Original Paper DOI: https://doi.org/10.5114/biolsport.2022.103575

Comparing the effects of plyometric and isometric strength training on dynamic and isometric force-time characteristics

AUTHORS: Danny Lum[1,2], Paul Comfort[3,4], Tiago M. Barbosa[2,5,6], Govindasamy Balasekaran[2]

[1] Sport Science and Sport Medicine, Singapore Sport Institute, Singapore, Singapore
[2] Physical Education and Sports Science, National Institute of Education, Nanyang Technological University, Singapore, Singapore
[3] Directorate of Sport, Exercise, and Physiotherapy, University of Salford, Salford, Greater Manchester M6 6PU, UK
[4] Centre for Exercise and Sports Science Research, Edith Cowan University, Joondalup, WA 6027, Australia
[5] Polytechnic Institute of Braganca, Braganca, Portugal
[6] Research Centre in Sports, Health and Human Development (CIDESD), Vila Real, Portugal

ABSTRACT: The purpose of the study was to compare the change in dynamic and isometric force-time characteristics after plyometric (PLYO) or isometric strength training (ISO). Twenty-two endurance runners (age = 37 ± 6 years, stature = 1.71 ± 0.05 m, body mass = 62.7 ± 8.6 kg, weekly mileage = 47.3 ± 10.8 km) performed a countermovement jump (CMJ) and isometric mid-thigh pull (IMTP) test during pre- and post-tests. They were then randomly assigned to either PLYO or ISO group and completed 12 sessions of intervention over six weeks. The PLYO included drop jump, single leg bounding and split jump, and the ISO included IMTP and isometric ankle plantar flexion. Significant and large time x group interactions were observed for CMJ countermovement depth ($P = 0.037$, $\eta^2_p = 0.21$) and IMTP and relative peak force (PF) ($P = 0.030$, $\eta^2_p = 0.22$). Significant and large main effects for time were observed in CMJ height, peak power, propulsive phase duration, countermovement depth, reactive strength index modified, IMTP PF and relative PF ($P < 0.05$, $0.20 \leq \eta^2_p \leq 0.65$). Effect for time showed small improvement in CMJ height for both PLYO ($P < 0.001$, $d = 0.48$) and ISO ($P = 0.009$, $d = 0.47$), small improvement in CMJ PP in PLYO ($P = 0.020$, $d = 0.21$), large increase in countermovement depth ($P = 0.004$, $d = 1.02$) and IMTP relative PF ($P < 0.001$, $d = 0.87$), and moderate increase in propulsive phase duration ($P = 0.038$, $d = 0.65$) and IMTP PF ($P < 0.001$, $d = 0.55$) in ISO. There were large differences between groups for percentage change in countermovement depth ($P = 0.003$, $d = 0.96$) and IMTP relative PF ($P = 0.047$, $d = 0.90$). In conclusion, both PLYO and ISO improved CMJ jump height via different mechanisms, while only ISO resulted in improved IMTP PF and relative PF.

CITATION: Lum D, Comfort P, Barbosa TM, Balasekaran G. Comparing the effects of plyometric and isometric strength training on dynamic and isometric force-time characteristics. Biol Sport. 2022;39(1):189–197.

Received: 2020-11-28; Reviewed: 2021-01-09; Re-submitted: 2021-01-21; Accepted: 2021-02-01; Published: 2021-03-07.

Corresponding author:
Danny Lum
3 Stadium Drive
Singapore 397630, Singapore
Tel.: +65 97290819
E-mail: dannylum82@gmail.com

ORCID:
Danny Lum
0000-0002-8908-3791

Paul Comfort
0000-0002-1131-8626

Tiago M. Barbosa
0000-0001-7071-2116

Govindasamy Balasekaran
0000-0001-6101-2695

Key words:
Isometric mid-thigh pull
Countermovement jump
Peak power
Reactive strength index modified

INTRODUCTION

Various forms of strength training including free weights, plyometrics (PLYO) and isometric strength training (ISO) have been used with the purpose of increasing force production to enhance athletic performances [1, 2]. The force producing capacity of a muscle is influenced by the muscle action (i.e. concentric, eccentric, isometric), due to differences in neural activation [3, 4]. Furthermore, each mode of strength training has been shown to result in different magnitude of adaptation to muscle hypertrophy, strength and power [1, 2]. Although eccentric strength training has been reported to induce enhanced hypertrophic response as compared to other modes of strength training [2], comparison of strength increases remains controversial as magnitude of adaptation resulting from each different mode of strength training is dependent on the method of assessment (i.e. eccentric training will induce greater increment in eccentric strength; concentric training will induce greater increment in concentric strength; and ISO will induce greater increment in eccentric strength) [1], indicating that adaptation is specific to the method of training.

Isometric strength training is characterised by the exertion of force without external movement. Increases in strength associated with this mode of training are dependent on several factors including the joint angle at which training occurs, duration, intensity and rate at which force is developed [1]. Researchers have also shown that ISO results in the improvement of various sports related movements [5–8]. In addition, the results of a recent study indicated that the inclusion of ISO to a traditional strength training intervention improved 3 repetition maximum squat performance to a greater magnitude than traditional strength training alone in powerlifters (10.4% vs 3.5%) [9]. Together, the results of the aforementioned studies indicate that ISO is a viable option to include in athletes' training regimes to enhance strength and dynamic performances.

Plyometric training is another form of training used to enhance force production characterised by ballistic movements that make use of the stretch shortening cycle, whereby a concentric muscle action is enhanced by prior eccentric muscle action of the muscle, enhancing force production through both neurological potentiation and storage and release of elastic energy [10–12]. This form of training includes jumping exercises that involves short (< 250 ms) (e.g. hopping) or long (> 250 ms) (e.g. countermovement jump) ground contact time [11], and is often included into strength training program to improve rapid force production [2, 10]. Plyometric training has also been shown to benefit various athletic performances [13–18].

To date, only two studies have compared the effects of PLYO and ISO on neuromuscular adaptations [19, 20]. It was reported that ISO resulted in greater increases in tendon stiffness and isometric force production, but lower improvements in jump height as compared to PLYO. In addition, ISO only improved jump height of a non-countermovement jump [19, 20]. These findings are in contrast with findings of other studies whereby ISO was shown to improve countermovement jump (CMJ) height [5, 7, 8]. This may be attributable to the fact that the ISO exercises used by Kubo et al. [20] was single joint exercise and executed at submaximal intensity while the exercises used by Bimson et al. [5] was executed at multiple joint angles, and that used by Lum et al. [7] and Lum and Joseph [8] were multi-joint exercise executed with maximal effort. In addition, despite showing the difference in the effects of PLYO and ISO on jump performances and morphological changes, Burgess et al. [19] and Kubo et al. [20] did not provide data on the changes in force-time characteristics which can provide practitioners with better understanding and comparison of the adaptations to the two modes of strength training. For example, acquiring information about countermovement depth and time to take off (which include all phases of the movement; unweighting, braking and propulsion phases) is important in understanding how a change in jump height is achieved [21]. Furthermore, the study conducted by Burgess et al. [19] and Kubo et al. [20] used participants who were not from athletic population, suggesting that the results might not be applicable to individuals of higher training status. In view of the gap in the literature, the purpose of this study was to compare the change in dynamic and isometric force-time characteristics after undergoing a period of either PLYO or ISO. It was hypothesized that PLYO and ISO would result in similar improvement in jump performance while ISO would result in greater improvement in isometric strength measures.

MATERIALS AND METHODS

Experimental Procedure

A randomized control trial research design was selected. Participants were required to complete one preliminary testing session which included CMJ and isometric mid-thigh pull (IMTP) test. Subsequently, participants were randomly assigned to either PLYO or ISO group. Participants completed 6 weeks of intervention training twice per week. At the end of the intervention, participants repeated the 2 preliminary tests. This study was part of another study which aimed to compare the effects of PLYO and ISO on endurance running performance.

Participants

Sixteen male and six female endurance runners (n = 22, age = 37 ± 6 years, stature = 1.71 ± 0.05 m, body mass = 62.7 ± 8.6 kg, weekly mileage = 47.3 ± 10.8 km) were recruited for participation in this study, with n = 11 for each group. Participants have been running more than 30 km per week for the last six months; and have not sustained any lower limb injury for the last six months. Eight of the participants were participating in regular (2–3 time per week) resistance training prior to the study while the rest of the 14 participants did not have any prior resistance training experience. An equal number of participants with prior resistance training experience were assigned to each training group.

The experiments reported in the manuscript were performed in accordance with the ethical standards of the Helsinki Declaration and that the participants signed an informed consent form. The study received ethical approval from the institutional review board of the local university.

Testing Procedures

Participants were requested to refrain from consuming alcohol and caffeine, and from participating in intensive training sessions for 24 hrs prior to all testing sessions. During the pre- and post-testing sessions, participants completed the CMJ test and IMTP. All testing sessions began with 5 minutes of moderate intensity jogging on a motorized treadmill, followed by lower body exercises including body weight squat, single leg stiff leg deadlift, side lunges and calf raises. One minute of recovery period was provided prior to commencing the test for that day.

Countermovement Jump Test. The CMJ test was conducted prior to the IMTP and was performed on dual force plates (Force Decks, VALD Performance, FD4000, Queensland, Australia) sampling at 1000 Hz. Participants were asked to keep their arms akimbo to eliminate arm swing and maintain their back upright to reduce angular displacement of the hips. Participants performed 3 jumps, separated by 30 s rest intervals. The commercially available ForceDecks software (VALD Performance, ForceDecks, Queensland, Australia) was used to analyse and generate the CMJ variables using conventional methods [22]. Participants were asked to stand as still as possible for > 1 s prior to the commencement of the countermovement. Take-off was defined as the time point at which the total vertical force fell below the threshold of 20 N [23]. Dependent variables included; jump height was calculated based on velocity of centre of mass at take-off, using the impulse momentum relationship, PF, and peak power (PP), time to take off (TTO), unweighting, braking and propulsion phase duration, countermovement depth and reactive strength index modified (RSImod) obtained from highest CMJ height were recorded and analysed. The PF and PP were expressed normalized to body mass (e.g., PF / body mass). The unweighting phase was identified as the onset of movement through to the point at when negative velocity peaks (when force returns to body mass). The braking phase was identified at the time between peak negative velocity and returning to zero velocity (which corresponds to the peak countermovement displacement), and propulsion phase determined as the period when velocity exceeds 0.01m/s through to take-off. The RSImod was obtained by dividing CMJ height by CMJ TTO [24].

The IMTP was performed on the same dual force plates following the procedure described by Comfort et al. [25]. Participants were asked to adopt a posture that reflected the start of the second pull of the clean resulting in a knee flexion angle of 125–145^o and hip flexion angle of 140–150^o stance measured using a handheld goniometer. Participants were required to fully extend the elbows, hold on to the bar with hands strapped to the bar with lifting straps to prevent grip from being a limiting factor. Upon the tester's command, participants were instructed to pull, by driving their feet into the floor, 'as hard and fast as possible'. Participants had to maintain the tension for a period of 5 s. Participants performed the IMTP twice, if the PF was within 250 N between trials. Each attempt was separated by a 2 min recovery period. The highest force generated during IMTP was reported as the absolute PF [26]. Relative PF was calculated by dividing the PF by participant's body mass. In addition, force at 100, 150 and 200 ms ($Force_{100}$, $Force_{150}$ and $Force_{200}$, respectively) from the onset of pull were determined for each trial [25, 27]. The onset of pull was determined using an algorithm-based analysis program (NMP Technologies LTD., London, UK) that has been shown to produce high reliability [28].

Training

Participants were instructed to continue with their usual endurance training but refrain from other forms of lower limb resistance training. On all training sessions, participants were required to perform either PLYO or ISO (Table 1) followed by 20 min of treadmill running at individual marathon pace.

Participants commence each session with 15 min of warm up including, jogging, lunges, squats and submaximal vertical jumps. For PLYO, participants were instructed to jump to maximum height for drop jump and split jump, and maximum distance for single leg bounding, during each repetition. Participants were also instructed to minimise ground contact time for drop jump and single leg bounding. For ISO, participants were instructed to exert maximum force as fast as possible and hold each repetition for 3 s duration [7]. The IMTP was performed in the same position as during the test. While during the isometric ankle plantar flexion,

TABLE 1. Plyometric and isometric strength training program.

Week	PLYO	ISO
	Exercise x Sets* x Repetitions	Exercise x Sets# x Repetitions#
1	40 cm drop jump x 3 x 5 Single leg bounding x 3 x 5/side Split Jump x 3 x 5/side	Isometric ankle plantar flexion x 3 x 3 IMTP x 3 x 3
2	40 cm drop jump x 4 x 5 Single leg bounding x 4 x 5/side Split Jump x 4 x 5/side	Isometric ankle plantar flexion x 3 x 4 IMTP x 3 x 4
3	50 cm drop jump x 4 x 5 † Single leg bounding x 4 x 5/side †Split Jump x 4 x 5/side	Isometric ankle plantar flexion x 3 x 5 IMTP x 3 x 5
4	50 cm drop jump x 4 x 5 † Single leg bounding x 4 x 5/side †Split Jump x 4 x 5/side	Isometric ankle plantar flexion x 4 x 5 IMTP x 4 x 5
5	60 cm drop jump x 4 x 5 †† Single leg bounding x 4 x 5/side ††Split Jump x 4 x 5/side	Isometric ankle plantar flexion x 4 x 5 IMTP x 4 x 5
6	60 cm drop jump x 2 x 5 †† Single leg bounding x 2 x 5/side ††Split Jump x 2 x 5/side	Isometric ankle plantar flexion x 2 x 5 IMTP x 2 x 5

Note: * Rest (passive) intervals between sets for Ply were 3 minutes. # Rest (passive) intervals between sets and repetitions for Iso were 3 minutes and 2 s, respectively. † Subjects held a weight plate on each hand that adds up to 5% of their body weight. †† Subjects held a weight plate on each hand that adds up to 10% of their body weight.

participants stood upright where the hips and knees were fully extended, and ankle in 0° plantar flexion. A bar was placed on the shoulder and fixed in position. Participants were required to maximally plantar flex the ankles while maintaining the extended hip and knee positions.

Statistical Analyses

All tested variables are expressed by Mean (± 1SD) and 95% of confidence intervals. Within session test-retest reliability was assessed using two-way mixed intraclass correlation coefficients (ICC) and coefficient of variation (%CV) for all measured variables. ICC values were deemed as poor if ICC < 0.50; moderate 0.50–0.74; good if 0.75–0.90; and excellent if ICC > 0.90 [29]. Acceptable within-session variability was classified as < 10% [30]. Mixed ANOVAs (between- x within-participant analysis; 2 training groups x 2 testing times; $P \leq 0.05$) was performed for each variable. Effect size was computed by partial eta-squared (η^2_p) and deemed: without effect if $0 < \eta^2_p \leq 0.01$; small if $0.01 < \eta^2_p \leq 0.06$; moderate if $0.06 < \eta^2_p \leq 0.14$ and; large if $\eta^2_p > 0.14$ [31]. All assumptions to run ANOVAs have been checked beforehand, including normality and sphericity. Degrees of freedom were corrected whenever sphericity's assumption was violated. Paired T-test was used to determine if there was any change in test measures within group. Cohen's *d* was calculated as standardized effect size for mean comparisons and deemed: (i) trivial if $d < 0.20$; (ii) small *d* 0.20–0.49; (iii) moderate if *d* 0.50–0.80; and (iv) large if $d > 0.80$ [31].

RESULTS

The ICC and%CV data for all measured variables showed high repeatability (Table 2). Test-retest data indicated ICC between 0.89–1.00 and %CV between 0.54–9.87 for all CMJ measures, and ICC between 0.94–1.00 and%CV between 1.51–6.47 for all IMTP measures.

Pre- and post-test results for all CMJ and IMTP measures are displayed in Table 3 and Table 4, respectively. Large time x group interactions were observed in countermovement depth ($P = 0.037$, $\eta^2_p = 0.21$), IMTP PF ($P = 0.071$, $\eta^2_p = 0.22$) and IMTP relative PF ($P = 0.030$, $\eta^2_p = 0.22$). Non-significant yet moderate time x group interactions were observed in CMJ PF, unweighting phase duration, RSImod and $Force_{150}$ ($P > 0.05$, $0.03 \leq \eta^2_p \leq 0.1$).

Significant large main effects for time were observed in CMJ height ($P < 0.001$, $\eta^2_p = 0.65$), CMJ PP ($P = 0.032$, $\eta^2_p = 0.21$), propulsion phase duration ($P = 0.021$, $\eta^2_p = 0.24$), countermovement depth ($P = 0.014$, $\eta^2_p = 0.288$), RSImod ($P = 0.022$, $\eta^2_p = 0.23$), IMTP PF ($P < 0.001$, $\eta^2_p = 0.53$) and relative PF ($P < 0.001$, $\eta^2_p = 0.53$). While non-significant but large effects were observed for $Force_{100}$ ($P = 0.073$, $\eta^2_p = 0.15$) and $Force_{200}$ ($P = 0.046$, $\eta^2_p = 0.18$). Non-significant, but moderate main effect for time was observed in CMJ PF ($P = 0.244$, $\eta^2_p = 0.07$). The effect for time showed significant and small improvements in CMJ height for both PLYO ($P < 0.001$, $d = 0.48$) and ISO ($P = 0.009$, $d = 0.47$). While a significant and small improvement in CMJ PP was observed in PLYO only ($P = 0.018$, $d = 0.31$). However, only ISO resulted in a significant and large increase in countermovement depth ($P = 0.004$,

TABLE 2. Reliability analysis of all measured variables.

	ICC	95%CI	%CV	95%CI
CMJ Height (cm)	1.00	0.99–1.00	1.20	1.00–1.50
CMJ PF ($N \cdot kg^{-1}$)	0.98	0.96–0.99	2.83	2.32–3.65
CMJ PP ($W \cdot kg^{-1}$)	1.00	0.99–1.00	1.65	1.36–2.13
CMJ TTO (s)	0.92	0.82–0.96	4.66	3.82–6.03
Unweighting Phase (s)	0.91	0.81–0.96	9.87	7.72–12.01
Braking Phase (s)	0.89	0.77–0.95	9.74	7.69–11.80
Propulsion Phase (s)	0.89	0.78–0.95	4.50	3.61–6.22
Countermovement Depth (cm)	0.93	0.85–0.96	3.48	2.77–4.75
RSImod ($m \cdot s^{-1}$)	0.97	0.94–0.99	4.03	3.30–5.21
IMTP PF (N)	1.00	0.99–1.00	1.25	1.03–1.61
IMTP Relative PF ($N \cdot kg^{-1}$)	1.00	0.99–1.00	1.25	1.03–1.61
$Force_{100}$ (N)	0.97	0.94–0.99	5.36	4.28–7.29
$Force_{150}$ (N)	0.98	0.95–0.99	4.71	3.76–6.39
$Force_{200}$ (N)	0.98	0.95–0.99	4.58	3.66–6.22

Note: ICC = intraclass correlation coefficient, CI = confidence interval, CV = coefficient of variation, CMJ = countermovement jump, PF = peak force, PP = peak power, TTO = time to take off, Depth = countermovement depth, RSImod = reactive strength index modified, IMTP = isometric mid-thigh pull, $Force_{100}$ = force at 100 ms, $Force_{150}$ = force at 150 ms, $Force_{200}$ = force at 200 ms.

TABLE 3. Analyses of countermovement jump measures.

		CMJ Height (cm)	CMJ PF ($N \cdot kg^{-1}$)	CMJ PP ($W \cdot kg^{-1}$)	CMJ TTO (s)	Unweighting Phase (s)	Braking Phase (s)	Propulsion Phase (s)	Countermovement Depth (cm)	RSImod ($m \cdot s^{-1}$)
PLYO	Pre	28.6 (6.3)	23.1 (1.8)	45.5 (7.2)	0.730 (0.067)	0.157 (0.046)	0.322 (0.043)	0.256 (0.028)	27.5 (5.8)	0.39 (0.08)
	Post	31.5 (5.9)	23.2 (2.7)	47.7 (6.9)	0.737 (0.108)	0.139 (0.028)	0.329 (0.066)	0.269 (0.043)	27.9 (7.1)	0.44 (0.11)
	(95% CI)	(2.0; 3.9)	(-1.3; 1.1)	(-4.0; -0.5)	(-0.06; 0.07)	(-0.052; 0.016)	(0.052; -0.067)	(-0.010; 0.036)	(-2.6; 3.5)	(< -0.01; 0.09)
	P	< 0.001	0.822	0.018	0.922	0.259	0.790	0.207	0.759	0.053
	d	0.48	0.04	0.31	0.11	0.47	0.13	0.36	0.06	0.52
ISO	Pre	28.6 (4.7)	23.9 (3.6)	44.4 (5.6)	0.754 (0.158)	0.137 (0.032)	0.352 (0.114)	0.266 (0.045)	27.1 (4.3)	0.39 (0.11)
	Post	31.1 (5.8)	22.7 (2.2)	46.5 (8.8)	0.767 (0.117)	0.139 (0.038)	0.344 (0.088)	0.284 (0.039)	31.7 (4.7)	0.42 (0.12)
	(95% CI)	(0.8; 4.3)	(-0.4; 2.9)	(-6.0; 1.7)	(-0.05; 0.07)	(-0.02; 0.03)	(-0.062; 0.047)	(-0.001; 0.034)	(-1.9; 7.3)	(-0.02; 0.07)
	P	0.009	0.127	0.244	0.650	0.812	0.767	0.038	0.004	0.222
	d	0.47	-0.4	0.28	0.14	0.06	0.08	0.65	1.02	0.26
Time x Group Interaction	F	0.194	2.179	0.002	0.069	1.246	0.166	0.111	5.047	0.597
	P	0.664	0.155	0.965	0.795	0.277	0.688	0.743	0.037	0.449
	η^2_p	0.01	0.10	< 0.01	< 0.01	0.06	0.001	< 0.01	0.21	0.03
Time Main Effect	F	37.640	1.444	5.294	0.167	0.693	< 0.001	6.263	7.384	6.123
	P	< 0.001	0.244	0.032	0.687	0.415	0.996	0.021	0.014	0.022
	η^2_p	0.65	0.07	0.21	0.01	0.03	< 0.01	0.24	0.28	0.23
Group Main Effect	F	0.006	0.021	0.140	0.318	0.562	0.554	0.687	0.572	0.024
	P	0.939	0.886	0.712	0.579	0.462	0.465	0.417	0.459	0.879
	η^2_p	< 0.01	< 0.01	< 0.01	0.02	0.03	0.03	0.03	0.03	< 0.01

Note: **Δ** = average change, CI = confidence interval, CMJ = countermovement jump, PF = peak force, PP = peak power, TTO = time to take off, Depth = countermovement depth, RSImod = reactive strength index modified.

TABLE 4. Analyses of isometric mid-thigh pull measures.

		IMTP PF (N)	IMTP Relative PF ($N \cdot kg^{-1}$)	$Force_{100}$ (N)	$Force_{150}$ (N)	$Force_{200}$ (N)
PLYO	Pre	2112.5 (409.6)	32.8 (5.6)	1136.5 (236.5)	1362.0 (305.0)	1586.0 (338.2)
	Post	2209.7 (448.7)	34.2 (5.1)	1194.9 (222.6)	1318.6 (448.4)	1697.0 (256.2)
	(95% CI)	(-35.4; 230.0)	(-0.7; 3.4)	(-62.9; 179.8)	(-294.5; 207.8)	(-49.0; 269.2)
	P	0.133	0.179	0.308	0.709	0.154
	d	0.23	0.26	0.25	-0.11	0.37
ISO	Pre	2040.9 (389.9)	33.5 (3.8)	1095.8 (321.7)	1379.5 (408.2)	1582.1(441.5)
	Post	2268.4 (440.4)	37.4 (5.1)	1181.4 (344.0)	1485.9 (440.5)	1713.5 (481.5)
	(95% CI)	(153.3; 301.6)	(2.6; 5.3)	(-32.9; 203.9)	(-51.5; 264.4)	(-65.5; 328.3)
	P	< 0.001	< 0.001	0.139	0.164	0.168
	d	0.55	0.87	0.26	0.25	0.28
Time x Group Interaction	F	3.642	5.487	0.127	1.266	0.035
	P	0.071	0.030	0.726	0.274	0.853
	η^2_p	0.15	0.22	< 0.01	0.06	< 0.01
Time Main Effect	F	22.659	22.696	3.581	0.224	4.517
	P	< 0.001	< 0.001	0.073	0.641	0.046
	η^2_p	0.53	0.53	0.15	0.01	0.18
Group Main Effect	F	0.001	0.890	0.055	0.337	0.001
	P	0.971	0.357	0.818	0.568	0.971
	η^2_p	< 0.01	0.04	< 0.01	0.02	< 0.01

Note: **Δ** = average change, CI = confidence interval, IMTP = isometric mid-thigh pull, $Force_{100}$ = force at 100 ms, $Force_{150}$ = force at 150 ms, $Force_{200}$ = force at 200 ms.

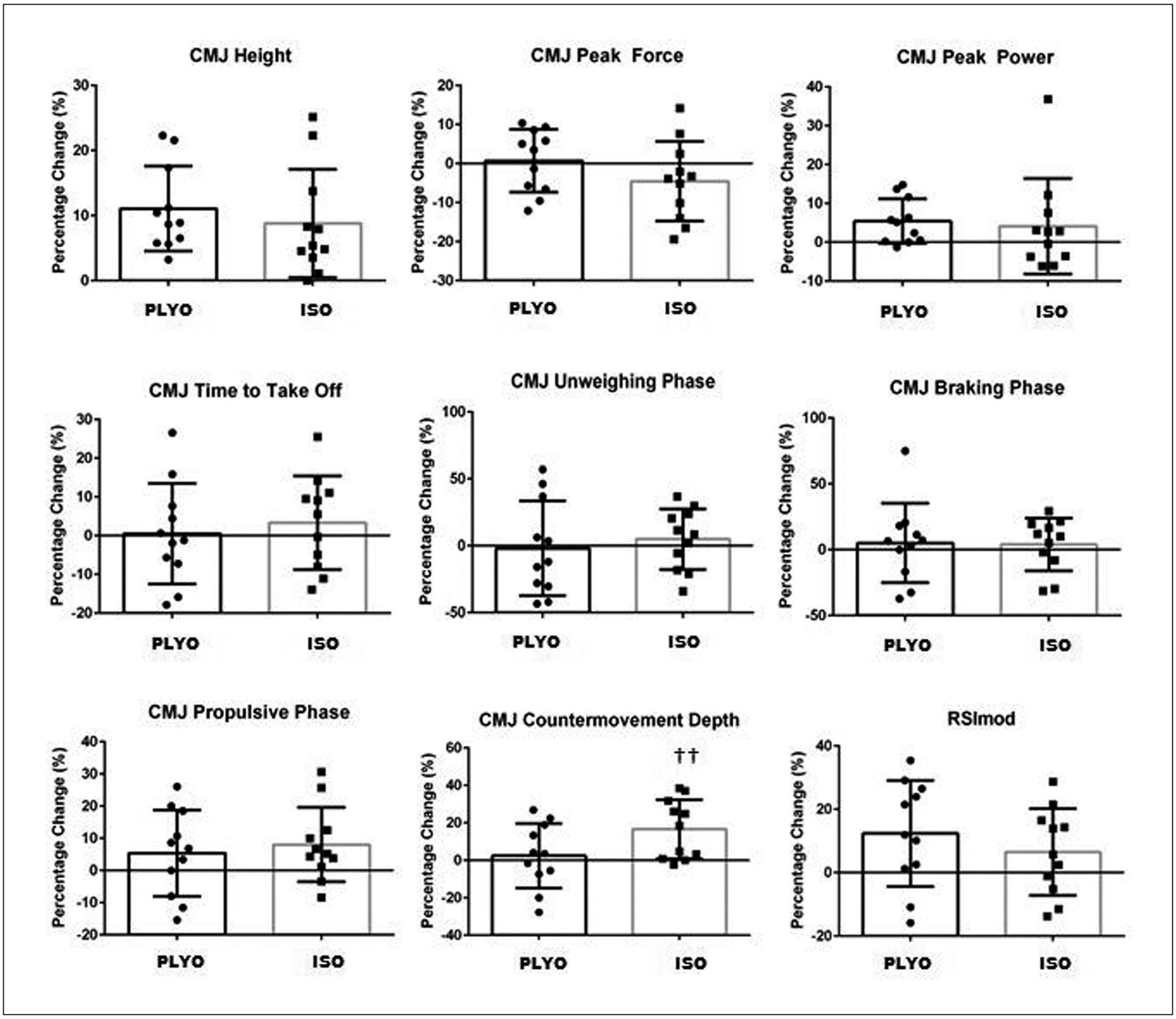

FIG. 1. Percentage change in CMJ measures. ††Denotes significant difference from PLYO (P < 0.01).

d = 1.02), a significant and moderate increase in propulsion phase duration (P = 0.038, d = 0.65), a significant and moderate improvement in IMTP PF (P < 0.001, d = 0.55) and a significant and large improvement in IMTP relative PF (P < 0.001, d = 0.87).

Non-significant and small group main effects were observed for CMJ TTO, unweighting, braking and propulsion phase duration, countermovement depth, IMTP relative PF and $Force_{150}$ (P > 0.05, $0.02 \leq \eta^2_p \leq 0.04$). A significant and large differences between groups was observed for percentage change in countermovement depth (P = 0.003, d = 0.96) (Figure 1), and relative PF (P = 0.047, d = 0.90) (Figure 2), although a non-significant yet large difference in IMTP PF (P = 0.061, d = 0.84) and non-significant and small differences for unweighting phase (P = 0.595, d = 0.23) and propulsion phase (P = 0.630, d = 0.21) durations (Figure 1) and Force150 (P = 0.333, d = 0.42) (Figure 2) were observed, with ISO showing greater changes. However, non-significant and small to moderate differences in favour of PLYO for percentage change in all CMJ measures except CMJ PP, was observed (P > 0.05, $0.22 \leq d \leq 0.58$) (Figure 1).

DISCUSSION

This study compared the change in dynamic and isometric force-time characteristics after undergoing a period of PLYO and ISO. Results showed that both groups improved CMJ height, but only the ISO group improved IMTP PF and relative PF. In addition, when percentage changes in CMJ measures were compared, there were only small differences between groups except for countermovement depth, where a larger increase was observed in ISO (ISO: 18.3% vs PLYO: 2.5%).

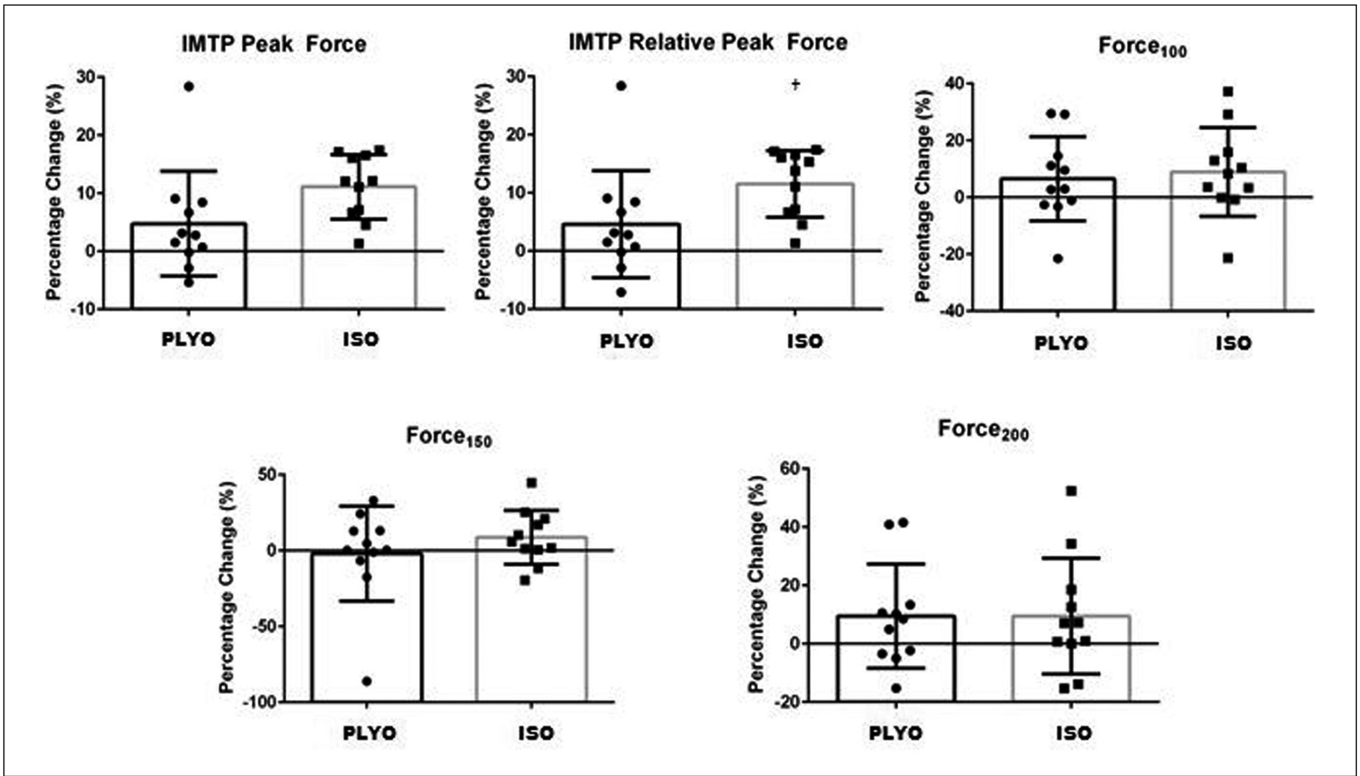

FIG. 2. Percentage change in IMTP measures. †Denotes significant difference from PLYO ($P < 0.05$).

However, when percentage changes in IMTP measures were compared, there were large differences for PF (ISO: 11.1% vs PLYO: 4.8%) and relative PF (ISO: 11.5% vs PLYO: 4.6%). These findings show that PLYO and ISO resulted in similar improvement in jump performance while ISO resulted in greater improvement in isometric strength measures, thus, supported our hypothesis and the theory of specificity.

The benefit of PLYO on CMJ performance is well documented [10, 11, 15, 20, 32]. Conversely, the effects of ISO on CMJ performance remain controversial as some researchers have reported no improvement [33, 34] while others reported improvements [5, 7, 8] in CMJ height after performing ISO. Furthermore, previous studies that compared the neuromuscular adaptations between PLYO and ISO reported that ISO only resulted in improved jump height of non-countermovement jumps [19, 20]. It was suggested that studies that reported no improvement in CMJ performance after ISO were likely because ISO was performed using single joint exercise and at single joint position; and ISO was not performed with rapid and maximal effort [1]. Indeed, studies that have reported improved CMJ, including the current study, have either performed ISO at multiple joint positions [5] or performed ISO with multi-joint exercise and rapid maximal contraction [7, 8]. The performance of ISO with multi-joint exercise and with rapid maximal contraction in this study probably better mimicked the neuromuscular demands of the CMJ action, which allowed for the improvement of task-specific motor coordination in addition to muscular strength, hence, the improvement in CMJ height observed in ISO in the current study.

Despite the improvement in CMJ height observed in both groups, there were only trivial to small changes to CMJ PF, PP and TTO. Although minimal change in CMJ TTO was observed, there were small reduction in unweighting phase duration and small increase in propulsion phase duration in PLYO, a moderate increase in propulsion phase duration for ISO, with no change in braking phase duration for both groups. The increased propulsion phase duration would have resulted in a greater propulsive impulse (force x time) that resulted in greater jump height in ISO. The lack of change in countermovement depth and small reduction in unweighting phase duration in PLYO, and the lack for change in unweighting phase duration despite the large increment in countermovement depth in ISO, indicate that a greater unweighting net impulse was produced as compared to pre-intervention. This eventually resulted in participants producing similarly greater braking impulse as compared to pre-intervention. The minimal change in breaking duration despite the increased braking impulse indicate that greater rate of eccentric force was applied. The moderate improvement in RSImod observed in PLYO indicated that the greater amount of propulsive impulse could have been partially contributed by the improved utilisation of the stretch shortening cycle. Conversely, small change in RSImod was observed in ISO indicating that the increase propulsive impulse was more likely attributed to increased force production overtime due to increased muscular strength and countermovement depth [35]. Based on these findings, improvement in CMJ height observed in PLYO and ISO were due to different mechanisms.

Similar to previous studies, the current results showed greater improvement in isometric PF and relative PF in ISO as compared to PLYO [19, 20]. In fact, it was previously reported that isometric peak force did not change after undergoing a period of PLYO [36]. The effect of ISO on improving isometric strength is well evident in the literature, and is attributed to improved motor unit activation, firing rate and synchronisation, muscle hypertrophy and tendon stiffness [1, 19, 20, 37]. This increased in ability to produce greater force in the lower limb could be a reason for the improved CMJ height as it was previously reported that individuals were able to jump higher by improving their muscular strength via strength training [36]. Although the neuromuscular adaptations attributed to the improved isometric PF and relative PF observed in ISO are also evident in PLYO [10, 19, 20, 32], the lack of specificity in motor coordination during training might be a reason for the small improvement in IMTP peak force and relative PF observed.

In contrast with previous studies that reported improved rate of force development (RFD) after a period of ISO and PLYO [7, 8, 19, 36, 38], the current results showed only small improvement in RFD as reflected by the small change in $Force_{100}$, $Force_{150}$ and $Force_{200}$. The interference effect of concurrent strength and endurance training in this study could be a reason for this discrepancy [39, 40]. Our participants continued with endurance run training while undergoing the intervention, but participants in studies showing improved RFD did not perform concurrent strength and endurance training [7, 8, 19, 36, 38]. Similar to the current findings, Häkkinen et al. [40] reported that participants who performed concurrent strength and endurance training did not improve maximum RFD despite the improved isometric leg extension PF. As adaptations to training differ according to specific mode of exercise, the combined effect of strength and endurance training might have resulted in certain degree of antagonism, leading to a blunted improvement in RFD [40].

Several limitations should be considered when interpreting the current results. Firstly, the benefits of ISO are dependent on the intensity and rate of force developed during each contraction [1, 7, 38]. Therefore, participants' compliance to perform each repetition with maximal effort would greatly affect the magnitude of strength gain. As force production was not measured during ISO, it was not known if all participants had complied with the instructions given. Secondly, the intervention training was performed in concurrent with endurance training, which might have induced an interference effect and blunted the adaptations for RFD. Hence, the current results might not be applicable to non-endurance sports athletes. Thirdly, there was a mixture of strength training experience among participants in the current study. The results may differ if intervention was performed by a more homogenous group of athletes. Future studies may attempt to fill in these gaps.

CONCLUSIONS

In conclusion, both ISO and PLYO led to improved CMJ height via different mechanisms. However, while ISO resulted in improved maximum force production capability, this improvement was not observed in PLYO. Finally, RFD was not improved in both training groups. This was possibly due to interference effect from concurrent strength and endurance training.

Acknowledgement

The authors declared that they have no conflict of interest.

Conflict of interest

The authors declared no conflict of interest.

REFERENCES

1. Lum D, Barbosa TM. Brief review: effects of isometric strength training on strength and dynamic performance. Int J Sports Med. 2019;40(6):363–375.
2. Suchomel TJ, Nimphius S, Bellon CR, Stone MH. The importance of muscular strength: training considerations. Sports Med. 2018;48(4):765–785.
3. Grabiner MD, Owings TM. EMG differences between concentric and eccentric maximum voluntary contractions are evident prior to movement onset. Exp Brain Res. 2002;145(4):505–511.
4. Tillin NA, Pain MTG, Folland JP. Contraction type influences the human ability to use the available torque capacity of skeletal muscle during explosive efforts. Proc R So. B. 2012;279(1736):2106–2115.
5. Bimson L, Langdown L, Fisher JP, Steele, J. Six weeks of knee extensor isometric training improves soccer related skills in female soccer players. J Train. 2019;6(2):52–56.
6. Kordi M, Folland JP, Goodall S, Menzies C, Patel TS, Evans M, Thomas K, Howatson G. Cycling-specific isometric resistance training improves peak power output in elite sprint cyclists. Scand J Med Sci Sports. 2020; 30(9):1594–1604.
7. Lum D, Barbosa TM, Joseph R, Balasekaran G. Effects of two isometric strength training methods on jump and sprint performances: a randomized controlled trial. J Sci Sport Exerc. 2020. (Accepted manuscript).
8. Lum D, Joseph R. Relationship between isometric force-time characteristics and dynamic performance pre- and post-training. J Sports Med Phys Fit. 2019;60(4):520–526.
9. Lum D, Goh JX, Soh SK. Effects of including isometric squat training on 3RM squat performance in powerlifters: a pilot study. J Strength Cond Res. 2020; 34(1):e54.
10. Markovic G. Does plyometric training improve vertical jump height? A meta-analytical review. Br J Sports Med. 2007; 41(6):349–355.
11. Ramirez-Campillo R, García-Pinillos F, García-Ramos A, Yanci J, Gentil P, Chaabene H, Granacher U. Effects of different plyometric training frequencies on components of physical fitness in amateur female soccer players. Frontiers in Physiol. 2018; 9:934.

12. Suchomel TJ, Wagle JP, Douglas J, Taber CB, Harden M, Haff GG, Stone MH. Implementing eccentric resistance training – part 1: a brief review on existing methods. J Funct Morphol Kinesiol. 2019;4(2):38.
13. Lum D. Effects of performing endurance and strength or plyometric training concurrently on running economy and performance. Strength Cond J. 2016; 38(3):26–35.
14. Lum D, Tan F, Pang J, Barbosa TM. Effects of intermittent sprint and plyometric training on endurance running performance. J Sport Health Sci. 2019; 8(5):471–477.
15. Ramírez-Campillo R, Álvarez C, Henríquez-Olguín C, Baez EB, Martinez D, Andrade DC, Izquierdo M. Effects of plyometric training on endurance and explosive strength performance in competitive middle- and long-distance runners. J Strength Cond Res. 2014;28(1):97–104.
16. Paton CD, Hopkins WG. Combining explosive and high-resistance training improves performance in competitive cyclists. J Strength Cond Res. 2005; 19(4):826–830.
17. Cossor JM, Blanksby BA, Elliot BC. The influence of plyometric training on the freestyle tumble turn. J Sci Med Sport. 1999;2(2):106–116.
18. Potdevin FJ, Alberty ME, Chevutschi A, Pelayo O, Sidney MC. Effects of a 6-week plyometric training program on performance in pubescent swimmers. J Strength Cond Res. 2011; 25(1):80–86.
19. Burgess KE, Connick MJ, Graham-Smith P, Pearson SJ. Plyometric vs isometric training influences on tendon properties and muscle output. J Strength Cond Res. 2007;21(3):986–989.
20. Kubo K, Ishigaki T, Ikebukuro T. Effects of plyometric and isometric training on muscle and tendon stiffness in vivo. Physiol Rep. 2017;5(15):1–13.
21. McMahon JJ, Suchomel TJ, Lake JP, Comfort P. Understanding the key phases of the countermovement jump force-time curve. Strength Cond J. 2018; 40(4):96–106.
22. Linthorne NP. Analysis of standing vertical jumps using a force platform. Am J Phys. 2001; 69(11):1198–1204.
23. Heishman A, Daub B, Miller R, Brown B, Freitas E, Bemben M. Countermovement jump inter-limb asymmetries in collegiate basketball players. Sports. 2019; 7(5):103.
24. Suchomel TJ, Sole CJ, Stone MH. Comparison of methods that assess lower-body stretch-shortening cycle utilization. J Strength Cond Res. 2016; 30(2):547–554.
25. Comfort P, Dos'Santos T, Beckham G, Stome MH, Stuart G, Haff GG. Standardization and methodological considerations for the isometric midthigh pull. Strength Cond. J 2019; 41(2):57–59.
26. Haff GG, Ruben RP, Lider J, Twine C, Cormie P. A comparison of methods for determining the rate of force development during isometric midthigh clean pulls. J Strength Cond Res. 2015; 29(2):386–395.
27. Oranchuk DJ, Robinson TL, Switaj ZJ, Drinkwater EJ. Comparison of the hang high pull and loaded jump squat for the development of vertical jump and isometric force-time characteristics. J Strength Cond Res. 2019; 33(1):17–24.
28. Carroll KM, Wagle JP, Sato K, DeWeese BH, Mizuguchi S, Stone MH. Reliability of a commercially available and algorithm-based kinetic analysis software compared to manual-based software. J Biomech. 2019; 18(1):1–9.
29. Koo TK, Li MY. A guideline of selecting and reporting intraclass correlation coefficients for reliability research. J Chiropr Med. 2016;15(2):155–163.
30. Cormack SJ, Newton RU, McGuigan MR, Doyle TLA. Reliability of measures obtained during single and repeated countermovement jumps. Int J Sports Physiol Perform. 2008;3(2):131–144.
31. Cohen J. Statistical power analysis for the behavioral sciences (2nd ed.). Hillsdale, NJ: Erlbaum, 1988.
32. Grgic J, Schoenfeld BJ, Mikulic P. Effects of plyometric vs. resistance training on skeletal muscle hypertrophy: A review. J Sport Health Sci. 2020. doi: 10.1016/j.jshs.2020.06.010.
33. Ball JR, Rich GQ, Wallis EL. Effects of isometric training on vertical jumping. Res Quart. 1964;35(3):231–235.
34. McKethan JK, Mayhew JL. Effects of isometrics, isotonics, and combined isometrics-isotonics on quadriceps strength and vertical jump. J Sports Med Phys Fit. 1974;14(3):224–229.
35. Mandic R, Jakovljevic S, Jaric S. Effects of countermovement depth on kinematic and kinetic patterns of maximum vertical jumps. J Electromyogr Kinesiol. 2015; 25(2):265–272.
36. Cormie P, McGuigan MR, Newton RU. Adaptations in athletic performance after ballistic power versus strength training. Med Sci Sports Exerc. 2010; 42(8):1582–1598.
37. Folland JP, Hawker K, Leach B, Little T, Jones DA. Strength training: isometric training at a range of joint angles versus dynamic training. J Sports Sci. 2005; 23(8): 817–824.
38. Tillin NA, Folland JP. Maximal and explosive strength trianing elicit distinct neuromuscular adaptations, specific to the training stimulus. Eur J Appl Physiol. 2014;114(2):365–374.
39. Glowacki SP, Martin SE, Maurer ANN, Baek W, Green JS, Crouse SF. Effects of resistance, endurance, and concurrent exercise on training outcomes in men. Med Sci Sports Exerc. 2004; 36(12):2119–2127.
40. Häkkinen K, Alen M, Kraemer WJ, Gorostiaga E, Izquierdo M, Rusko H, Mikkola J, Häkkinen A, Valkeinen H, Kaarakainen E, Romu S, Erola V, Ahtiainen J, Paavolainen L. Neuromuscular adaptations during concurrent strength and endurance training versus strength training. Eur J Appl Physiol. 2003;89(1):42–52.