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Original Article

Effect of a school-based resistance training program using a suspension training system on strength parameters in adolescents

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Abstract:
Introduction: Recent research data show a significant decline in youth's muscle strength. **Purpose:** The purpose of the present study was to assess the efficacy of a suspension training intervention during physical education (PE) lessons on strength parameters in adolescents, compared with a control group. **Methods:** The sample of the study included 321 adolescents (158 boys and 163 girls, M_{age} = 16.54, *SD* = .91). The intervention group followed a suspension training program twice a week for a total of eight weeks during the PE lesson, while the control group attended the regular PE class throughout the intervention. A pre-intervention, a post-intervention and a detraining test were conducted. Field tests that measure muscle strength and endurance were used to assess lower body, core, upper body and handgrip strength (standing long jump, sit-up, push-up, handgrip). A two-way (2 groups X 3 measurements) analysis of variance (ANOVA) was used to test the efficacy of the intervention. **Results:** The results showed that students in the intervention group improved performance significantly from pre- to post-intervention in all tests compared to control participants. Regarding retention, the performance of the students in the intervention group, although decreased, remained significantly higher than that of the participants in the control group. **Conclusions:** These results suggest that suspension training is an effective and feasible resistance training method that can be integrated in PE lessons. Furthermore, due to the promptly observed improvements in strength, the suspension training program could lead to an increase in motivation to participate in the PE lesson and consequently, integrating strength training into the PE lesson throughout the school year could increase the academic learning time.
Keywords: **physical education, suspension training, youth, detraining.**

Introduction

Youth physical activity (PA) guidelines have recognized strength as an important health-related factor (Aston et al., 2018) and current public health goals promote an increase in the number of school-age youth participating in muscle strengthening activities (Barnett et al., 2015). Resistance training (RT) is an activity specifically designed to increase muscle strength and endurance through increased muscle workload (Ferret et al., 2021; Lubans et al., 2010). As a norm, RT has not been recommended for children, due to the perceived risk of injury and the belief that it could impede normal development (Faigenbaum, 2000; Landry & Driscoll, 2012). Nowadays, there are clear indications that RT can be a safe, effective and worthwhile activity for children and adolescents (Barnett et al., 2015; Faigenbaum et al., 2013), provided that age-appropriate training guidelines are followed under the guidance of a professional coach or Physical Education (PE) teacher (Behm et al., 2008; Lloyd, et al., 2013; Lubans et al., 2011; Pichardo et al., 2019**).** Despite the recognized acceptance of RT in children and adolescents by medical and health-related organizations (American Academy of Pediatrics, 2008; American College of Sports Medicine [ACSM], 2017; Lloyd et al., 2012; Mountjoy et al., 2011; U.S. Department of Health and Human Services, 2018), recent research data show a significant decline in children's muscle strength (Mischenko et al., 2020; Sandercock & Cohen, 2019). Oddly, at the same time, a significant increase in the popularity of RT with new methods is observed (Eather et al., 2016; Kennedy et al., 2018). Suspension training (ST) is a relatively new form of exercise suitable to train all components of physical fitness in one interval-style workout (Dudgeon et al., 2015). It is a very popular method of training in gyms and other training facilities, either as an individual training program or as part of exercise programs.

In ST, as the name suggests, straps and/or ropes are used to support specific parts of the body (arms or legs) in the air. This type of training consists of movements against gravity, with body weight as resistance. The level of training difficulty is adjusted by changing the "working angle" (i.e., inclination of the body from an upright position) (Mok et al., 2015). Individuals exercise "against" their bodyweight as they complete the exercises in unstable conditions. Regarding stable and unstable conditions, various devices and techniques have occasionally been used to create instability, such as Bosu, Wobble Board or Swiss balls (Maté-Muñoz et al., 2014; Ragevic & Ponorac, 2018; Saeterbakken et al., 2019). Recently, ST has been used as an additional device for practicing in unstable conditions (Cugliari & Boccia, 2017). Suspension training has attracted a lot of research interest regarding strength (Marta et al., 2019), electromyographic activity (Atkins et al., 2015; Snarr et

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al., 2016), biomechanical analysis (Giancotti, Fusco, Varalda, et al., 2018; Gulmez, 2017), physiologic and metabolic effects (Dungeon et al., 2015). Although ST is presented as an innovative training method, the historical use of such equipment is related to gymnastic rings and the first references date back to the mid-1800's when gymnasts and acrobatic artists performed part or their entire program using suspension equipment (Byrne et al., 2014). Later in the mid-1990's, suspension equipment in its current form was commercially available on the market. Nowadays, it has become a popular type of training due to its versatility, simplicity, low space requirements and wide variety of exercises (Mok et al., 2015). Furthermore, it has functional training features, given that many daily activities as well as most sports activities take place in non-static and therefore relatively unstable conditions. An additional advantage of training in unstable conditions is that it can provide a more efficient transfer of training adjustments to daily activities (Behm & Anderson, 2006; Byrne et al., 2014).

Suspension training has been shown to be just as effective as the traditional RT (Marta et al., 2019; Radjevic & Ponorac, 2018) and improvement in muscle strength has been observed regardless of age (Soligon et al., 2020; St. Laurent et al., 2018) and gender (Dannelly et al., 2011; Maté-Muñoz et al., 2014). For instance, when non-athlete underweight females trained with two different methods, ST and traditional RT, both methods created almost the same improvements in physical fitness factors and it was concluded that ST can be considered an equally efficient choice alongside with traditional RT or as its alternative (Arazi et al., 2018). With regard to older ages, when participating in a ST intervention, strength gains were mostly reported (Gaedtke & Morat, 2015). Recently, youth judokas have improved lower-body muscle power and muscle endurance after a 5-week training period with a suspension training routine (Norambuena et al., 2021). Suspension training is also used with success in rehabilitation. For example, female athletes with functional ankle instability improved strength and proprioception accuracy after six weeks of suspension training (Khorjahani et al., 2021). In addition to the above, according to Behm and Colado (2013), strength training in conditions of instability is recommended for young people, the elderly, people engaged in leisure activities and those who seek variety in training.

One of school's most important roles is to promote positive values and attitudes towards an active and healthy lifestyle (Görner & Reineke, 2020; Nesterchuk et al., 2020). More particularly, is the ideal environment to promote a lifestyle with high health values (Hills et al., 2015), such as engaging in muscle strengthening activities, because at the most crucial age it can massively influence the behavior of young people, through an institutionalized and well-organized operating framework, without requiring significant additional costs. Global health recommendations aim to increase the frequency with which young people involve in muscle-strengthening activities (Myer et al., 2011; World Health Organization [WHO], 2010). People, as they grow older from childhood to adolescence and from adolescence to adulthood, tend to exercise less (Corden et al., 2019; Farooq et al., 2018), while at the same time increasing their unhealthy habits with health problems being on the rise. While adolescence is an important period for the adoption of healthy behaviors, research from Metcalf et al. (2015) supports that PA declines during adolescence across different environmental settings, and muscle strength diminishes alongside with it. Through PE, children gain knowledge, skills and confidence by participating in a variety of physical activities, namely they become physically literate, in order to acquire a more active lifestyle towards PA (Faigenbaum et al., 2015). Additionally, the development and dexterity of selected physical abilities, such as strength, during the developmental age is fundamental for continued participation in moderate to vigorous physical activity (MVPA) later in life (Barnett et al., 2008; de Souza et al., 2014; Faigenbaum et al., 2020). According to Behringer et al. (2011), RT is an effective method for enhancing motor performance skills during childhood and youth, and thus strengthens future participation in games, sports and fitness activities.

Occasionally, different strength training methods have been implemented into school setting. In primary education, a core conditioning intervention improved significantly core muscular endurance (Allen et al., 2014). Benefits from integrating strength training in primary school PE were also found in a study by Faigenbaum et al. (2015). As far secondary education in concerned, Kennedy et al. (2018) implemented a school-based intervention called "Resistance Training for Teens". After the intervention participants achieved immediate improvements in upper body muscular fitness and RT skill competency. More recently, a strength training program was implemented in the PE lesson with duration of 15-20 minutes (Martins et al., 2020). Despite the short duration, it was found that the experimental group obtained higher gains, when compared to the control group. Non-traditional RT methods have also been implemented, such as CrossFit (Eather et al., 2016) and Calisthenics (Guerra et al., 2019) and both methods led to improvement in health-related fitness and strength parameters. Although ST as a non-traditional RT method is thought to elicit higher muscle activations than traditional exercises, only limited information is available on its acute effects on strength and power performances, especially in a school setting (Giancotti, Fusco, Iannaccone & Cortis, 2018).

Few studies have implemented ST as a strength enhancement in a school environment and mainly concerned younger ages. In particular, when ST was delivered to elementary school-aged children, it was concluded that it was beneficial for muscular endurance and as effective as the traditional RT (Marta et al., 2019; St. Laurent et al. 2018). Additionally, in a study with the use of ST in prepubescent boys, explosive strength was found to improve significantly (Marta et al., 2018). Inferentially, ST seems effective by improving parameters of fitness, such as strength, and consequently health. Nonetheless, there is a lack of studies that examine the efficacy of school-based ST on children of older age, especially adolescents who are in a transitional period, from childhood to adulthood, during which lifelong behaviors are established. Additionally, and to the best of our knowledge, no prior studies have evaluated the retention of ST benefits post-intervention. In consideration of the foregoing, as well as a) the findings of a positive effect of ST, b) the fact that adolescence is a critical period for the promotion of exercise and PA and c) that schools play an important role directly affecting attitudes toward sports and PA, the need has arisen for the present study. Therefore, the purpose of this study was to assess the efficacy of an 8-week ST intervention followed by a 4-week detraining period on strength parameters in adolescents, compared with a control group.

Materials and Methods

Participants The participants were 321 secondary education students (158 boys, 163 girls) aged from 15-18 years (M_{age} = 16.54, SD = .91). None of them had any history of orthopedic, musculoskeletal or neurological disorder that might have affected their ability to execute the ST program and the strength tests. The ST intervention group (IG) consisted of 154 participants (76 boys, 78 girls) and the control group (CG) of 167 participants (82 boys, 85 girls). There were no significant differences in age, body height, body mass and Body Mass Index (BMI) between groups at baseline (Table 1).

Table 1. Demographic characteristics of study participants

Variables	Mean ± SD			P
	All (n = 321)	IG (n = 154)	CG (n = 167)	
Age (years)	16.54 ± .91	16.52 ± .88	16.56 ± .94	.72
Body Mass (kg)	65.51 ± 11.02	65.89 ± 11.45	65.17 ± 10.63	.56
Body Height (m)	1.71 ± .09	1.71 ± .09	1.72 ± .09	.41
BMI (kg/m^2)	22.20 ± 2.45	22.44 ± 2.60	21.98 ± 2.29	.09

Note. SD= Standard Deviation; IG= Intervention Group; CG = Control Group; P = *p* values for IG and CG Independent Samples t-test; BMI = Body Mass Index

Intervention The ST program was specifically designed to be time-efficient, developmentally appropriate for adolescents and was based on previous studies (Faigenbaum et al., 2015). It was implemented twice a week, on non-consecutive days, during the first 25-30 minutes of the 45-minute PE lesson. At the beginning of each lesson, the PE teacher demonstrated the proper technique of the exercises and then supervised and corrected technical errors where needed. Moreover, instructions were given with analogies (Chatzopoulos et al., 2020). After a short dynamic warm-up (e.g., squats, arm and leg swings, jumping jacks) (Chatzopoulos et al., 2015), participants in pairs performed 2 sets in each exercise for 12 repetitions throughout the intervention, while the exercises progressed from simple to complex (Table 2). For weeks 1-4 they performed a total of 8 exercises, while for weeks 5-8 they performed 10 exercises. The duration of the rest time between the exercises was equal to the execution of the exercise by the 2nd participant of the pair, namely one student was performing and the other was resting. The suspension training sessions consisted of total body workouts with a variety of exercises. The exercises had an increasing degree of difficulty and were renewed by 50% every two weeks, that is, half of the exercises were new. Great importance was given to the safety of the participants and the correct execution of the exercises. Before each session, for the convenience of participants and with a view to saving time, illustrated photos of the exercises were posted in a visible and accessible place, while during the exercises the participants were receiving instructions/feedback concerning the correct execution. The IG after the ST session followed the regular PE lesson, while the CG followed the regular PE lesson. The regular PE lesson, according to the PE curriculum focused on skill development in various individual sports (i.e., track and field events, badminton) and team sports (i.e., volleyball, soccer).

Table 2. Structure of Suspension Training program

	Body part	Exercises			
Order		Week 1-2	Week 3-4	Week 5-6	Week 7-8
1	Lower body	Squat	Side lunges*	Side lunges	Jump Lunges*
2	Lower body	Reverse Lunges	Reverse Lunges	Jump Squat*	Jump Squat
3	Upper body pushing	Chest Press	Chest Press	Chest Flyes*	Chest Flyes
4	Upper body pulling	Low Row	Low Row	Alligator (split fly) *	Alligator (split fly)
5	Upper body pulling	High Row	T-fly *	T-fly	I-fly*
6	Core	Knee Rollout	Mountain Climber*	Mountain Climber	Reverse Crunch *
7	Upper body arms	Overhead Triceps Extension	Overhead Triceps Extension	Biceps Curl*	Biceps Curl
8	Combo	Crunch & Biceps Curl	Squat & Biceps Curl *	Squat & Low Row*	Squat & High Row*
9	Combo	------------	------------	Squat & I-fly	Squat & T-fly *
10	Combo	------------	------------	Push Up & Reverse Crunches	Push Up & Reverse Crunches

Note. * = new exercise

Procedure

Participants in IG completed a series of exercises of a total body workout with ST equipment within the first minutes of their PE lesson, while in CG they performed their regular PE class as part of the school's curriculum. Data were collected at baseline, post-intervention and after a 4-week period (detraining). Measurements targeted a full body muscle strength assessment and were purposely selected to address common barriers to implementing school-based fitness assessment (e.g., lack of resources and insufficient time). The study protocol followed the Helsinki Declaration and was approved by the Ethics Committee of the Aristotle University of Thessaloniki. Permission to conduct the study was obtained from school principals and PE teachers, while participants' inclusion was only confirmed after prior written authorization of the parents/guardians of each student. Participation was voluntary and participants were informed that they could withdraw at any time.

Test Protocol

Anthropometric measurements. Body mass was measured to the nearest 0.1 kg with a digital flat scale (Seca 803, Seca, Germany) with participants wearing light clothing and no shoes. Body height was measured to the nearest 0.1 cm using a portable stadiometer (Seca 213, Seca, Germany) with participants standing erect and looking straight, without shoes. Instruments were calibrated to ensure acceptable accuracy (i.e., standard weight and height). BMI was calculated using measured weight and height as weight/height squared (kg/m^2).

Standing long jump. The standing long jump (SLJ) was used to evaluate the explosive strength of lower body. Participants were positioned standing with their feet shoulder-width apart behind a line marked on the ground and attempted to jump as far as possible without falling backwards. A two-foot take-off and landing was used with swinging of the arms and bending of the knees to provide forward drive. The distance was measured from the take-off line to the point where the back of the participant's heels landed. Three attempts were allowed and the longest distance was recorded to nearest centimeter (Guerra et al., 2019). Standing long jump is part of the Eurofit test battery and considered valid and reliable field-based measure of muscular fitness among adolescents (Artero et al., 2012; Fernandez-Santos et al., 2015; Ruiz et al., 2011).

Sit-ups for 30 seconds. Abdominal strength was evaluated with the Sit-ups (SU) for 30 seconds test. Participants lay down in a supine position with knees bent at an angle of approximately 90 degrees, their feet flat on the floor, legs slightly apart and their fingers interlocked behind the head, while a partner held their ankles firmly to keep the feet to the ground. With an upward movement participant's elbows had to touch the knees and then the two sides of scapular should return to touch the floor. The aim was to repeats this movement as many times as possible during 30 seconds. If the participant failed to touch the knees with his/hers elbows, to keep fingers interlocked behind the head or to return his/hers back to the floor, the SU was not counted. The maximal number of correctly performed SUs in 30 seconds was recorded. Sit-ups, which are also part of the Eurofit test battery, are a widely used measurement of abdominal/core endurance (Tomkinson et al., 2018) and are safe to perform by children and adolescents (Contreras & Schoenfeld, 2011).

Push-ups. To evaluate the muscular endurance of upper body, the Push-ups (PU) test was used. Due to sex-related differences in upper body strength, all males were instructed to perform push-ups on their toes whereas all females performed push-ups on their knees (Smith et al., 2018). Participants had to perform as many PUs as possible, consecutively without rest. According to ACSM's (2017) guidelines for exercise testing, the starting position for males is in a high plank position (hands pointing forward and under the shoulder, back straight, head up, using the toes as the pivotal point) and for females in the modified "knee PU" position (legs together, lower leg in contact with mat with ankles plantar-flexed, back straight, hands shoulder width apart, head up, using the knees as the pivotal point). Both had to lower themselves in a controlled manner towards the floor until a 90 degree angle was formed at the elbow before returning to the starting position. The test was stopped when the participant strained forcibly or was unable to maintain the appropriate technique within two repetitions and the maximal number of correctly performed PUs, regardless of time, was recorded. Push-up test is a common muscular endurance test for the upper body and is part of fitness test batteries (e.g., FitnessGram), while the modified "knee PU" has also content validity and high reliability (Kolovelonis et al., 2011).

Handgrip strength. Handgrip (HG) strength was assessed using a portable Saehan hydraulic handgrip dynamometer (Saehan, Model SH5001, Saehan Corp., Korea). After adjusting the dynamometer handle to fit the hand size of each participant, they were asked to squeeze the dynamometer continuously and as hard as possible for 3 seconds, with the elbow fully extended and next to their body (Smith et al ., 2016). All participants performed 3 trials of the dominant hand with at least 60 seconds rest between attempts, and the best performance was used for further analysis. Raw HG strength was normalized as strength per body mass (ie, HG Strength [kg] / Body Mass [kg]) (Peterson et al., 2018). Handgrip strength has been found to be correlated with muscle strength in children and adolescents (Wind et al., 2010) and has excellent validity and reliability (Ruiz et al., 2011).

Statistical Analysis

Statistical analyses were computed using IBM SPSS Statistics software (Version 25). Data are presented as the mean and standard deviation (SD). A repeated measures (2 groups X 3 measurements) analysis of variance (ANOVA) was used to test for interactions and main effects for group (intervention vs. control) and time (pre-intervention vs. post-intervention vs. detraining). Sphericity was tested using the Mauchly's test, and the Greenhouse-Geisser correction was applied when necessary. Post hoc analysis with Bonferroni correction was used in the case of significant effects. Effect sizes are reported as partial eta-squared (η_p^2), with cut-off values of 0.01, 0.06, and 0.14 for small, medium, and large effects, respectively, and as Cohen's d (*d*) classified as trivial ($d < 0.2$), small ($0.20 < d < 0.49$), medium ($0.50 < d < 0.79$), and large ($d < 0.80$) (Cohen, 1988). For the push up test, it was decided that results be analyzed separately due to sex-related differences in upper body strength and therefore different execution of the exercise. Statistical significance was set at $p < .05$.

Results

Participants completed the ST program according to the aforementioned procedures, and none reported any training-related injury. Table 3 describes pre-intervention, post-intervention and detraining results for all outcome variables. Overall, there were no statistically significant differences in baseline values between IG and CG ($p > .05$).

Table 3. Mean and standard deviations for pre-intervention, post-intervention and detraining measurements

Variables	Group	Pre-intervention	Post-intervention	Detraining
		Mean ± SD		
Standing long jump (m)	IG	1.51 ± .33	1.67 ± .31*§	1.62 ± .33*#†
	CG	1.53 ± .29	1.54 ± .28	1.54 ± .28
Sit-ups in 30 second (repetitions)	IG	19.92 ± 5.18	24.27 ± 5.19*§	23.56 ± 5.20*#§
	CG	19.84 ± 4.95	20.37 ± 4.19*	19.80 ± 4.25#
Push-ups (boys) (repetitions)	IG	22.75 ± 11.02	28.96 ± 11.97*§	26.03 ± 11.32*#§
	CG	22.12 ± 8.69	19.93 ± 7.85*	19.88 ± 7.63*
Modified Push-ups (girls) (repetitions)	IG	20.76 ± 9.12	27.29 ± 9.33*§	23.40 ± 9.23*#§
	CG	20.09 ± 8.12	17.69 ± 7.09*	17.12 ± 6.80*#
Handgrip strength (Normalized to Body Mass)	IG	0.55 ± .16	0.62 ± .12*§	0.60 ± .13*#§
	CG	0.56 ± .10	0.54 ± .11*	0.54 ± .11*

Note. SD = Standard Deviation; IG= Intervention Group; CG = Control Group; * = $p < .001$ from pre-intervention; # = $p < .001$ from post-intervention; § = $p < .001$ from Control Group; † = $p < .05$ from Control Group.

Standing long jump

A significant main effect of "Time" was found for the SLJ test ($F_{1.45,461.69} = 486.16$, $p < .001$, $\eta_p^2 = .604$) (Figure 1). Yet, no significant main effect of "Group" was found ($F_{1,319} = 3.11$, $p = .079$, $\eta_p^2 = .010$). In addition, a significant "Time x Group" interaction ($F_{1.45,461.69} = 370.60$, $p < .001$, $\eta_p^2 = .537$) revealed that IG performance significantly increased from pre- to post-intervention ($p < .001$, $d = -.49$) and from pre-intervention to detraining ($p < .001$, $d = -.34$). From post-intervention to detraining IG performance decreased significantly ($p < .001$, $d = .15$). Regarding CG performance, no significant changes were found ($p > .05$).

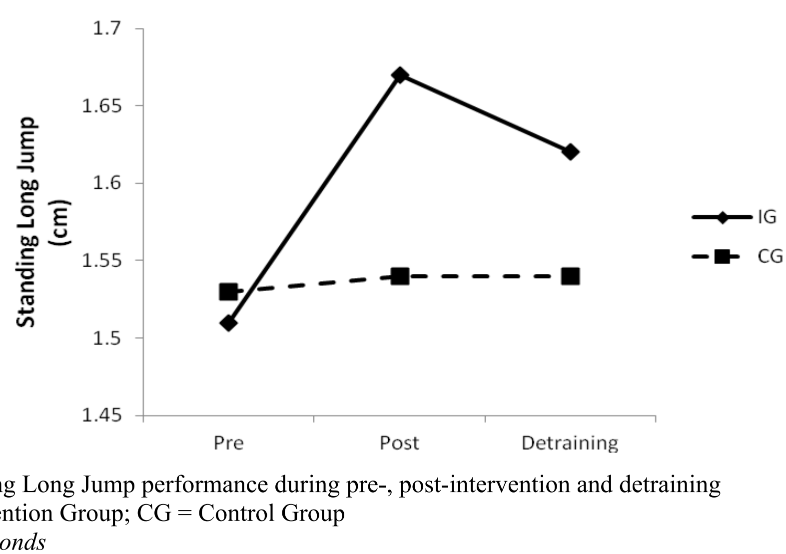

Figure 1. Standing Long Jump performance during pre-, post-intervention and detraining
Note. IG= Intervention Group; CG = Control Group

Sit-ups for 30 seconds

A significant main effect of "Time" was found for the SU test ($F_{1.68,534.55} = 448.57$, $p < .001$, $\eta_p^2 = .584$) (Figure 2). Also, a significant main effect of "Group" was found ($F_{1,319} = 23.58$, $p < .001$, $\eta_p^2 = .069$). In addition, a significant “Time x Group” interaction ($F_{1.68,534.55} = 328.55$, $p < .001$, $\eta_p^2 = .507$) revealed that IG performance significantly increased from pre- to post-intervention ($p < .001$, $d = -.84$) and from pre-intervention to detraining ($p < .001$, $d = -.70$). From post-intervention to detraining IG performance decreased significantly ($p < .001$, $d = .14$). Regarding CG performance, there was found a significant increase from pre- to post-intervention ($p < .001$, $d = -.12$), no significant changes from pre-intervention to detraining (p > .05) and a significant decrease from post-intervention to detraining ($p < .001$, $d = .14$).

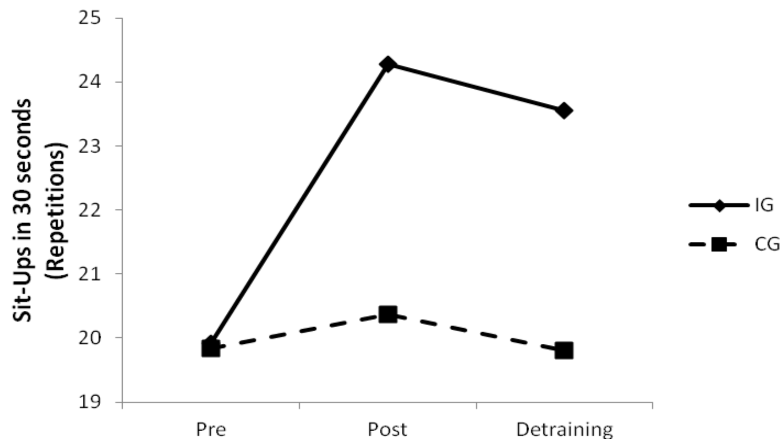

Figure 2. Sit-Ups in 30 seconds performance during pre-, post-intervention and detraining
Note. IG= Intervention Group; CG = Control Group

Push-ups

For boys, a significant main effect of “Time” was found for the PU test ($F_{1.88,292.90} = 100.81$, $p < .001$, $\eta_p^2 = .393$) (Figure 3). Also, a significant main effect of “Group” was found ($F_{1,156} = 11.45$, $p < .001$, $\eta_p^2 = .068$). In addition, a significant “Time x Group” interaction ($F_{1.88,292.90} = 422.96$, $p < .001$, $\eta_p^2 = .731$) revealed that IG performance significantly increased from pre- to post-intervention ($p < .001$, $d = -.54$) and from pre-intervention to detraining ($p < .001$, $d = -.29$). From post-intervention to detraining IG performance decreased significantly ($p < .001$, $d = .25$). Regarding CG performance, there was found a significant decrease from pre- to post-intervention ($p < .001$, $d = .27$) and from pre-intervention to detraining ($p < .001$, $d = .27$), yet no significant changes were found from post-intervention to detraining ($p > .05$).

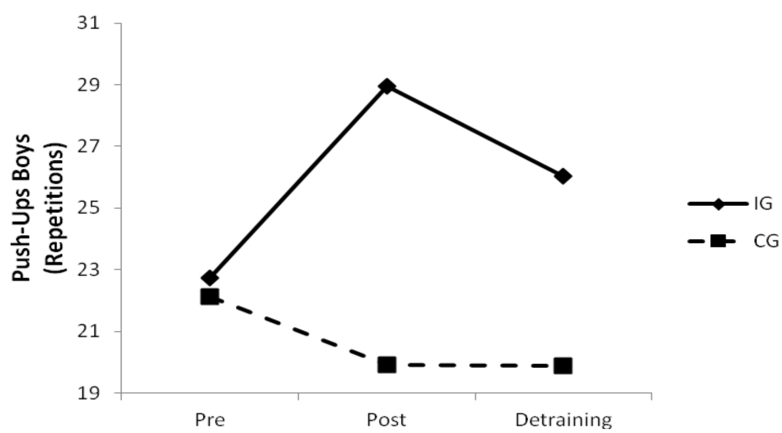

Figure 3. Push-Ups performance during pre-, post-intervention and detraining (Boys)
Note. IG= Intervention Group; CG = Control Group

For girls, a significant main effect of “Time” was found for the modified PU test ($F_{1.71,274.86} = 177.10$, $p < .001$, $\eta_p^2 = .524$) (Figure 4). Also, a significant main effect of “Group” was found ($F_{1,161} = 18.18$, $p < .001$, $\eta_p^2 = .101$). In addition, a significant “Time x Group” interaction ($F_{1.71,274.86} = 582.23$, $p < .001$, $\eta_p^2 = .783$) revealed that IG performance significantly increased from pre- to post-intervention ($p < .001$, $d = -.71$) and from pre-intervention to detraining ($p < .001$, $d = -.29$). From post-intervention to detraining IG performance decreased significantly ($p < .001$, $d = .42$). Regarding CG performance, there was found a significant decrease from pre- to post-intervention ($p < .001$, $d = .31$), from pre-intervention to detraining ($p < .001$, $d = .40$) and from post-intervention to detraining ($p < .001$, $d = .08$).

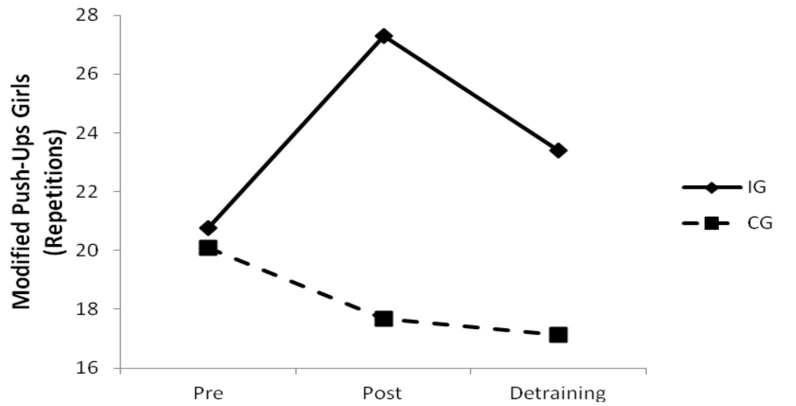

Figure 4. Modified Push-Ups performance during pre-, post-intervention and detraining (Girls)
Note. IG= Intervention Group; CG = Control Group

Handgrip strength

A significant main effect of "Time" was found for the HG test ($F_{1.62,517.48} = 31.51$, $p < .001$, $\eta_p^2 = .090$) (Figure 5). Also, a significant main effect of "Group" was found ($F_{1,319} = 12.93$, $p < .001$, $\eta_p^2 = .039$). In addition, a significant "Time x Group" interaction ($F_{1.62,517.48} = 100.28$, $p < .001$, $\eta_p^2 = .239$) revealed that IG performance significantly increased from pre- to post-intervention ($p < .001$, $d = -.59$) and from pre-intervention to detraining ($p < .001$, $d = -.38$). From post-intervention to detraining IG performance decreased significantly ($p < .001$, $d = .17$). Regarding CG performance, there was found a significant decrease from pre- to post-intervention ($p < .001$, $d = .18$) and from pre-intervention to detraining ($p < .001$, $d = .14$), yet a significant increase was found from post-intervention to detraining ($p < .01$, $d = .14$).

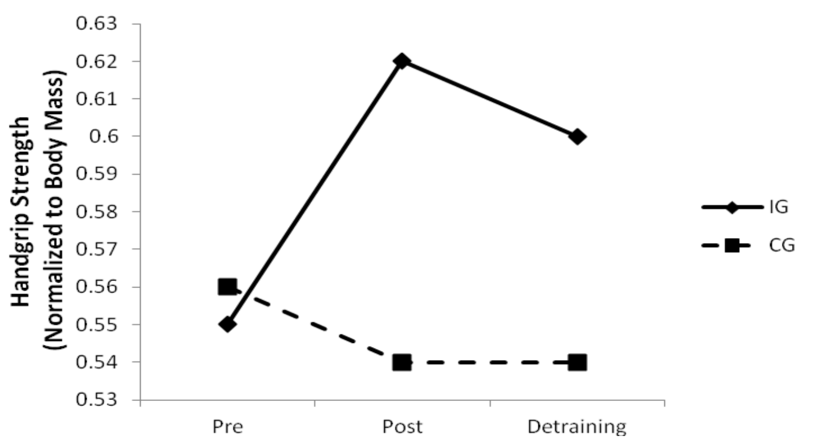

Figure 5. Handgrip strength performance during pre-, post-intervention and detraining
Note. IG= Intervention Group; CG = Control Group

Discussion

Physical activity decreases dramatically during adolescence (Dumith et al., 2011) and only 19% of adolescents worldwide are sufficiently active (WHO, 2018). Schools are considered an ideal place to promote PA, as they provide an environment in which children and adolescents can exercise regularly. Physical education is the preferred environment to introduce children and adolescents to a range of lifelong physical activities, including strength training. Introducing strength training in the school environment can provide young people with the skills and confidence needed to participate in this important type of PA throughout their lives (Kennedy et al., 2018). The purpose of this study was to assess the efficacy of an 8-week ST intervention followed by a 4-week detraining period regarding strength parameters in adolescents (ie., standing long jump, sit-ups in 30 seconds, push-ups and handgrip strength). To the authors' knowledge, this study is the first to investigate the efficacy of a ST program in adolescents in the PE lesson.

In general, the IG participants improved their performance in all tests from pre- to post-intervention and significantly differed from the CG participants. A strong lower body denotes functionality, stability and endurance in everyday life activities. Moreover, jumping ability is a complex multi-joint movement that we encounter both in our daily lives and in sports. The SLJ test improvements are in agreement with previous studies using ST in the PE lesson (Marta et al., 2018; Marta et al., 2019). Furthermore, in sports the use of ST is found to promote improvements in lower body strength. In a study with young fencers, two experimental groups (ST and traditional RT) and a control group were used to assess a 10-week strength training program (Hamza, 2013). Both experimental groups improved their performances in SLJ, but the ST group even more than the traditional RT group. In another study with university female students, the implementation of an 8-week ST program resulted in a significant increase in SLJ test (Chen et al., 2016). Conversely, few studies that implemented RT training, such as ST in younger children (St. Laurent et al., 2018), calisthenics (Guerra et al., 2019) and bodyweight training (Winwood & Buckley, 2019) in adolescents, did not observe significantly improvements. Perhaps the differences in the age group under study or the different RT types are responsible for the lack of improvement in SLJ.

Abdominal/core strengthening has been widely studied, as it is considered a key factor for health, rehabilitation and athletic performance (Cugliari & Boccia, 2017). In the present study, it was found that SU performance improved significantly. These results are consistent with the findings of previous studies (Chen et al., 2016; Guerra et al., 2019; Hamza, 2013). In a school-based study, when a manual RT program was implemented for 20-30 minutes within the PE lesson, core endurance was improved (Dorgo et al., 2009). Additionally, an 8-week implementation of a PE curriculum focused on physical fitness in high school students elicited improved performance in the core endurance test (Goudas et al., 2010). In another study, the implementation of ST in younger children did not improve core endurance (St. Laurent et al., 2018). Contrary to St. Laurent et al. (2018) findings, other studies that have examined the effects of RT in the same age group concluded that RT elicited significant improvements (Allen et al., 2014; Faigenbaum et al., 2011). Core strength has always been considered an important aspect of total fitness and since ST elicits significant improvements, recent studies examined the core muscle activation during various ST exercises (Harris et al., 2017; Mok et al., 2015; Snarr et al., 2016). They concluded that performing exercises in unstable conditions with the use of ST equipment requires greater core muscle activity to maintain the desired body position during the exercise (McGill et al., 2014) and therefore a high level of muscle activation is beneficial to improve muscular strength.

The PU test was used to assess upper body muscular endurance as proposed by the ACSM (2017) guidelines for exercise testing, namely boys used their toes and girls their knees as the pivotal point. Although some studies analyzed and reported results for both genders together despite the different execution of the test (Alberga et al., 2016; Guerra et al., 2019; Smith et al., 2018), in the present study it was considered preferable to analyze and report them separately, so the differences (if any) due to sex-related issues and exercise execution would be addressed respectively. Nonetheless, both genders in IG performed alike, with a significant increase in performance after the ST intervention. Participants improved their upper body muscular strength similar to other studies with RT interventions in the PE lesson (Dorgo et al., 2009; Goudas, et al., 2010; Guerra et al., 2019; Martins et al., 2020), supporting the notion that ST is as effective as traditional RT (Arazi et al,. 2018). Strength training in unstable conditions, in this case with ST equipment, improved the performance for both sexes and is consistent with previous studies in males (Maté-Muñoz et al., 2014) and females (Dannelly et al., 2011). However, in another study with younger children the use of ST did not elicit significant differences between intervention and control group (St. Laurent et al., 2018), while, in contrast with their results when a RT program was implemented in the same age group, significant improvements were found in the PU test (Faigenbaum et al., 2011).

Handgrip strength was also assessed, mainly because grip strength affects performance not only in daily activities that require prolonged or maximal muscular effort (Nicolay & Walker, 2005), but also in sports and events where a strong grip is essential, such as wrestling, team sports, track and field and more. (Katsoula et al., 2016). In addition, HG is an effective, safe, quick and easy-to-administer tool and is often used as a proxy measure of overall strength (Buckner et al., 2019). In the present study, despite the fact that the ST did not involve the muscles activated during a grip, the HG strength improved significantly from pre- to post-intervention. This may be due to the necessary use of a strong grip when performing the majority of exercises with ST equipment. Similar results, namely improvement in HG strength, were observed in studies that examined different types of RT (traditional vs. functional) (Magnani Branco et al., 2020) or long-term implementation of a modified PE curriculum (Czarniecka et al., 2012). Contrary to the findings of the present study, when three different programs (aerobic training, RT, and combined training) were compared to a control group, no significant increase in HG was found (Alberga et al., 2016). Likewise, no improvements in HG were observed after a 5-week ST intervention in young judokas (Norambuena et al., 2021), although in another study from Franchini et al. (2015) significant improvement in HG was found as a result of two strength training programs. It is worth noting that the research from Franchini et al. (2015) had the same duration as the present study, while both lasted longer than the research from Norambuena et al. (2021). According to Stricker et al. (2020), the duration of training is one of the many different variables that affect performance.

The lack of similar ST studies regarding detraining made the comparison very challenging. In general, although the IG participants' performance decreased in all tests from post-intervention to detraining, their scores remained significantly higher than pre-intervention and still differed significantly from the CG participants. Several studies have reported controversial results regarding the effects of detraining on fitness parameters in children and adolescents (Faigenbaum et al., 2013), where participants sometimes retained the benefits of intervention (Santos & Janeira, 2009) and sometimes not (Tsolakis et al., 2004). In the present study, decreased performance in the SLJ test during detraining is consistent with findings in previous studies (Faigenbaum et al., 2013; Granacher et al., 2011). Perhaps the short-term training stimulus was not enough to preserve the benefits during the detraining period as observed in other studies with younger children (Chaouachi et al., 2019; Faigenbaum et al., 1996). Despite the decrease, the SLJ values in detraining were higher than those in pre-intervention.

Core endurance decreased from post-intervention to detraining. From the literature review, no studies were found to evaluate the retention of the effects when ST interventions are implemented. In a relevant study with younger children, regarding muscular fitness enhancement, opposite findings were observed, since there was no decrease in performance (Faigenbaum et al., 2013). According to the researchers, their findings suggest that strength of the core muscles may be more resistant to regression if achieved with a variety of exercises that focus on increasing muscle strength combined with improving motor skills. A strong and stable core allows optimal force production when performing certain motor skills (Oliver & Adams-Blair, 2010) and maintaining the gains from a RT program should be considered when designing PE courses (Faigenbaum et al., 2013). Although a significant decrease was observed in detraining, the SU performance was higher than in pre-intervention.

Regarding upper body muscle endurance, performance in the PU test decreased from post-intervention to detraining for both sexes. Despite the growing research interest in ST and to the best of our knowledge, no studies have yet evaluated retention of the gains. In the present study, the training stimulus led to significant improvements in upper body muscle endurance, but was not enough to retain the benefits of the ST program post-intervention. Nevertheless, it is worth noting that for both sexes the detraining performance in the PU test was higher than pre-intervention.

During detraining assessment, HG performance also decreased. In a study where the effects of detraining following a RT program in children (boys only) were examined, HG strength gains retained (Chaouachi et al., 2019). The difference in the findings between the aforementioned and the present study may be due to the age difference (older children in the present study), the inclusion of both sexes in the present study, and different intervention protocols. Beyond controversial results, it is an indisputable fact that a strong grip is important for any sport in which the hands are used for catching, throwing or lifting, but also in daily activities. Furthermore, HG is often referred to as a health biomarker (Buckner et al., 2019) and the relationship between HG (as expression of overall strength) and mortality is often used to emphasize the importance of exercise with RT (Peterson et al., 2018). Similar to the previous tests, despite the decrease, the HG values in detraining were higher than those in pre-intervention.

Overall, the ST program, with a duration of 25-30 minutes, produced significant improvements to muscular strength, and the findings of the present study are consistent with previous studies, both with instability equipment and traditional RT. In addition, it seems that instability training can produce similar effects to traditional RT, but with less external strain (Behm et al., 2002). Furthermore, detraining is a more complex process in youth because of developmental improvements in performance, and some skills are retained better than others (Stricker et al, 2020). In the present study, the short-term ST program was not enough to retain the gains at post-intevention level after a 4-week detraining period. Since physical inactivity and sedentary behavior have became a worldwide pandemic, an important target group for implementing and promoting fitness programs, are the adolescents, because healthy behaviors during childhood and adolescence can affect a healthy lifestyle in adulthood for life (Granacher et al., 2011). Adolescents, therefore, should be involved in a variety of physical activities, especially those that are common with adult activities. Resistance training is one of them and ST, in particular, seems to be effective regardless of age, sex, training background or body mass. Thus, starting with PE, adolescents that are encouraged to be active at school and stay active during leisure time, have an increased chance of being lifelong active.

Conclusions

The results of the present study illustrated that ST is an effective, feasible and safe (i.e., no injuries reported) training modality that enhances muscle strength and endurance and, despite the short time of implementation, all strength parameters examined were improved. During the detraining period, the training stimulus was not able to retain the strength gains observed. The conclusions may be important for PE teachers concerning new RT activities that can be taught safely with immediate improvements in strength parameters and adding variety in the PE lessons. Furthermore, due to the promptly observed improvements in strength, ST could lead to an increase in motivation to participate in the PE lesson and consequently, integrating strength training into the PE lesson throughout the school year could increase the academic learning time. Limitations of the present study might include the short-term implementation period and the relatively small sample, therefore generalizations are not recommended. Further studies should investigate longer training and detraining periods, especially in the school environment, as well as bigger samples from different age groups. To conclude, ST is a type of RT that can be easily taught in the PE lesson and then used safely by youth during their leisure time promoting lifelong physical activity.

Conflicts of interest – None.

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