Original Research Article

Differentiating Maturational Influence on Training-Induced Strength and Endurance Adaptations in Prepubescent Children

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Objective: To analyze the effect of biological maturation on training-induced strength and endurance adaptations in the prepubertal growth spurt.

Methods: One hundred and twenty-five healthy children (58 boys, 67 girls), aged 10–11 years old (10.8 ± 0.4 years), who were self-assessed as belonging to Tanner stages I and II, were randomly divided into two experimental groups, a strength training group (19 boys, 22 girls) and an endurance training group (21 boys, 24 girls) that would train twice a week for 8 weeks, as well as a control group (18 boys, 21 girls; no training program).

Results: After 8 weeks of training, there were improvements in all strength and endurance measures ($P < 0.01$) for both groups of Tanner stage I and II children. No significant differences in training response were observed relative to biological maturity or gender ($P > 0.05$).

Conclusions: These data suggest that more biologically mature prepubescent children seem to have no advantage in training-induced strength and endurance adaptations compared with their less mature peers. Additionally, gender did not affect the training-induced changes in strength or aerobic fitness. These results are meaningful for the development of optimized well-rounded training programs in prepubertal children. Am. J. Hum. Biol. 26:469–475, 2014.

Fitness has been proposed as a major marker of health status at all ages. It is an important supportive element for the maintenance and enhancement of health and quality of life and, hence, for the improvement of the holistic development of a child (Malina, 2001). Unfortunately, evidence suggests that physical fitness and physical activity among children and adolescents have declined worldwide in recent decades (Matton et al., 2007). The school environment seems to provide an excellent setting to enhance and promote physical activity and physical fitness levels (Strong et al., 2005) by implementing training programs (Marques et al., 2011). Many children and adolescents are only exposed to vigorous physical activity during school-based physical education classes (Coleman et al., 2004). Therefore, physical education classes represent a cornerstone to promote health-related physical fitness development and an active lifestyle by ensuring moderate-to-vigorous physical activity.

Children aged 10–11 years are going through a dynamic developmental period that is marked by rapid changes in body size, shape, and composition (Malina and Bouchard, 1991). At this age in Portugal, they attend the second stage of basic education school and are involved in the same physical education classes and extracurricular activities (sports clubs and organized sports activities). Thus, we believe that it is useful for teachers, trainers, and coaches to understand whether more biologically mature prepubescent children have an advantage in training-induced adaptations compared with their less mature peers during a time of rapid changes such as this prepubertal growth spurt. Their maturation includes changes in the nervous and endocrine systems and the corresponding anthropometric and physiological changes (Sunnegårdh et al., 1988), and it affects not only their current level of motor performance but also their responses to learning and training stimuli (Degache et al., 2010; Duzgun et al., 2011).

Because low aerobic capacity among children is associated with cardiovascular disease risk factors (Anderssen et al., 2007), most research has focused on activities that enhance cardiorespiratory fitness, disregarding, for instance, neuromuscular fitness based on muscular strength (Cepero et al., 2011). However, it is recognized that youth strength training approaches can provide a safe and effective method of conditioning and should be an important component of youth fitness, health promotion, and injury prevention programs (Faigenbaum et al., 2009). Some studies have reported differences in training-induced strength (changes in muscle size and function) and endurance (maximal oxygen uptake) adaptations before and after the prepubertal growth spurt due to the effects of circulating androgens, particularly testosterone (Ramsay et al., 1990), and improvements in maximum stroke volume (Obert et al., 2003) at puberty. However, there is evidence that a maturational threshold exists before which children are unable to undergo physiological changes in response to training, with the consequent difficulty in increasing their muscle mass in response to a strength training program (Ozmun et al., 1994) or increasing their maximal oxygen uptake in response to aerobic training (Baxter-Jones and Maffulli, 2003). In this

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respect, to the best of our knowledge, few studies have analyzed the effect of maturation in prepubertal stages (Tanner stage I and II). The existing studies relate this parameter exclusively to training responses in young trained players (Degache et al., 2010) or were published years ago, using different training programs in nonschool environments (Lillegard et al., 1997). Thus, we believe that training-induced changes in strength, as well as in aerobic capacity, in untrained school children at different maturity levels (Tanner stages I vs. II) require further clarification.

The purpose of this study was to analyze the effect of biological maturity on strength and aerobic capacity trainability in 10- and 11-year-old children. We hypothesized that during this dynamic period of development marked by rapid changes in body size, shape, and composition, maturation would have a significant effect on the training responses of untrained prepubescent boys and girls.

METHODS

Experimental approach to the problem

A randomized controlled trial was conducted in a Portuguese public elementary school. From the initial sample of 151 students who fulfilled the inclusion criteria, only 134 volunteered to participate. Groups were determined using a random number generator (R Foundation for Statistical Computing version 2.14), which resulted in the following assignments: the strength group (SG), which included 20 boys and 24 girls; the endurance group (EG), including 25 boys and 26 girls; and the control group (CG), including 18 boys and 21 girls. This procedure was established in accordance with the "CONSORT" statement (http://www.consort-statement.org/). The proportions of participants successfully completing the protocol were 93% (strength training), 88% (endurance training), and 100% (CG). Thus, analysis was conducted on the remaining 125 children (strength training: 19 boys, 22 girls; endurance training: 21 boys, 24 girls; and the CG of 18 boys, 21 girls, which followed the physical education curriculum without a training program). There were no significant differences among the groups for decimal age or Tanner stage in anthropometric, morphological, or performance variables at the beginning of the protocol for either gender.

Prior to training, the 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 counterclockwise, until the entire joint seemed to move smoothly. Stretching exercises included the back and chest; shoulders and sides; and quadriceps, calf, groin, and hamstrings. At the end of the training sessions, subjects performed 5 min of static stretching exercises. After the warm-up period, the SG group participated in an explosive strength training program comprising upper body (1- and 3-kg medicine ball throws) and lower body (jumps onto a box and hurdle jumps from 0.3 to 0.5 m) plyometric exercises, as well as a speed drill (sets of 20–40 m speed runs). The EG group was subjected to a 20-m shuttle run exercise. This endurance task was developed based on an individual's training volume-set to approximately 75% of the number of completed 20-m laps achieved on a previous test. After 4 weeks of training, the EG subjects were reassessed using 20-m shuttle run tests to readjust the volume of the 20-m shuttle run exercise. Before the beginning of the training, subjects completed two familiarization sessions to practice the drill and routines that they would be expected to perform during the training period (i.e., power training exercises and 20-m shuttle run test). During this time, the children were instructed on the proper technique for each training exercise, and their questions were answered to clear any doubts. During the training, we ensured the children's security and the maintenance of safe hydration levels, and we encouraged them to do their best to achieve the best results. We also provided clear instructions regarding the importance of adequate nutrition. The same researcher conducted the training program and the anthropometric and physical fitness assessments. Throughout the preliminary and experimental periods, the subjects reported not being involved in any additional regular exercise programs to develop or maintain strength and endurance performance. A more detailed description of the program can be found in Table 1.

Subjects

The sample consisted of 125 prepubescent children (58 boys, 67 girls), all of whom volunteered for this study. Inclusion criteria were children aged 10–11.5 years (fifth and sixth graders) who were self-described as belonging to Tanner stages I and II, had no chronic pediatric diseases or orthopedic limitations, and performed no regular extra-curricular physical activity (e.g., practicing sport at a club). The distribution of students according to their maturation stage was as follows: (i) boys: CG, stage I, 77.8% and stage II, 22.2%; SG, stage I, 73.7% and stage II, 26.3%; EG, stage I, 90.5% and stage II, 9.5%; (ii) girls: CG, stage I, 47.6% and stage II, 52.4%; SG, stage I, 50% and stage II, 50%; EG, stage I, 62.5% and stage II, 37.5%. 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 declaration of Helsinki and was approved by the institutional review boards of the University of Beira Interior, Polytechnic Institute of Guarda, and Research Centre in Sports, Health and Human Development, Portugal. Pretest anthropometric parameters and physical performance measures were ascertained for all subjects (Table 2).

Procedures

Anthropometric and morphological measurements. All anthropometric measurements were assessed according to international standards for anthropometric assessment (Marfell-Jones et al., 2006) and were carried out prior to any physical performance testing. Body mass (kg) was measured to the nearest 0.1 kg using a standard digital floor scale (Seca, model 841, Germany). Standing height was assessed with a precision stadiometer to the nearest 0.10 cm (Seca, model 214). To assess maturational development in both girls and boys, the Tanner scale (Tanner, 1962), based on external primary and secondary gender characteristics, was used. Due to natural variation, individuals proceed through the Tanner stages at different rates, depending, in particular, on the timing of puberty. Children were self-described (Duke et al., 1980) as belonging to Tanner stage I (boys: testicular volume less than 1.5 ml, small penis, 3-cm long or shorter, no pubic hair at all; girls: breasts without glandular tissue, areola

TABLE 1. Training program design

	Sessions					
Exercises	1	2	3	4	5	6
Chest 1-kg medicine ball throw[a]	2 × 8	2 × 8	2 × 8	2 × 8	6 × 8	6 × 8
Chest 3-kg medicine ball throw[a]	2 × 8	2 × 8	2 × 8	2 × 8		
Overhead 1-kg medicine ball throw[a]	2 × 8	2 × 8	2 × 8	2 × 8	6 × 8	6 × 8
Overhead 3-kg medicine ball throw[a]	2 × 8	2 × 8	2 × 8	2 ×8		
Counter movement jump onto a box[a]	1 × 5	1 × 5	3 × 5	3× 5	3 × 5	4 × 5
Plyometric jumps above three hurdling[a]	5 × 4	5 × 4	5 × 4	5 × 4	2 × 3	2 × 3
SPRINT running (m)[a]	4 × 20	4 × 20	3 × 20	3 × 20	3 × 20	3 × 20
20-m Shuttle Run (MAV)[b]	75%	75%	75%	75%	75%	75%
Exercises	7	8	9	10	11	12
Chest 1-kg medicine ball throw[a]						
Chest 3-kg medicine ball throw[a]	2 × 5	2 × 5	3 × 5	3 × 5	3 × 5	2 × 5
Overhead 1-kg medicine ball throw[a]						
Overhead 3-kg medicine ball throw[a]	2 × 8	2 × 8	3 × 8	3 × 8	3 × 8	
Counter movement jump onto a box[a]	4 × 5	5 × 5	5 × 5	5 × 5	5 × 5	4 × 5
Plyometric Jumps above three hurdling[a]	3 × 3	4 × 3	4 × 3	4 × 3	4 × 3	
Sprint running (m)[a]	4 × 30	4 × 30	4 × 30	4 × 30	4 × 30	3 × 40
20-m shuttle run (MAV)[b]	75%	Test M	75%	75%	75%	75%
Exercises	13	14	15	16		
Chest 1-kg medicine ball throw[a]						
Chest 3-kg medicine ball throw[a]	2 × 5	1 × 5				
Overhead 1-kg medicine ball throw[a]		3 × 8	2 × 8	2 × 8		
Overhead 3-kg medicine ball throw[a]	3 × 8					
Counter movement jump onto a box[a]	4 × 5	2 × 5	2 × 4	2 × 4		
Plyometric jumps above three hurdling[a]	4 × 3	3 × 3				
Sprint running (m)[a]	3 × 40	4 × 40	2 × 30	2 × 30		
20-m shuttle run (MAV)[b]	75%	75%	75%	75%		

Legend: for the medicine-ball throwing and jump onto box the first number corresponds to sets and second corresponds to repetitions. For sprint running, first number corresponds to sets and second 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 pretest and after this test M moment until program end, ran 75% of maximum individual aerobic volume performed on testM. MAV-maximum individual aerobic volume.
[a]Power strength training protocol (SG).
[b]Endurance training protocol (EG).

TABLE 2. Descriptive data of anthropometric and morphological parameters and physical performance measures in pretest condition: Tanner stages I and II (Mean ± SD)

	Tanner stage I			Tanner stage II		
	CG	SG	EG	CG	SG	EG
Decimal age (years)	10.8 ± 0.5	10.7 ± 0.4	10.7 ± 0.4	11.0 ± 0.4	10.9 ± 0.3	11.0 ± 0.3
Body height (cm)	138.5 ± 6.6	139.9 ± 4.9	140.8 ± 6.5	143.0 ± 5.8	148.6 ± 7.3	146.7 ± 7.8
Body mass (kg)	36.7 ± 7.6	35.3 ± 5.7	36.8 ± 7.0	39.1 ± 6.2	47.8 ± 11.1	45.0 ± 10.0
Body mass index	18.8 ± 2.7	17.9 ± 2.1	18.4 ± 2.5	19.1 ± 3.3	21.4 ± 3.9	21.8 ± 2.9
Counter movement jump (cm)	22.8 ± 4.1	21.4 ± 5.0		21.0 ± 5.2	20.9 ± 3.5	
Standing long jump (cm)	135.4 ± 20.5	126.7 ± 13.3		130.6 ± 18.4	121.4 ± 12.5	
1-kg medicine ball throw (cm)	359.5 ± 61.5	334.4 ± 54.7		369.5 ± 50.8	370.1 ± 62.0	
3-kg medicine ball throw (cm)	227.0 ± 44.5	213.3 ± 35.7		225.9 ± 35.6	240.6 ± 38.9	
20-m sprint (sec)	4.33 ± 0.2	4.32 ± 0.1		4.45 ± 0.2	4.44 ± 0.2	
VO_{2max} (ml kg^{-1} min^{-1})	45.0 ± 3.3		45.0 ± 3.1	43.8 ± 3.4		42.8 ± 3.0

CG-Control group; SG-Strength training group; EG-Endurance training group.

following the skin contours of the chest, no pubic hair at all) or Tanner stage II (boys: testicular volume between 1.6 and 6 ml, skin on scrotum thinned/reddened/enlarged, penis length unchanged, small amount of long downy hair with slight pigmentation at the base of the penis and scrotum; girls: breast bud formed with small area of surrounding glandular tissue, areola beginning to widen, small amount of long downy hair with slight pigmentation on the labia majora).

Testing procedures. 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 aerobic fitness (20-m 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 investigator.

Counter movement vertical jump. This test was conducted on a contact mat connected to an electronic timer, control box, and handset (Globus Ergojump, Italy). From a standing position, with the feet slightly apart and the hands placed on the hips, the children performed a counter movement with the legs before jumping. This movement makes use of the stretch-shorten cycle, in which the muscles are prestretched before shortening in the desired direction (Linthorne, 2001). Each participant performed three jumps, and the highest jump (cm) was recorded. The counter movement vertical jump has shown an intraclass correlation coefficient (ICC) of 0.94.

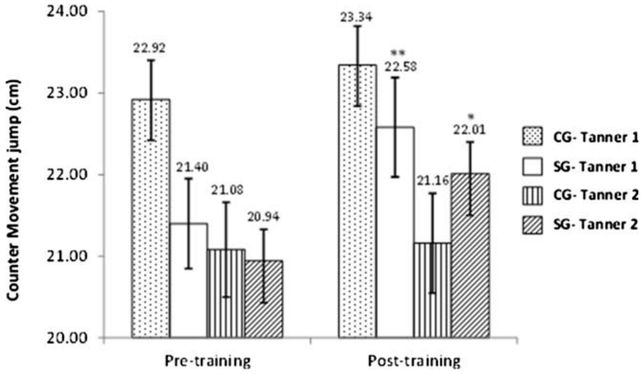

Fig. 1. Counter movement jump (cm): Tanner stages I and II. CG-Control group; SG-Strength training group. *($P < 0.05$), **($P < 0.01$) Significant difference from pretraining to post-training.

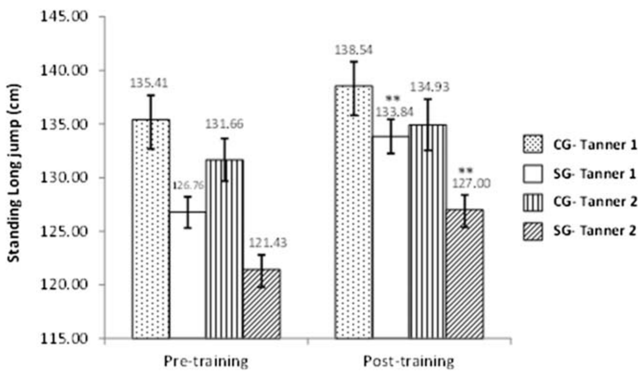

Fig. 2. Standing long jump (cm): Tanner stages I and II. CG-Control group; SG-Strength training group. **($P < 0.01$) Significant difference from pretraining to post-training.

Standing long jump. This test was assessed using EUROFIT test battery (Adam et al., 1988). The participants stood with their feet slightly apart behind a starting line and jumped forward as far as possible. Three trials were conducted and the longest distance was measured in centimeters 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. (1997). Subjects were seated with the back side of the trunk touching a wall. They were required to throw 1 kg (Vinex, model VMB-001R, perimeter 0.72 m) and 3 kg (Vinex, model VMB-001R, perimeter 0.78 m) medicine-balls forward for maximum distance. Hip flexion was not allowed, nor was removal of the torso from its position against the wall. Three trials were conducted, and the longest throw was measured from the wall to initial ground contact. The ICC of data for 1- and 3-kg medicine ball throwing was 0.94 and 0.97, respectively.

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

Twenty-meter multistage shuttle run. This test involved continuous running between two lines 20 m apart in time to recorded beeps. The subjects ran between the two lines, turning when signaled by the recorded beeps. After approximately 1 min, a sound indicated an increase in speed, with the beeps occurring closer together. The beeps sounded every minute (level). The standard version, which has an initial running velocity of 8.5 km/h and increments of 0.5 km/h each minute (Léger et al., 1988), was used. When the participants failed to reach the line on two 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 (Léger et al., 1988), 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 calculation of the means and standard deviations. The normality of the distribution was checked by applying the Kolmogorov–Smirnov test. The within-subject reliability of endurance and power tests was determined by the ICC. The training-related effects in the control and experimental groups were assessed using a paired-samples *t*-test. One-way analysis of variance (ANOVA), followed by Scheffe's post hoc multiple comparison tests, was used to determine the differences in explosive strength and endurance among the control and experimental groups. To determine the effect of the Tanner stage and gender on the post-training explosive strength, we estimated a multivariate analysis of covariance (MANCOVA), with the pretraining measures as covariates. The normality of the residuals was validated by the Kolmogorov–Smirnov and the homogeneity of variance-covariance matrix was validated by the Box's M test. Because this assumption was verified, we used the Wilk's Lambda test statistics. ($M = 55.652$, $F(30, 3114.5) = 1.43$, $P > 0.05$). To determine the effect of these factors on VO_{2max} gains, we estimated an analysis of covariance (ANCOVA). Data were analyzed using SPSS 17.0. The statistical significance was set at $P \leq 0.05$.

RESULTS

At baseline, there were no significant differences between the control and experimental groups in the explosive strength measures for the height in the counter movement vertical jump ($F = 0.699$, $P = 0.499$), distance in the standing long jump ($F = 2.911$, $P = 0.058$), 1-kg ($F = 0.706$, $P = 0.496$) and 3-kg ($F = 0.049$, $P = 0.952$) medicine ball throwing distance, or running speed ($F = 0.033$, $P = 0.967$). Similarly, there were no significant differences between groups for baseline VO_{2max} values ($F = 0.287$, $P = 0.759$).

Compared with the values at the beginning of the protocol, both training programs (EG and SG) produced significant similar improvements in vertical and horizontal jumps, 1- and 3-kg medicine ball throw, time-at-20 m, and VO_{2max} ($P < 0.01$) for members of both groups in Tanner stages I and II. No significant changes were observed in the CG (Figs. 1–6).

When the data were analyzed with MANCOVA, we observed that the effect of the Tanner stage factor on training-induced explosive strength measures was not significant (Wilk's Lambda = 0.82, $F = 1.172$, $P > 0.05$,

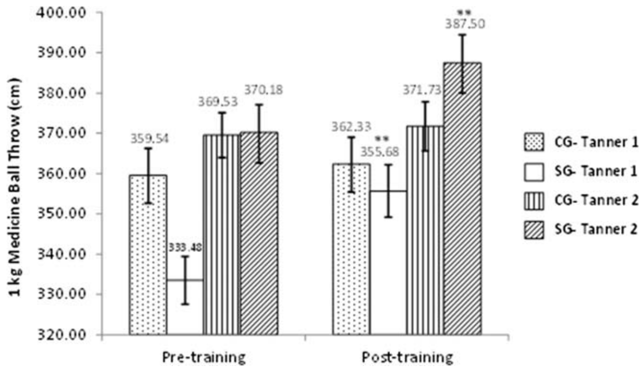

Fig. 3. One-kilogram medicine ball throwing (cm): Tanner stages I and II. CG-Control group; SG-Strength training group. **($P < 0.01$) Significant difference from pretraining to post-training.

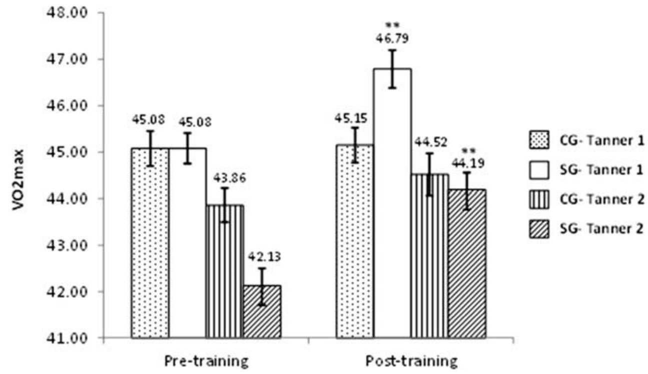

Fig. 6. VO_{2max} (ml kg^{-1} min^{-1}): Tanner stages I and II. CG-Control group; EG-Endurance training group. **($P < 0.01$) Significant difference from pretraining to post-training.

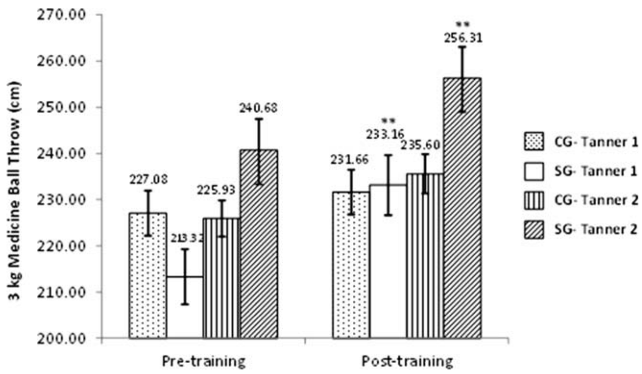

Fig. 4. Three-kilogram medicine ball throwing (cm): Tanner stages I and II. CG-Control group; SG-Strength training group. **($P < 0.01$) Significant difference from pretraining to post-training.

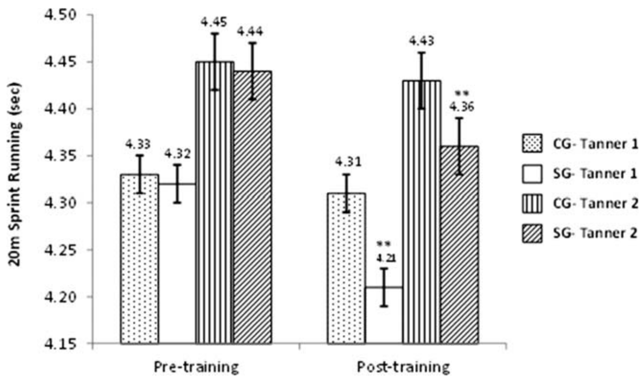

Fig. 5. Time-at-20 m (s): Tanner stages I and II. CG-Control group; SG-Strength training group. **($P < 0.01$) Significant difference from pretraining to post-training.

$\eta_P^2 = 0.17$, Power = 0.35). When the data were analyzed by ANCOVA, using the pretraining VO_{2max} values as the covariate, no significant effects were observed ($F = 2.53$, $P > 0.05$, $\eta_P^2 = 0.06$, Power = 0.34). For the children in Tanner stage I, the training-induced strength gains ranged from 2.3 to 9.30%. Among the children in Tanner stage II, strength gains ranged from 1.80 to 6.48%. In both Tanner stage groups, the least gains were observed in the time at 20 m, and the greatest gains were observed in the 3-kg medicine ball throw. The training-induced VO_{2max} gains ranged from 3.77% (Tanner stage I) to 4.86% (Tanner stage II). The body mass index was higher among children in Tanner stage II in both experimental groups and the CG, with significant differences between Tanner stages I and II ($P < 0.01$). Additionally, it seems that the variable "sex" had no influence on training-induced strength (Wilk's Lambda = 0.97, $F = 0.15$, $P > 0.05$, $\eta_P^2 = 0.02$, Power = 0.08) or endurance ($F = 3.04$, $P > 0.05$, $\eta_P^2 = 0.07$, Power = 0.39) changes.

DISCUSSION

The aim of this study was to analyze the effect of biological maturity on training-induced strength and endurance adaptations in prepubescent children. The findings suggest that the Tanner stage does not significantly influence training-induced strength and endurance gains. Additionally, our data suggest that gender does not affect training-induced changes in strength or aerobic fitness. These findings suggest that being in Tanner stage I or II is not a crucial factor affecting training-induced strength and VO_{2max} adaptations in children aged 10–11 years.

It was interesting to observe the positive effect of a strength training program, resulting in a significant increase in the explosive strength of the upper limbs (e.g., medicine ball throw with 1 and 3 kg) and lower limbs (e.g., standing long jump and counter movement vertical jump), as well as an improvement in 20-m sprint running. These results suggest that the implementation of a school-based strength training program can be a positive stimulus to enhance explosive strength in healthy prepubescent children. Our results also showed a significant enhancement of VO_{2max} (ml kg^{-1} min^{-1}), highlighting the potential for the application of endurance training programs in untrained boys and girls in this age group. These findings are consistent with the results of previous studies conducted with prepubescent children, in which strength (Faigenbaum et al., 2005; Tsolakis et al., 2004) and endurance training (Baquet et al., 2003; Obert et al., 2003) programs were conducted.

In this study, biological maturity (Tanner stages I and II) did not significantly affect the explosive strength or aerobic capacity trainability of children between 10- and

11- year-old. Because physical maturation is related to changes in the nervous and endocrine systems and the corresponding anthropometric and physiological changes (Sunnegårdh et al., 1988), affecting not only the current level of motor performance as well as the responses to learning and training stimuli (Degache et al., 2010; Duzgun et al., 2011), we would expect significant differences in training response between prepubescent children at different maturational levels.

Children aged 10–11 years are going through a dynamic developmental period, that is, a prepubertal growth spurt, marked by rapid changes in body size and composition (Malina and Bouchard, 1991), and there is evidence that these factors have an impact on their aerobic capacity (Gastin et al., 2013), muscular strength (De Ste Croix, 2007), and running speed (Mendez-Villanueva et al., 2011). In this context, we observed that the more biologically mature prepubescent children had the highest body mass index compared with their less mature peers. The body weight associated with this measure for human body shape is based on an individual's lean mass, fat mass, and height and can thus affect motor performance differently. Muscle mass is positively associated with tasks that require muscular strength and power. In contrast, fat mass represents an inert noncontributory load and thus an increased metabolic cost for children, making them less efficient in terms of cardiorespiratory response and their performance of tasks in which the body must be projected (Dumith et al., 2010). From a mechanical point of view, this noncontributory mass could lead to biomechanical movement inefficiency and could be detrimental to motor proficiency. (D'Hont et al., 2009). It should also be pointed out that during the age period studied, which precedes peak height velocity, the children experience significant growth with large metabolic costs, which lead to a decrease in the general resistance of the body (Malina and Bouchard, 1991). In addition to changes in body size and composition, the prepubertal growth spurt is also marked by rapid changes in body shape (Malina and Bouchard, 1991). A recent study by Marta et al. (2013) showed that the morphological constitution affects training-induced explosive strength and aerobic adaptations more strongly than fat mass in children aged 10- and 11- year-old in Tanner stages I and II. In this study, the musculoskeletal magnitude on explosive strength and relative linearity on aerobic capacity have proven to be crucial factors related to training-induced gains. In contrast, the relative adiposity has a negative effect on the training response (Marta et al., 2013). Furthermore, the literature reports that, during the prepubertal period, growth and dimensional increases are not accompanied by muscle development because the effects of circulating androgens, particularly testosterone, only manifest themselves at puberty (Ramsay et al., 1990). In the same way, a maturational threshold exists before which children are unable to elicit physiological changes in response to endurance training (Baxter-Jones and Maffulli, 2003). It appears that relative maximal oxygen uptake remains steady in boys from maturational ages of -6 to $+2$ maturity years (where 0 years represents peak height velocity), with a slight declining trend from -1 to $+2$ maturity years. In girls, relative maximal oxygen uptake shows a progressive decline from -3 to $+2$ maturity years (Mirwald and Bailey, 1986). Genetic makeup seems to play a prominent role in children's endurance capabilities and responses to training (Bouchard et al., 1992); only approximately 30% of maximal oxygen uptake can be accounted for by training itself (Baxter-Jones and Helms, 1996). Kemper and van de Kop (1995) discussed the influences of growth and development on VO_{2max} in boys and girls between ages 4 and 14 and concluded that 50–70% of the variability in VO_{2max} can be explained by genetic differences. According to the authors, similar training effects could be found in children at different Tanner stages when a training program reached an optimal minimum stimulus in terms of intensity, frequency, and duration.

Comparison between the two sexes revealed no effect on training-induced strength or aerobic fitness adaptations. These data corroborate the results of previous studies conducted with prepubescent children, which reported no significant differences in aerobic training response related to gender (Obert et al., 2003; Rowland and Boyajian, 1991). Aerobic training increased VO_{2max} in children of both sexes, mediated by an improvement in maximum stroke volume (Obert et al., 2003). Similar mechanisms, including loading conditions and cardiac morphology, appear to be involved in both boys and girls, explaining such an improvement (Obert et al., 2003). According to Vinet et al. (2003), no significant gender differences in maximal heart rate and arterio-venous oxygen could be observed during preadolescence. The observed similarity of adaptations for boys and girls in terms of explosive strength is also consistent with the findings of previous studies conducted with prepubescent children (Faigenbaum et al., 2003; Lillegard et al., 1997). 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 contrast, 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. However, during preadolescence, boys still present reduced muscle mass because the effects of circulating androgens, particularly testosterone, only manifest themselves at puberty (Ramsay et al., 1990).

Children aged 10–11 years attend the second stage of basic education school, and they are involved in the same physical education classes and extracurricular activities. Thus, children of both sexes who may have different maturity levels are often involved in the same training groups. Biological maturation is a dynamic process encompassing a broad spectrum of changes in body size, shape, and composition, all of which are sexually dimorphic, and these changes have, as reported above, an effect on motor performance and training response. The knowledge that sex and biological maturity do not significantly affect training-induced strength and aerobic adaptations at a time of rapid changes such as the prepubertal growth spurt should be taken into consideration to optimize well-rounded training programs in schools.

Future studies will be needed to examine the mechanisms underlying training responses in prepubescent children of different maturity levels.

Several limitations associated with this study should be considered: (i) the training period of 8 weeks was brief; (ii) different training program designs or different methods of organizing training workouts may have led to different training-induced outcomes; (iii) different methods of evaluating pretraining and post-training muscular strength and aerobic capacity may have led to data bias; and

(iv) due to the methodological approach (i.e., no electrophysiological measures), it was not possible to clarify the mechanisms underlying the observed effects.

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