UNSTABLE COMPARED TO STABLE CORE EXERCISES IMPROVE MUSCULAR ENDURANCE IN PREADOLESCENTS AND ADOLESCENTS: AN EIGHT-MONTH RANDOMIZED TRIAL

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Abstract:

Although previous studies have indicated the importance of a core strength and muscular endurance training in preadolescents and adolescents, there is a lack of evidence regarding effects of a long-term core training in unstable conditions. The purpose of this study was to compare the effects of core training in stable versus unstable body positions on core and upper body strength and muscular endurance in non-trained children aged 11-14 years. Participants were randomly assigned to either stable (SC, N=569) or unstable (UC, N=633) core-exercise group and assessed at baseline, after four, and eight months for sit-ups, dynamic trunk extension, static trunk extension, and push-ups. Repeated measures ANOVA, with time as a within factor, and exercise group, age, and gender as between factors, was employed for data analysis. *Post-hoc* comparisons showed greater absolute improvements after the eight-month training in UC compared to SC for all measures, age groups, and both genders ($p \leq .01$), and greater relative improvements (differences in Cohen's d between UC and SC ranged from 0.08 to 1.58), except for static trunk extension in 11- and 12-year-old participants. However, the differences between SC and UC in four-month effects were inconsistent. These results point out that core exercises in unstable compared to stable conditions have a greater capacity for long-term improvement of core and upper body strength and muscular endurance in non-trained preadolescents and adolescents.

Key words: *children, resistance training, abdominal strength, lower back strength*

Introduction

Muscular strength and endurance are recognized as important elements of health-related fitness (Caspersen, Powell, & Christenson, 1985). There is a growing body of research trying to elicit resistance training programmes that can be efficient for optimal improvement of muscular strength, muscular endurance, and physical performance in different populations (Allen, Hannon, Burns, & Williams, 2014; Behm, et al., 2017; Coratella & Schena, 2016; Faigenbaum, et al., 2001; Sekendiz, Cug, & Korkusuz, 2010). Some of the widely used programmes for enhancing body strength and functionality are oriented towards the body core.

The core is described as a muscular corset surrounding the lumbar spine that serves as an engine of all limb movements (Akuthota & Nadler, 2004). A stable, strong, and enduring core is important for musculoskeletal injuries prevention (Hibbs, Thompson, French, Wrigley, & Spears, 2008; McGill, 2010; Mendiguchia, Ford, Quatman, Alentorn-Geli, & Hewett, 2011), in rehabilitation (Akuthota & Nadler, 2004), as well as for improving physical performance in everyday functioning (Granacher, Gollhofer, Hortobágyi, Kressig, & Muehlbauer, 2013) and specific sports activities (Kibler, Press, & Sciascia, 2006; Myer, Ford, Palumbo, & Hewett, 2005; Reed, Ford, Myer, & Hewett, 2012). Core training mostly refers to a variety of exercises that involve both global, dynamic core muscles (e.g., *m. rectus abdominis*) and local, postural core muscles (e.g., *mm. multifidi*), and focuses on their proper inter-activation in order to improve core stability and strength. Furthermore, a body of evidence suggests that neural coordination in core muscle recruitment is more important for the core and whole-body functionality than the core muscle hypertrophy (Akuthota & Nadler, 2004; Hibbs, et al., 2008). In line with this, unstable and asymmetric core exercises could provide additional stimulation to the neuromuscular system for improving parameters of core stability, strength, and muscular endurance (Behm, Leonard, Young, Bonsey, & MacKinnon, 2005; Vera-Garcia, Grenier, & McGill, 2000).

Neuromuscular stimulations could be especially important in preadolescents' core training, bearing in mind that their strength improvements during resistance training can be obtained rather due to neural adaptations (i.e., motor unit activation, coordination, recruitment, and firing) than to muscle hypertrophy related to a hormonal spurt (Behringer, vom Heede, Yue, & Mester, 2010; Faigenbaum, 2000; Ozmun, Mikesky, & Surburg, 1994). On the contrary, adolescents have greater strength improvement as a result of their hormonal status (e.g., increased levels of circulating androgens in males and growth hormone and insulin-like growth factor in females) (Kraemer, 1987) and it is not clear whether additional neuromuscular stimulation (e.g., engaging, unstable exercises) would be beneficial or detrimental for strength during adolescents' resistance training. Bearing in mind the different physiological mechanisms of strength gains in preadolescents and adolescents, establishing a core resistance training that would be beneficial for core strength and muscular endurance in both preadolescents and adolescents is quite challenging.

Oliver, Adams-Blair, and Dougherty (2010) proposed feasible core-strength training for preadolescents, which consisted of four isometric core exercises (the fifth exercise was a modified form in case of failing to perform one of the exercises) in one set for 30 seconds. Although this training increased muscular endurance of trunk flexors in the first two months, the achieved plateau was maintained throughout the rest of the ten-month training period. The authors concluded that there was a need for additional neuromuscular stimulation in order to prolong positive training effects. This issue was partially addressed in another study by designing training that consisted of ten engaging dynamic core conditioning exercises performed during 30 seconds each, one after another (Allen, et al., 2014). This one-per-week training routine lasted six weeks and showed significant gains in trunk muscular endurance in both preadolescents and adolescents. However, due to the short training period, it could not be concluded whether this training would have prolonged positive effects on trunk muscular endurance. Both of the previously mentioned studies did not include a control group, and therefore trunk muscular endurance gains could not be attributed solely to the training. In another study (Granacher, et al., 2014), resistance training in stable and unstable conditions was organized two times a week for a total of six weeks as a randomized control trial for adolescents. Increasing the training load every two weeks (i.e., the number of repetitions in the dynamic exercises and contraction time in the isometric exercises) improved core muscular endurance but did not show greater effects in either of the two condition groups. The reason for such findings might be the short training period (six weeks), with insufficient time for neuromuscular adaptation as an answer to the complexity of the unstable exercises.

To address the mentioned shortcomings in previous research, we designed a feasible eight-month core resistance training that consisted of engaging exercises in unstable body positions. Moreover, to address the issue of the lacking control group in previous research, in this study we included resistance training with similar exercises, but in stable body positions. This study aimed to compare the efficacy of core training in unstable versus stable conditions (UC vs SC) in improving core strength and muscular endurance in 11-14 years old children of both sexes. Also, we aimed to reveal whether functional core training can improve upper body muscular endurance, if we have in mind that engaging core exercises could be beneficial for multiple parts of the kinetic chain (Kibler, et al., 2006; Reed, et al., 2012). Bearing in mind the importance of neuromuscular stimulation for strength gains (Behm, et al., 2005; Vera-Garcia, et al., 2000), especially in preadolescents (Behringer, et al., 2010; Faigenbaum, 2000), we hypothesized that younger children (i.e., 11-year-olds) would show greater improvements in core muscle strength and endurance as well as in upper body muscular endurance when trained using UC compared to SC exercises. We could not hypothesize which of the two types of training would be more efficient in adolescents, when considering their greater hormonal response to strength and muscular endurance training, compared to preadolescents (Behringer, et al., 2010; Tsolakis, Vagenas, & Dessypris, 2004).

Methods

Study design

This randomized trial involved 1202 non-trained participants randomly assigned to SC or UC. After familiarization with the testing protocol, the participants undergone a baseline testing of muscular strength and endurance, body weight and body height. The intervention programme lasted for two four-month periods with a 3-week pause apart and mid-intervention testing in between. The programme consisted of 12 exercises in SC vs UC with volume monthly increased. At the end of the programme, the final testing was applied.

Participants

In the first phase of the participant recruitment 1348 students aged 11-14 (not younger than 10.5 years and not older than 14.5 years at the pretest; mean age ≈ 12.5 years), without neurological or physical impairment, from five public schools who had not trained any sports for at least six months (i.e., non-athletes), volunteered to participate in this study. The Local Ethics Committee approval was obtained, and the children's parents or legal guardians provided all the required information and gave their written informed consent. Participants were informed about the benefits and risks of the study and gave verbal assent. They were randomly assigned either to SC or UC. During the eight-month study, 146 participants dropped out due to being absent for 15 or more classes (N=80), being involved in some sport within the study period (N=9), lacking one or more testing sessions (N=47) or residential relocation (N=10). At the end of the experiment, 1202 participants (569 in SC; 596 females) completed the study.

Testing procedures

Prior to baseline testing, participants were given a 45 min instruction-session in order to become familiar with the techniques of the four testing exercises (sit-ups, dynamic trunk extension, push-ups, and static trunk extension). All the participants completed a standardized dynamic warm-up and as many practice-attempts as needed to learn the proper exercise technique. After a five-day pause, they attended two testing sessions separated by three days. Prior to both sessions, participants completed a ten-minute standardized warm-up consisting of dynamic bodyweight exercises, gradually increased in intensity. During the first session, the participants' body height and body weight were measured, and they performed sit-ups and dynamic trunk extensions, with at least 5-minute rest between the exercises. During the second session, participants performed static trunk extensions and push-ups, with the same pause in between. The testing protocol was identical for the middle effect testing (after four months) and postintervention testing (after eight months) and performed at the same time of a day. The same experimenters within each school obtained the measures at each of the three time points, and they were not aware of the core exercise group (SC or UC) to which the participants were assigned.

Anthropometric assessment

Body height was measured using stadiometers (Seca Instruments Ltd., Hamburg, Germany) to the nearest 0.1 cm, and body weight was measured with portable weighing scales (Tanita Europe GmbH., Sindelfingen, Germany) to the nearest 0.1 kg. Body mass index (BMI) was calculated using the standard formula and expressed in $kg\cdot m^{-2}$.

Strength and muscular endurance assessment

Sit-ups in 30 seconds was used as an exercise for assessing the muscular endurance of trunk flexors (Adam, Klissouras, & Ravazzolo, 1988). The participant lay supine on the floor with 90° flexion in the knee joints, hands at the side of his/her head, with elbows pointing straight forward and the feet securely held by a partner. In a correct sit-up, the elbows should touch the knees and, when going back, the shoulders should touch the floor. The number of correctly completed repetitions in 30 s was used for data analysis.

Dynamic trunk extension test was used for assessing muscular endurance of trunk extensors because it requires proper activation of the *m. erector spinae* (Kearns, Brechue, Bauer, Pollock, & Fulton, 1997). The participants performed the test on a Roman chair with their legs fixed by one experimenter. They started at a 180º angle between the back and legs while keeping their arms folded across the chest (neutral position). The participants flexed their trunk in a controlled manner until they reached a 90º angle between the trunk and legs and then extended back to the neutral position. An indicator of a well flexed position was the paperclip (at a free end of a chain attached to the participants' shirt), which would barely touch the floor at the 90º trunk flexion angle. The participants performed the trunk extensions at a pace of one repetition every three seconds. The test stopped when the participant was unable to keep up with a required pace of 20 extensions per minute or voluntarily stopped. The total number of repetitions was used for data analysis.

Static trunk extension test was used for assessing trunk extension strength (Cooper Institute for Aerobics Research, 1999). Participants lay in the prone position on a mat with their hands under the thighs and performed trunk extension as high as possible in a slow and controlled manner, keeping the feet in contact with the floor and the head in the Frankfurt plane. The contraction lasted until the tester measured the distance from the floor to the participants' chin (up to 5 s). Two trials were performed, and the better score was recorded.

Push-ups test, which assesses upper body muscular endurance, was modified by placing the hands on a higher surface (a 55 cm high gymnastics bench). We used this exercise despite the fact that it is not a core exercise, in order to investigate if the core strengthening would improve strength and muscular endurance parameters in a task that is indirectly dependent on core stability and strength (McGill, McDermott, & Fenwick, 2009; Santana, Vera-Garcia, & McGill, 2007). The other validated versions of the push-up test were not chosen for this study because the 90° push-up (Cooper Institute for Aerobics Research, 1999) was too challenging for a great proportion of the participants, and the knee push-up test was not challenging enough for the body core engagement. Except for the modified placement, the hands were under the shoulders and wider than a vertical shoulder projection

(10 cm each), arms straight, and legs together and straight with the toes tucked downward. The participants lowered the body by bending their elbows outwardly to a 90° angle and continued the movement in reverse until the arms were straight again (the back and legs were in a straight line throughout the movement). The participant needed to repeat this movement as many times as possible. The test ended when the participant voluntarily stopped, did not maintain the correct body position, or did not achieve a 90° bend at the elbow on two consecutive trials (after the first mistake the participant was warned to correct his/her technique).

Training procedure

Prior to initiating training programmes, all participants completed three familiarization sessions, separated by 24h, during which they mastered the performance of 12 exercises implemented during the core training programme (Table 1). At the end of the instruction week, they were tested without a strict testing procedure in each exercise for the maximal number of repetitions (except for the exercises which were the same as the test, i.e., sit-ups and push-ups in SC), or maintaining the proper body position for as long as possible (i.e., plank with hands on a medicine ball). This information was used in defining the conservatively progressed training volume and intensity (not at the expense of technical properness) for each exercise (Table 1). Three different exercises were performed in one training session, three times a week (total of 12 exercises in a four-week-cycle). Each exercise was performed in four sets: 60, 70, 80, and 90% of the MNR (maximal number of repetitions performed at baseline), with a 1-minute pause between the sets. Training volume was increased monthly: in sets 1-3 for 5% MNR, in the 4th set 3 to 1 repetition in reserve (10 to 5 s, for plank on a medicine ball). In the UC group, one-leg-standing exercises were counted as a whole set, and the next set began with the support on the opposite leg (e.g., left-right-left-right, in four sets, respectively). In the next month-cycle, the first set of the same exercise was performed on the leg opposite to the one at the beginning of the previous month. The tenseness of the resistance band was adjusted individually, according to MNR ≈ 15. The training programmes were incorporated into the mandatory physical education programme, in the form of an introductory and preparatory phase of a class. In the main phase of a class, all participants (SC and UC) were involved in their regular physical education programme for 20 min, which consisted of athletics (running, jumping) in each grade (age group), and technique-oriented exercises related to handball, basketball, volleyball, and soccer (for 11-, 12-, 13-, and 14-year-old participants, respectively). A physical education teacher supervised the training process and corrected the exercise technique if needed. Due to perturbation during exercises in UC, participants were instructed to continue the exercise after a mistake (e.g., losing balance in one-leg-standing exercises). After the four-month training period, participants had a three-week rest (school holidays), and when they were back in school, the last training month-cycle, in terms of the training volume and intensity, was repeated. The following month-cycles were executed with a gradual increase in training volume as prior to the three-week rest.

Statistical analysis

Descriptive statistics (mean, SD, skewness, and kurtosis) was used to inspect participants' characteristics and measures' distribution prior to the intervention. A repeated-measures ANOVAs with time as within- and exercise group (SC vs. UC), age (11 vs. 12 vs. 13 vs. 14 years), and sex (male

Table 1. Stable core exercises and unstable core exercises in a one-month training cycle

Week	SC	UC
1st	Glute bridge	One leg glute bridge
	Seated oblique twists with 624 gr ball (LS)	Seated oblique twists with 624 gr ball (LR)
	Knee push-ups	T knee push-ups
2nd	Dynamic trunk extension	Back scale
	Push-ups (hands on a 55 cm high surface)	One-leg-standing chest press with RB
	Sit-ups	Standing-on-heel crunches
3rd	Squat to overhead press with MB	One leg half squat to overhead press with MB
	Horizontal chopping with RB	One-leg-standing horizontal chopping with RB
	Reverse push-ups	One leg reversed push-ups
4th	Crossed-leg single-leg glute bridge	Single leg glute bridge on MB
	Down-to-upward facing dog	Plank with hands on MB
	Split squat	Sliding split squat

Note. SC = stable core exercises group; UC = unstable core exercises group; LR = legs raise; LS = legs sustained; RB = resistance band; MB = medicine ball.

Table 2. Descriptive statistics for the pretest measures in the stable conditions and unstable conditions

	SC			UC		
	M (SD)	Skew (SE)	Kurt (SE)	M (SD)	Skew (SE)	Kurt (SE)
BMI (kg·m^{-2})	19.84 (2.85)	0.07 (0.10)	-0.53 (0.20)	19.51 (2.95)	0.58 (0.10)	0.61 (0.19)
Sit-ups (n)	21.13 (3.80)	-0.17 (0.10)	0.49 (0.20)	20.79 (5.16)	0.13 (0.10)	0.17 (0.19)
Dynamic trunk extension (n)	36.53 (7.13)	-0.29 (0.10)	-0.06 (0.20)	33.20 (8.58)	-0.21 (0.10)	0.03 (0.19)
Push-ups (n)	13.56 (3.63)	-0.12 (0.10)	0.41 (0.20)	12.76 (4.73)	0.28 (0.10)	-0.05 (0.19)
Static trunk extension (cm)	21.27 (4.24)	0.18 (0.10)	2.08 (0.20)	19.32 (5.38)	0.63 (0.10)	0.45 (0.19)

Note. SC = stable core exercises group; UC = unstable core exercises group; M = mean; SD = standard deviation; Skew = skewness; Kurt = kurtosis; SE = standard error; n = number of repetitions.

Table 3. Results of the repeated measures ANOVA[a]

		T	T × E	T × E × A	T × E × G	T × E × A × G
Sit-ups	F	2881.47**	403.30**	7.05**	3.43	1.69
	Partial η^2	.71	.25	.02	.003	.004
	df (Error)	1.54 (1832)	1.54 (1832)	4.63 (1832)	1.54 (1832)	4.63 (1832)
Dynamic trunk extension	F	1916.40**	375.64**	4.30**	0.75	3.70**
	Partial η^2	.62	.24	.01	.00	.01
	df (Error)	1.61 (1904)	1.61 (1904)	4.82 (1904)	1.61 (1904)	4.82 (1904)
Push-ups	F	4238.84**	907.12**	4.92**	3.19	4.25**
	Partial η^2	.78	.43	.01	.003	.01
	df (Error)	1.59 (1889)	1.59 (1889)	4.78 (1889)	1.59 (1889)	4.78 (1889)
Static trunk extension	F	1070.87**	166.55**	3.02*	.57	.86
	Partial η^2	.47	.12	.01	.00	.002
	df (Error)	1.37 (1627)	1.37 (1627)	4.12 (1627)	1.37 (1627)	4.12 (1627)

Note. T = time (baseline, four-month, eight-month); E = exercise group (stable core exercises, unstable core exercises); A = age (11, 12, 13, 14 years); G = gender (females, males); [a]degrees of freedom with Greenhouse-Geisser's correction; ** p<.01; * p<.05.

vs. female) as between-participants factors were performed on each dependent variable. Accompanied *post-hoc* tests (*t*-test) were used for detecting the absolute mean difference between pre- and mid-test as well as pre- and post-test in each group, and Cohen's *d* was calculated as a measure of their relative improvement (Rhea, 2004). In order to reduce Type I error possibility, Bonferroni–Holm correction was applied (Cramer, et al., 2016). Greenhouse-Geisser's correction was used due to a violated assumption of sphericity. Alpha level of significance was set at p≤.05. Bearing in mind that sample size was not an issue, *post-hoc* power analysis indicated statistical power of 1.00 for these data.

Results

Descriptive statistics for BMI, strength and muscular endurance measures at the baseline showed relatively normal distribution in both the SC and UC (Table 2). The highest significant interactions for each measure, yet with small effect sizes, were time × exercise group × age × gender for dynamic trunk extension and push-ups, and time × exercise group × age for sit-ups and static trunk extension (Table 3). *Post-hoc* analysis (Bonferroni–Holm correction) showed statistically significant (p<.01) four- and eight-month improvements for all measures in both groups (SC and UC), all age groups (11-14), and both genders (males and females), except there was no gain in dynamic trunk extension in 11-year-old males in SC after four months (mean difference 0.131, p=1.00). Compared to SC, after the eight-month training UC showed greater absolute improvements in all measures (independent samples *t*-tests, p≤.01) and greater relative improvements (Cohen's *d*) in all measures, except in the strength of trunk extensors (static trunk extension) in 11- and 12-year-old participants (Table 4, Figure 1). Differences between the groups (SC vs. UC) in four-month training-effects were not consistent.

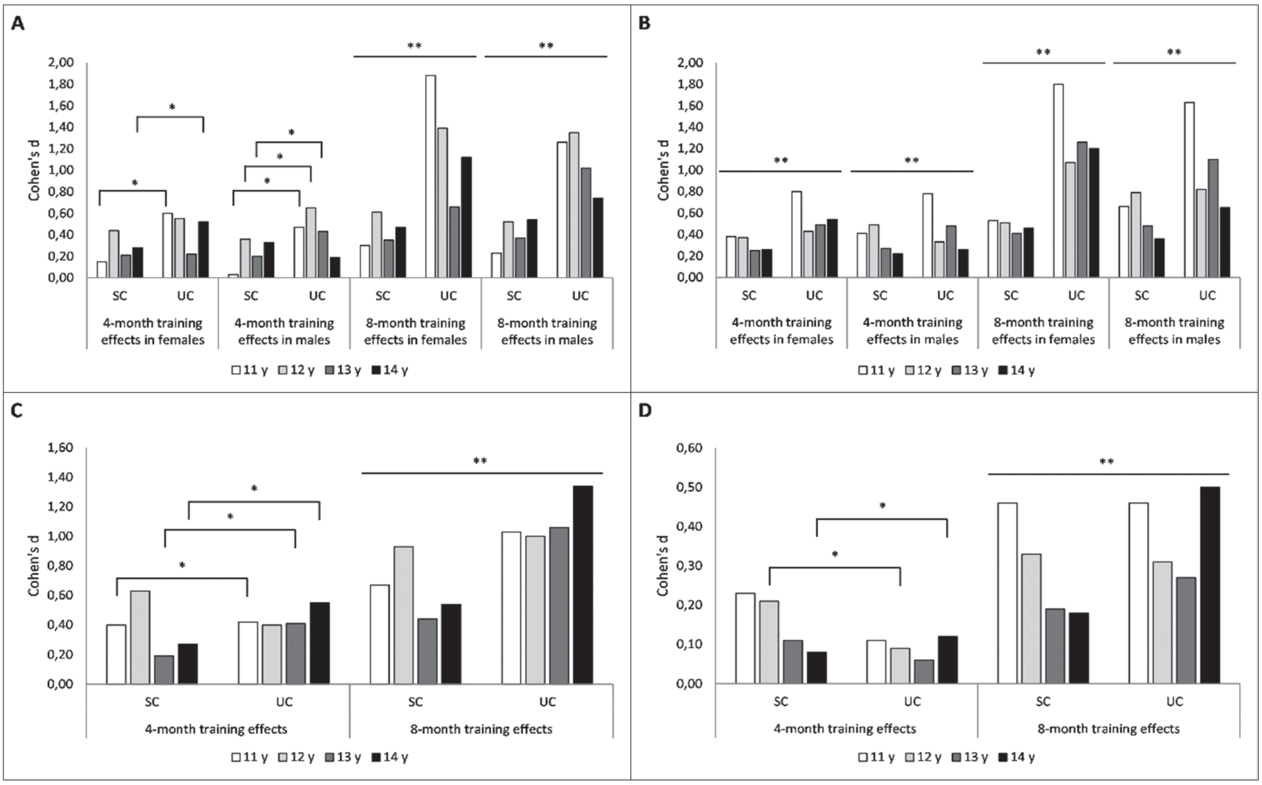
Discussion and conclusions

In this study we aimed to create a feasible core training in SC and UC in order to improve core strength and endurance. In spite of the different modalities of instability in the previous studies, we assumed that unstable body positions while performing resistance exercises would be appropriate for activating core muscles in order to ensure lumbar stabilization and maintain the body's center

Table 4. Effect size (Cohen's d) for strength and muscular endurance gains in the stable conditions and unstable conditions

			By age and gender[a]								Overall[b]
			11		12		13		14		
			F	M	F	M	F	M	F	M	
Sit-ups	4-month	SC	0.40		**0.63**		0.19		0.27		0.36
		UC	**0.42**		0.40		**0.41**		**0.55**		**0.38**
	8-month	SC	0.67		0.93		0.44		0.54		0.63
		UC	**1.03**		**1.00**		**1.06**		**1.34**		**0.96**
Dynamic trunk extension	4-month	SC	0.15	0.03	0.44	0.36	0.21	0.20	0.28	**0.33**	0.21
		UC	**0.60**	**0.47**	**0.55**	**0.65**	**0.22**	**0.43**	**0.52**	0.19	**0.28**
	8-month	SC	0.30	0.23	0.61	0.52	0.35	0.37	0.47	0.54	0.35
		UC	**1.88**	**1.26**	**1.39**	**1.35**	**0.66**	**1.02**	**1.12**	**0.74**	**0.71**
Push-ups	4-month	SC	0.38	0.41	0.37	**0.49**	0.25	0.27	0.26	0.22	0.31
		UC	**0.80**	**0.78**	**0.43**	0.33	**0.49**	**0.48**	**0.54**	**0.26**	**0.40**
	8-month	SC	0.53	0.66	0.51	0.79	0.41	0.48	0.46	0.36	0.48
		UC	**1.80**	**1.63**	**1.07**	**0.82**	**1.26**	**1.10**	**1.20**	**0.65**	**0.95**
Static trunk extension	4-month	SC	**0.23**		**0.21**		**0.11**		0.08		**0.12**
		UC	0.11		0.09		0.06		**0.12**		0.08
	8-month	SC	0.46		**0.33**		0.19		0.18		0.20
		UC	0.46		0.31		**0.27**		**0.50**		**0.31**

Note. **Bold** font indicates exercise group (SC or UC) which has higher Cohen's *d* for each age/gender category;
SC = stable core exercises group; UC = unstable core exercises group; F = females; M = males.
[a]For the measures (dynamic trunk extension and push-ups) where the highest order interaction was T × E × A × G, the exercise group effect throughout time is displayed by age and gender, and for the measures (sit-ups and static trunk extension) where the highest order interaction was T × E × A, the exercise group effect throughout time is displayed only by age.
[b]Effect size of exercise group after four- and eight-month training, when data are collapsed over age and gender.



Note. **Significantly greater absolute improvement in the unstable conditions (UC) compared to the stable conditions SC (p≤.01) for all age groups (11, 12, 13, 14 years), and both genders (males and females).
*Significantly different absolute improvement between UC and SC (p≤.01) for specific gender and/or age group.

Figure 1. Participants' relative improvement (Cohen's d) and absolute improvement (independent samples t-test) after 4- and 8-month training in dynamic trunk extension (a) and push-ups (b) as a function of age (11, 12, 13, and 14 years) and gender (males and females), and in sit-ups (c) and static trunk extension (d) as a function of age.

of gravity within its base and thus to retain the balance. Along with this, an eight-month training duration can be long enough for continuous neuromuscular adaptations and therefore a continuous improvement in core strength and endurance measures. In line with our hypothesis, both the absolute and relative improvement in this study (Figure 1, Table 4) indicated that resistance core training in UC was more beneficial than the one in SC, when observing the sample as a whole, especially for muscular endurance of trunk flexors (sit-ups), trunk extensors (dynamic trunk extension), and upper body (push-ups). The lower efficacy in improving the strength of trunk extensors (static trunk extension) in both groups (SC and UC) could be because both interventions were mainly focused on increasing the number of repetitions, rather than on increasing load.

Further, smaller trunk extensors' strength gains in UC compared to SC after four months may be in line with the findings of previous research (Anderson & Behm, 2004; Behm, Anderson, & Curnew, 2002), which indicated that maximal isometric force was decreased when performing movements under UC. Although those studies refer to an unstable testing position in which force cannot be produced fully (which was not an issue in our stable-position static trunk extension test), resistance training in UC could indeed result in smaller strength gains compared to resistance training in SC. However, after eight months, UC showed greater improvement in trunk extensors' strength than SC. Moreover, in all muscular endurance measures, UC demonstrated more substantial gains in the second four-month training-cycle (i.e., from the fourth to the eighth month of the intervention) compared to the first four-month cycle, while in SC, a pattern of strength and muscular endurance gains was rather opposite (Figure 1). The reason for such a positive acceleration curve of core strength and endurance in UC could be assigned to prolonged neuromuscular adaptation to unstable conditions, hence a prolonged period of improvements in strength and muscular endurance throughout time. In line with this, Oliver et al. (2010) pointed out the importance of additional neuromuscular stimulation in resistance training of preadolescents in order to overcome a plateau in core strength and endurance improvement.

When the training effects are presented as the function of gender, there was a similar pattern of the training effects in males and females throughout the 11-14 age span within each training group (SC, UC) and each measure of muscular endurance and strength (Figure 1). This is in line with the results of Allen et al. (2014), who did not find any differences between male and female youth in trunk muscular endurance after resistance core training. When data were described additionally by age, the greatest efficacy in SC was revealed in 12-year old participants for all the measures except the muscular endurance of trunk extensors (dynamic trunk extension), which improved fairly equally in 12- and 14-year old males. Contrary to that, the pattern of improvement in UC showed decreased gains after the age of 11 year (except for sit-ups, due to a large standard deviation in 11-year-old participants), especially in 12-13 years old participants (Figure 1). According to our hypothesis, we argue that the relatively largest effect of unstable core exercises on core strength and muscular endurance in 11-year-old participants compared to other age groups could be one of the benefits of the prepubescent or early pubescent period (Nielsen, Nielsen, Behrendt-Hansen, & Asmussen, 1980; Pfeiffer & Francis, 1986). Proper sensory integration, neurocognitive processing and neuromuscular control that could be jeopardized by puberty onset are important prerequisites of controlling body stature and movements by timely activating specific core muscles and may be a valuable basis for strength and muscular endurance gains in preadolescents exercising in UC (Behringer, et al., 2010; Faigenbaum, 2000; Ozmun, et al., 1994). In addition, when analyzing gains in SC in order to conclude the reasons for the largest strength and muscular endurance gains in 12-year-old participants, we cannot attribute this improvement to a hormonal spurt related to puberty onset, due to the lack of maturation measures. Although it is quite certain that female participants were in puberty after the 12th year, such information for males cannot be inferred.

Our study presented novel conclusions based on previous research results on core training in preadolescents and adolescents (Allen, et al., 2014; Granacher, et al., 2014; Oliver, Adams-Blair, & Dougherty, 2010). Taking the conclusion on the rapid-achieved plateau in the muscular endurance of trunk flexors after 10-month isometric core training in preadolescents as a starting point (Oliver, et al., 2010), we designed core training in engaging, dynamic, unstable conditions, with gradually increased volume and therefore showed prolonged effects on core/upper body muscular endurance and core strength. In addition, if a core training is too short (i.e., six weeks), the differences in efficacy of exercises in SC and UC on core strength and muscular endurance might not be detected (Granacher, et al., 2014), or could be trivial to small (Allen, et al., 2014), according to the standards of treatment effects in strength training research (Rhea, 2004). Addressing this shortcoming, after our eight-month intervention, the conservatively interpreted Cohen's *d* for all measures in almost all age groups and both genders indicated trivial to small effects in SC (Cohen's $d < 0.50$, and 0.50-1.25, respectively), and small to moderate effects in UC (Cohen's *d* for moderate effects range 1.25-

1.90), except for strength of trunk extensors (static trunk extension), for which the effect in UC was trivial to small, too.

As a possible limitation of our research, it should be stressed that both SC and UC performed exercises that were not focused only on the body core but also on other parts of kinetic chains (e.g., the upper body's activity in push-ups and one-leg-standing chest press with resistance band). For the push-ups test, in which core muscles have only a stabilizing role, muscular endurance improvement was probably greatly due to the mobilizers' endurance gains (upper body muscular endurance), but this does not diminish the benefits of the functional training in UC. Further, in this study, we did not control the variables that could potentially impact the efficacy of the exercise programmes, such as sleep, nutrition, hydration, body composition, maturation and hormonal status, nor the menstrual cycle in female students. Nevertheless, in our large sample in which students were randomly assigned to training conditions, those variables were probably randomly distributed across the whole sample and did not produce a difference between the conditions. As it was not in the scope of this research, future studies need to include an additional control group in order to account for the effects of maturation on overall gains in core strength and muscular endurance, as well as to expand the age range of the sample in order to obtain more reliable results for depicting the patterns of strength and muscular endurance improvement in females and males throughout preadolescence and adolescence.

Our results revealed that an eight-month functional core training in UC was more efficient in improving core and upper body muscular endurance than training in SC, in a sample of preadolescents and adolescents who were involved only in regular physical education classes and not in systematically guided physical activity (i.e., sports). Bearing in mind the hypothesis on a prolonged period of neuromuscular adaptation when children are trained using unstable functional core exercise, training that lasts eight months or even more might result in considerable gains in core and upper body muscular endurance. This training is especially efficient in 11-year-old males and females. Alternatively, traditional core training could be a fairly good option for core strengthening in 12-year-old children, especially when having less time for the training-cycle (i.e., four months). The proposed 20-min exercises for both training groups are low cost, children-appropriate, and easy to administer in class, as a part of the regular physical education programme. Further, those exercises are feasible not only in school settings but in every other indoor and outdoor space that can be used for core strength and muscular endurance improvement.

References

Adam, C., Klissouras, V., & Ravazzolo, M. (1988). *EUROFIT: European test of physical fitness.* Rome: Council of Europe, Committee for the Development of Sport.

Akuthota, V., & Nadler, S.F. (2004). Core strengthening. *Archives of Physical Medicine and Rehabilitation, 85*, 86-92. doi: 10.1053/j.apmr.2003.12.005

Allen, B.A., Hannon, J.C., Burns, R.D., & Williams, S.M. (2014). Effect of a core conditioning intervention on tests of trunk muscular endurance in school-aged children. *Journal of Strength and Conditioning Research, 28*(7), 2063-2070. doi: 10.1519/JSC.0000000000000352

Anderson, K.G., & Behm, D.G. (2004). Maintenance of EMG activity and loss of force output with instability. *Journal of Strength and Conditioning Research, 18*(3), 637-640. doi: 10.1519/1533-4287(2004)18<637:MOEAAL>2.0.CO

Behm, D.G., Anderson, K., & Curnew, R.S. (2002). Muscle force and activation under stable and unstable conditions. *Journal of Strength and Conditioning Research, 16*(3), 416-422. doi: 10.1519/1533-4287(2002)016<0416:MFAAUS>2.0.CO

Behm, D.G., Leonard, A.M., Young, W.B., Bonsey, W.A.C., & MacKinnon, S.N. (2005). Trunk muscle electromyographic activity with unstable and unilateral exercises. *Journal of Strength and Conditioning Research, 19*(1), 193-201. doi: 10.1519/1533-4287(2005)19<193:tmeawu>2.0.co

Behm, D.G., Young, J.D., Whitten, J.H., Reid, J.C., Quigley, P.J., Low, J., . . ., & Chaouachi, A. (2017). Effectiveness of traditional strength vs. power training on muscle strength, power and speed with youth: A systematic review and meta-analysis. *Frontiers in Physiology, 8*, 423. doi: 10.3389/fphys.2017.00423

Behringer, M., vom Heede, A., Yue, Z., & Mester, J. (2010). Effects of resistance training in children and adolescents: A meta-analysis. *Pediatrics, 126*(5), e1199-e1210. doi: 10.1542/peds.2010-0445

Caspersen, C.J., Powell, K.E., & Christenson, G.M. (1985). Physical activity, exercise, and physical fitness: Definitions and distinctions for health-related research. *Public Health Reports, 100*(2), 126-131.

Cooper Institute for Aerobics Research. (1999). *FITNESSGRAM®Test administration manual* (2nd ed.). Champaign, IL: Human Kinetics.

Coratella, G., & Schena, F. (2016). Eccentric resistance training increases and retains maximal strength, muscle endurance, and hypertrophy in trained men. *Applied Physiology, Nutrition, and Metabolism, 41*(11), 1184-1189. doi: 10.1139/apnm-2016-0321

Cramer, A.O., van Ravenzwaaij, D., Matzke, D., Steingroever, H., Wetzels, R., Grasman, R.P., . . ., & Wagenmakers, E.-J. (2016). Hidden multiplicity in exploratory multiway ANOVA: Prevalence and remedies. *Psychonomic Bulletin and Review, 23*(2), 640-647. doi: 10.3758/s13423-015-0913-5

Faigenbaum, A.D. (2000). Strength training for children and adolescents. *Clinics in Sports Medicine, 19*(4), 593-619. doi: 10.1016/S0278-5919(05)70228-3

Faigenbaum, A.D., Loud, R.L., O Connell, J., Glover, S., O Connell, J., & Westcott, W.L. (2001). Effects of different resistance training protocols on upper-body strength and endurance development in children. *Journal of Strength and Conditioning Research, 15*(4), 459-465. doi: 10.1519/00124278-200111000-00010

Granacher, U., Gollhofer, A., Hortobágyi, T., Kressig, R.W., & Muehlbauer, T. (2013). The importance of trunk muscle strength for balance, functional performance, and fall prevention in seniors: A systematic review. *Sports Medicine, 43*, 627-641. doi: 10.1007/s40279-013-0041-1

Granacher, U., Schellbach, J., Klein, K., Prieske, O., Baeyens, J.-P., & Muehlbauer, T. (2014). Effects of core strength training using stable versus unstable surfaces on physical fitness in adolescents: A randomized controlled trial. *BMC Sports Science, Medicine and Rehabilitation, 6*(1), 40. doi: 10.1186/2052-1847-6-40

Hibbs, A.E., Thompson, K.G., French, D., Wrigley, A., & Spears, I. (2008). Optimizing performance by improving core stability and core strength. *Sports Medicine, 38*(12), 995-1008. doi: 10.2165/00007256-200838120-00004

Kearns, C.F., Brechue, W., Bauer, J., Pollock, M., & Fulton, M. (1997). Muscle activiation during isolated and non-isolated lumbar extension exercise. *Medicine and Science in Sports and Exercise, 29*(5), S165. doi: 10.1097/00005768-199705001-00943

Kibler, W.B., Press, J., & Sciascia, A. (2006). The role of core stability in athletic function. *Sports Medicine, 36*(3), 189-198. doi: 10.2165/00007256-200636030-00001

Kraemer, W.J. (1987). *Endocrine responses to resistance exercise*. Natick, MA: Army Research Institute of Environmental Medicine. Available at https://apps.dtic.mil/sti/pdfs/ADA188681.pdf

McGill, S. (2010). Core training: Evidence translating to better performance and injury prevention. *Strength and Conditioning Journal, 32*(3), 33-46. doi: 10.1519/SSC.0b013e3181df4521

McGill, S.M., McDermott, A., & Fenwick, C.M. (2009). Comparison of different strongman events: Trunk muscle activation and lumbar spine motion, load, and stiffness. *Journal of Strength and Conditioning Research, 23*(4), 1148-1161. doi: 10.1519/JSC.0b013e318198f8f7

Mendiguchia, J., Ford, K.R., Quatman, C.E., Alentorn-Geli, E., & Hewett, T.E. (2011). Sex differences in proximal control of the knee joint. *Sports Medicine, 41*(7), 541-557. doi: 10.2165/11589140-000000000-00000

Myer, G.D., Ford, K.R., Palumbo, J.P., & Hewett, T.E. (2005). Neuromuscular training improves performance and lower-extremity biomechanics in female athletes. *Journal of Strength and Conditioning Research, 19*(1), 51-60. doi: 10.1519/13643.1

Nielsen, B., Nielsen, K., Behrendt-Hansen, M., & Asmussen, E. (1980). Training of ”functional muscular strength” in girls 7-19 years old. In K. Berg and B. Eriksson (Eds.), *Children and exercise IX* (pp. 69-77). Baltimore, MD: University Park Press.

Oliver, G.D., Adams-Blair, H.R., & Dougherty, C.P. (2010). Implementation of a core stability program for elementary school children. *Athletic Training and Sports Health Care, 2*(6), 261-266. doi: 10.3928/19425864-20100630-01

Ozmun, J.C., Mikesky, A.E., & Surburg, P.R. (1994). Neuromuscular adaptations following prepubescent strength training. *Medicine and Science in Sports and Exercise, 26*(4), 510-514.

Pfeiffer, R.D., & Francis, R.S. (1986). Effects of strength training on muscle development in prepubescent, pubescent, and postpubescent males. *The Physician and Sportsmedicine, 14*(9), 134-143. doi: 10.1080/00913847.1986.11709173

Reed, C.A., Ford, K.R., Myer, G.D., & Hewett, T.E. (2012). The effects of isolated and integrated ‘core stability' training on athletic performance measures. *Sports Medicine, 42*(8), 697-706. doi: 10.2165/11633450-000000000-00000

Rhea, M.R. (2004). Determining the magnitude of treatment effects in strength training research through the use of the effect size. *Journal of Strength and Conditioning Research, 18*, 918-920. doi: 10.1519/14403.1

Santana, J.C., Vera-Garcia, F.J., & McGill, S.M. (2007). A kinetic and electromyographic comparison of the standing cable press and bench press. *Journal of Strength and Conditioning Research, 21*(4), 1271. doi: 10.1519/R-20476.1

Sekendiz, B., Cug, M., & Korkusuz, F. (2010). Effects of Swiss-ball core strength training on strength, endurance, flexibility, and balance in sedentary women. *Journal of Strength and Conditioning Research, 24*(11), 3032-3040. doi: 10.1519/JSC.0b013e3181d82e70

Tsolakis, C.K., Vagenas, G.K., & Dessypris, A.G. (2004). Strength adaptations and hormonal responses to resistance training and detraining in preadolescent males. *Journal of Strength and Conditioning Research, 18*(3), 625-629. doi: 10.1519/1533-4287(2004)18<625:SAAHRT>2.0.CO;2.

Vera-Garcia, F.J., Grenier, S.G., & McGill, S.M. (2000). Abdominal muscle response during curl-ups on both stable and labile surfaces. *Physical Therapy, 80*(6), 564-569. doi: 10.1093/ptj/80.6.564

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