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Research article

Effects of 8-Week Jump Training Program on Sprint and Jump Performance and Leg Strength in Pre- and Post-Peak Height Velocity Aged Boys

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Abstract

The purpose of this study was: (a) to determine the effects of an 8-week jump training program on measures of neuromuscular performance in 12-14-year-old boys before and after peak height velocity (PHV), and (b) to compare the effects of the jump training program to the effects of the regular physical education program. One hundred and twenty-six participants were categorized into two maturity groups (pre- or post-PHV) and then randomly assigned to either a jump training (pre-PHV, n = 26; post-PHV, n = 24) or a control (pre-PHV, n = 33; post-PHV, n = 19) group. Jump training consisted of twice-weekly training for 8 weeks, while control groups continued with their regular physical education lessons. Squat jump and countermovement jump height (cm), reactive strength index (the ratio between jump height and ground contact time (mm/ms)), 20-m sprint time (s), and isokinetic knee extensors muscle strength (peak toque (Nm)) were assessed pre- and post-intervention. Following the 8-week intervention, both pre- and post-PHV jump training groups made significant gains in measures of neuromuscular performance irrespective of the maturity (where $p < 0.05$, $d = 0.28$-1.00), while changes in these measures in the control groups were not significant (all $p \geq 0.05$, $d = -0.14$-0.15). A series of repeated measures analyses of variance (ANOVA) indicated that (a) the maturity-related differences between jump training groups were observed only for reactive strength index, and (b) the improvements in all measures of neuromuscular performance were greater in jump training than in control group. This study demonstrated that important components of physical fitness in 12-14-year-old schoolboys may be acutely enhanced through a well-structured jump program and maturity seems to at least play a limited role in mediating these enhancements.

Key words: Plyometric training, physical education, maturation, children, adolescents.

Introduction

Developmentally appropriate, well-supervised resistance training (RT) is safe and effective in stimulating positive adaptations on a range of physical performance measures in children and adolescents (Lloyd et al., 2014). In this regard, over the last two decades, several position stands from various national associations have been published in the literature, and the international agreement regarding safety and efficacy of RT in youth is evident. For example, the key guidelines produced by the British Association of Sports and Exercise Sciences state that “all young people should be encouraged to participate in safe and effective resistance exercise at least twice a week”, and that “resistance exercise should be part of a balanced exercise and physical education program” (Stratton et al., 2004). National Strength and Conditioning Association in its updated position stand paper (Faigenbaum et al., 2009) concludes that “youth RT has the potential to offer observable health and fitness value to children and adolescents, provided that appropriate training guidelines are followed and qualified instruction is available”. Similarly, Canadian Society for Exercise Physiology in its position paper states that “with proper training methods, RT for children and adolescents can be relatively safe and improve overall health” (Behm et al., 2017).

Plyometric training (PT) is considered a form of RT and, to date, it has been proven effective in improving various physical qualities in children and adolescents including, for example, jump and sprint performance, change-of-direction speed, leg stiffness and strength (Lloyd et al., 2012; Michailidis et al.,2013; Moran et al., 2017). However, the evidence that shows the effectiveness of that type of training on improving various components of neuromuscular performance and potential interaction with maturation in youth populations in general, and in healthy untrained youth in particular, is still limited.

In that regard, Lloyd et al. (2016) compared the effectiveness of 6-week training interventions using different modes of resistance (traditional strength training, PT and combined training) on sprint and jump performance in boys before and after peak height velocity (PHV). All training groups made significant gains in measures of sprinting and jumping irrespective of the mode of RT and maturity, and PT produced greater changes in squat jump and acceleration performances in the pre-PHV group compared with the post-PHV cohort. The study showed that PT might be more effective in eliciting short-term gains in jumping and sprinting in boys who are pre-PHV, whereas those who are post-PHV may benefit from the additive stimulus of combined training. Similarly, Radnor et al. (2017) examined the individual response to different forms of resistance training in school-aged boys varying in maturity status (i.e., pre- vs. post-PHV boys). They found that PT, whether as a stand-alone method or in combination with traditional strength training, is effective in pre-PHV stage when attempting to improve jump and sprint ability.

A review by Moran et al. (2017) attempted to establish if PT is more effective at enhancing power performance (as assessed using the countermovement jump height) in male youth athletes at specific junctures across childhood and adolescence. They concluded that PT is moderately effective during the pre- and post-PHV periods but seems to be less so around the time when growth

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achieves its greatest rate of progression. The findings in the literature regarding the effects of PT on neuromuscular performance in youth are not consistent, however, as a recent meta-analysis by Behm et al. (2017) showed a moderate effect of PT (referred to as "power training" in that paper) upon power measures (as assessed using various jump types) in children and in adolescents, with small effect upon sprint performance in children and only trivial effect in adolescents. Lesinski et al. (2016) conducted a systematic review and meta-analysis of intervention studies that investigated the effects of RT (various forms) on physical performance in youth athletes. They found no significant differences in effect sizes for any measure of physical performance between prepubertal and postpubertal young athletes. Importantly, they stated that most studies did not report the biological maturity status of their participants and that further research is needed to elucidate maturity-specific RT effects on physical performance in youth. Taken together, the findings from the abovementioned studies by Lloyd et al. (2016) and Radnor et al. (2017), the reviews by Moran et al. (2017), Behm et al. (2017), and Lesinski et al. (2016), along with the earlier findings from reviews by Behringer et al. (2011; 2010) and Rumpf et al. (2012), showed that maturity may play a role in the trainability of youth.

The purpose of this study was two-fold: (a) to determine the effects of a structured 8-week jump training program on measures of neuromuscular performance in school-aged boys attending the same grades of the elementary school (i.e., grade 7 and grade 8), but of different maturity status; and (b) to compare the effects of the structured 8-week jump training program to the effects of the regular physical education program commensurate with the national curriculum. Neuromuscular performance was assessed using a battery of tests designed to evaluate jump and sprint performance, and to measure muscle strength. The term "jump training" rather than "plyometric training" is used in the present study to describe the training intervention since some of the jump type exercises used in the intervention (i.e., squat jump, seated jump, drop landings etc., see Methods for details) are not characterized by a so-called stretch-shortening cycle (SSC) muscle action and, therefore, could not be considered plyometric exercises. It was hypothesized that, following the training intervention, the improvements in jump and sprint performance in schoolboys participating in the structured jump training program will be greater in pre-PHV cohort, whereas post-PHV cohort will display greater improvements in muscle strength (Hypothesis 1); and that the overall improvements in neuromuscular performance will be greater in schoolboys participating in the structured jump training program than in schoolboys continuing with their regular physical education program (Hypothesis 2).

Methods

Participants

A priori power analysis with "ANOVA/repeated measures/within–between interaction" as the statistical test, 0.25 as the expected effect size (f), 0 .05 as α, the statistical power of 0.90, and correlation of 0.5, indicated that the total required sample size was n = 64. To account for the expected drop-outs and/or incomplete test results, 126 male participants were initially recruited. The participants were schoolboys attending grades 7 and 8 (i.e., 12-14-year-old boys) from two local elementary schools, who volunteered to participate in the study and satisfied the inclusion criteria. The participants were recruited from grades 7 and 8 based on the assumption that PHV in European population takes place around the age of 14 (Malina et al., 2004) with the onset of PHV occurring approximately one year prior to the point of PHV (Tanner et al., 1966). In other words, in grades 7 and 8, an approximately equal number of boys on both sides of the PHV spectrum was expected to be identified. Following anthropometric measurements that were used to calculate the PHV offset (see Testing procedures for details), they were categorized into two maturity groups: a pre-PHV group (age at PHV < 0.0) and a post-PHV group (age at PHV > 0.0). To obtain a clearer distinction between the two maturity groups, four participants whose calculated PHV offset value equaled "0.0" were removed from final analyses (although they participated in the experiment). Following the categorization into maturity groups, the participants were assigned to either a jump training program group (two jump training sessions per week for 8 weeks), or to a control group (continuing with regular, games-based physical education classes).

The participants were included in the study if they had no prior experience in organized sport activity or were participating in such organized activities no more than twice per week. The exclusion criteria were a chronic pediatric disease or an orthopedic condition that would limit their ability to perform exercise. Between initial and final testing sessions, the participants were required to complete ≥14 out of 16 total training sessions within their respective program. Following the final testing session, 24 participants that started the study were removed from further analysis due to incomplete test results (14 participants) and/or completing <14 training sessions of the experiment (6 participants) and/or having their PHV offset equal to "0.0" (4 participants). Therefore, 102 participants were subjected to statistical analyses. Participants' characteristics are presented in Table 1. Parental informed consent and participant assent were obtained in advance of the study, and ethical approval for the research was granted by the University Research and Ethics Committee (approval number 122/2016) in accordance with the Declaration of Helsinki.

Testing Procedures

In weeks before the start of the intervention period, the participants followed familiarization sessions, which provided opportunities to practice both jump and sprint test protocols. Participants were allowed to complete as many practice trials as required to ensure they fully understood the protocols and could demonstrate consistent technical execution as determined by the principal investigator. For the purposes of the actual testing sessions, participants completed a standardized 15-minute dynamic warm-up inclusive of 5 minutes of submaximal multidirectional running and 10 mins of light dynamic mobilization and activation

Table 1. Descriptive statistics for age, body height, body mass, and peak height velocity (PHV) offset for experimental (EXP) and control (CON) groups. Data are expressed as mean ± SD.

Maturity group	Treatment group	Sample size	Age (years)	Height (cm)	Body mass (kg)	PHV offset years)
Pre-PHV	EXP	26	13.1 ± 0.6	159.8 ± 6.3	49.4 ± 8.7	-1.0 ± 0.5
	CON	33	13.2 ± 0.5	163.0 ± 7.2	54.1 ± 10.7	-0.7 ± 0.5
Post-PHV	EXP	24	14.0 ± 0.4	176.3 ± 6.8	68.5 ± 10.2	0.8 ± 0.4
	CON	19	13.9 ± 0.5	174.7 ± 7.0	65.3 ± 11.7	0.6 ± 0.5

There were no significant differences between EXP and CON groups of pre-PHV and post-PHV maturity groups (all p=0.081-0.451). Post-PHV boys in the EXP group were chronologically older, taller and heavier than their counterparts in the pre-PHV EXP group (all p<0.001), and post-PHV boys in the CON group were chronologically older, taller and heavier than their counterparts in the pre-PHV CON group (all p<0.001-0.001).

exercises targeting the main muscle groups of the lower extremities. After the warm-up and practice attempts of the test protocols, participants completed the battery of tests in the following order: anthropometrics, squat jump (SJ) test, countermovement jump (CMJ) test, 5-maximal rebound test and 20-m sprint test. All tests were supervised and recorded by the same investigators. For each test of neuromuscular performance, participants completed 3 trials, with the best of 3 trials used for further analyses. Two- and four-minute rest periods were given between each trial and test, respectively, to limit the effects of fatigue on consecutive efforts. Isokinetic knee extensors muscle strength was assessed two days following the mentioned procedures at a nearby medical rehabilitation center.

Anthropometrics

Standing height (cm) and seated height (cm) were measured using portable stadiometer (Seca 213; seca gmbh, Hamburg, Germany), whereas body mass (kg) was measured using a balance beam scale (Seca V/700; seca gmbh, Hamburg, Germany). These data were then incorporated into a sex-specific regression equation to calculate the PHV offset (Mirwald et al., 2002).

Jump Protocols

SJ (cm) and CMJ (cm) were calculated from the vertical velocity of the center of mass data by a mobile force plate (Kistler MARS Type 2875A; Winterthur, Switzerland) accompanied with a measurement, analysis and reporting software (MARS 4.0, Kistler, Winterthur, Switzerland). The SJ was performed starting from an initial semi-squat position (knee ~90° and trunk/hips in a flexed position), with participants holding the position for approximately 2 seconds before jumping vertically as quickly and as explosively as possible in order to perform the highest possible jump in the shortest possible time on the command of the tester (Lloyd et al., 2009). Hands remained akimbo for the entire movement to eliminate any influence from arm swing, and participants were instructed to maintain fully extended lower limbs throughout the flight period.

The CMJ was performed starting from the upright standing position. On the command of the tester, the participants performed a downward countermovement by a fast flexion of the legs. Immediately after, coupling the eccentric and concentric phase of the action, the vertical jump began by an explosive extension of the legs. The participants were instructed that their lowest position, i.e. eccentric to concentric transition, should be a semi-squat position (knee ~90° and trunk/hips in a flexed position) and that the jump should be performed as quickly and explosively as possible in order to make the highest possible jump in the shortest possible time. Reactive strength index (mm/ms) was determined during a 5-maximal rebound test, with participants required to perform 5 consecutive maximal vertical rebounds on the mobile force plate. Participants were instructed to maximize jump height and minimize ground contact time (Dalleau et al., 2004). The first jump in each trial served as a CMJ and consequently was discounted for analysis, whereas the remaining 4 rebounds were averaged for analysis of RSI (Lloyd et al., 2009).

Sprint Protocol

20-m Sprint time was recorded using two pairs of wireless timing gates on the outdoor soccer field with grass surface, and data were instantaneously collected via a handheld PDA (Microgate, Witty System; Mahopac, NY, USA). The participants had 20-m for acceleration to the first pair of timing gates. Participants were counted down “3 – 2 – 1 – GO” and were instructed to run as fast as they could and to begin decelerating only after they have passed the second pair of timing gates (20-m distance from the first pair of the timing gates). The environmental conditions for both pre- and post-intervention measurements were similar (sunny days, no or minimal wind, similar air temperature) and on both occasions the participants wore their usual footwear that they use for physical education classes.

Strength Protocol

The maximal voluntary concentric muscle strength of the knee extensors of the dominant leg (determined as the preferred leg used to kick the ball) was measured using a protocol on the isokinetic dynamometer (Humac Norm 2009; Boston, MA, USA). Prior to the protocol, the participants underwent 10 mins of a combined jogging and light dynamic mobilization and activation exercises targeting the main muscle groups of the lower extremities. The participants were then placed in a seated position and stabilization straps were applied to the trunk, waist, thigh, and shin. The lateral femoral epicondyle of the dominant leg was aligned with the dynamometer’s axis of rotation. The range of motion of the knee joint was individually adjusted for each participant by asking them to perform maximal knee extension. Testing was performed at an angular velocity of 60°/s, previously reported to be highly reliable in children (Chaouachi et al., 2011). The participants first performed 10 familiarization repetitions to “get a feel” for the speed of the lever arm. Then, following a one-minute break, they performed five maximal knee extensions and flexions with verbal encouragement and repetition count from the tester.

For the five maximal knee extensions and flexions, the participants were instructed to "extend and flex the knee (to "kick" and "pull") five times as hard and as fast as they could". Peak torque in N/m obtained during the knee extension movement pattern, indicating highest muscular force output and automatically calculated by the device, was used as the measure of the knee extensors muscle strength.

Training Program

The framework for the training program was partly based on a study by Lloyd et al. (2016) who implemented the plyometric training program with male (untrained) school children as participants. Training program was implemented twice per week for 8 weeks, while the training sessions in each week were separated by 48 hours. The same coach was present for each session to monitor technique and training volume and to oversee the implementation of the program. Both maturity groups (i.e., pre- and post-PHV groups) trained together to ensure that they train with similar intensity. Jump drills involved the bilateral and unilateral (left/right) use of jumps, hops, bounds, and skips in sagittal, frontal, and transverse planes of motion. The total number of different exercises in the jump training program was 20. Each training session consisted of 4 different exercises and 2 to 4 sets of 5 to 12 repetitions, while the exercise volume was determined by the number of ground contacts, i.e., number of the series x number of repetitions (Table 2). The training program was periodized in 2 progressive mesocycles of 3 weeks and 1 final progressive mesocycle of 2 weeks, while the relationship between relative and absolute training program volume was determined by the percentage of the type of exercises according to the type of corresponding muscle action (i.e., eccentric, concentric, and plyometric exercises), presented in detail in Table 3.

The progression of jump training was also determined by the jump technique (first 2 weeks bilateral jumps only, last 6 weeks both bilateral and unilateral jumps). Training sessions lasted no longer than 40 minutes, while prescribed inter-set rest periods ranged between 1 and 2 minutes. All exercises were executed in sport halls with parquet flooring and jump training sessions were performed immediately after the warm-up (the same procedure as before testing). Most children did not have any history of jump training; therefore, attention was paid to exercise demonstration and execution. Four important points were stressed: (a) correct posture (i.e., spine erect, shoulders back) and body alignment (i.e., chest over knees) throughout the jump; (b) jumping straight up for vertical jumps, with no excessive side-to-side or forward-backward

Table 2. Overview of the jump training program.

Week	Exercise	Sets	Repetitions	Total foot contacts
I	Drop landings[a]	2	10	74
	Squat jump[b]	3	6	
	Seated jump[b]	4	6	
	Lateral landing from lateral jump[c]	2	6	
II	Split landings[a]	2	9	78
	Seated jump[b]	4	7	
	Countermovement jump[c]	2	6	
	Jumping jacks[c]	2	10	
III	Single leg forward hop and stick[a]	3	8	81
	Squat jump[b]	3	8	
	Standing long jump[c]	3	5	
	Pogo hopping[c]	3	6	
IV	Jump with safe landing, single leg[a]	3	6	79
	Seated box jump[b]	3	7	
	Countermovement box jump[c]	4	5	
	Criss cross jumps[c]	2	10	
V	Drop landings, single leg[a]	2	6	84
	Single leg vertical jump[b]	2	7	
	Countermovement jump[c]	4	7	
	Balet dancer jumps[c]	3	10	
VI	Single leg forward hop and stick[a]	2	5	90
	Squat jump[b]	2	5	
	180 s jump[c]	3	10	
	Scissors jumps[c]	4	10	
VII	Jump with safe landing, single leg[a]	2	6	88
	Seated box jump[b]	2	6	
	Countermovement jump[c]	3	8	
	Pogo hopping[c]	4	10	
VIII	Drop landings, single leg[a]	2	6	94
	Box squat jump[b]	2	6	
	Countermovement box jump[c]	3	8	
	Balet dancer jumps[c]	4	12	

a: eccentric exercise, characterized by a muscle action in which the muscle is generating active tension while being lengthened by external force; b: concentric exercise, characterized by a muscle action in which the muscle is generating active tension while shortening; c: plyometric exercise, characterized by a rapid transition between the initial lengthening of the muscle (i.e., eccentric action) and its subsequent shortening (i.e., concentric action).

Table 3. Relationship between relative and absolute training program volume (%).

Week	Mesocycle	Low / High	The type of jump exercises according to the type of corresponding muscle action		
			Eccentric	Concentric	Plyometric
I	1	80 / 20	20	60	20
II		70 / 30	30	40	30
III		60 / 40	30	30	40
IV	2	50 / 50	25	25	50
V		40 / 60	20	20	60
VI		30 / 70	15	15	70
VII	3	20 / 80	10	10	80
VIII		10 / 90	5	5	90

Eccentric = characterized by a muscle action in which the muscle is generating active tension while being lengthened by external force; concentric = characterized by a muscle action in which the muscle is generating active tension while shortening; plyometric = characterized by a rapid transition between the initial lengthening of the muscle (i.e., eccentric action) and its subsequent shortening (i.e., concentric action).

movement; (c) soft landings including toe-to-heel rocking and bent knees; and (d) instant recoil preparation for the next jump. Correct technical execution was stressed at all times throughout the program with relevant feedback provided on an individual basis. There were no adverse events during the training intervention, there were no modifications made to the initially designed jump training program, and all participants progressed through the full program without exception. Throughout the intervention period, the control groups received 40 mins games-based physical education lessons, also twice per week, commensurate with the requirements of the national curriculum. These lessons incorporated practicing individual elements of soccer, basketball, volleyball, and handball as well as playing these games in various forms.

Statistical Analyses

All values are reported as mean ± standard deviation (SD) and were calculated for all performance variables (20-m sprint time, SJ height, CMJ height, RSI, knee extensors muscle strength) for both pre- and post-training intervention data. Differences in all performance variables were analyzed using separate 2 x 2 x 2 (time x group x maturity) repeated measures ANOVAs, where "time" denotes pre- to post-training data, "group" represents jump training group or control group, while "maturity" refers to pre- vs. post-PHV. Effect sizes were calculated for all performance variables in each training group and assessed using the magnitude of effect sizes according to Cohen's *d* statistic. In that regard, outcomes were, according to Cohen (1988), interpreted as trivial (0-0.19), small (0.2-0.49), moderate (0.5-0.79), or large (>0.79). The statistical significance threshold was set at $p < 0.05$. All analyses were performed using the Statistica software (version 13.4.0.14; TIBCO Software Inc., Palo Alto, CA, USA).

Results

Mean changes in sprint and jump performances as well as in knee extensors muscle strength, including effect sizes, for all groups are displayed in Table 4 for pre- and post-PHV groups, respectively. Where changes in measures of neuromuscular performance were significant, the corresponding effect sizes in both pre-PHV and post-PHV groups ranged from 0.28 (i.e., small) to 1.00 (i.e., large). Within-group analysis showed that the pre-PHV training group significantly improved in all of the evaluated measures of neuromuscular performance in response to the 8-week jump training program (i.e., 20-m sprint time, CMJ, SJ, RS, isokinetic strength; all $p \leq 0.001$; all $d = 0.41$ - 1.00), while the post-PHV training group significantly improved in 20-m sprint time, CMJ and isokinetic strength (p = 0.001 - 0.045, d = 0.28 - 0.46). Neither of these measures changed pre- to post-intervention in the control groups.

Regarding sprint performance, as evident in Table 5, a significant main effect was reported for 20-m sprint test for time and maturity while significant interaction effects were found for time x group and time x maturity. As evident in Table 4, jump training program significantly improved sprint performance in both pre-PHV and post-PHV training groups.

Regarding jump performance, as evident in Table 5, two jump performance tests (CMJ, SJ) showed significant main effects for both time and maturity, while RSI showed significant main effect for time. Significant interaction effects were found for time x group in all three jump performance tests (CMJ, SJ and RSI). Additionally, significant time x group x maturity interaction effect was reported for RSI. As evident in Table 4, within-group analysis indicated that significant improvements, following training intervention, were observed in all three jump tests for pre-PHV youth (mean ES = 0.69; range 0.41 - 1.00), while in post-PHV group only CMJ performance increased significantly (ES = 0.28).

Finally, regarding knee extensors muscle strength, significant main effect was reported for time and maturity with significant time x group interaction effects (Table 5). Within-group analysis (Table 4) indicated that both pre-PHV and post-PHV boys demonstrated significant improvements in knee extensors muscle strength over the 8-week intervention period (ES = 0.58 and 0.46, respectively).

Table 4. **Changes in neuromuscular performance for pre- and post-PHV boys after the 8-week jump training intervention (mean ± SD).**

Maturity group	Treatment group	Condition	20-m sprint (s)	CMJ (cm)	SJ (cm)	RSI (mm/ms)	Isokinetic strength (Nm)
Pre-PHV	EXP	Pre	3.24 ± 0.32	21.4 ± 5.2	20.0 ± 5.3	0.53 ± 0.14	101.4 ± 21.4
		Post	3.03 ± 0.32	23.7 ± 5.7	24.0 ± 6.6	0.74 ± 0.22	114.5 ± 21.7
		p-value	p < 0.001	p = 0.001	p < 0.001	p < 0.001	p < 0.001
		Effect size	0.62 (moderate)	0.41 (small)	0.65 (moderate)	1.00 (large)	0.58 (moderate)
	CON	Pre	3.29 ± 0.46	22.7 ± 6.3	21.5 ± 6.0	0.68 ± 0.31	106.6 ± 23.8
		Post	3.24 ± 0.46	22.4 ± 6.6	21.8 ± 6.9	0.64 ± 0.25	110.5 ± 27.2
		p-value	p = 0.156	p = 0.491	p = 0.729	p = 0.353	p = 0.050
		Effect size	0.11 (trivial)	-0.05 (trivial)	0.05 (trivial)	-0.14 (trivial)	0.15 (trivial)
Post-PHV	EXP	Pre	2.99 ± 0.29	25.8 ± 5.7	25.0 ± 6.4	0.71 ± 0.25	145.7 ± 28.3
		Post	2.89 ± 0.32	27.6 ± 7.0	26,4 ± 8.0	0.79 ± 0.28	159.0 ± 28.9
		p-value	p = 0.003	p = 0.045	p = 0.226	p = 0.059	p = 0.001
		Effect size	0.32 (small)	0.28 (small)	0.20 (small)	0.30 (small)	0.46 (small)
	CON	Pre	2.94 ± 0.46	25.7 ± 5.1	24.1 ± 6.4	0.70 ± 0.19	150.1 ± 33.4
		Post	2.95 ± 0.49	25.3 ± 5.4	24.5 ± 5.1	0.71 ± 0.21	148.8 ± 33.4
		P - value	p = 0.843	p = 0.597	p = 0.731	p = 0.794	p = 0.812
		Effect size	-0.02 (trivial)	-0.08 (trivial)	0.07 (trivial)	0.05 (trivial)	-0.04 (trivial)

PHV = peak height velocity; CMJ = countermovement jump; SJ = squat jump; RSI = reactive strength index; effects sizes are presented as Cohen's *d*.

Table 5. **Differences in measures of neuromuscular performance in participants, analyzed using 2 x 2 x 2 (time x group x maturity) repeated measures ANOVAs. P-values are presented for 3-way and 2-way interaction effects and for the main effects.**

	20-m sprint (s)	CMJ (cm)	SJ (cm)	RSI (mm/ms)	Isokinetic strength (Nm)
Time x group x maturity	p = 0.368	p = 0.687	p = 0.128	p = 0.032	p = 0.384
Time x group	p < 0.001	p < 0.001	p = 0.008	p < 0.001	p < 0.001
Time x maturity	p = 0.015	p = 0.605	p = 0.159	p = 0.319	p = 0.416
Group x maturity	p = 0.435	p = 0.607	p = 0.682	p = 0.481	p = 0.735
Time	p < 0.001	p = 0.009	p = 0.001	p = 0.002	p < 0.001
Group	p = 0.396	p = 0.616	p = 0.476	p = 0.776	p = 0.828
Maturity	p = 0.001	p = 0.003	p = 0.010	p = 0.081	p < 0.001

PHV = peak height velocity; CMJ = countermovement jump; SJ = squat jump; RSI = reactive strength index. "Time" denotes pre- to post-training data, "group" represents jump training group or control group, and "maturity" refers to pre- vs. post-PHV.

Discussion

The purpose of this study was two-fold: (a) to determine the effects of a structured 8-week jump training program on measures of neuromuscular performance in 12-14-year-old schoolboys of different maturity status, and (b) to compare the effects of the structured 8-week jump training program to the effects of the regular physical education program commensurate with the national curriculum. The main findings of the study are as follows: (a) pre-PHV schoolboys improved some, but not all aspects of neuromuscular performance in response to the 8-week jump training intervention to a greater extent compared to their post-PHV peers; and (b) schoolboys who participated in the jump training intervention improved all aspects of neuromuscular performance while in the boys who concurrently followed games-based physical education lessons, no corresponding changes in neuromuscular performance were evident.

Effects of Jump Training Program in Pre- vs. Post-PHV Boys

The first hypothesis of the present study was that the structured jump-training program would enhance jump and sprint performance in pre-PHV children to a greater degree compared to their post-PHV peers, as this has been acknowledged before (Lloyd et al., 2012; Lloyd et al., 2016). Significant 3-way (time-by-group-by-maturity) interaction effects were found for RSI, a measure that represents an individual's ability to change quickly from eccentric to concentric muscle action (Flanagan and Comyns, 2008). Pre-post intervention change in RSI in pre-PHV boys was the change with the greatest magnitude in the present study, and it amounted to a large ES of 1.00 (corresponding control group: ES = -0.14). In post-PHV boys participating in jump training program, ES for RSI was considerably lower (0.30, small; corresponding control group: ES = 0.05). The mechanism behind this improved SSC function in pre-PHV boys may be an increased tolerance to eccentric loading placed on the musculotendon unit during maximal hopping, as suggested before in a study that observed similar improvements in RSI in 12-year-old boys following a 4-week PT intervention (Lloyd et al, 2012).

In contrast to the findings regarding RSI, no significant 3-way interaction effects were observed for slow SSC (CMJ) and concentric-only (SJ) jump tests. However, the inspection of the within-group changes indicated that the ES in pre-PHV boys amounted to 0.41 (for CMJ) and 0.65 (for SJ), perhaps indicating a "greater potential for improvement" compared to their post-PHV peers in whom corresponding improvements produced lower effects sizes and were statistically significant only for CMJ (ES = 0.28), but not for SJ (ES = 0.20). These findings seem generally in agreement with the meta-analysis by Behm et al. (2017) that examined the effectiveness of PT upon jump measures in youth. The authors reported moderate overall effects for both children and adolescents, however, the calculated standardized mean difference (SMD) was indeed slightly greater in children (SMD = 0.74) compared to adolescents (SMD = 0.57). This "greater potential for improvement" in SJ and CMJ performance following a jump training intervention in pre-PHV boys as compared to their post-PHV peers might be due to the possible inability of the post-PHV youth to adequately increase concentric strength, as was suggested recently by Radnor et al. (2017). Other factors that have also been suggested to contribute to the observed larger effects of jump type training in pre- vs. post-PHV youth include an increase in neural coordination and central nervous system maturation (Myer et al. 2013). In that regard, Lloyd et al. (2016) have proposed the term "synergistic adaptation", which refers to the symbiotic relationship between specific adaptations of an imposed training demand with concomitant growth and maturity-related adaptations.

A non-significant time-by-group-by-maturity interaction effect for 20-m sprint performance indicated that there were no differences in terms of sprint performance responses between pre- and post-PHV boys participating in jump training program. Within-group analysis indicated that the 20-m sprint performance following the 8-week jump training improved significantly in both of the experimental maturity groups, and, similar to the effect sizes in jump performance measures, they were again greater in the pre-PHV group (ES = 0.62) compared to the post-PHV group (ES=0.32). Although jump training is a non-specific training form with regard to sprint running, its effectiveness in improving sprint performance in youth has been observed before. For example, Kotzamanidis (2006) reported that a 10-week PT program consisting of various types of jumps improved running performance in untrained prepubertal boys, and a review by Rumpf et al. (2012) concluded that PT is indeed an effective method of improving sprint performance in pre-PHV youth, even to a greater degree compared to sprint training. A recent meta-analysis by Behm et al. (2017), however, reported somewhat contradicting findings regarding the effects of PT (referred to in the paper as "power training") upon sprint performance. Specifically, while the SMD for children amounted to 0.47 (i.e., a small effect), the SMD for adolescents amounted to 0.13 (i.e., a trivial effect) and was not significant. The authors of the review concluded that "there was no power training specific advantage with sprint results", possibly due to the greater ground reaction forces acting on the body in sprinting vs. jumping.

The present study, along with the studies by Lloyd et al. (2016) and an earlier study by Kotzamanidis (2006) are, to the best of the authors' knowledge, the only studies that examined the effects of jump type training on sprint performance in untrained youth. The study by Lloyd et al. (2016) reported that sprint performance of both pre- and post-PHV boys also improved to a similar extent as in the present study, and the improvements were again slightly greater in the pre-PHV boys (ES = 0.45) than in the post-PHV boys (ES = 0.34) following PT intervention. A possible inability to adequately increase concentric strength (an important factor for accelerating the body) in post-PHV boys, suggested by Radnor et al. (2017), might be a contributing factor in this tendency for post-PHV boys to display a decreased magnitude of improvement in sprint performance compared to their pre-PHV peers. On a final note, the training intervention in the present study consisted of jump type exercises that were almost exclusively vertical in nature. Given that PT outcomes seem to follow the principle of training specificity (Peitz et al., 2018), had a greater proportion of horizontal type jump exercises been included in the intervention, it may be speculated that the improvements in sprint performance times would have been even more pronounced.

There are very few studies that have examined the influence of jump type training on lower body strength in youth (Behm et al., 2017). The findings of Chaouachi et al. (2014), for example, indicated that PT intervention in 10-12-year-old children in their pre-pubescent years was more likely to elicit better training adaptations compared to traditional RT for isokinetic muscle strength. In the present study, although the hypothesis suggested that greater improvements in muscle strength of the knee extensors would be observed in post-PHV boys, no differences, as evident from the statistically insignificant time-by-group-by-maturity interaction effect, were observed between the maturity groups. Looking at the within-group changes independently, both pre- and post-PHV boys participating in jump training program improved their leg strength and the effect sizes were slightly greater in pre-PHV boys (ES = 0.58) compared to their post-PHV peers (ES = 0.46). Again, as was the case for the improvements in aspects of jump performance and the improvements in sprint performance, the comparison of the within-group changes may indicate that pre-PHV boys seem to display a "greater potential for improvement" in leg strength following a jump training intervention compared to their post-PHV peers; however, this could not be confirmed due to the insignificant time-by-group-by-maturity interaction effect. Possible mechanisms that could explain the improvements in muscle strength in schoolboys participating in jump training program may include changes in muscle size and/or changes in the extent of motor unit activation. However, these factors were not evaluated in the current study. Note that the jump training intervention consisted of compound, multi-joint exercises. Isokinetic strength testing is performed during isolated, closed-kinetic, uniplanar movements. Thus, muscle strength assessment was not specific to the training mode which may have limited the transfer of the training effects.

To sum up the comparison of responses to the jump training program between 12-14-year-old schoolboys of different maturity status, it can be stated that healthy but untrained 12-14-year-old pre-PHV boys are likely to generally benefit to a similar, and in some instances to a greater extent, from a structured short-term jump training program compared to their post-PHV peers. An important limitation in this regard pertains to the fact that any differences observed between pre- and post-PHV groups of participants may not be attributable specifically to their maturity status. As evident in Table 1, pre- and post-PHV boys differed in chronological age and body size, and these factors, independent of maturity, may have contributed to the observed changes in measures of neuromuscular performance. Also, the large standard deviations reported in this study highlight the considerable variation in responses to training interventions in pediatric populations. And finally, regression equation used in the present study to calculate the PHV offset has a standard error of about 0.5 years in males (Mirwald et al., 2002). While, as indicated in the Methods, four participants with PHV offset equal to 0.0 were excluded from the analyses and only those with positive and negative PHV offset values were included, an argument can be made that the participants with a PHV offset value within ±0.5 years from the PHV=0.0 cannot be considered "truly pre- or post-PHV".

Effects of Jump Training Program vs. Effects of Regular Physical Education Program

The structured 8-week jump training program provided a more effective stimulus to improve sprint and jump performance and leg strength in 12-14-year-old schoolboys compared to the regular physical education program. This finding is based on the significant time-by-group interaction effects observed for all five measures of neuromuscular performance that were examined in the present study. Apparently, games-based physical education lessons, incorporating individual elements of soccer, basketball, volleyball and handball, as well as playing these games in various forms (e.g., 3-on-3 basketball game etc.), do not stimulate the development of sprint and jump ability and leg strength in healthy untrained 12-14-year-old schoolboys as effectively as the structured jump training program of the same frequency and total duration (i.e., twice-weekly for 8 weeks). This finding is practically significant for physical education teachers and practitioners as short-term jump training program can readily be implemented when seeking to induce specific acute adaptations in various aspects of neuromuscular performance in 12-14-year-old schoolboys. The improvements in various aspects of neuromuscular performance following the 8-week jump training program, as displayed in the present study, were achieved without any occurrence of musculoskeletal injury, further justifying the application of jump/plyometric training interventions in pediatric populations.

Conclusion

This study proved that important components of physical fitness (i.e., jump and sprint performance and leg strength) in healthy but untrained 12-14-year-old schoolboys may be enhanced through a well-structured jump training program. Maturity seems to at least play a limited role in mediating these enhancements. Physical education teachers and coaches working with these age groups may consider applying the findings of the present study when designing training programs suitable for their own students. In that regard, jump training program should not be an independent entity, but rather a component of an integrated approach to all-round physical development.

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Key points

- A well-structured jump training program can be effective for acute improvements in components of physical fitness in 12-14-year-old schoolboys.
- Maturity, as assessed by the year at peak height velocity, seems to at least play a limited role in mediating these enhancements.
- A well-structured jump training program improves components of physical fitness in 12-14-year-old schoolboys to a greater degree compared to the regular physical education program.

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