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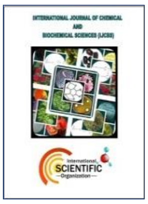


The effectiveness of a physical education teaching intervention based on biomechanical modeling on anaerobic power and sprint running performance of youth male students with deficit force profile

Rachid Boujdi*[1*], Abdeljabbar Rouani*[1]***, Aziz Elouakfaoui*[1]***, Driss Lamri*[2]***, El mehdi Al Ibrahimi*[1]***

[1]Materials and Subatomic Physics Laboratory. Department of Physics Faculty of Science, University Ibn Tofail. Kenitra, Morocco.

[2]Scientific and Pedagogical Research Laboratory. Regional Center of Education and Training trades Rabat-Sale-Kenitra. Rabat, Morocco.

Abstract

This study investigates the effect of a short-term (6-week) teaching-training intervention combining plyometric and bodyweight training on anaerobic capacities, the mechanical outputs, the orientation of the Force-Velocity profile and on the sprint performance in youth male physical education students with deficit force on their F-V profile. An experimental randomized controlled study design was adopted with a pre-post-intervention tests to address the problematic. Where is, the biomechanical modeling was used to calculate anaerobic mechanical outputs. Results had shown that the proposed training program did enhance almost all of force-velocity sprint mechanical outputs variables especially the maximal theoretical horizontal force (HZT-F0), the maximal horizontal power (HZT-P_{max}) the effectiveness of force application (RF_{max}) and force-velocity slope (S_{FV}) in addition to sprint time performance at $p < 0.01$ with values in favor of the experimental group, when compared using inferential statistics to the control group receiving habitual physical education. In conclusion, this study indicates that a teaching-training program, combining bodyweight to plyometric training may be a good decision-making for students with deficit force at lower velocity when attempting to remediate their force-velocity profile and elicit effective motor learning by targeting sprinting-specific biomechanical technical factors and improve their anaerobic performance.

Keywords: Physical Education; Anaerobic Performance; Biomechanical Modeling; Sprint Running; Motor Learning.

Full length article **Corresponding Author*, e-mail: rachid.boujdi@uit.ac.ma

1. Introduction

In the pediatric literature, anaerobic capacity as a performance indicator has received slightly less attention, especially when anaerobic parameters (maximal velocity and peak power for example) were compared to aerobic ones such as exchange thresholds and peak oxygen uptake ($\dot{V}O_2$ max). Numerous tests have been developed as a result of the lack of agreement regarding the best way to measure anaerobic performance, including the cycling Wingate widely used in pediatric populations [1], sprinting [2] [3], and other types of vertical jumps like counter-movement jumps [4], [5]. Recently, sprint running or accelerated running is becoming increasingly a popular method of short-term anaerobic performance assessment in pediatric populations [2], [6], it's Analysis using straightforward data collection techniques coupled with macroscopic biomechanical modeling may quantify the underlying kinetics and provide estimates of power production along with velocity, providing more comprehensive assessments of anaerobic performance. Teaching physical education seems to be a difficult task by arranging pedagogical aspects and sports training ones, whereas, physical education teachers should enable students by providing appropriate motor learning content by taking mechanical parameters, biomechanical, physiological and neuromuscular mechanisms into account that affect their overall performance in conjunction. Moreover, greater transfer is observed when the biomechanics target particular technical sprint features in comparison to conventional interventions, according to motor learning studies indicating that it is crucial for physical education same as coaches to comprehend and work on improving biomechanical features [7] in dealing with a youth population. The development of sport science, portable technology, and biomechanical modeling allows physical education teachers same as coaches to reach the necessary information in the field of monitoring and training, particularly in the field of physical activity biomechanics. Sprint running acceleration is an anaerobic explosive action that calls for a high rate of force and maximal strength expression in a short period of time [8]. It describes all-out efforts intended to cross a distance in the shortest possible amount of time or the greatest distance in a specific time duration. In several team or athletic sports, sprint running acceleration is a crucial performance factor, and it appears to be advantageous for advancing to higher levels of sport practice. The method of evaluating sprint performance (i.e., using only time performance) is constrained because the underlying biomechanical and neuromuscular mechanisms affecting sprint acceleration performance are not explained. Thus, analyzing those biomechanical variables could help to better understand the physical aspects that underlie performance. Where is, from a biomechanical perspective and according to fundamental dynamics principles, the movement of a sprinter's center of mass (CoM) is primarily dependent on the ground reaction force that is applied to the (CoM), this latter force is a direct outcome of the external force that the sprinter transmitted to the ground [9]. A macroscopic inverse dynamics method called sprint force-velocity profiling has recently been used to clarify and quantify the influence of sprint's force, velocity, and anaerobic power parameters on its overall performance [10]. With the use of this method, practitioners have a better understanding of the individual force-velocity properties of athletes as well as the impact that mechanical factors have on sprinting performance. These relationships (i.e. force-velocity, power-velocity) in sprinting offer an objective assessment of force and power production capacities via the theoretical maximal horizontal force (HZT-F0) the athlete is able to transfer into the ground and related to the production of high horizontal forces at low running velocities, the maximal power output (HZT-P_{max}) that he's capable of producing in the horizontal direction, and the theoretical maximal velocity (HZT-V0) where he keeps generating positive net horizontal force. In addition, other mechanical parameters can be provided by this assessment, which each identify distinct neuromuscular features such as the rate of force application (RF_{max}) or effectiveness, the reduction in the rate of force application within a running speed increase (Drf) and the F-V slope (S_{FV}) [11].

Moreover, the sprint running F-V and P-V relationships incorporate the capacity to "effectively" (i.e., in the antero-posterior direction) apply the external force to the ground and refer to the entire capacity for propulsion during a sprint rather than just muscle characteristics. These several important mechanical parameters are the consequence of relationships between the various neurological, physiological, and biomechanical mechanisms contributing to the generation of total external force and identifying the various athletic abilities [12]. The athlete's mechanical F-V profile can be determined by the ratio of HZT-F0 to HZT-V0, the slope of the F-V linear relationship (S_{FV}) [13] and can explain the difference between two athletes with the same maximal power capability (HZT-P_{max}), and it has been found to have significant between-subject variances, despite the fact that athletes may participate in an identical training program [14]. This demonstrates how an individualized intervention training program may be necessary for promoting physical adaptations and managing any resulting force or velocity deficits in mechanical outcomes of the sprint running performance [15].

Among these differences in the mechanical F-V profile and force production capacities, the adequate training intervention for enhancing sprint running performance and how to program training taking into account the continuum between these two parameters (HZT-F0 and HZT-V0) of the F-V profile seem to be pertinent questions. With mention, as far as we are aware, no study has investigated the effect of a standardized teaching-training program designed for the youth student population aiming to manage the force deficit in the F-V profile and improve their performance in sprint running. Therefore, this study aims to test the effect of an intervention training-teaching program based on the relative difference on the mechanical F-V profile designed for students characterized with a deficit force (HZT-F0) on their F-V profile (i.e. $S_{FV} > -1$) within a short-term duration (six weeks) compared to a control group of students receiving habitual physical education and try to answer the following questions, A) Could the teaching-training intervention effect a change in the F-V slope (i.e., a decrease in S_{FV} specifically) and create a balance between the capacities of force and velocity independently from its overall position? B) Did the program shift the overall F-V relationship to the right and upward (i.e., an increase in the maximal power HZT-P_{max})? C) And also contribute to improve the anaerobic performance of all-out sprint running?

We hypothesize that a combined teaching-training intervention using plyometric and bodyweight exercises would improve sprint running performance (Hypothesis 1), shift the overall F-V relationship to the right and upwards (Hypothesis 2), and elicit a

balance between the capacities of force and velocity of the F-V profile (Hypothesis 3) in youth physical education students characterized by a deficit force (HZT-F0) on their sprint F-V profile.

2. Materials and methods

2.1. Study Design and Participants

To determine the effect of the training intervention, an experimental randomized controlled study design (RTC) was adopted with a pre-post-intervention tests, two groups (Combined Training group [CTG] and control group [CG]) were created and the students were randomly assigned to either [CTG] or [CG], the sample was recruited from two high schools located at Kenitra city, Morocco.

In accordance to the statements of the Declaration of Helsinki and in advance of the study, an approval from the Institutional Review Board of Ibn Tofail University -Biology Team and Pedagogical Innovation- was accorded after evaluating the protocol (authorization Reference P-680/D-

4727/2023 dated of February 26, 2023) and an authorization from the Department of Legal Affairs, Communication and Partnership of the Ministry of National Education, Preschool and Sports of Morocco (MNEPS) was accorded, also informed parental consent was signed after all participants and their parents or legal gardens were properly informed about the study's purpose, the types of assessment and eventual risks. All guaranties of confidential personal information were presented.

Participants in this study had to meet the required criteria in order to be selected as flowing: (a) Boy aged 14 to 18 years old, (b) healthy, no chronic pediatric diseases, no physical pain or musculoskeletal injuries occurred in the last six months, (c) Force-Velocity sprint profile oriented force deficit (i.e., $S_{FV} <-1$) and (d) don't have previous experience in plyometric and/or bodyweight formalized training. The diagram of the study as a flow chart is presented in (Figure 1.), whereas, Participants' age and anthropometric measurements are displayed in (Table 1.).

2.2. Equipment and Tools

The equipment and tools used in this research were: Electronic smart scale (Xiaomi MI scale 2, Anhui Huami Information Technologies Co. Ltd, Hefei, China) and a Stadiometer (Kinlee, Hong Kong, China) for anthropometric measurements, an iPhone camera mobile (version 11 Pro, Apple, USA) and tripods for video acquisition, Kinovea 2D motion analysis open software (version 9.5), a personal computer mark *hp*® for treatment and modeling operations, other material (medicine balls, cones, whistle, measuring tape, vertical marker poles …).

2.3. Research Procedures

All participants were tested at baseline and after the 6-week training intervention at the same time of day for 30m linear speed performance with split time of 5m. A 48h of rest at list was ensured before the first training session and the pre-test, and after the last training session and the post-test. A biomechanical modeling was subsequently applied to linear sprint performance to extract the relevant mechanical outputs. Moreover, the independent variable was the training intervention groups (CTG and CG).

2.3.1. linear sprint performance

The participants were invited to perform a standardized warm-up for 15-min including low to moderate jogging cadence, dynamic stretching, repeated sprint 10m to 20m with 2~3min inter-set active recovery. After warm-up, participants perform 2 to 3 repetitions for familiarization to the testing protocol. Each student performed tree 30 m sprints trailers at maximal effort with at list 5-min recovery, they were instructed to take a crouched ready position (tree points start) with one hand at distance of tree centimeters behind the starting line (Figure 2.), they were free to select their favorite starting leg and hand to put on ground. After the whistle signal, students were incited to run (as fast as they can) through the track until the finish line at 34m to avoid deceleration before the sprint's completion, allowing the biomechanical model to precisely represent the performance. Moreover, the teacher motivates participants to perform correctly and as fast as possible.

To determine the 5m, 10m, 15m, 20m, 25m, and 30m split times, vertical marker poles were placed in a handball outdoor filed at adjusted locations as indicated by *Romero-Franco* and colleagues [16], split time was assessed by recording each sprint using a high speed camera phone iPhone 11 Pro (Apple, USA) with sampling rate recording of 240 fps and a resolution of 720p, the phone was mounted on a 1m height tripod and 18m from the "15m split" marker. To avoid the effect of reaction time on performance, the start of the sprint was inspected visually frame by frame using a 2D motion analysis open software (Kinovea, version 9.5, 2023), start time was started up when participant hand left the ground and crossed the starting line however the splits time was when participants hip aligned with pole markers, furthermore, the finish time was when participants hip aligned with "30m split" pole marker [16]. All trials for pre-test and post-test was assessed in the same field at same time interval (between 9 and 12 AM), with no wind and an average air pressure and temperature of 980± 20bar and 20.2 ± 7.4ºC respectively, to minimize the effects of atmospheric variables pre- and post-intervention.

2.3.2. Biomechanical modelling

All split time performances recorded at the tree 30-m sprint trailers were used in inter-class correlation, Standard error of measurement (SEM) calculation, and also to determine the smallest worthwhile change (SWC) discussed further in this paper. However, only the best trailer (with the best 30m time performance) was used for modeling and calculating mechanical outputs of sprint performance.

Split times data (i.e., sprint position-time) was used along with environmental conditions (atmospheric pressure and temperature) and subjects' body mass, body height as inputs to calculate sprint mechanical outputs and individual linear F-v profiles by implementing the equations developed by *Samozino et al.* [13] and validated by comparison to direct ground reaction force measurements from in-ground force plates [10]. A full description of the fitting method and equations used is available in the original research. A custom-made Microsoft Excel spreadsheet for assessing the force-velocity-power profile of sprint running proposed by [17] was used on Microsoft excel (Microsoft Corporation 2016, USA) with the Solver add-in macro for computing the biomechanical model and to derive all sprint mechanical outputs dependent variables and presented as:

- HZT-F0 (N/kg): the relative Theoretical maximal horizontal force.
- HZT-V0 (m/s): the theoretical maximal velocity of running.
- HZT-P_{max} (W/kg): the relative Maximal mechanical power outcome horizontally oriented, calculated as HZT-F0 x HZT-V0/4.
- RF_{max} (%): maximal Ratio of force (as a percentage of the ground-reaction force).
- DRF: Rate of decrease in RF with increasing speed during sprint acceleration.
- F-V Slope ($N.m.\ s^{-1}.kg^{-1}$): Slope of the linear F-V relation, calculated as S_{FV} = - HZT-F0/ HZT-V0.
- MSS ($m.s^{-1}$): Maximal Speed Sprint.
- V_{opt} ($m\cdot s^{-1}$): Optimal Velocity (the velocity wish HZT-P_{max} is produced).

A more detailed explication of sprint mechanical outputs is available in the original article [11].

2.4. The Training Program

The experimental training group [CTG] trained with a weekly frequency of two sessions on nonconsecutive days spaced by at least 48 hours according to previous pediatric literature [18], a combined training program of plyometric and bodyweight exercises (e.g. using their own body weight as resistance against gravity when exercising) organized into four periods composed of three sessions with incremented volume, load, and intensity for six weeks under carefully monitored and controlled conditions. The training program is illustrated in Table 2.

2.5. Statistical Analysis

Statistical analysis was computed using SPSS Statistics Software (IBM SPSS version 27.0, Chicago, IL, USA) with significance level seated at $p < 0.05$. Descriptive statistics were reported as mean ± standard deviation (SD). Before inferential analyses a Kolmogorov-Smirnov test was used to confirm normality of data distribution and Levene's test for homogeneity of variance for all variables. However, the reproducibility of split time of 5m, 10m, 15m, 20m, 25m and 30m was evaluated using the coefficient of variation (CV%) calculated as a percentage of standard deviation of the tree trails divided by their average, and the intra-class correlation coefficients (ICCs) computed using a custom-made spreadsheet presented by *Hopkins* for trial to trial reliability analysis. The relative reliability based on the ICC values were categorized as low (0.20 to 0.49), moderate (0.50 to 0.74) and high (0.75 to 0.99), with a coefficient of variation considered acceptable under 10%. Thus, measures were highly reliable for ICC ≥ 0.75 and CV ≤10%, moderately reliable for ICC < 0.75 ether CV > 10%, and poor and unacceptable for an ICC < 0.75 and CV > 10% [19]. A paired-samples t-test was conducted to analyze the impact of the proposed teaching-training program on sprint performance and mechanical variables within-group for normally distributed variables and a Wilcoxon Signed Ranks Test for non-normally distributed, however an independent t-test for independent samples was taken to evaluate between-groups changes for normally distributed variables and a Mann-Whitney U Test for non-normally distributed ones. Therefore, the analysis of Cohen's d effect size clarified the amount of differences between variables between the pre and post tests and between groups performances, it was classified as shown in (Table 3.) for positive (as an increase) and negative (as a decrease) Effect Sizes [19]; And to clearly assess results practical meaning, Sprint performance Times (split times) were analyzed using the magnitude-based inference approach [19] Therefore the smallest worthwhile change (SWC) was used to determine the degree of improvement necessary to ensure a meaningful change in performance. calculated for different effect sizes as:

$$SWC_X = X * SD_{\text{between subject}}$$

with X= effect size 0,2 or 0,6.

Moreover, the standard error of measurement (SEM) calculated to evaluate the absolute reliability and to provides a direct measure of the amount of error associated with the test a SEM < 10% was deemed acceptable. (SEM) formula:

$$SEM= SD_{pooled} * \sqrt{(1 – ICC)}.$$

SD_{pooled} = Standard Deviation pooled between participant's standard deviation.

The model's ability to detect changes was considered marginal while SEM ≥ SWC, satisfactory while SEM = SWC and good while SEM ≤ SWC.

3. Results

The mean session compliance was 93% and 97% for CTG and CG respectively after removing data of participant not achieving (i.e. ≥ 80% of sessions). All data for sprint performance and mechanical variables was normally distributed (p = 0.61 to 0.20), except the force-velocity slope (S_{FV}) variable (p = 0.018).

3.1.1. linear sprint performance

Regarding the reproducibility of split times performance, results show high reproducibility for 5m split time (CV < 5%, ICC > 0.75) and very high reproducibility (ICC > 0.80) for 10m and 15m with (CV < 4%) and for 20m, 25m and 30m split time with (CV < 3%) respectively. Reliability measures, Overall mean ± SD with (95% CI) standard error of measurement (SEM), the smallest worthwhile change (SWC) and data for sprint performance (split times) are illustrated in (Table 4.).

The standard error of measurement (SEM) for all split times performance ranges from 3.36% to 3.59% and it was absolutely higher than $SWC_{0.2}$ (range from 1.4% to 1.6%) whereas, it was lower than $SWC_{0.6}$ (range from 4.21% to 4.94%) all conveyed as a percentage of mean performance at baseline, indicating that our model of measurement allows marginal detection (SEM ≥ SWC) for small changes (*ES* ≤ ± 0.2) and good detection (SEM ≤ SWC) for at list moderate (*ES* ≥ ±0.6) changes in split times performance.

Scores pre-post-intervention and mean changes in sprint split time performances including effect sizes (95% CI) and the change ratio from the pre-test scores (Δ%) are displayed in Table 4 for experimental (CTG) and control group (CG) respectively.

Large to very large improvement was noticed for the experimental group (CTG) with lower values in split times, the corresponding effect sizes ranged from -1.97 (i.e., large) to -2.46 (i.e., very large) at $p < 0.01$ as shown in (Table 4.), the improvement in time performance ranged from -6.91 to -11.73% compared to baseline and it's deemed below the $SWC_{-0.6}$ and considered as a clear improvement in performance. However, for the control group (CG) a moderate improvement was noticed, the effect sizes raged from -0.74 to -1.04 (i.e., moderate) at $p < 0.05$ and the coefficient of variation ranged from -1.24 to -2.60% compared to baseline which in zone of marginal consideration as improvement ($>SWC_{-0.2}$ and $<SWC_{-0.6}$).

The independent t-test for independent samples between CTG and CG was associated with a statistically significant effect in all sprint split time performances, t-values ranged from 7.06 to 9.46, with degree of freedom range 50 – 57 at $p < 0.01$. Thus, the CTG was associated with less values in times performances, the *ES* was ranging from large (-1.63) to very large (-2.17) at $p < 0.01$.

Table 1. Age and anthropometric characteristics for students per group (Mean ± standard deviation)

	Pre-test M ± SD		**Post-test M ± SD**	
	CG (N=38)	**CTG (N=42)**	**CG (N=38)**	**CTG (N=42)**
Body mass (kg)	50.19 ± 9.87	55.94 ± 7.77	50.14 ± 7.84	53.77 ± 8.68
Height (m)	1.61 ± 0.11	1.67 ± 0.08	1.62 ± 0.11	1.71 ± 0.10
BMI(kg.m^{-2})	19.41 ± 2.79	19.74 ± 2.23	18.96 ± 2.73	18.47 ± 3.58
Age (years)	15.54 ± 0.91	15.21 ± 0.85	—	—

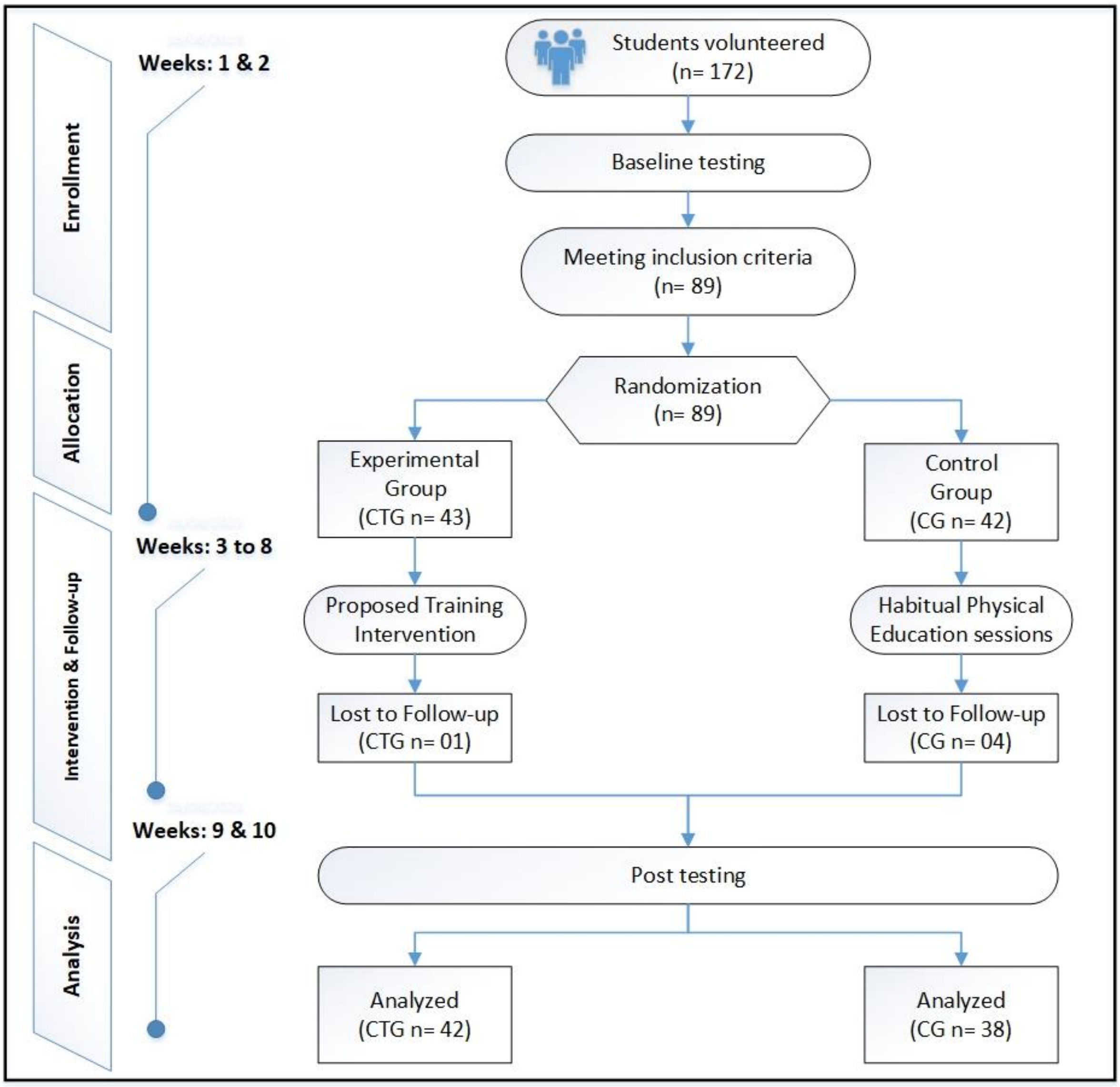


Figure 1. Diagram of the study design as a flow chart.

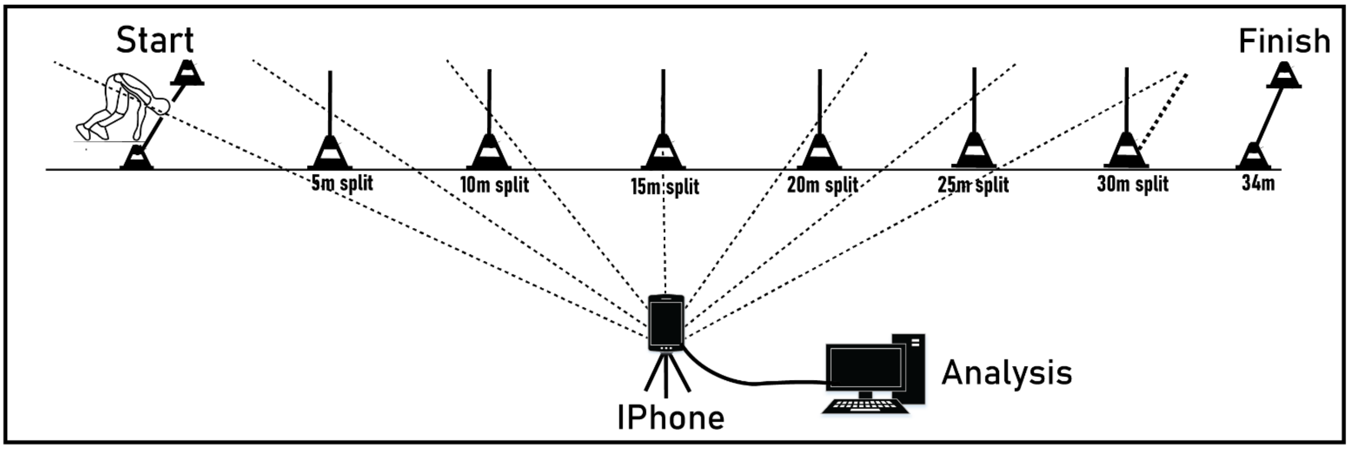


Figure 2. the experimental set-up for linear sprint run

Table 2. The proposed combined training program

Period	Exercises		Volume (Set x Repetition; Load; direction)		
			Session 1	**Session 2**	**Session 3**
I. Low intensity plyometric (jumps in place- stand hops)	1- Double Leg Squat [b] 2- Lunge Squat [a] 3- Double Leg Hops [b] 4- Stand broad jumps [b] 5- Trunk Curl		2 x 10; BW; IP 2 x 12; BW; IP 2 x 6; BW; IP 1 x 6; BW; IP 2 x 6	2 x 10; BW; IP 2 x 12; BW; IP 2 x 6; BW; IP 1 x 6; BW; IP 2 x 6	2 x 10; MB; IP 2 x 10; MB; IP 2 x 10; BW; IP 2 x 6; BW; IP 2 x 6
	Recovery	Inter-sets	60s	60s	60s
		Inter- exercises	90s	90s	90s
	Total Foot Contact (per session)		76	62	62
II. Medium intensity plyometric (Multiple bilateral jumps)	1- CMJs [b] 2- Low Hurdle Jump [b] 3- Side to Side jump [b] 4- Lunge Walk/Jump [b] 5- Prone Plank		3 x 8; BW; IP 3 x 6; BW; F 3 x 8; BW; L 1 x 8; BW; F 2 x 10 sec	3 x 8; BW; IP 3 x 6; BW; F 3 x 8; BW; L 1 x 8; BW; F 2 x 10 sec	3 x 8; BW; IP 3 x 8; BW; F 3 x 10; BW; L 1 x 10; BW; F 3 x 10 sec
	Recovery	Inter-sets	90s	90s	90s
		Inter- exercises	120s	120s	120s
	Total Foot Contact (per session)		76	76	76
III. Medium intensity plyometric (Multiple Unilateral jumps)	1- Lateral Abduction Hops [a] 2- Skipping Drills [a] 3- Single Leg Hop [a] 4- Leg Bonding [a] 5- Push-up		3 x 8; BW; L 3 x 8; BW; F 3 x 8; BW; IP 2x 8; BW; F 2 x 6	3 x 8; BW; L 3 x 8; BW; F 3 x 8; MB; IP 2 x 8; BW; F 2 x 8	3 x 6; MB; L 3 x 10; BW; F 3 x 10; BW; F 3 x 8; BW; F 2 x 10
	Recovery	Inter-sets	90s	90s	90s
		Inter- exercises	180s	180s	180s
	Total Foot Contact (per session)		88	88	90
IV. Medium intensity plyometric (Multiple Unilateral jumps + sprint)	1- Skipping to run [a] 2- Ankle Bonding to run [a] 3- Hurdle Hoping to run [a] 4- Bonding to run [a] 5- Side Plank		2 x 8; BW; 5m 2 x 8; BW; 5m 3 x 8; BW; 10m 2x 8; BW; 10m 2 x 10 sec	2 x 8; BW; 5m 2 x 8; BW; 5m 3 x 8; BW; 15m 2x 8; BW; 15m 2 x 10 sec	2 x 8; BW; 10m 2 x 8; BW; 10m 2 x 8; BW; 20m 2x 8; BW; 20m 2 x 10 sec
	Recovery	Inter-sets	90s	90s	90s
		Inter- exercises	180s	180s	180s
	Total Foot Contact (per session)		72	72	64
	Total Distance sprint		20m	40m	60m

**BW= bodyweight, MB= medicine ball, IP= in place, F=Forward, L=Lateral, a=Alternate, b=Bilateral, m= meter, s= second.*

Table 3. the interpretation of positive and negative Cohen's *d* Effect Sizes.

Magnitude	Negative Effect Size	Positive Effect Size
Trivial	< -0.20	<0.20
Small	$-0.20 < d < -0.60$	$0.20 < d < 0.60$
Moderate	$-0.60 < d < -1.20$	$0.60 < d < 1.20$
Large	$-1.20 < d < - 2.0$	$1.20 < d < 2.0$
Very Large	$-2.0 < d < -4.0$	$2.0 < d < 4.0$
Extremely Large	> -4.0	> 4.0

Table 4. Results for pre-post sprint time performances analysis for experimental group [CTG] and control group [CG] with within group effect sizes at 95% confidence interval

Performance Time			Mean	SD	Δ%±SD	t-value	df	*p*-value (2-tailed)	ES (95% CI)
5m split (s)	**CTG**	**Pre-test**	1.597	0.099	-11.73 ± 4.64	-14.491	41	$p < 0.01$	-2.23 (-2.80 to -1.66)
		Post-test	1.407	0.059					
	CG	**Pre-test**	1.630	0.106	-2.60 ± 2.31	-6.413	37	$p < 0.01$	-1.04 (-1.43 to -0.64)
		Post-test	1.588	0.104					
10m split (s)	**CTG**	**Pre-test**	2.475	0.137	-9.27 ± 3.37	-15.986	41	$p < 0.01$	-2.46 (-3.07 to -1.85)
		Post-test	2.243	0.091					
	CG	**Pre-test**	2.598	0.201	-2.25 ± 2.28	-6.413	37	$p < 0.01$	-1.00 (-1.39 to -0.61)
		Post-test	2.540	0.201					
15m split (s)	**CTG**	**Pre-test**	3.261	0.186	-8.06 ± 2.92	-15.917	41	$p < 0.01$	-2.45 (-3.06 to -1.84)
		Post-test	2.995	0.133					
	CG	**Pre-test**	3.405	0.257	-1.60 ± 2.00	-5.100	37	$p < 0.01$	-0.82 (-1.19 to -0.45)
		Post-test	3.350	0.262					
20m split (s)	**CTG**	**Pre-test**	3.977	0.233	-7.41 ± 3.03	-14.211	41	$p < 0.01$	-2.19 (-2.75 to -1.62)
		Post-test	3.678	0.152					
	CG	**Pre-test**	4.206	0.337	-1.44 ± 1.80	-5.236	37	$p < 0.01$	-0.84 (-1.21 to -0.47)
		Post-test	4.146	0.342					
25m split (s)	**CTG**	**Pre-test**	4.786	0.295	-7.19 ± 3.16	-13.073	41	$p < 0.01$	-2.01 (-2.54 to -1.48)
		Post-test	4.435	0.177					
	CG	**Pre-test**	5.018	0.401	-0.71 ± 2.40	-2.152	37	$p < 0.05$	-0.74 (-0.87 to -0.41)
		Post-test	4.980	0.376					
30m split (s)	**CTG**	**Pre-test**	5.496	0.351	-6.91 ± 3.13	-12.806	41	$p < 0.01$	-1.97 (-2.49 to -1.44)
		Post-test	5.108	0.225					
	CG	**Pre-test**	5.805	0.489	-1.24 ± 1.61	-5.164	37	$p < 0.01$	-0.83 (-1.20 to -0.46)
		Post-test	5.735	0.503					

Table 5. Results for pre-post sprint mechanical outputs analysis for experimental group [CTG] and control group [CG] with within group effect sizes at 95% confidence interval:

Mechanical variables			**Mean**	**SD**	**Δ%±SD**	**t or z-value**	***p*-value (2-tailed)**	**ES (95% CI)**
HZT-F0 (N·kg^{-1})	**CTG**	**Pre-test**	5.986	0.782	31.50 ± 18.60	14.015	$p < 0.01$	2.16 (1.60 to 2.71)
		Post-test	7.776	0.778				
	CG	**Pre-test**	5.712	0.751	4.92 ± 5.88	5.725	$p < 0.01$	0.92 (0.54 to 1.30)
		Post-test	5.983	0.791				
HZT-V0 (m·s^{-1})	**CTG**	**Pre-test**	7.215	0.601	2.79 ± 7.93	1.888	0.066	0.29 (-0.01 to 0.59)
		Post-test	7.374	0.244				
	CG	**Pre-test**	6.757	0.725	-0.32 ± 1.11	-1.499	0.142	-0.24 (-0.56 to 0.08)
		Post-test	6.739	0.758				
HZT-Pmax (W·kg^{-1})	**CTG**	**Pre-test**	10.876	1.848	36.51 ± 22.19	15.943	$p < 0.01$	2.46 (1.84 to 3.06)
		Post-test	14.523	1.327				
	CG	**Pre-test**	9.731	2.106	5.65 ± 4.95	9.249	$p < 0.01$	1.50 (1.03 to 1.96)
		Post-test	10.253	2.169				
RF max (%)	**CTG**	**Pre-test**	37.120	2.371	13.29 ± 6.42	14.595	$p < 0.01$	2.25 (1.67 to 2.82)
		Post-test	41.940	1.733				
	CG	**Pre-test**	35.180	3.458	2.30 ± 2.59	6.459	$p < 0.01$	1.04 (0.64 to 1.44)
		Post-test	35.953	3.299				
DRF (%)	**CTG**	**Pre-test**	-8.027	0.658	24.21 ± 11.84	-15.058	$p < 0.01$	-2.32 (-2.90 to -1.73)
		Post-test	-9.915	0.668				
	CG	**Pre-test**	-8.185	0.654	7.92 ± 7.31	-7.074	$p < 0.01$	-1.14 (-1.55 to -0.73)
		Post-test	-8.820	0.781				
Vopt (m·s^{-1})	**CTG**	**Pre-test**	3.608	0.332	2.00 ± 6.99	1.332	0.190	0.20 (-0.10 to 0.51)
		Post-test	3.660	0.149				
	CG	**Pre-test**	3.380	0.362	-0.35 ± 1.13	-1.663	0.105	-0.27 (-0.59 to 0.05)
		Post-test	3.370	0.379				
MSS (m.s^{-1})	**CTG**	**Pre-test**	6.871	0.578	4.15 ± 6.90	3.504	$p < 0.01$	0.54 (0.21 to 0.86)
		Post-test	7.121	0.273				
	CG	**Pre-test**	6.428	0.650	0.05 ± 0.78	0.556	0.582	0.09 (-0.22 to 0.40)
		Post-test	6.433	0.668				
F-V slope (N.m.s^{-1}.kg^{-1})	**CTG**	**Pre-test**	-0.819	0.092	30.06 ± 17.97	-5.645	$p < 0.01$	-0.87
		Post-test	-1.052	0.072				
	CG	**Pre-test**	-0.83	0.08	-0.25 ± 13.91	-3.140	$p < 0.05$	-0.48
		Post-test	-0.86	0.09				

** CTG: combined training group, CG: control group, CI = confidence interval; HZT-F0: relative Theoretical maximal horizontal force; HZT-V0: maximal theoretical velocity; HZT-Pmax: maximal horizontal power outcome; DRF: decrease in ratio of force; FV slope = force-velocity slope; RF max: maximal ratio of force; V opt = optimal velocity; W: watt; m: meter; Kg: kilogram; s: second; N: Newton.*

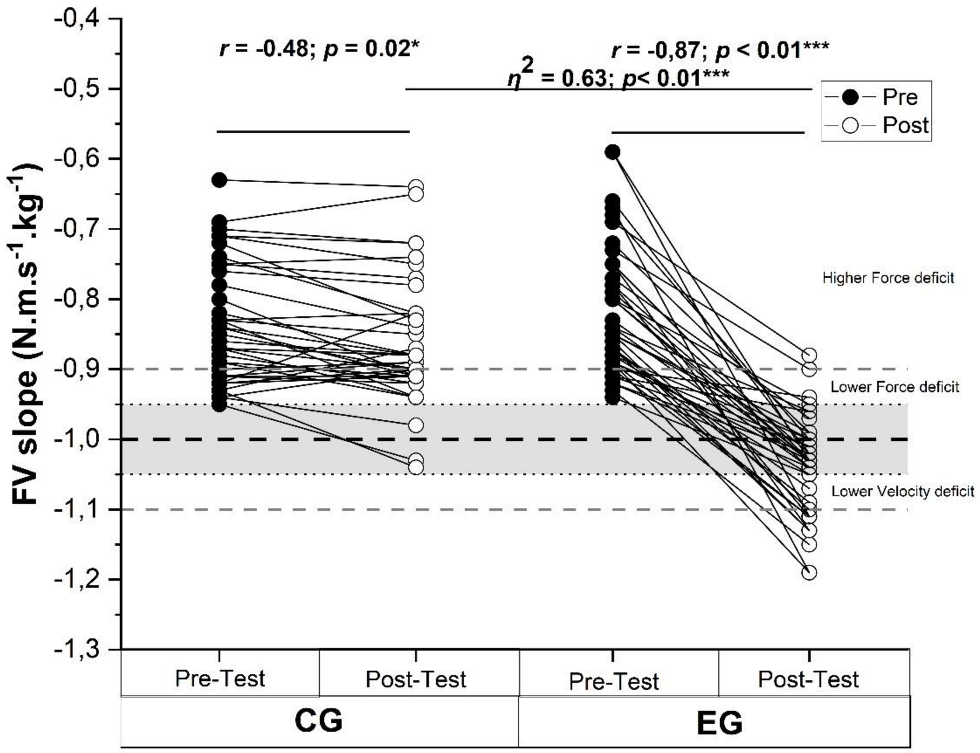
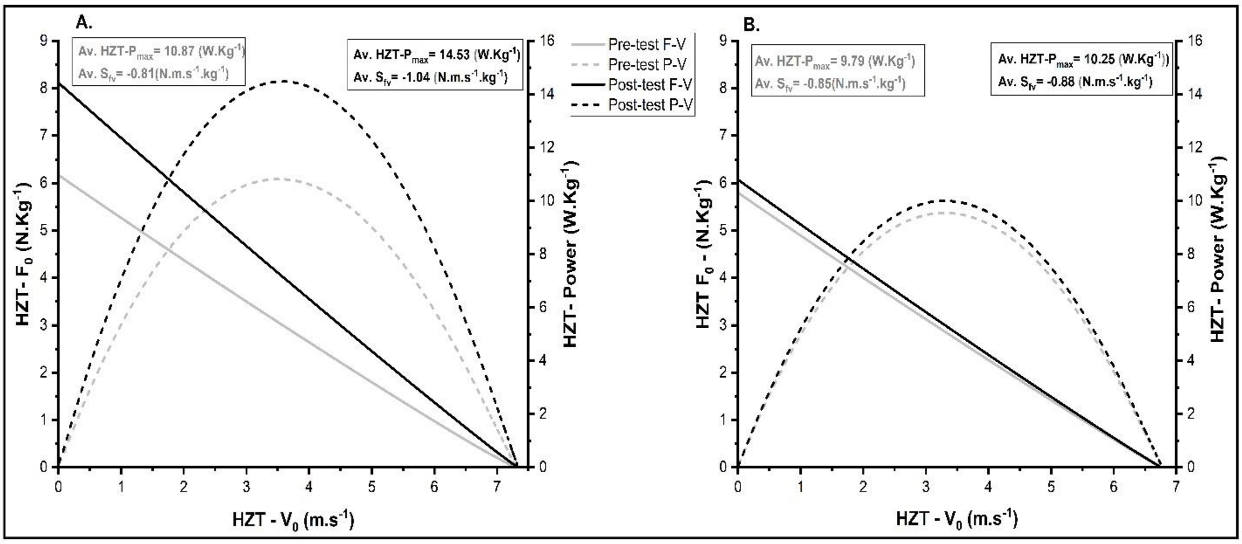


Figure 3. individual changes (connected lines), with within-group *r* effect size and between-groups eta squared (η^2) effect size, from pre- to post-intervention for CG (left) vs. CTG (right) in Force-Velocity Slope.



**F-V= force-velocity, Av. S_{FV}= group average F-V slopes, P-V= power-velocity, Av. HZT-Pmax = group average maximal Horizontal Power.*

Figure 4. Average of force-velocity power-velocity profile of sprint running for (A.) Experimental group [CTG]; (B.) Control Group [CG] pre-and post-6-week intervention.

3.1.2. Force-Velocity Variables

Scores from pre and post-intervention and mean changes in sprint mechanical output variables with effect sizes at 95% confidence interval (95%CI) and the change ratio (Δ%) are displayed in (Table 5) for experimental and control groups respectively. The independent t-test for independent samples between CTG and CG reported significant differences in all Sprint mechanical output variables, therefore the CTG was associated with better values with very large effect size for the relative theoretical maximal horizontal force HZT-F0 ($N\cdot kg^{-1}$) ($t_{(78)}$= -10.209, *d*= 2.28, $p < 0.001$),for the relative maximal mechanical power HZT-P_{max} (W/kg) ($t_{(60)}$= 10.490, *d* = 2.38, $p < 0.001$) and maximal ratio of force RF_{max} (%) ($t_{(55)}$= 10.008, *d* = 2.28, $p < 0.001$) and moderate effect size for the theoretical maximal velocity HZT-V0($m\cdot s^{-1}$),for the rate of decrease in ratio of force DRF (%), for the optimal velocity V_{opt} ($m\cdot s^{-1}$) and the maximal sprint speed MSS ($m.s^{-1}$) with effect sizes ranges from 1.01 to 1.60 at $p < 0.01$. Whereas Mann-Whitney U test for F-V Slope ($N.m.\ s^{-1}.kg^{-1}$) result indicated that CTG (-1.05 ± 0.07) had significantly improved their values than CG (-0.84 ± 0.08) with very large effect size ($\eta^2 = 0.63$), *Z*=-7.054 at $p < 0.001$ as graphically shown in (Figure 3.). Average groups pre and post-intervention changes in sprint force-velocity profile over 30-meters are illustrated in (Figure 4.). The assessment of the post intervention Force-Velocity profiles highlighted 73.76% of students (31/42) in the experimental group had a F-V ratio ranges ($S_{FV} = -1\pm0.1$), 57.1% of them (24/42) presented an equilibrated Force-Velocity profile ($S_{FV} = -1\pm0.5$) however only 4.75% of them still had lower force deficit in their F-V profile ($S_{FV} <-0.90$) in comparison to control group which 44.73% of students (17/38) still have a F-V profile oriented deficit force ($S_{FV} < -0.9$) and only 1.5% of them modified their profile to more equilibrated ratio ($S_{FV} = -1\pm0.5$).

4. Discussions

The present study was conducted to investigate the effects of a 6-week proposed sprint teaching-training program combining bodyweight and plyometric training on sprint time performance, considering the subsequent changes in sprint mechanical outputs (kinematics) in youth student boys with deficit force in their F-V profile in comparison to a control group adopting a within-between-group analysis approach as most similar studies in the field of sport and physical education [20]. To the best of our knowledge, this is the first investigation that has examined the effect of a custom training intervention while concentrating on mechanical outputs to remediate the deficit of force in the sprint F-V profile continuum onto untrained physical education students. Considering the results of the 6-week training intervention, the CTG compared to the baseline had significantly improved their linear speed time performance, results indicated large to very large significant improvements in linear sprint split time performances from 5 to 30-meters (*d* =-1.97 to -2.46) in line with our first hypothesis. However, CG showed moderate changes (*d*=-0.74 to-1.04). Additionally, results of between-group differences had shown large to very large significant differences for all linear sprint split time (*d* = -1.63 to -2.17) in favor of the CTG (table 4). Moreover, individual changes in CTG indicate a substantial proportion of participants (93%) demonstrated a decrease in 5 m, 10 m and 15 m (83%) in 20 m (81%) in 25 m and (74%) in 30m sprint split-time performance greater than the smallest worthwhile change $SWC_{0.6}$ (>SEM) referring to a “true improvement” in performance throughout the intervention. In contrast, only (5.3%) of participants showed a decrease in 5 m, 10 m, 15 m, 20 m and 25 m and (2.6%) in 30m sprint split-time performance greater than the $SWC_{0.6}$ for CG and classified as below “true changes” [19] and can’t be associated with a clear learning effect. These results demonstrate that our intervention approach was successful in improving linear speed across all split times analyzed, as a real change in performance ($SEM<SWC_{0.6}$) however changes observed in CG was at marginal consideration ($SWC_{0.2}<SEM<SWC_{0.6}$) highlighting the significance of a personalized approach when assessing the efficacy of training interventions taking the smallest worthwhile change as magnitude based inference [19]. The improvement in split sprint times by (-6.91% to -11.73%) was associated with significant improvements in mechanical output variables (Table 5) especially the production of force at lower velocity (HZT-F0) by (31.50% ± 18.60) and the horizontal maximal power (HZT-P_{max}) by (36.51% ± 22.19), thus the ability levels in sports can be distinguished by high anaerobic power outputs, which are regarded as fundamental characteristics for performance [9] and linked with the overall of sprint performance; Students with weak force side of the F-V spectrum most probably present a high relative maximal velocity (HZT-V0) capabilities, which can explain the insignificant changes ($p > 0.05$) in the theoretical maximal velocity HZT-V0, also the visual analysis of the average Pre-Post F-V profile (Figure 4) identified a big shift of the F-V curve upward and to the right for the CTG in line with our second hypothesis. However, changes in mechanical characteristics for the control group was small to moderate improvements (*ES*: -1.19 to 1.50); Where is, results showed moderate to very large differences in HZT-F0 (*d* = 2.28), HZT-P_{max} (*d* =2.38), RF_{max} (d =2.28) and maximal sprint speed MSS (*d* =1.35) with values in favor of the experimental group at $p < 0.01$ when the two groups were compared. In addition, CTG had shown significant improvement in the maximum ratio of force (RF_{max}) by (13.29% ± 6.42), indicating a greater amount of antero-posterior force applied to the ground during sprinting in comparison to the total ground reaction force (F_{TOT}), the induced ground reaction force vector orientation change will ultimately lead to an improvement in horizontal velocity upon the stance phase [21] as a result of improving technical ability and the angle of the application of the force, thereby, this increase in (RF_{max}) as reported by *Morin and al.* [22] would lead the ground reaction force to be more horizontally oriented during the first steps of the acceleration, impacting the ability to accelerate in accordance with Newton's laws of motion and reducing time performance in stance (contact time) and overall sprint performance, which can explain the enhancement observed in sprint performance in the CTG and demonstrate the efficiency of the proposed training program to improve qualitatively force production in sprint running.

Linear sprint performance is defined by the concomitant expression of force and velocity [8] the force-velocity slop (S_{FV}) displays the subject’s individual ratio of force (i.e., HZT-F0) with regard to velocity (i.e., HZT-V0). In reference to our third hypothesis, and post intervention, the force-velocity slop (S_{FV}) was shifted to a more equilibrated rapport (S_{FV}= -1.05 ± 0.07) (*ES*: -0.87) and a more balanced F-v profile [13] was noticed at the post-test for the CTG (Fig.

3). This results in line with our initial hypothesis, regarding significant changes noticed in performance and its mechanical characteristics due to the transfer of the training effect to the production of force at lower velocity in the early acceleration phase, the training program used in this study was able to address the lack of force production in lower velocity (the early acceleration) to enhance linear speed. The findings support these biomechanical changes in performance, by large to very large effect sizes for relative and absolute maximal theoretical force and sprint performance for 5 m and 10m split times ($-1.66 \leq ES \geq 2.71$). The amount of improvement in sprint mechanical outcomes observed in the present study may be explained by the effect of plyometric exercises commonly used to develop maximum force in a short amount of time by training the stretch-shortening cycle (SSC) allowing using stored elastic energy, which enhances strength and power, also improvement in coordination and students' capacity to quickly raise muscle tension, which increases the maximal rate of force development (RFD) that increases the mechanical force outcome required for explosive anaerobic movement such as sprinting. Plyometric training has been approved safe for a pediatric population and might increase youth's capacity to develop power and speed [23] when appropriate training design and guidelines are carried out, and have a significant potential to enhance sprint performance, especially plyometric exercises horizontally oriented showing similar biomechanical patterns to sprint running and comparable ground contact times during the initial early sprint acceleration as reported by Maria z. et al. [24] and increases muscle fibers (type II) recruitment in the muscles involved in sprint running, which increases propulsive force production, which enhances the acceleration in sprint running. The bodyweight training was taking part of this training program in absence of adequate strength and resistance training material in schools (the Moroccan case for example), bodyweight training can be an alternative and a plausible option [25], in addition to its efficiency in enhancing balance, postural control, and relative strength [26], [27] and in contrast to traditional resistance training (externally loaded), bodyweight exercise promotes awareness of space and general motor skills while maximizing relative strength [28] and its proponents argue that this approach enables exercises to be adjusted to each person's anthropometric characteristics, allowing for better individualization and easy must be managed to prevent injuries [29]. Remarkably, the proposed teaching-training program did enhance almost all the force-velocity sprint outputs variables (i.e., HZT-F0, HZT-P_{max}, RF_{max} and MSS) especially the maximal theoretical horizontal force (HZT-F0), maximal horizontal power (HZT-P_{max}) and force-velocity slope (S_{FV}) indicating that sufficient input was provided to trigger significant changes in several mechanical outcome metrics in addition to sprint time performance.

5. Conclusions

The findings of this intervention study indicate that a program combining bodyweight to plyometric teching-training approach may be a good decision-making for students with deficit force at lower velocity in their force-velocity profile when attempting to remediate their mechanical outputs underlining their sprint performance and elicit motor learning by targeting sprinting-specific biomechanical technical factors, in this case improving the theoretical maximal horizontal force HZT-F0 matters more than the theoretical maximal velocity HZT-V0 when it comes to improve the maximal horizontal power HZT-P_{max}. Practically speaking, this suggests an eventual window of trainability to improve the overall sprint running performance by focusing on the force side of the force-velocity curve applying a program that combines bodyweight and plyometric training.

6. Recommendations

In line with the results of this study, we present the following practical recommendations:

- ✓ We encourage sport practitioners, physical education teachers and coaches to adopt this biomechanical approach (described rigorously in this paper) when evaluating their students or athletes to get practical information underlining the sprint performance in contrast to sprint time performance only.
- ✓ We encourage the adoption of this type of programs to enhance anaerobic power and efficient force production in sprinting. The program presented, especially plyometric training establishes previous recommendations when targeting strength, power and force production in monitoring sprint running.
- ✓ We encourage the introduction of bodyweight exercises when dealing with youth unexperienced population it can be an alternative and a plausible option in absence of adequate strength and resistance training material as the case in schools, and enables exercises to be adjusted to each person's anthropometric characteristics, allowing for better individualization and easy managed to prevent injuries.

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