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Concurrent training in prepubescent children: the effects of eight weeks of strength and aerobic training on explosive strength and VO_{2max}

Running head: Sequence of concurrent training on explosive strength and maximal oxygen uptake (VO_{2max})

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ABSTRACT

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 two different sessions (GCOM2) on explosive strength and maximal oxygen uptake (VO_{2max}) in prepubescent children. 168 healthy children, aged 10-11 years old (10.9±0.5), were randomly selected and assigned to three training groups to train twice a week for 8 weeks: GS (n=41), GCOM1 (n=45), GCOM2 (n=38) groups and a GC group (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, $p<0.001$), 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 VO_{2max}, muscular strength and explosive strength from pre- to post-training. The higher gains were observed for concurrent training when it was performed in different sessions. These results suggest that concurrent training in two different sessions appears to be an effective and useful method for training-induced explosive strength and VO_{2max} in prepubescent children. This could be considered an alternative way to optimize explosive strength training and cardiorespiratory fitness in school-based programs.

Key words: Strength; Aerobic; Exercise; Youth; Power.

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 (25). Moreover, it is often assumed that physical activity during childhood and adolescence have 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, 27).

The children should benefit from the development of strength and cardiovascular parameters and these two 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). Afterwards, it was reported that concurrent training impairs the development of strength and muscular power but did not affect the development of aerobic capacity compared to both forms of stand-alone training (17, 39). Nevertheless, some studies have shown no antagonistic effects on strength (30) or aerobic performance (32) following 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 post training (19). These could result in beneficial effects of concurrent training and recent studies tried to clarify it, namely in child population (26, 27, 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 (VO_{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/or training protocols (20). 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 pre puberty 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 intra-session 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, the current 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 VO_{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 VO_{2max} increases independently from the different combination approaches.

METHODS

Experimental Approach to the Problem

The aim of the current 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 two different sessions (GCOM2) on explosive strength and maximal oxygen uptake ($VO_{2max)}$ in prepubescent children. The study followed a repeated measures design with each participant being randomly assigned into a specific program or a control group (no training program), and evaluated in pre- and post-test momentum. Concerning the training protocol applied, it was verified in previous studies (27, 39) strength and cardiovascular improvements in children using the same training protocol. Based on those studies and in the knowledge of an experienced coach and researcher, it was structured 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 into 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 old (from 5th and 6th grade), without a chronic pediatric disease or orthopedic limitation and without a regular oriented extra-curricular 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 prior to this experiment. Efforts were made to collect a sample for making comparable groups. After local ethics board approval, ensuring compliance with the declaration of Helsinki, the 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 and 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 control group as follows: 1 group performing strength training only (GS: n=41, 22 girls, 19 boys); another group performing combined strength and aerobic training in the same session (GCOM1: n=45, 24 girls, 21 boys); the third performing combined strength and aerobic training in different sessions (GCOM2: n= 38, 17 girls, 21 boys); and the control group (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 into 1 of 4 intervention arms. Randomization was performed using R software version 2.14 (R Foundation for Statistical Computing). Before the start of 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. Prior to the training, the subjects warmed up for approximately 10 min 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 counter-clockwise, 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 min 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 to 0.5 m), vertical jumps above a 0.3-0.5 m hurdle and sets of 30 to 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 min (strength training) to 60 min (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 min and that between exercises was 2 min. 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 (with 3 days between training sessions) on the same morning hour that GS and GCOM1 groups.

Before the start of the training, subjects completed two familiarization sessions to practice the drill and routines they would further perform during the training period (i.e., power training exercises and 20m 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, 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 delivered. 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 the pre- and experimental periods, the subjects reported their non-involvement 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.

(Table 1 about here)

The experimental groups were assessed for upper and lower body explosive strength (ball throws 1-3kgs and jumps, respectively), running speed (20m-sprint run), and VO_{2max} (20-m shuttle run test) before and after the 8-weeks of the 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 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 scale range of 0.10 cm was used (Seca, model 214, Germany).

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 (Vinex, model VMB-001R, perimeter 0.72 m) and 3 kg (Vinex, model VMB-003R, perimeter 0.78 m) with their hands (abreast of 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 (in 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 (ICC) for the 1 kg 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 (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.

Counter Movement 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 counter movement 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). The subjects were informed that they should try to jump vertically as high as possible. Each participant performed three jumps with a 1 min recovery between attempts. The highest jump (in cm) was recorded. The counter movement vertical jump has shown an ICC of 0.91.

20-meter Sprint Running. On a 20 m length track, the subjects were required to cover the distance in the shortest time possible. The time (in sec) 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 Analysis

Standard statistical methods were used to calculate the means and standard deviations. 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 intraclass correlation (ICC) and 95% confidence interval (CI 95%). We performed an univariate analysis (one-way ANOVA and Qui-Squared test) to compare physical performance variables, age, BMI and body fat at baseline between groups. To evaluate the changes from pre-treatment and post-treatment 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 VO_{2max} ($F(1,161) = 11.49$, $p < 0.001$). Bonferroni test showed that the VO_{2max} was significantly lower on the GCOM2 group than the other experimental groups.

(Table 2 about here)

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

(Table 3 about here)

Explosive strength measures have increased significantly on GS group, except on VO_{2max}. Explosive strength measures have also increased significantly on GCOM1 and GCOM2 groups. GC group presented no statistical increases on the explosive strength measures (table 4). These results did not corroborate the hypothesis that VO_{2max} increases independently from the different combination approaches.

Changes from pre- to post training momentum were observed with pair t-test (table 4) showed better results on GCOM2 group in VO_{2max}, 1kg medicine ball throw, and CM jump tests compared to the other experimental groups; GCOM1 group presented better results than the other experimental groups on 3kg medicine ball throw and SL jump. On 20 m sprint running all experimental groups showed similar results.

(Table 4 about here)

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 pre-training and post-training momentum was found ($\eta_p^2 = 0.293$, $p < 0.001$). Moreover, medium effect sizes were found on the 1kg medicine ball throw ($\eta_p^2 = 0.357$, $F(3, 160) = 29.58$, $p < 0.001$), 20 m sprint running ($\eta_p^2 = 0.294$, $F(3,160) = 22.19$, $p < 0.001$), and VO_{2max} ($\eta_p^2 = 0.374$, $F(3,160) = 31.87$, $p < 0.001$). Small effect sizes were verified on the 3 kg medicine ball throw ($\eta_p^2 = 0.222$, $F(3,160) = 12.69$, $p < 0.001$), SL jump ($\eta_p^2 = 0.117$, $F(3,160) = 7.09$, $p < 0.001$), and on the CM jump ($\eta_p^2 = 0.088$, $F(3,160) = 5.17$, $p < 0.01$). Bonferroni test showed on the 1kg (Figure 1) and 3kg 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 group; increases on the CM jump were significantly higher on GCOM2 group than GCOM1, and GC groups (Figure 4). In addition, the VO_{2max} increases more significantly on GCOM1 and GCOM2 groups than GS and GC groups (Figure 6).

(Figure 1 about here)

(Figure 2 about here)

(Figure 3 about here)

(Figure 4 about here)

(Figure 5 about here)

(Figure 6 about here)

With regard to the sex factor, there was found no influence on the evolution from pre-training to post-training 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 (Figure 7 and Figure 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 VO_{2max} ($F(1, 160) = 1.91$ $p > 0.05$) (Figure 12).

(Figure 7 about here)

Figure 8 about here)

(Figure 9 about here)

(Figure 10 about here)

(Figure 11 about here)

(Figure 12 about here)

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 VO_{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 VO_{2max} was shown that GCOM1 and GCOM2 groups were increased from pre- to post-training momentum. Thus, concurrent training in two different sessions is suggested to be an effective method to increase explosive strength and VO_{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 (25). 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, 25). 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, standing long jump, countermovement jump), in the 20 m sprint running and in VO_{2max} demonstrate that, although the concurrent training performed in different sessions obtained better results, when performed in the same session and strength training alone 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 (27) in this area that have been conducted with prepubescent children. Furthermore, no differences were found post training in the GC group in any variable related to explosive strength, and in the post training VO_{2max} in the GS group. Our findings are consistent with the results of previous studies (9, 27, 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 (25). Previous studies reported that concurrent training appears to be effective on both strength and aerobic fitness features of prepubescent children and also in adults (27, 40). Moreover, performing concurrent training allows the benefits from both aerobic and strength training to be acquired simultaneously (13, 17, 27). Furthermore, introducing both aerobic and muscular fitness is fundamental to promote health and should be a suitable goal in a training program (43).

The current 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 appears to impair running performance the following day, and may compromise adaptation compared to 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 allows 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 $VO_{2máx}$ 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. (26) 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, 2x1h week^{-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 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 (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 $VO_{2máx}$ adaptations in boys and girls, according to Vinet et al. (44) 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.

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 the majority of 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). The current 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: i) different training program design or different methods of organizing training workouts can lead to different training-induced outcomes; ii) the training period of 8 weeks is rather short; iii) different training durations between strength training and concurrent training groups may have conditioned training-induced gains; iv) it was not possible to elucidate the mechanisms responsible for the observed effects (i.e., no electrophysiological measures); v) 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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FIGURE LEGENDS

Figure 1 - Spaghetti Plot. Obtained values in pre- and post-test of training in strength training alone (GS), combined strength and aerobic training in the same session (GCOM1), or in two different sessions (GCOM2), and control group (GC) on 1kg medicine ball throw.

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

Figure 3 – Spaghetti Plot. Obtained values in pre- and post-test of training in strength training alone (GS), combined strength and aerobic training in the same session (GCOM1), or in two different sessions (GCOM2), and control group (GC) on standing long jump.

Figure 4 – Spaghetti Plot. Obtained values in pre- and post-test of training in strength training alone (GS), combined strength and aerobic training in the same session (GCOM1), or in two different sessions (GCOM2), and control group (GC) on counter movement jump.

Figure 5 – Spaghetti Plot. Obtained values in pre- and post-test of training in strength training alone (GS), combined strength and aerobic training in the same session (GCOM1), or in two different sessions (GCOM2), and control group (GC) on 20m sprint running.

Figure 6 – Spaghetti Plot. Obtained values in pre- and post-test of training in strength training alone (GS), combined strength and aerobic training in the same session (GCOM1), or in two different sessions (GCOM2), and control group (GC) on maximal oxygen uptake (VO_{2max}).

Figure 7 - Spaghetti Plot**.** Obtained values in pre- and post-test of training in prepubescent girls and boys on 1kg medicine ball throw (cm).

Figure 8 - Spaghetti Plot. Obtained values in pre- and post-test of training in prepubescent girls and boys on 3kg medicine ball throw (cm).

Figure 9 - Spaghetti Plot. Obtained values in pre- and post-test of training in prepubescent girls and boys on standing long jump (cm).

Figure 10 - Spaghetti Plot. Obtained values in pre- and post-test of training in prepubescent girls and boys on counter movement jump (cm).

Figure 11 - Spaghetti Plot. Obtained values in pre- and post-test of training in prepubescent girls and boys on 20 m sprint running (sec).

Figure 12 - Spaghetti Plot. Obtained values in pre- and post-test of training in prepubescent girls and boys on VO_{2max} (ml.kg-1.min-1).

Table 1 – Training Program Design (sets x repetitions/distances).

	Sessions					
Exercise	1	2	3	4	5	6
1kg Ball Throw	2x8	2x8	2x8	2x8	2x8	2x8
3kg Ball Throw	2x8	2x8	2x8	2x8	2x8	2x8
SL Jump	2x4	2x4	2x4	2x4	2x4	2x4
CM Jump	1x5	1x5	1x5	1x5	2x5	2x5
20m Sprint	2x20 m	2x20 m	2x20 m	2x20 m	3x20 m	3x20 m
20m Shuttle Run (MAV)	70%	70%	70%	70%	75%	75%
	Sessions					
Exercise	7	8	9	10	11	12
1kg Ball Throw	2x8	2x8	3x8	3x8	3x8	3x8
3kg Ball Throw	2x8	2x8	2x8	2x8	3x6	3x6
SL Jump	2x4	2x4	3x4	3x4	3x4	3x4
CM Jump	2x5	2x5	2x5	2x5	3x5	3x5
20m Sprint	3x20 m	3x20 m	3x20 m	3x20 m	3x30 m	3x30 m
20m Shuttle Run (MAV)	75%	75%	75%	75%	80%	80%
	Sessions					
Exercise	13	14	15	16		
1kg Ball Throw	3x8	3x8	3x8	3x8		
3kg Ball Throw	3x6	3x6	3x6	3x6		
SL Jump	4x4	4x4	4x4	4x4		

CM Jump	3x5	3x5	3x5	3x5
20m Sprint	3x30 m	3x30 m	3x30 m	3x30 m
20m Shuttle Run (MAV)	80%	80%	80%	80%

1kg Ball Throw – Chest 1 kg Medicine Ball Throwing (cm); 3kg Ball Throw – Chest 3kg Medicine Ball Throwing (cm); SL Jump – Standing Long Jump (cm); CM Jump – Counter Movement Jump onto a box (cm); 20m Sprint – 20m Sprint Running (sec); MAV- maximal individual aerobic volume.

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
VO_2max	44.1 ± 3.1	44.4 ± 3.3	41.1 ± 2.2	44.8 ± 3.6	0,000***
1kg Ball Throw	347.8 ± 59.8	358.2 ± 62.6	336.5 ± 72.7	364.3 ± 55.9	0,205
3kg 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
20m Sprint (sec)	4.4 ± 0.2	4.4 ± 0.3	4.4 ± 0.4	4.4 ± 0.3	0,997

*** $p < 0.001$

Percentage (%) of sex, mean ± SD of age, body mass index (BMI), % fat mass (FAT), maximal oxygen uptake (VO_{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 two different sessions (GCOM2), and control group (GC). VO_{2max} – Multistage Shuttle Run (ml.kg-1.min-1); 1kg Ball Throw – Chest 1 kg Medicine Ball Throwing (cm); 3kg Ball Throw – Chest 3kg Medicine Ball Throwing (cm); SL Jump – Standing Long Jump (cm); CM Jump – Counter Movement Jump onto a box (cm); 20m Sprint – 20m Sprint Running (sec); ** $p<0.01$

Table 3 – Intraclass correlation (95% confidence interval for ICC) of maximal oxygen uptake (VO_{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 two different sessions (GCOM2), and control group (GC).

	Overall	GS	GCOM1	GCOM2	GC
VO_{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)
1kg 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)
3kg 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)
20m 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)

VO_{2max} – Multistage Shuttle Run (ml.kg-1.min-1); 1kg Ball Throw – Chest 1 kg Medicine Ball Throwing (cm); 3kg Ball Throw – Chest 3kg Medicine Ball Throwing (cm); SL Jump – Standing Long Jump (cm); CM Jump – Counter Movement Jump onto a box (cm); 20m Sprint – 20m Sprint Running (sec).

Table 4 – Mean ± SD and paired t-test to maximal oxygen uptake (VO_{2max}) and muscle strength variables pre and post-training momentum in strength training alone (GS), combined strength and aerobic training in the same session (GCOM1), combined strength and aerobic training in two different sessions (GCOM2), and control group (GC).

		Pre	Post	Difference (Pre - Post)	p
GS	VO_{2max}	44.1 ± 3.1	44.4 ± 4	-0.4 ± 1.5	0,124
	1kg Ball Throw	347.8 ± 59.8	368.1 ± 63.8	-20.3 ± 10.8	0,000***
	3kg 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***
	20m Sprint	4.4 ± 0.2	4.3 ± 0.2	0.1 ± 0.1	0,000***
GCOM1	VO_{2max}	44.4 ± 3.3	46.1 ± 4.1	-1.7 ± 1.9	0,000***
	1kg Ball Throw	358.2 ± 62.6	378.6 ± 63.7	-20.4 ± 10.7	0,000***
	3kg 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***
	20m Sprint	4.4 ± 0.3	4.3 ± 0.3	0.1 ± 0.1	0,000***
GCOM2	VO_{2max}	41.1 ± 2.2	44.2 ± 2.8	-3.1 ± 1.5	0,000***
	1kg Ball Throw	336.5 ± 72.7	357.5 ± 70.7	-21.0 ± 9.4	0,000***
	3kg 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***
	20m Sprint	4.4 ± 0.4	4.3 ± 0.4	0.1 ± 0.1	0,000***
GC	VO_{2max}	44.8 ± 3.6	45.0 ± 4	-0.2 ± 1.6	0,386
	1kg Ball Throw	364.3 ± 55.9	367.5 ± 59.4	-3.3 ± 10.8	0,053
	3kg 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
	20m Sprint	4.4 ± 0.3	4.4 ± 0.3	0.0 ± 0.1	0,076

VO_{2max} – Multistage Shuttle Run (ml.kg-1.min-1); 1kg Ball Throw – Chest 1 kg Medicine Ball Throwing (cm); 3kg Ball Throw – Chest 3kg Medicine Ball Throwing (cm); CM Jump – Counter Movement Jump onto a box (cm); SL Jump – Standing Long Jump (cm); 20m Sprint – 20m Sprint Running (sec).