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The Effects of Horizontal and Vertical Plyometric Training on Sprinting Kinetics in Post-Peak Height Velocity Female Student-Athletes

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ABSTRACT

Plyometric training is a form of jump training that is a useful method to improve sprinting speed due to its propensity to improve neural efficiency, increase joint stiffness and contraction speed. While research has shown that plyometrics can improve jumping and sprinting performance, no studies have investigated the effects of different types of plyometric training on sprinting speed in young females. Therefore, the aim of the study was to compare different forms of plyometric training (horizontal and vertical) on sprinting performance in young females. Thirty young females from a private girls college were randomly divided into two groups and trained for seven weeks, twice a week; vertical plyometric (n=11, age 13.50 ± 0.96, peak heigh velocity-PHV: 1.60 ± 1.14), horizontal plyometric training (n=10, 13.40 ± 0.92, PHV:1.60 ± 0.93), and a physical education class as a control (n=9, age, 15.60 ± 0.31, PHV: 2.90 ± 0.55). Participants were tested for sprinting kinetics i.e. force (Fo), maximum power (Pmax), theoretical velocity (Vo), maximal velocity (Vmax), 10, 20 and 30 m split times using a radar gun over 30 m, isometric strength, vertical jump height and horizontal jump distance before and after the intervention. Both the intervention groups significantly improved all performance variables (g= 0.32- 1.30; p<0.05). The vertical group improved all kinetic variables except *Fo* and *Pmax* whereas the horizontal group improved all kinetic variables with a greater effect size g= 0.40-1.30. In comparison to the control group, the vertical group significantly improved Vo, Vmax, vertical and broad jump scores whereas the horizontal group significantly improved broad jump and 20 m split time scores (p<0.05). The findings of this study suggest that both HT and VT are effective in improving sprinting kinetics but within group changes in the horizontal plyometric training group was greater in this cohort.

Keywords: female, youth development, sprinting, plyometrics, sport

INTRODUCTION

Plyometric training (PT) has repeatedly been shown to improve jumping and sprinting ability in adults (Saez de Villarreal et al., 2012). Recent research has also shown plyometrics to be an effective means to improve sprinting speed in youth (Lloyd et al., 2016;

Bogdanis et al., 2019; Gonzalo-Skok et al., 2019). PT is characterized by rapid movements that can improve neural efficiency (Davies et al., 2015). It consists of three phases: 1) the eccentric (pre-activation) phase, 2) the isometric (amortization) phase, and 3) the concentric (shortening) phase (Davies et al., 2015). This process is termed as the stretch shortening cycle (SSC) and is considered as an integral part of PT due to the ability of the muscle to produce force, transferred via the musculotendinous unit in the shortest amount of time (Saez de Villarreal et al., 2012). During the eccentric phase, the Golgi tendon organs are stretched more than in regular strength training (ST), which results in greater inhibition of the protective function of these organs and, thus, greater power output (Davies et al., 2015; Sale,1988). These physiological adaptations are associated with increased joint stiffness, improved muscle strength, increased contraction speed, and improved dynamic stability and neuromuscular control (Sale, 1988).

In the youth population, various forms of PT have been used to improve the power characteristics of athletes in girls and boys (Moran et al., 2019; Thomas, French, & Hayes, 2009; Vaczi, et al., 2013). For example, a combined vertical and horizontal PT programme significantly improved 15 m (-5.9%) and 30 m (-6.5%) sprint times in a group of 10-15 years old soccer players after 6-weeks of training compared to a control group (-0.2 and 0.4%) respectively (Ramirez-Campillo et al., 2015a). Similarly, Asadi et al. (2018) reported PT using a drop jump from various height (20, 40, 60 cm) over 6 weeks to significantly improve 20 m speed in pre, mid and post PHV male soccer players with trivial to moderate training effect ($p<0.05$). In comparison, Lloyd et al. (2016) also reported PT that included both horizontal and vertical jumps was effective at improving sprint time for 10 and 20 m, Cohen's d = 0.4 and 0.5, respectively in pre PHV boys after 6 weeks of training. Interestingly, the effect size (ES) was greater for 10 m sprint time in this study for a combined ST and PT group compared to a PT training group (Lloyd et al., 2016). This suggests that PT along with ST can be useful in improving sprinting speed in youth, particularly in young males.

Limited studies have investigated the effects of PT on sprinting speed in young females (Siegler et al., 2003; Myer et al., 2005; Hopper et al., 2017; Bogdanis et al., 2019; Chaabene et al., 2019). Moreover, of the studies that do exist, most have investigated PT in combination with ST (Siegler et al., 2003, Myer et al., 2005; Hopper et al., 2017). For instance, Siegler et al. (2003), Myer et al. (2005) and Hopper et al. (2017) found significant improvements in sprinting speed (distance: 9.1-20 m) over a period of 6-10 weeks of combined ST and PT ($p<0.01$). However, because a mixed training method was used in these studies it is difficult to determine the efficacy of PT alone on sprinting speed in this population.

Recently two studies have investigated the effect of PT alone on sprinting speed in young female athletes (Bogdanis et al., 2019; Chaabene et al., 2019). Bogdanis et al. (2019) reported significant changes in 10 and 20 m sprinting speed in pre PHV gymnasts after 8 weeks of PT (*d*= 1.10 and 1.14; $p<0.01$) for 10 and 20 m, respectively). Similarly, Chaabene et al. (2019) reported improvements in 5, 10 and 20 m sprinting speed in post PHV handball players after 8 weeks of PT (ES = 0.81, 0.84, and 0.56 for 5, 10 and 20 m, respectively). In order, to optimize the transfer from PT to performance measures such as sprinting, the direction of applied force needs to be considered (Gonazlo-Skok et al., 2019). The importance of applying horizontal force to improve sprinting speed has been reported to be an optimal movement strategy as opposed to just increasing the GRFs (Morin, 2013). Accordingly, multiple studies have reported that horizontal plyometric exercises such as broad jump (BJ) and bounding can be useful in improving sprinting speed (Gonzalo-Skok et al., 2019; Morin et al., 2017). In the youth population, previous researchers have reported greater improvements in sprinting speed over 5 and 25 metres with horizontal PT compared to vertical PT in young male athletes (1.6-4.9% vs. 0.8-2.2%) (Gonzalo-Skok et al., 2019). Therefore, it is believed that plyometric movements that include application of force similar to that required in sprinting positively affects sprinting speed (Young et al., 1995).

To the authors knowledge, no previous studies have compared different forms of PT i.e. vertical (VT) vs. horizontal (HT) on sprinting performance in young females. Therefore, this study was designed to address two questions a) does 7-weeks of VT and HT improve isometric strength, sprinting kinetics, vertical and horizontal jump in post PHV female athletes?, and b) Are the within-group changes in sprinting kinetics similar between HT and VT in young lesser trained female athletes? It was hypothesised that both forms of plyometric training would effect sprinting performance differently.

MATERIALS AND METHODS

Experimental Approach to the Problem

To investigate these questions, two groups, horizontal (HT) and vertical (VT) PT comprised of student-athletes, participated in the study along with a control (CON) group of physical education students. The HT performed two sessions a week of horizontal PT for a total duration of seven weeks, whereas the VT group performed two sessions a week of vertical PT for a total duration of seven weeks. The CON group continued with their regular physical education classes. The selected variables of interest (isometric strength, 30 m sprinting speed, vertical and horizontal jumps) were tested pre and post the 7- week intervention in all groups.

Participants

Twenty-one student athletes from different sports (hockey, soccer, netball, and water polo) and 9 physical education students from a private secondary girls' school in Auckland, New Zealand were recruited to participate in this study. Most of the participants were European New Zealander (n= 24) with two Asian New Zealanders and three Polynesian New Zealanders. Participants were randomly divided into two groups: HT and VT. The CON group consisted of regular physical education students that participated in sports skills and health lessons. The participants had a minimum of one year of training in their respective sports. All participants were healthy with no recent (minimum of three months) injuries. All participants and their legal guardians were informed of the risks and benefits of participation and both legal guardians and participants provided written consent and assent to volunteer for this study. The participants' characteristics are provided in Table 1. The study was approved by the Auckland University of Technology Ethics Committee.

Procedure

Participants were tested for anthropometrics, 30 m sprint speed, strength and power before and after the seven week training intervention. Testing sessions began with a standardised warm-up, including 20 m multi-directional runs (forward, backward and shuffle), dynamic stretching and a series of sub-maximal sprints (50%, 75%, 90% effort). To control for environmental conditions as much as possible, testing sessions were performed at approximately the same time of the day. A familiarisation session was conducted two days before any data were collected. Participants completed the tests in the following order: anthropometrics, 30 m sprint, vertical and horizontal jump and the isometric mid-thigh pull.

Anthropometry

Anthropometric measurements and date of birth were taken before familiarisation. Height (m), sitting height (m), leg length and body mass (kg) were measured. The maturity status of the female participants was calculated using the equation of Mirwald et al. (2002). This method is considered non-invasive and practical, and using anthropometric variables predicts years from PHV as a measure of maturity offset. According to this method, maturity status is defined as pre-PHV (-3 years to -1 years from PHV), mid-PHV (-1 to +1 years from PHV), and post PHV (+1 to +3 years from PHV) (Rumpf et al., 2012). The maturity offset for each group in the present study is shown in Table 1. The equation for maturity offset for girls was:

Maturity Offset for girls (years) = –9:376 + (0.0001882 × (leg length × sitting height)) + (0.0022 × (age × leg length)) + (0.005841 × (age × sitting height)) – (0.002658 × (age × mass)) + (0.07693 × (mass by stature ratio ×100))

30m Sprinting Test

Sprinting speed and a range of kinetic variables were assessed over 30 m using a radar gun (Version 5.0.2.1, Applied Concepts, Inc, Texas, USA). Participants sprinted from a static split stance position with their leading foot immediately behind the start line. The operating range of the gun was

Table 1. Descriptive statistics for anthropometrics per group

Groups	Age (years)	Mass (kg)	Height (m)	Maturity offset (years from PHV)
HT (n=10)	13.40 ± 0.92	54.73 ± 7.16	1.65 ± 0.06	1.60 ± 0.93
VT (n=11)	13.50 ± 0.96	56.25 ± 14.87	1.64 ± 0.10	1.60 ± 1.14
CON (n=9)	15.60 ± 0.31*	57.54 ± 5.75	1.68 ± 0.06	2.90 ± 0.55*

***p**<0.05, HT- Horizontal Training, VT- Vertical Training, CON – Control group set at 0 m/s (low-from zero acceleration starting position) to 14 m/s (high- typical top end speed that is not surpassed). The radar gun, set on a tripod at 0.9 m above ground and 5 m directly behind the start line, and with a sampling rate of 47 Hz, was approximately aligned with the centre of mass of the participants (Morin et al., 2006). No false start was allowed and participants were instructed to sprint maximally to a marker 5 m past the 30m line (Simperingham et al., 2017). Participants performed two maximal sprints interspersed with five minutes of passive rest. The best trial was used for analysis.

Horizontal velocity was measured continuously using the radar device connected to a laptop running Stalker ATS System software (Version 5.0.2.1, Applied Concepts Inc, Texas, USA) (Simperingham et al., 2017). The raw data files were automatically processed using the digital filter "dig light". This function is available within the software and precisely removes noise frequencies while preserving data frequency being measured. The dig light filter applies minimal filtering and suitable for "clean" radar data and applies a fourth order (one round trip), Butterworth low-pass zero lag filter with a cut off frequency of 8 Hz. To improve consistency all trials were nominated to be acceleration runs hence forcing the start of the velocity-time curve through the zero point (Simperingham et al., 2017). The processed data were then imported into a custom-made Lab View (Version 13.0, National Instruments, Corporation, Texas, USA) to calculate all outcome variables (*Fo, Vo, Pmax, Vmax* and split times between 0 and 30 m) (Buchheit et al., 2014). The velocity-time curve [v(t)] for each sprint was calculated using the exponential function $v(t) = V_{max} \times (1 - e^{-t/\tau})$ (Al Haddad et al., 2015), horizontal acceleration was calculated from Newton's second law of motion $Fh(t) = [m \times a(t)] + Fair(t)$ (Arsac & Locatelli, 2002) and Pmax was calculated through the equation $P_{max} = (0.5 \times F_o) \times (0.5 \times V_o)$ (Bezodis et al., 2012). Data recorded for both the trials were used in the assessment of intra-day and the best trials on each for the inter-day reliability. A moderate to strong intraclass correlation coefficient (ICC) = 0.74-0.98 with a coefficient variation (CV) ranging from 1.70-12.70% across all kinetic variables (*Fo, Vo, Vmax, Pmax*, 10, 20, and 30 m split times) were reported for both intra-day and inter-day reliability in this population (young female athletes) (Talukdar et al., 2021).

Vertical Jump

Vertical jump (VJ) performance was assessed using the Just Jump System (Probiotics, US). Participants were required to step on the mat with feet parallel to each other and hips shoulder width apart. Participants were then required to perform a quick countermovement by flexing their hips and knees to a self-selected depth before explosively extending at the knees, hips and ankles to attain a maximal jump height (Nuzzo et al., 2011). All participants were allowed to use arm swing for each jump (Nuzzzo et al., 2011). A total of three attempts were provided with a one minute recovery between each attempt and the best result was used for analysis. The reliability between trials for VJ in this study was high (ICC= 0.94, CV= 3.60%). The overestimation of jump height from Just Jump System was corrected using the equation (Adjusted jump height (m) = 0.8747*jump height−0.0666) (McMahon et al., 2016). Previous research has also reported strong intersession reliability of VJ performance in females using the Just Jump System aged 19.5 ± 1.3 (ICC = 0.92, CV = 4.4%) (Nuzzo et al., 2011).

Horizontal Jump

Horizontal jump (HJ) performance was assessed using the standing broad jump (BJ). Participants stood behind a start line and were instructed to jump forwards as far as possible by pushing off the ground explosively at a self-selected depth without the hands on the hips. For a trial to count, participants had to land with the feet together without falling over. The jump distance, measured to the nearest 0.01 m with a tape measure, was taken from the take off line to where the back of the heel nearest to the take off line after landing. A total of three attempts were provided with a one minute recovery between each attempt and the best of the three were considered for analysis (Fernandez-Santos et al., 2015). The reliability between trials for HJ in this study was high (ICC = 0.94 & CV = 3.40%) Previous researchers have found standing HJ to be highly reliable with inter trial difference of 0.3 ± 9.0 cm in adolescent females (Ortega et al., 2008).

Isometric Mid-Thigh Pull

Isometric strength was assessed using the isometric mid-thigh pull (IMTP). An immovable bar was positioned at the participants' mid-thigh region above a force platform interfaced with computer software sampling at 600 Hz (Ballistic Measurement System, Innervations, Australia). Force plate was zeroed before the participants stepped onto the force platform. Participants obtained a self-selected knee and hip angle with the immovable bar resting at mid-thigh (Thomas et al., 2015). Participants stood on the force platform with their hands gripping (prone grip) the bar and performed two warmup pulls at 50% and 75% of their perceived maximum effort (Thomas et al., 2015). The set up included participants to place their feet hip width apart, the bar was positioned at midthigh and the torso was upright with a neutral spine (Moeskops et al., 2018). The customised portable IMTP allowed for incremental bar adjustments to accommodate participants of different statures (Moeskops et al., 2018). They were then instructed to pull maximally pushing the feet down on the force platform as hard as possible and applying force quickly. Participants performed 3 maximal pull efforts for 5 seconds, separated by 1 minute of passive rest (Thomas et al., 2015). Verbal encouragement was provided during each trial and the best of the three trials was considered for analysis. Data were filtered using a fourth-order Butterworth filter with a 16 Hz cut off frequency (Thomas et al., 2015). IMTP measures such as absolute and relative peak force have been reported to be reliable within and between sessions in pre and post PHV female athletes (ICC = 0.87 and 0.92; CV ≤ 9.4% and ≤ 7.3% respectively (Moeskops et al., 2018).

Training Programmes

Both the intervention groups trained twice per week for a total of 7 weeks supervised by accredited strength and conditioning coaches with a coach to athlete ratio of 1:5. There was a minimum of 48 hours difference between sessions to allow for full recovery (Lloyd et al., 2016). All the training sessions were preceded by a RAMP (Raise, activate, mobilise and potentiate) based warm-up protocol that included multi-directional runs, dynamic stretching and activation, and semi-structured games and movement exploration (Jeffreys & Moody, 2016; Barreiro & Howard, 2017). Participants were asked not to perform any other training except for their sports skill sessions throughout the intervention period such as dribbling (hockey and soccer), shooting (Netball and Water polo). A training log was maintained to keep a track of training sessions and activity outside the intervention to avoid physiological interference. The log included total duration, and session rating of perceived exertion (SRPE) for each skill session participants performed using the modified Borg category ratio-10 (CR 10) scale (Scantlebury et al., 2017; Foster 1998).

Vertical and Horizontal Plyometric Training

Jump training was gradually progressed throughout the intervention based on movement complexity and eccentric muscle contraction demands (Tables 2 and 3). In addition to the vertical and horizontal jumping movements, upper body power, strength (vertical pulling) and trunk stability (anti-lumbar extension) movements were included for both groups to ensure continued development of upper body and trunk musculature. In general, jumping volume increased from 3 sets of 5 repetitions to 5 sets of 5 repetitions by week 4. The total number of jumps progressed from 75 to 125 foot contacts per session over 7 weeks. If technical competency was not achieved for any movements then a regression was provided. Once competency was achieved, complexity was added (Tables 2 and 3). Whilst no increase in the number of sets completed after week 3, number of repetitions for chin ups and stability ball roll outs were increased when technical competency was maintained. The intervention groups performed their exercises in the same order on each training

Table 2. Vertical training programme

Exercise	Sets	Reps	Progression
Countermovement jumps	Week 1-3: 3 Week 4-7: 5	5	Repeated jumps (low ground contact time)
Chin Up	3	5	Increase repetitions
Single leg box jumps	Week 1-3: 3 Week 4-7: 5	5 each	Increase height
Medicine ball slams	Week 1-3: 3 Week 4-7: 5	5	Increase load
Drop jump (vertical)	Week 1-3: 3 Week 4-7: 5	5	Increase height
Stability ball roll outs	3	10	Decrease size of ball
Squat Jumps	Week 1-3: 3 Week 4-7: 5	5	Increase height

Table 3. Horizontal training programme

Exercise	Sets	Reps	Progression
Broad jump	Week 1-3: 3 Week 4-7: 5	5	Repeated jumps (low ground contact time)
Chin Up	3	5	Increase repetitions
Mini-hurdle jump and stick	Week 1-3: 3 Week 4-7: 5	5 each	Repeated/unilateral landing
Medicine ball chest throw	Week 1-3: 3 Week 4-7: 5	5	Increase load
Drop jump (horizontal)	Week 1-3: 3 Week 4-7: 5	5	Increase height
Stability ball roll outs	3	10	Decrease size of ball
Bound and stick	Week 1-3: 3 Week 4-7: 5	5	Repeated (low ground contact time)

occasion, separated by 60-120 s of passive rest depending on the phase, intensity, and complexity of the movements.

STATISTICAL ANALYSIS

Means and standard deviation were calculated for all dependent variables of interest as measures of centrality and spread of data. Levene's test was used to check homogeneity of variance across samples. Paired t-tests were used to determine significant differences across variables of interest for pre and posts scores for all groups. Effect sizes (ESs) were calculated for all performance variables in each training group and assessed using the magnitude of ESs according to Hedge's g statistics due to a smaller sample size (Lakens, 2013). ESs were classified as follows trivial (≤ 0.19), small (0.20 to 0.59), moderate (0.60 to 1.19), large (1.20 to 1.99). and very large (2.0 to 4.0) (Hopkins, 2002). Descriptive statistics, ANOVA and paired t-tests were computed using SPSS V.25 (SPSS Inc, Chicago, IL, USA), with statistical significance for all tests set at an alpha level of $p \leq 0.05$. A one-way analysis of variance (ANOVA) was used to determine significant differences between the groups. Bonferroni post hoc and Dunnett's tests were used to correct error rate and provide specific comparisons between the groups i.e. VT vs. HT vs. CON.

RESULTS

Mean changes in the dependent variables are displayed in Table 4 for all the groups. There were significant changes across both the intervention groups in all variables from pre to post testing ranging from small (g=0.40) to large (g=1.30) ES ($p<0.05$). The VT group significantly improved in all variables of interest except for *Fo* and *Pmax*, with ES ranging from g=0.32 to g=0.64. The HT group significantly improved in all dependent variables with ES ranging from g=0.47 to g=1.30 ($p<0.05$). In contrast, the CON group did not show any significant changes from pre to post testing (Table 4).

Post hoc analysis showed that the VT group had significantly higher post scores compared to the CON group for Vo, Vmax, VJ, and BJ whereas the HT group had significantly higher post scores for 20 m split time and BJ compared to the CON group ($p<0.05$). There was no significant difference in post scores for any variable between the intervention groups.

DISCUSSION

This study showed that, compared to a normal physical education class, post PHV girls were able to make significant improvements in speed, vertical and horizontal jump following 7 weeks of VT and HT training. With regards to sprinting kinetics, following VT, participants showed significant improvements in *Vo, Vmax*, 10, 20 and 30 m sprint time (ES: g=0.40 - 0.50; $p<0.05$) but not *Fo* and *Pmax*. Following HT, participants significantly improved all sprinting variables with greater effects in most of the variables (ES: g=0.47-1.30; $p<0.05$) than the VT group. There were no significant changes in the CON group across all variables. The findings indicate that both HT and VT can be effective in improving sprinting

Table 4. Means, % changes and effect size (ES) pre and post-test across variables for all group

Variables	VT (pre)	VT (post)	Change%	ES	HT (pre)	HT (post)	Change%	ES	CON (pre)	CON (post)	Change %	ES
Vo (m/s)	7.06 ± 0.49	7.35 ± 0.61	4.11*	*g*=0.50	6.67 ± 0.42	6.92 ± 0.58	3.74*	*g*=0.47	6.68 ± 0.62	6.70 ± 0.40	0.30	*g*=0.04
Vmax (m/s)	6.79 ± 0.46	7.03 ± 0.53	3.53**	*g*=0.47	6.40 ± 0.37	6.62 ± 0.42	3.44**	*g*=0.53	6.41± 0.54	6.43 ± 0.37	0.31	*g*=0.04
Fo (N)	295.54 ± 128.01	365.45 ± 261.37	23.65	*g*=0.33	255.00 ± 53.45	327.60 ± 53.30	28.47**	*g*=1.30	267.00 ± 45.25	272.56 ± 55.38	2.08	*g*=0.10
Pmax (W)	503.64 ± 213.77	589.09 ± 291.80	16.96	*g*=0.32	438.00 ± 93.22	529.20 ±106.96	20.82*	*g*=0.87	433.33 ± 90.28	423.78 ± 92.39	-2.20	*g*=0.10
10 m (s)	3.11 ± 0.50	2.83 ± 0.65	9.00*	*g*=0.47	2.98 ± 0.32	2.67 ± 0.25	10.40**	*g*=1.03	2.86 ± 0.16	2.90 ± 0.15	-1.40	*g*=0.25
20 m (s)	4.60 ± 0.54	4.32 ± 0.63	6.09*	*g*=0.46	4.51 ± 0.25	4.21 ± 0.21	6.65**	*g*=1.24	4.49 ± 0.24	4.48 ± 0.24	0.22	*g*=0.04
30 m (s)	6.01 ± 0.60	5.73 ± 0.74	4.66*	*g*=0.40	6.08 ± 0.37	5.74 ± 0.34	5.59**	*g*=0.92	6.03 ± 0.35	6.04 ± 0.39	-0.17	*g*=0.03
IMTP (N)	773.59 ± 144.96	849.81 ± 198.60	9.85*	*g*=0.42	774.40 ± 105.56	850.02 ± 81.99	9.76*	*g*=0.77	726.00 ± 216.10	735.33± 194.82	1.29	*g*=0.04
IMTP (N/kg)	14.25 ± 2.81	15.56 ± 3.02	9.19*	*g*=0.43	14.41 ± 2.58	15.83 ± 3.10	9.85*	*g*=0.48	12.71 ± 4.12	12.81 ± 3.41	0.78	*g*=0.03
VJ (m)	0.33 ± 0.05	0.35± 0.05	8.44*	*g*=0.40	0.31 ± 0.03	0.33± 0.04	7.33*	*g*=0.57	0.28 ± 0.05	0.28 ± 0.05	0.43	*g*=0.00
BJ (m)	1.82 ± 0.16	1.93 ± 0.17	6.04*	*g*=0.64	1.81 ± 0.17	1.90 ± 0.15	4.97*	*g*=0.54	1.62 ± 0.22	1.61 ± 0.18	-0.62	*g*=0.05

**P*<0.05, ***p*<0.01,VT- vertical training, HT- horizontal training, CON- control, ES- effect size, Vo- theoretical velocity, Vmax- velocity max, Fo- Force, Pmax- Power max, IMTP- isometric midthigh pull, VJ- vertical jump, BJ- broad jump* kinetics in young female athletes. However, within group changes in the HT group seems to be greater.

More specifically, greater within-group improvements were observed for all the split times following HT (*g*= 0.92 -1.24 for the 10, 20 and 30 m, respectively compared to VT training (*g*=0.40-0.47). This finding supports previous research that investigated the effects of PT in young (u-13 and u 14) male basketball players (Gonzalo- Skok et al., 2019). Specifically, Gonzalo- Skok et al. (2019) showed significant changes in 5, 10, and 25 m (ES=0.30-0.78) sprint time after 6-weeks of unilateral HT compared to bilateral VT (ES = 0.13 to 0.28). In contrast, Yanci et al. (2016) reported trivial changes in 5 and 15 m sprinting speed (ES = 0.10-0.20) after 6 weeks of HT training in adult semi-professional soccer players. However, the participants in the Yanci et al. (2016) study were highly trained athletes compared to the lesser trained youth in the present study. There might be a larger scope of improvement with regards to sprinting performance in young lesser trained athletes compared to adult trained athletes. Therefore, based on the findings of the above studies it seems that HT may help to achieve greater improvement in sprinting kinetics due to force vector associated with sprinting motor pattern (Gonzalo-Skok et al., 2019; Morin, 2013). This study also supports a recent systematic review that reported HT to be the most effective way to enhance jump and sprint performance in young and adult males (Moran et al., 2020).

The findings from this study showed that VT improved split times with small effect sizes 10 m (*g*=0.47), 20 m (*g*=0.46), and 30 m (*g*=0.40). This finding agrees with previous research that investigated the effectiveness of VT on sprinting performance in young male athletes (Ramirez-Campillo et al., 2015b). Ramirez-Campillo et al. (2015b) also reported improvements with relatively small ES in 15 m (ES = 0.50) and 30 m sprint time (ES = 0.30) in young soccer players after 6 weeks of PT that emphasized VJs. In young females, Bogdanis et al. (2019) also showed positive changes in 10 and 20 m sprinting speed with small ES (*d*= 0.26) and (*d*= 0.50) following 8 weeks of PT that predominantly included vertical jump training. However, the participants in Bogdanis et al. (2019) study were pre PHV girls (8.1 ± 0.7 years) and sprinted a shorter distance (20 m) compared to (30 m) in this study. Due to the heightened neural drive prior to the PHV phase, it is possible that any form of PT maybe useful to influence sprinting performance particularly over a shorter distance (Lloyd et al., 2016). Combined, this data suggests that VT may be useful in improving sprinting speed in young males and females, but more research is warranted with regards to magnitude of change in post PHV female athletes for longer sprints >20 meters.

The present study showed that Vo and Vmax improved significantly following both VT and HT (Table 4). However, significant improvements in *Fo* and *Pmax* were only observed in the HT group (p<0.05). This finding may be the result of the dominant direction of force applied during the training intervention, horizontal as opposed to vertical (Gonzalo-Skok et al., 2019; Moran et al., 2020). The importance of applying force in the horizontal direction could have positively influenced maximal velocity and power in this study due to motor pattern specificity (Morin, 2013). Since the direction of force in sprinting is predominantly in a horizontal plane (Stavridis et al., 2019). Therefore, greater improvements were seen in *Fo* and *Pmax* in the HT group compared to the VT group.

The VT group significantly improved both VJ and BJ scores in this study (p<0.05). This finding agrees with previous research that reported positive changes in counter movement jump and standing long jump after 8 weeks of PT that incorporated predominantly VT in young females (*d*= 0.67 and 1.57 respectively) (Bogdanis et al., 2019). In addition, both relative and absolute IMTP scores also significantly improved after VT in this study (p<0.05). Since VT group significantly improved non-sprint specific force and power measures (IMTP, VJ, and BJ) but not sprinting specific *Fo* and *Pmax*. Therefore, it can be assumed that changes in force and power involved in sprinting may be independent to IMTP, VJ and BJ due to force vector and motor pattern specificity in this population (Gonzalo-Skok et al., 2019; Moran et al., 2020).

Both VJ and BJ scores improved following HT in this study (p<0.05). A recent systematic review also reported that HT was as effective as VT in enhancing vertical performance in young and adult males (-0.04, p=0.77) (Moran et al., 2020). However, in adult male athletic (soccer) population, researchers have reported significant changes in horizontal jump performance after eight weeks of HT training with no meaningful changes in VJ performance (p<0.01) (Manouras et al., 2016). This could be because the participants in the Manouras et al. (2016) study were trained adults and might have required more specific vertical plyometric training to improve VJ performance compared to this study. In addition, both relative and absolute IMTP scores for HT group improved similarly compared to VT group (9.19-9.85%, p<0.05). However, the ES for absolute IMTP for the HT group was greater than VT group (*g*= 0.77 vs. 0.42). Therefore, suggesting that HT can be effective in improving vertical, horizontal jump performance along with absolute and relative isometric strength in lesser trained post PHV females.

The CON group in this study did not improve performance in any dependent variables with a substantial not significant decrease in *Pmax*, 10 m split time and BJ (-2.20, -1.40% and 0.62% respectively). Furthermore, the baseline mean scores for all the variables in the CON group were very similar to both the intervention groups. This could be because the CON group was significantly older (15.6 years) than both the intervention groups (13.5 and 13.6 years respectively) hence affecting force and velocity measures. However, there were no significant differences in the anthropometrical measures such as height and body mass between the CON group and the intervention groups. Therefore, suggesting that although natural development can improve speed and power measures, but this change could be further developed with specific progressive training in this cohort.

The ANOVA and post hoc analysis reported that post scores for the VT group were significantly higher in Vo, Vmax and VJ compared to the CON group (p<0.05). Whereas, 20 m split time in the HT group was significantly higher compared to the CON group post-training (p<0.05). In addition, both VT and HT group significantly improved BJ scores compared to the CON group. There were no significant differences between the VT and HT groups across all variables. This study supports previous research that reported significant changes in 20 m sprint speed and jumping performance in boys after 8 weeks of PT that included both HJ and VJ training compared to the CON group (p<0.05) (Fischetti et al., 2018). However, having a low sample size is considered a limitation of this study. A sample size of 12 participants per group was determined on the power calculation: 1-β = 0.80, α = 0.05, effect size 0.5 (Bogdanis et al., 2019), due to the school curriculum number of participants in each group was lower. Therefore, PT programme that includes both vertical and horizontal jumping movements can improve sprinting kinetics, isometric strength and jump performance in post PHV female athletes compared to the conventional physical education class but more research in a larger cohort is warranted.

CONCLUSION

This study showed that both VT and HT can improve sprinting kinetics, isometric strength and jump performance in young female athletes. Moreover, within group changes in sprinting performance was greater in the HT group, likely due to more specific motor patterns and direction of force involved. Future research should compare the effects of VT and HT on sprinting performance across a larger cohort and investigate changes across maturation (pre to post PHV). Furthermore, movements should be gradually progressed with regards to complexity, volume and intensity. For example, jumps should be gradually progressed based on the eccentric demands, and foot contact per session.

DISCLOSURE STATEMENT

This is to acknowledge that there was no financial interest or benefit that has arisen from the direct applications of our research.

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