate session (on the next day) after the warm-up. This aerobic task was developed based on an individual training volume that was set to approximately 75% of the established maximum aerobic volume achieved on a previous test. After 4 weeks of training, the GCOM1, GCOM2, and GS subjects were reassessed using 20-m shuttle run tests to readjust the volume and intensity of the 20-m shuttle run exercise. Each training session lasted approximately 45 minutes (strength training) to 60 minutes (concurrent training). It is important to mention that GCOM2 performed strength training alternate with aerobic training in different days (strength–aerobic–strength-aerobic). The rest period between sets was 1 minute and that between exercises was 2 minutes. Both GS and GCOM1 trained on the same day of the week (with 2/3 days between training sessions) and at the same morning hour. GCOM2 trained between Monday and Thursday

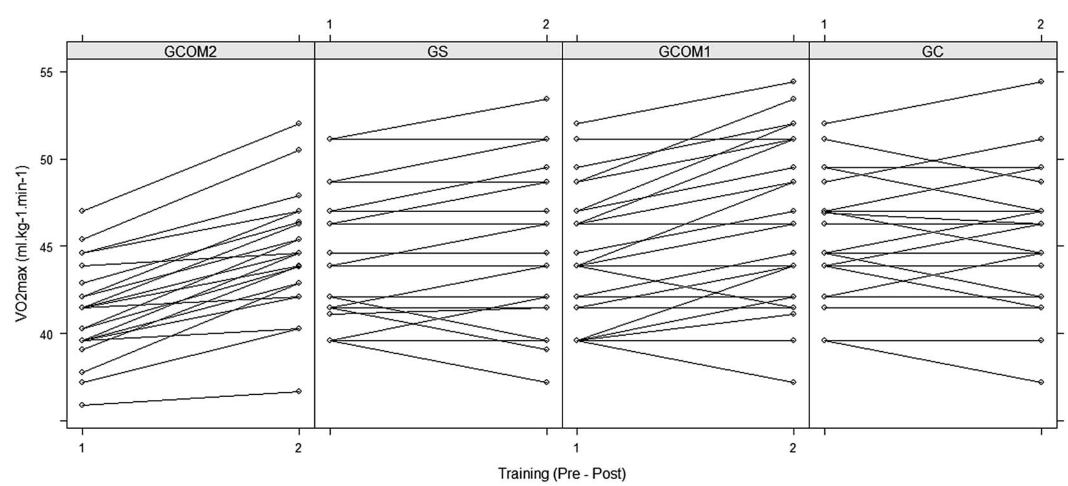

Figure 6. Spaghetti plot. Obtained values in pretest and posttest of training in strength training alone (GS), combined strength and aerobic training in the same session (GCOM1), or in 2 different sessions (GCOM2), and control group (GC) on maximal oxygen uptake ($\dot{V}O_2$max).

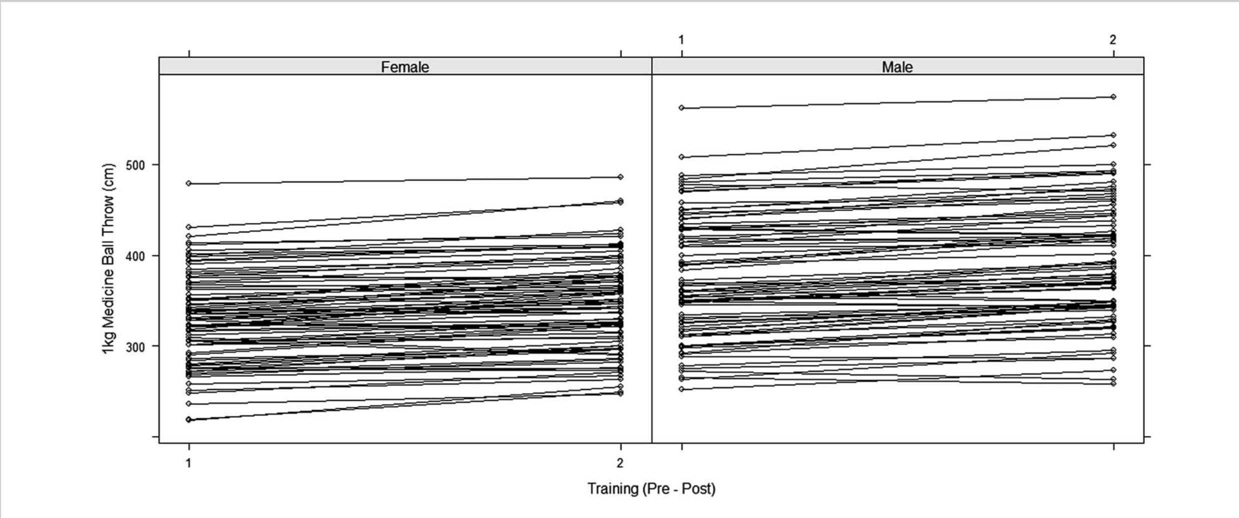

Figure 7. Spaghetti plot. Obtained values in pretest and posttest of training in prepubescent girls and boys on 1-kg medicine ball throw (centimeter).

(with 3 days between training sessions) on the same morning hour that GS and GCOM1 groups.

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 on each training exercise, and any of their questions were properly answered to clear out any doubts. During the training program, there was a constant concern to ensure the necessary security and maintenance of safe hydration levels and to encourage all children to do their best to achieve the best results. Clear instructions about the importance of adequate nutrition were also delivered. For the 20-m shuttle run, the instructions were given with the aid of a multistage fitness test audio CD of the FITNESSGRAM test battery. Throughout the pre-experimental and postexperimental periods, the subjects reported their noninvolvement in additional regular exercise programs for developing or maintaining strength and endurance performance besides institutional regular physical education classes. A more detailed analysis of the program can be found in Table 1.

The experimental groups were assessed for upper and lower body explosive strength (ball throws, 1–3 kg and jumps, respectively), running speed (20-m sprint run), and $\dot{V}O_2max$ (20-m shuttle run test) before and after the 8 weeks of the

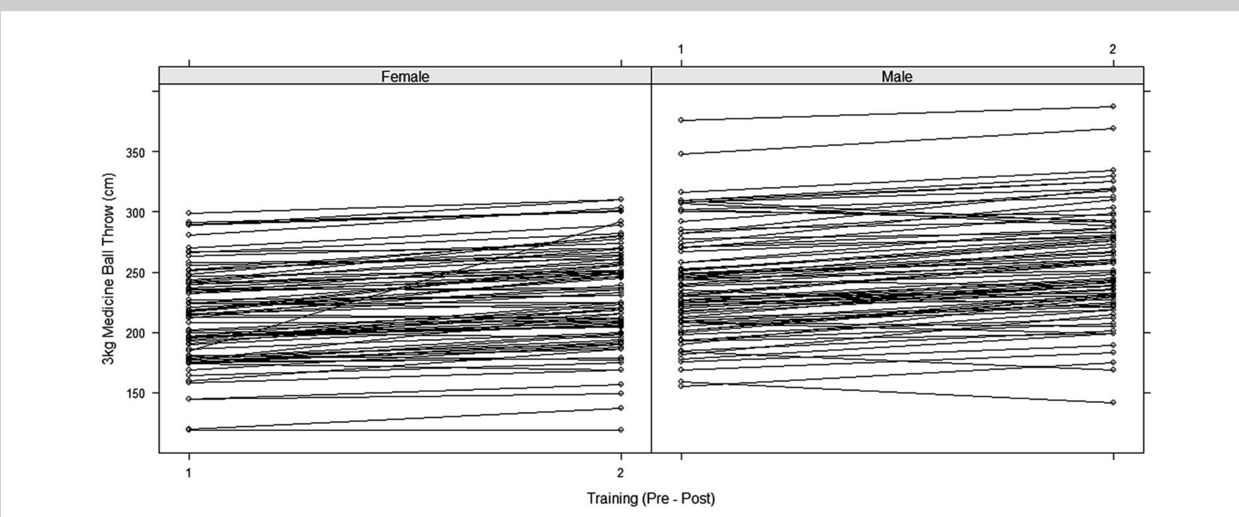

Figure 8. Spaghetti plot. Obtained values in pretest and posttest of training in prepubescent girls and boys on 3-kg medicine ball throw (centimeter).

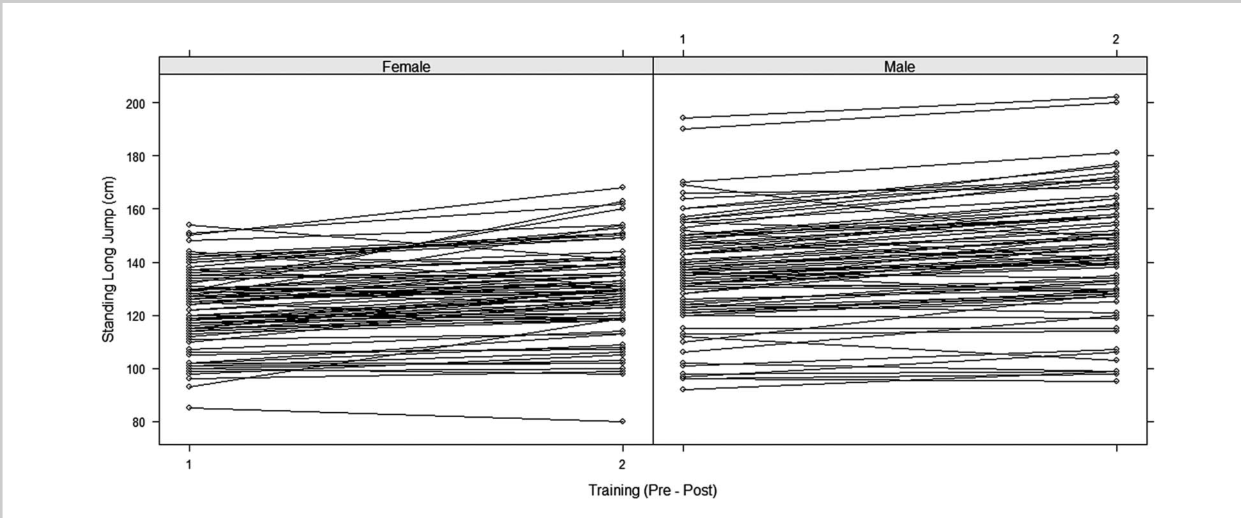

Figure 9. Spaghetti plot. Obtained values in pretest and posttest of training in prepubescent girls and boys on standing long jump (centimeter).

training program. The testing assessment procedures were always conducted in the same indoor environment and the same weekly in the schedule. Each subject was familiarized with the power training tests (ball throws, jumps, and sprint) and with the 20-m multistage shuttle run test. The same researcher performed the training program, anthropometric and physical fitness assessments, and data collection.

Testing Procedures. ***Anthropometric Measurements.*** All anthropometric measurements were assessed according to international standards for anthropometric assessment (23) and were obtained before any physical performance test. The participants were barefoot and wore only underwear. Body mass (in kilo gram) was measured to the nearest 0.1 kg using a standard digital floor scale (model 841; Seca, Hamburg, Germany). To evaluate body height (cm), a precision stadiometer with a scale range of 0.10 cm was used (model 214; Seca).

Medicine Ball Throwing. This test was performed according to the protocol described by Mayhew et al. (29). The subjects were seated with the backside of their trunk touching a wall. They were required to hold medicine balls (Bhalla International–Vinex Sports, Meerut, India) that weighed 1 kg (model VMB-001R; perimeter, 0.72 m; Vinex) and 3 kg (model VMB-003R; perimeter, 0.78 m; Vinex) with their hands (abreast of

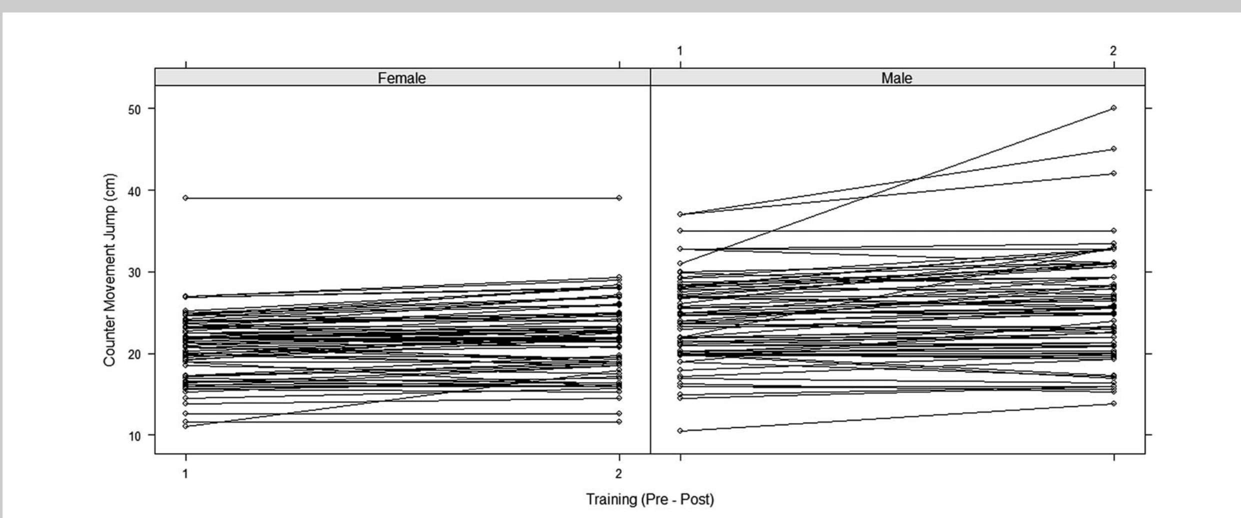

Figure 10. Spaghetti plot. Obtained values in pretest and posttest of training in prepubescent girls and boys on countermovement jump (centimeter).

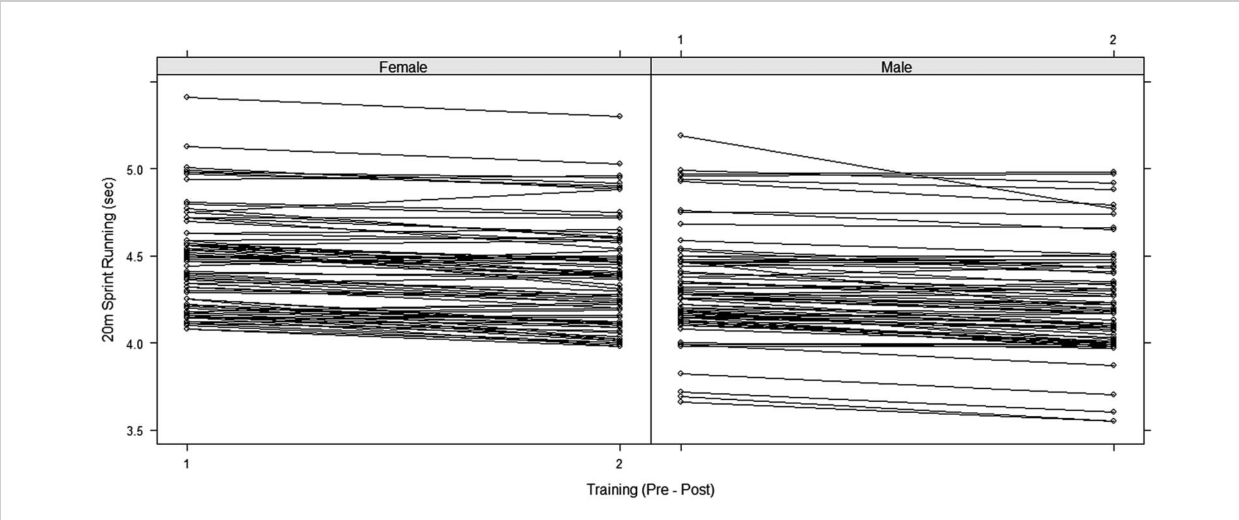

Figure 11. Spaghetti plot. Obtained values in pretest and posttest of training in prepubescent girls and boys on 20-m sprint running (seconds).

chest) and throw the ball forward for the maximum possible distance. Hip inflection was not allowed nor was withdrawal of the trunk away from the wall. Three trials were given, and the furthest throw was measured (cm) from the wall to the first point at which the ball made contact with the floor. One minute of rest was provided between the 3 trials. The intraclass correlation coefficients (ICCs) for the 1 and 3-kg medicine ball throwing data were both ~0.98.

Standing Long Jump. This test was assessed using the EUROFIT test battery (1). The participants stood with their feet slightly apart (toes behind a starting line) and jumped as far forward as possible. Three trials were given, and the furthest distance was measured (cm) from the starting line to the heel of the foot nearest to this line. The standing long (SL) jump has shown an ICC of 0.94.

Countermovement Vertical Jump. This test was conducted on a contact mat that was connected to an electronic power timer, control box, and handset (Globus Ergojump, Italy). From a standing position, with their feet shoulder–width apart and hands placed on the pelvic girth, the subjects performed a countermovement (CM) with their legs before jumping. Such movement makes use of the stretch-shorten cycle in which the muscles are pre-stretched before shortening in the desired direction (21).

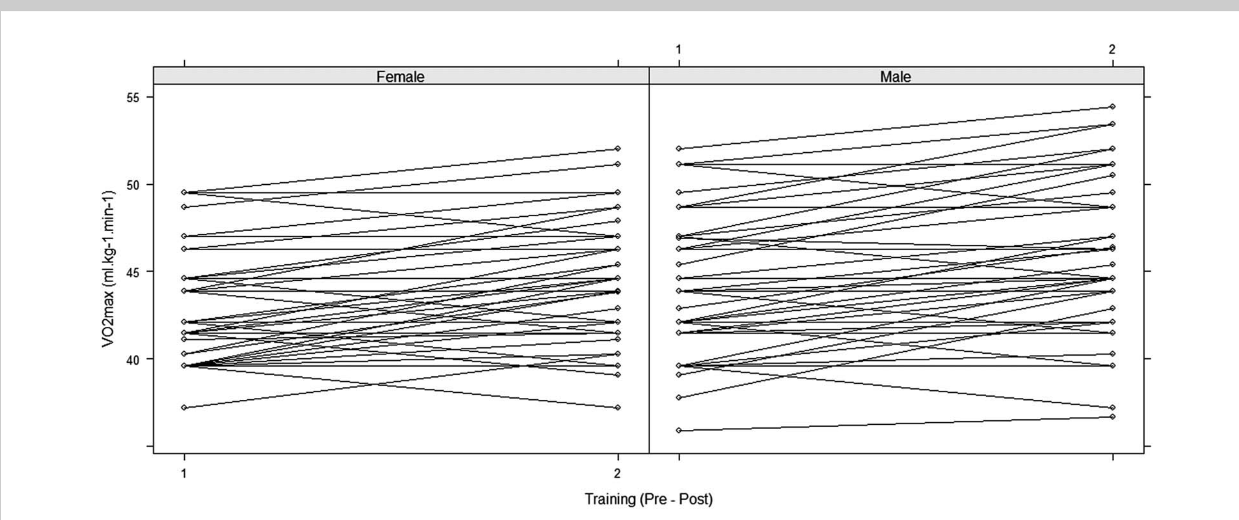

Figure 12. Spaghetti plot. Obtained values in pretest and posttest of training in prepubescent girls and boys on $\dot{V}O_2$max (ml·kg^{-1}·min^{-1}).

The subjects were informed that they should try to jump vertically as high as possible. Each participant performed 3 jumps with a 1-minute recovery between attempts. The highest jump (cm) was recorded. The CM vertical jump has shown an ICC of 0.91.

Twenty-meter Sprint Running. On a 20-m length track, the subjects were required to cover the distance in the shortest time possible. The time (seconds) to run 20 m was obtained using photocells (Brower Timing System, Fairlee, VT, USA). Three trials were performed, and the best time scored (seconds and hundredths) was registered. The sprint running (time) has shown an ICC of 0.97.

Statistical Analyses

Standard statistical methods were used to calculate the mean and *SD*. The normality of the distribution was verified by the Kolmogorov-Smirnov test. The within-subject reliability of the aerobic and strength tests was determined using the ICC and 95% confidence interval (95% CI). We performed a univariate analysis (1-way analysis of variance and Qui-squared test) to compare physical performance variables, age, body mass index (BMI), and body fat at baseline between groups. To evaluate the changes from pretreatment and posttreatment, we used a paired *t*-test for each group and we performed a multivariate analysis of covariance (MANCOVA) with sex and group as fixed-effect and age, BMI, and body fat as covariates. The normality of the residuals was validated by the Kolmogorov-Smirnov test, and the homogeneity of the variance-covariance matrix was validated by the Box M test. This assumption was not verified and we used the Pillai's trace test statistics. When statistically significant differences were observed between groups, an analysis of covariance (ANCOVA) was estimated for each dependent variable, followed by Bonferroni's post hoc comparison tests. From the ANCOVA, it was also possible to analyze the effect size of group on the physical performance variables. The data were analyzed using SPSS 20.0. The statistical significance was set at $p \leq 0.05$.

Results

At baseline (Table 2), there were no differences among the groups on sex, age, BMI, body fat, and all physical performance variables, except on $\dot{V}O_2max$ ($F\,(1,161) = 11.49$, $p < 0.001$). Bonferroni test showed that the $\dot{V}O_2max$ was significantly lower on the GCOM2 group than the other experimental groups.

Test-retest reliability measurements of physical performance variables (Table 3) showed ICC values from 0.808 to 0.986, demonstrating very good results.

Explosive strength measures have increased significantly on GS group, except on $\dot{V}O_2max$. Explosive strength measures have also increased significantly on GCOM1 and GCOM2 groups. Control group presented no statistical increases on the explosive strength measures (Table 4). These results did not corroborate the hypothesis that $\dot{V}O_2max$ increases independently from the different combination approaches.

Changes from pretraining to posttraining momentum were observed with paired *t*-test (Table 4) showed better results on GCOM2 group in $\dot{V}O_2max$, 1-kg medicine ball throw, and CM jump tests compared with the other experimental groups; GCOM1 group presented better results than the other experimental groups on 3-kg medicine ball throw and SL jump. On 20-m sprint running, all experimental groups showed similar results.

The results of MANCOVA showed that a statistical significant differences on changes of explosive strength measures were found between groups, and a medium effect of the group factor on changes of explosive strength measures from pretraining and posttraining momentum was found (0.293, $p < 0.001$). Moreover, medium effect sizes were found on the 1-kg medicine ball throw (0.357, $F\,(3, 160) = 29.58$, $p < 0.001$), 20-m sprint running (0.294, $F\,(3,160) = 22.19$, $p < 0.001$), and $\dot{V}O_2max$ (0.374, $F\,(3,160) = 31.87$, $p < 0.001$). Small effect sizes were verified on the 3-kg medicine ball throw (0.222, $F\,(3,160) = 12.69$, $p < 0.001$), SL jump (0.117, $F\,(3,160) = 7.09$, $p < 0.001$), and CM jump (0.088, $F\,(3,160) = 5.17$, $p < 0.01$). Bonferroni test showed on the 1-kg (Figure 1) and 3-kg medicine ball throw (Figure 2), SL jump (Figure 3), and 20-m sprint running (Figure 5) that changes were significantly higher on GS, GCOM1, and GCOM2 groups than GC; increases on the CM jump were significantly higher on GCOM2 group than GCOM1 and GC (Figure 4). In addition, the $\dot{V}O_2max$ increases more significantly on GCOM1 and GCOM2 groups than GS and GC groups (Figure 6).

With regard to the sex factor, there was found no influence on the evolution from pretraining to posttraining momentum on 1-kg ($F\,(1, 160) = 0.80$, $p > 0.05$) and 3-kg ($F\,(1, 160) = 1.51$, $p > 0.05$) medicine ball throw (Figures 7 and 8, respectively), SL jump ($F\,(1, 160) = 0.04$, $p > 0.05$) (Figure 9), CM jump ($F\,(1, 160) = 0.80$, $p > 0.05$) (Figure 10), 20-m sprint running ($F\,(1, 160) = 0.48$, $p > 0.05$) (Figure 11), and $\dot{V}O_2max$ ($F\,(1, 160) = 1.91$, $p > 0.05$) (Figure 12).

Discussion

The main purpose of this study was to compare the effects of 8-week training periods of concurrent training in the same session, concurrent training in different sessions, and strength training on explosive strength and $\dot{V}O_2max$ in a sample of prepubescent girls and boys. The main results confirmed that explosive strength was improved in all the experimental groups with better results in the concurrent training group, which performed the training in different sessions, followed by the concurrent group that performed the training in the same session and finally by the strength group. In addition, on the $\dot{V}O_2max$ was shown that GCOM1 and GCOM2 groups were increased from pretraining to posttraining momentum. Thus, concurrent training in 2 different sessions is suggested to be an effective method to increase explosive strength and $\dot{V}O_2max$ in prepubescent children.

Several studies have suggested that concurrent training could have an interference effect on muscle strength development (13,38,39). The main reasons for these results are deeply related to acute fatigue and with the different neuromuscular adaptations from the aerobic or strength training (27). Moreover, small reductions in overload during the training period could also compromise adaptations, and no clear findings describe an inhibition in strength or aerobic adaptation by different neuromuscular adaptations (17,27). Hereupon, the relevance of these mechanisms either in isolation or together in inhibiting adaptation during concurrent training must be clarified.

The increased explosive strength of the upper and lower limbs that was observed in the training groups (e.g., 1 and 3-kg medicine ball throwing, SL jump, countermovement jump), in the 20-m sprint running, and in $\dot{V}O_2max$ demonstrate that although the concurrent training performed in different sessions obtained better results, when performed in the same session, and GS may also be a beneficial training stimuli to improve explosive strength in prepubescent children. These results may have a special significance to optimize exercise programs in prepubescent children. The current data are congruent with the results of previous study (26) in this area that have been conducted with prepubescent children. Furthermore, no differences were found posttraining in the GC in any variable related to explosive strength and in the posttraining $\dot{V}O_2max$ in the GS group. Our findings are consistent with the results of previous studies (9,26,39) that mentioned that resistance training programs are not effective in improving aerobic fitness in prepubescent children.

Strength and aerobic training are regularly performed concurrently at school or in extracurricular activities (39) in an attempt to obtain gains in several physiologic systems to achieve total conditioning, to meet functional demands, or to improve several health-related components simultaneously (27). Previous studies reported that concurrent training seems to be effective on both strength and aerobic fitness features of prepubescent children and also in adults (26,40). Moreover, performing concurrent training allows the benefits from both aerobic and strength training to be acquired simultaneously (13,17,26). Furthermore, introducing both aerobic and muscular fitness is fundamental to promote health and should be a suitable goal in a training program (43).

This study also showed better results in the groups that performed concurrent training in different sessions. The literature is far from be consensual regarding the efficacy of concurrent training performed on the same day (7) or on the alternate days each week (14). According to Doma and Deakin (8), strength and aerobic training performed on the same day seems to impair running performance the following day and may compromise adaptation compared with alternate day concurrent training (10,17). In addition, Fyfe et al. (12) reported that concurrent training performed on the same day can lead to increased energy expenditure, which consequently causes a higher saturation and residual fatigue. However, it is worth mentioning that there were no significant differences between the groups. This may be explained by the faster recovery of children when submitted to physical exercise compared with adults (15). Indeed, lower muscle glycolytic activity and higher muscle oxidative capacity allow the faster resynthesizing of phosphocreatine in children (37). Regarding to the gender gap, the results seem to suggest that there is no significant effect on training-induced strength or $\dot{V}O_2max$ adaptations. These data corroborate the results of previous studies conducted with children, reporting no significant differences in strength and aerobic response related to sex. Marta et al. (25) found that sex did not affect training-induced strength or aerobic fitness adaptations in prepubescent children (8-week strength training program and endurance training program, 2×1 h·wk^{-1}, intensity: 75% heart rate maximum). Siegel et al. (41) 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 favor 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 (18). 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 (36). Regarding the training-induced $\dot{V}O_2max$ adaptations in boys and girls, according to Vinet et al. (44) during preadolescence, 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.

According to our results, concurrent training performed in different sessions is effective to improve explosive strength in prepubescent children and may emerge as an innovative and support tool for teachers, coaches, and researchers and may be used in clubs or YMCA's when appropriately prescribed and supervised. Although most studies on physical fitness have focused on aerobic capacity and have neglected muscular fitness, there is evidence that neuromotor aptitude based on muscular force can be as important as aerobic capacity in the maintenance of health (3), and both are essential for promoting health (43). This study provides both promising results for the application of concurrent training in different sessions to evaluate explosive strength in prepubescent children and remarks for future research in this area.

There are some main limitations to be considered: (a) different training program designs or different methods of organizing training workouts can lead to different training-induced outcomes; (b) the training period of 8 weeks is rather short; (c) different training durations between strength training and concurrent training groups may have conditioned training-induced gains; (d) it was not possible to elucidate the mechanisms responsible for the observed effects (i.e., no electrophysiological measures); (5) the sample included normal-weight, physically active prepubescent children. Thereupon, some care shall be taken when translating these findings to children with different parameters.

Practical Applications

Performing concurrent strength and aerobic training in different sessions does not impair strength development in healthy prepubescent children but it seems to be an effective, exercise program that can be prescribed as a means to improve explosive strength and aerobic capacity. This should be considered when designing the school-based programs or in the designing of strength training in sports clubs to improve its efficiency. Thereupon, this innovative and safe methodology provides a new path to reduce the monotony of training or classes and to prepare the individual for a healthy future. It is important to know that training in different sessions can be performed without implications on prepubescent children's growth and health.

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