Original Article

Changes in vertical jump performance and body composition before and after COVID-19 lockdown

ERIK TAN[1], SAMUEL MONTALVO[2,3] ✉, MATTHEW P. GONZALEZ[4], MARTIN DIETZE-HERMOSA[5], SEE MIN[1], SANDOR DORGO[4]

[1]*Sport Sciences Department, National Sports Institute of Malaysia, Malaysia*
[2]*Clinical Applied Physiology Laboratory, Rehabilitation Sciences Department, The University of Texas at El Paso, El Paso, United States of America*
[3]*Department of Kinesiology, The University of Texas at El Paso, El Paso, United States of America*
[4]*The University of Texas at San Antonio, United States of America*
[5]*Brigham Young University, Idaho, United States of America*

ABSTRACT

This study aimed to determine the effects of a 16-week COVID-19 lockdown on body composition and vertical jump performance. Thirteen martial artists participated in this study. Participants were tested at: 1) pre-lockdown (pre), 2) post-lockdown (post), 3) two-weeks-post-lockdown (post+2), and 4) four-weeks-post-lockdown (post+4). Repeated-measures-ANOVAs were conducted with post-hoc analyses. Differences were observed in vertical jump height (VJH) (10.33%), peak velocity (PV) (3.10%), reactive-strength-index-modified (RSImod) (13.8%), and peak-propulsive-power (PPP) (6.00%) from pre-to-post. There as an increase from post-to-post+2 in VJ (13.06%), PV (4.12%), RSImod (14.0%), and PPP (4.66%). There was an increase from post to post+2 in VJH (10.8%), PV (3.1%), RSImod (14.0%), and PPP (3.0%). Fat mass (FM) and BF% increased from pre to post (13% and 11%, respectively) and decreased from post to post+4 (8% and 11%, respectively); fat-free mass (FFM) decreased from pre-to-post (11%) and decreased from post-to-post+4 (8%). There were moderate associations (rmc = 0.42-0.47) between FFM and VJH, FMM and PPP, FFM and PV, BF% and PV, and FM and PV. While the lockdown resulted in a significant decrease in vertical jump performance and increases in BF and FM, participant's performance returned to pre-lockdown levels after only 2-4 weeks of post-lockdown training by decreasing BF, FM, and increasing FFM.
Keywords: COVID-19; Vertical jump; Wushu; Martial arts; Performance analysis of sport.

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✉ **Corresponding author.** *Clinical Applied Physiology Laboratory, Rehabilitation Sciences Department, The University of Texas at El Paso, El Paso, United States of America.* *https://orcid.org/0000-0003-3104-3428*
E-mail: smontalvo@utep.edu
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INTRODUCTION

The COVID-19 pandemic has immensely impacted sports and exercise activities. To control the spread of COVID-19, sports teams, and exercise facilities throughout the world were forced to implement a temporary lockdown, which involved suspending or drastically adjusting their training practices. Recent attention has been given to changes in training and physical activity due to the COVID-19 situation (Choi & Bum, 2020; Wong et al., 2020; Woods et al., 2020). Health and sanitary recommendations have also been given following the COVID-19 current pandemic status (Metzl et al., 2020), including physical examinations and appropriate tracking and monitoring of athletes (Löllgen et al., 2020). However, scientific data are lacking on the impact of the COVID-19 lockdown on athletic performance. In addition, no studies have assessed the outcomes of a temporary at-home strength and conditioning program implementation and the changes in athletic performance after returning to the pre-pandemic strength and conditioning program.

In Wushu, a Chinese martial art commonly known as Kung-Fu, vertical jump performance is an important characteristic of high-level performers (Huang et al., 2018). The sport of Wushu is recognized by the International Olympic Committee and will be part of the 2022 summer Youth Olympic Program to be held in Dakar. Wushu requires increased jump demands when compared to other competitive martial arts such as Karate (Cheah et al., 2016). Vertical jump performance as measured by vertical jump height (VJH) is regarded as an indicator of maximal neuromuscular power and explosiveness (Tan, Beaven, et al.; Tan, Vallejo, et al.; Tan). A previous cross-sectional investigation of world-class Wushu athletes from the 2013 World Wushu Championships reinforced the importance of rapid application of vertical ground reaction forces and peak velocity production during vertical jumps (Tan). This finding is further supported by previous literature on vertical jumps in Wushu athletes (Tan, Beaven, et al.; Tan, Vallejo, et al.), in where peak velocity was largely associated with higher vertical jump performance.

The interplay between force and time during the CMJ depends on the phase of CMJ. A detailed description exploring these factors has been outlined in prior research (McMahon et al., 2018). Moreover, increased jump height and power appear to have a meaningful transfer to certain martial art movements. For instance, Loturco et al. (2019), indicated that short-term optimum power load training increased vertical jump power output by 12% with an accompanying 8% gain in punch power in elite boxing athletes. Moreover, authors noted an effective transference effect (TEC = 0.80) of jumping performance improvements to punching impact force, indicating that increases in lower-limb power can be directly transferred to punching impact. Similarly, another study indicated that mean propulsive power during the squat jump was a significant predictor of maximum punch impact ($R^2 = 0.640$; $p < .01$) in karate athletes with authors suggesting that training strategies increasing jump performance may improve punch speed and impact (Loturco et al., 2019). Findings suggest that the lower-body is the primary contributor to punch execution as the ground reaction forces generated by the lower body effectively transfer to the upper body and ultimately result in a more powerful punch (Lenetsky et al., 2013).

Yet, detraining can affect athletes' performance. A previous investigation has noted that a short detraining period of four weeks can induce changes at the ankle muscle-tendon complex resulting in decreased VJH performance by as much as 8-12% (Kannas et al., 2015). However, it is unknown if athletes could maintain their vertical jump performance through a reduced volume and intensity home-based general strength and conditioning program. Given the decrement in training volume and intensity for the home-based training program and the inaccessibility of training facilities, it was hypothesized that athletes would experience a decrease in vertical jump performance post-lockdown and that these decrements could be then reversed following a retraining period. Furthermore, it was also hypothesized that changes in vertical jump performance and its biomechanical components would be modulated by changes in body composition. Therefore, the purpose of this study was to determine how vertical jump performance of professional Wushu athletes would be affected by a 16-week COVID-19 lockdown and following a four-week retraining period.

MATERIALS AND METHODS

A retrospective cohort study design was adopted. Subjects were tested at four time points: 1) two days prior to COVID-19 lockdown; 2) following a 16-week lockdown period and immediately before returning to training (Post); 3) two weeks after returning to training (Post+2); and four weeks after returning to training (Post+4). The same set of body composition and vertical jump performance variables were tested at each of these time points by the same researcher.

Thirteen Wushu martial artists (N = 13; males = 7, females = 6) participated in this retrospective cohort study design. All subjects were elite martial artists who competed in Wushu with > 10 years of elite supervised training experience and world championship level competition participation. These athletes trained at the Malaysia National Training Center under the supervision of professional trainers using a periodized strength and conditioning model and were regularly assessed by the CMJ protocol. Out of the 13 subjects, 7 have competed at a World Wushu Championships and 5 have medalled; 4 other subjects have competed at the World Junior Wushu Championships and all 4 medalled; also, 4 of the 13 subjects competed at the Asian games, with all 4 medalling. Subjects were closely monitored by a medical team before and after the lockdown period. None of the subjects reported any illness or musculoskeletal injuries at any of the testing time points. A priori power analysis conducted on G*Power (version 3.1, Universität Kiel, Germany) indicated that 13 subjects would be sufficient to yield a medium effect size f = 0.35, at an alpha (α) of 0.05, and power (1-β) of 0.82. The study protocols conformed to the Deceleration of Helsinki and were approved by the Institutional Review Board committee (International IRB EX26/9/2020). All subjects provided written consent for their study participation.

For each testing session, subjects were assessed for anthropometrics before performing five minutes of general warm-up on a stationary bicycle or treadmill, followed by five minutes of static and dynamic stretching. Three maximal effort attempts of the CMJ were performed with 1-2 minutes of rest in between trials. To reduce the influence of the arm-swing, the hands-on-hips method was adopted (akimbo). Additionally, athletes were allowed to squat freely at their desired depth. All jumps were assessed using a commercial uni-axial Force Platform (400s series Fitness Technology, Australia) at a sampling frequency of 1,000 Hz. All data collection sessions were monitored by a Certified Strength and Conditioning Specialist who regularly supervised the athletes' day-to-day strength and conditioning training and testing.

Body composition assessment was conducted via Bioelectrical Impedance Analysis (BIA: InBody 770, InBody USA). The BIA assessments were conducted in a fasting and non-exercising state. For each of the assessments, athletes were instructed to remove their shoes and socks, with hands and feet sanitized with alcohol-containing wipes. Athletes were then positioned on the 8-electrode BIA device with the arms and legs straight. The selection of the BIA device was primarily due to the social-distancing requirements enforced during the pandemic. The InBody BIA device was previously validated and demonstrated small individual error when compared to DEXA, indicating that the InBody BIA device can surrogate the DEXA and has also demonstrated good reliability with intra-class correlation coefficients of > .90 for body fat, fat mass, and fat-free mass (McLester et al., 2020).

Prior to the mandatory COVID-19 lockdown, athletes were in the power and strength phase of their macrocycle and trained three strength and conditioning sessions per week in addition to their Wushu training. Two of these weekly sessions focused on power and strength development, including plyometrics for power training, and generally using four sets of six to eight repetitions of multi-joint exercises (e.g., squats, lunges, bench press, etc.) at the individual's self-selected heaviest load possible for strength development. The third weekly session focused on muscular endurance development with athletes completing the same movements with lighter resistance. All training sessions were performed in the morning and were monitored by the same certified strength and conditioning coach (Table 1).

Table 1. Example of programming before COVID-19 lockdown (Strength/Power Phase).

Day 1	**Sets & Reps**	**Day 2**	**Sets & Reps**	**Day 3**	**Sets & Reps**
General Warm-up	5-10 mins	General Warm-up	5-10 mins	General Warm-up	5-10 mins
Reverse Lunges	4 x 8	Keiser Squat*	4 x 8	Forward + Backward + Lateral Lunges	4 x 20s
Barbell Step Ups*	4 x 8	Hurdle Jumps + Box Jumps*	4 x 6	Battle Ropes	4 x 20s
Single Leg Box Jumps*	4 x 8	Deficit Romanian Deadlift	4 x 8	Med ball Slams	4 x 20s
Sumo Deadlift	4 x 8	Isometric Calf Raise (5s) *	4 x 10	Mountain Climbers	4 x 20s
Dumbbell Chest Press	4 x 10	Drop Jumps*	4 x 8	Kettlebell Swings	4 x 20s
TRX Row	4 x 10	Bench Press	4 x 10	BOSU Push-up	4 x 20s
Dumbbell Lateral Raise	4 x 12	Lat Pulldown	4 x 10	Skipping	4 x 20s
CORE circuit***	3 rounds	Back Extension	4 x 12	Stretch and Foam Roll	10 mins
Stretch and Foam Roll	10 mins	CORE circuit***	3 rounds		
		Stretch and Foam Roll	10 mins		

*Note. *Rest time between 60s-90s. ** Contrast sets; resistance exercise paired with subsequent plyometric exercise. ***CORE circuit: 1) Weighted Sit Up x 20, 2) Bridge Combo (Front bridge 20s, R side bridge 20s, L side bridge 20s, 2 Point bridge 20s), 3) Contra Superman (Hold 5s every 5 reps) x 20, and 4) Partner Kneeling Pallof Hold (Rubber band) x 45s each side.*

During the lockdown period, no access to the training facility was permitted. Subjects were prescribed three bodyweight resistance training sessions per week in an attempt to mitigate expected losses in physical performance. Subjects performed the sessions at home, using common household items as external resistance, and were monitored through virtual video communication tools by their strength and conditioning coach. Each of these at-home sessions primarily consisted of multi joints exercises (variations of squats, lunges, push up, etc.) with four to five sets of 10-12 repetitions each. Subjects were asked to use additional loading such as water bottles, gallon jugs, and heavy books when possible; however, these were not standardized among athletes (Table 2).

Upon returning to the training facility from the lockdown, athletes were first assessed and then resumed their pre-lockdown training program. Training frequency was maintained at three sessions per week. However, for the first two weeks of the program, training volume and intensity were adjusted to 70% of the pre-lockdown program to avoid any injuries or overtraining. By the fourth week after the lockdown both volume and intensity returned to the pre-lockdown training program levels. Prior retraining literature support implementing the loads and volume used in the present study (Psilander et al., 2019; Suarez-Arrones et al., 2019). Greater neural adaptations follow high load resistance training (80% 1RM) which may help mitigate some of the negative impacts of detraining on neuromuscular capacity, an important factor for vertical jump performance (Spyrou et al., 2021) (Table 3).

Table 2. Example of programming during COVID-19 lockdown (Maintenance circuit training).

Day 1	**Sets & Reps**	**Day 2**	**Sets & Reps**	**Day 3**	**Sets & Reps**
General Warm-up	5-10 mins	General Warm-up	5-10 mins	General Warm-up	5-10 mins
Skipping	4 x 20	Jumping Jacks	4 x 20	High Knee	4 x 20
Gallon Jug Swings	4 x 20	Mountain Climbers	4 x 20	Mountain Climbers	4 x 20
Reverse Crunch + Twist	4 x 20	Dowel Overhead Squat	4 x 20	Dowel Front Squat	4 x 20
Single Leg BW Squat	4 x 15	Weighted Sit Ups	4 x 20	Plank to Push-up Hold	4 x 20
Gallon Jug Russian Twist	4 x 20	Dive Bomb Push-ups	4 x 20	Gallon Jug Russian Twist	4 x 20
Single Leg Deadlift	4 x 15	Heel Touch	4 x 20	Lateral Lunges	4 x 20
Superman	4 x 20	Lunges	4 x 20	Heel Touch	4 x 20
Towel Row	4 x 20	Moving Planks	4 x 20	Lateral Raise	4 x 20
Calf Raise	4 x 20	Chair Dips	4 x 20	Side Plank	4 x 20
360 Jumps	4 x 15	Squat Jumps	4 x 15	Split Jumps	4 x 15
Stretch and Foam Roll	10 mins	Stretch and Foam Roll	10 mins	Stretch and Foam Roll	10 mins

Note. Rest time between each circuit was 3-4 mins. BW = bodyweight.

Table 3. Example of programming after COVID-19 lockdown (Return to Training).

Day 1	**Sets & Reps**	**Day 2**	**Sets & Reps**	**Day 3**	**Sets & Reps**
General Warm-up	5-10 mins	General Warm-up	5-10 mins	General Warm-up	5-10 mins
Goblet Squat	3 x 8	Lunges	3 x 8	Kettlebell Swing	3 x 8
Barbell Step Ups	3 x 8	Sumo Deadlift	3 x 8	Back Squat	3 x 8
Reverse Hypers	3 x 8	Seated Pulley Row	3 x 8	Hex Bar Deadlift	3 x 8
Lat Pulldown	3 x 8	BOSU Push-ups	3 x 8	Resistance Band Back Extension	3 x 8
Dumbbell Shoulder Press	3 x 8	Standing Calf Raise	3 x 8	Dumbbell Chest Press	3 x 8
3 Way Ankle	3 x 10	Triceps Pushdown	3 x 12	Internal/External Rotation	3 x 12
CORE circuit*	3 rounds	CORE circuit*	3 rounds	CORE circuit*	3 rounds
Stretch and Foam Roll	10 mins	Stretch and Foam Roll	10 mins	Stretch and Foam Roll	10 mins

*Note. Rest time between 75s-90s with volume and intensity were reduced during "return to training" phase. *CORE circuit: 1) Weighted Sit Up x 20, 2) Bridge Combo (Front bridge 20s, R side bridge 20s, L side bridge 20s, 2 Point bridge 20s), 3) Contra Superman (Hold 5s every 5 reps) x 20, and 4) Partner Kneeling Pallof Hold (Rubber band) x 45s each side.*

Vertical ground reaction force (vGRF) data from the force platforms were imported into MATLAB (R2020b; The MathWorks, Inc., Natick, MA) for data processing. A Fast-Fourier Transform analysis was conducted to determine the appropriate cut-off frequency. Subsequently, data were filtered by a fourth order Butterworth filter with a low-pass at 40-Hz. Body mass was obtained using the average of one second while subjects remained still prior jumping, while take-off and landing thresholds were selected as five times the standard deviations of the flight vGRF over an epoch (time window) of 30 milliseconds. Thereafter, kinetic and kinematic variables were obtained through forward dynamics by numerical integration using the trapezoidal rule. In short, vertical acceleration was obtained by using Newton's second law of motion (Force (N) = subject's mass (kg) * acceleration (m/s^2). Velocity was obtained as the integral of velocity with respect to time. Lastly, the vertical displacement of the centre of mass was obtained by the integration of velocity with respect to time. The start of the unweighing phase was defined as 30 milliseconds prior to when the subject's mass dropped below five standard deviations of the subject's weight calculated; the braking phase was defined as the lowest velocity achieved, and the propulsion phase was defined to the first instance in where positive vertical velocity was achieved (*see figure 1s in supplemental materials*).

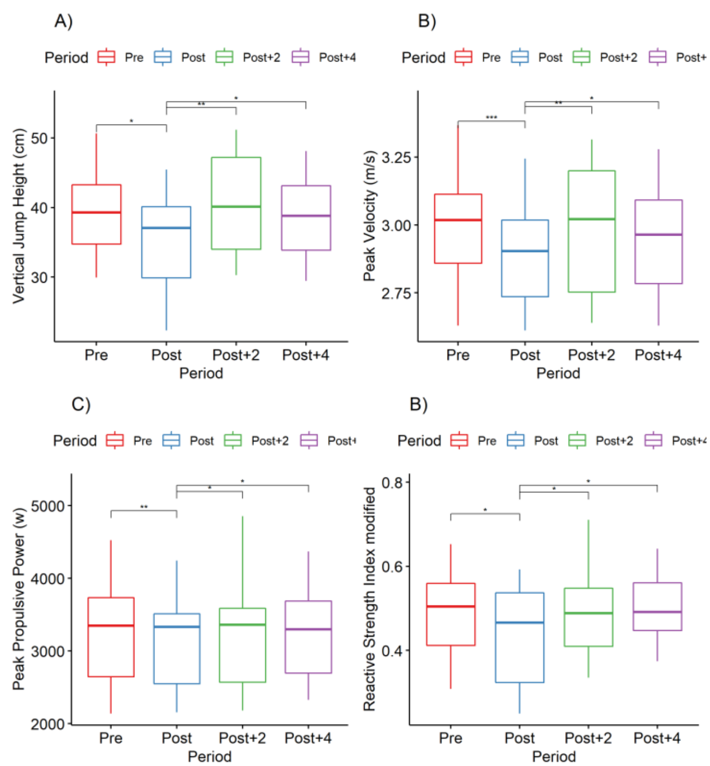
Assessed kinematic variables included velocity and time of the various CMJ components, and kinetic variables included peak and mean force, rate of force development, peak and mean power, rate of power development, and impulse. All calculations and definitions for these computed variables have been described in detail elsewhere (McMahon et al., 2018). Vertical jump height was obtained using the impulse-momentum method, where total impulse (integration of force * time) is subtracted from the subject's body weight resulting in jump impulse. Then, take off velocity was obtained as the derivative of jump impulse and the subject's mass. Thus, VJH was computed as:

$$VJH = \frac{\sqrt{\text{Velocity at takeoff}}}{2\ *\ \text{Gravity}}$$

Processed data were imported into the open-source RStudio (version 1.3.959, RStudio, Boston, MA, USA) for data analysis using R statistical language; the "*dplyr*" library was used for data grammar and manipulation, "*psych*" and "*rcompanion*" libraries for descriptive statistics, "*rstatix*" for statistical analysis and effect sizes, "*ggpurb*" and "*ggplot2*" for data visualization, "*psych*" library for reliability analysis, and finally, "*lme4*" and "*rmcorr*" for repeated measures correlations . Intra-subject reliability of Vertical Jump performance was assessed through a two-way random-effects model intra-class correlation coefficient (ICC_{2k}) for consistency and interpreted as follows: > 0.75 as "*good*", and > 0.90 as "*excellent*". The trial with the greatest vertical jump height was utilized for the analysis. Assumptions of data normality were assessed through the Shapiro-Wilk test. All data appeared to be normally distributed, hence, separate individual repeated-measures analysis of variance (RM-ANOVA) were conducted for all variables of interest during the jump trials. A Mauchly's test for sphericity was conducted, if sphericity was violated, then the Greenhouse-Geiser sphericity correction was applied; magnitude of the RM-ANOVAs were presented as partial eta squared (η^2) and interpreted as small ($\eta^2 \geq 0.02$), medium ($\eta^2 \geq 0.13$) and large ($\eta^2 \geq 0.26$). When appropriate, a Fisher's Least Significant Differences correction was conducted to find pairwise differences among the time testing periods. Additionally, *Cohen's D with a Hedge's g correction* were computed to estimate the magnitude of the effect between pairwise comparisons. The resultant values were interpreted as: trivial = 0–0.2 small = 0.2–0.6, moderate = 0.6–1.2, large = 1.2–2.0, and very large = 2.0–4.0, and nearly perfect > 4.0. Data were represented as mean and standard deviation along with 95% confidence intervals (95% CI) by bootstrap method of 1000 samples for each of the variables of interest. Finally, in order to assess the association between body composition and measures of the vertical jump, and vertical jump performance, a series of individual person's correlation and an overall repeated measure correlation were utilized; repeated measures correlation (RMC) allows for assessing within-individual association for paired measures across multiple testing periods for multiple individuals. Moreover, correlation assumes that observations are independent, whereas RMC does not, hence, leading to greater statistical power (Bakdash & Marusich, 2017). The strength of the associations were interpreted as 0.0-0.1 as trivial, 0.1-0.3 as small, 0.3-0.5 as moderate, 0.5-0.7 as moderate, 0.7-0.9 as large, and 0.9-1 as large. The scripts and data used for the analysis is provided in the supplemental section of this manuscript. Statistical significance was set at an alpha level of .05.

RESULTS

The VJH from the vertical jump trials showed an "*excellent*" reliability for pre-testing (ICC_{2k} = 0.98 [95%CI = 0.95-0.99]), post-testing (ICC_{2k} = 0.95 [95%CI = 0.89-0.98]), post+2 (ICC_{2k} = 0.96 [95%CI = 0.91-0.98]), and post+4 (ICC_{2k} = 0.99 [95%CI = 0.98-1.00]). There as a large significant effect of time for vertical jump height (VJH) [F (3,36) = 6.231, p < .001, η^2 = 0.387], and a moderate effect for peak velocity (PV) [F (3,36) = 6.731, p < .001, η^2 = 0.028], reactive strength index modified (RSImod) [F (3,36) = 3.801, p = .018, η^2 = 0.076], and peak propulsive power (PPP) [F (3,36) = 3.1291, p = .038, η^2 = 0.05]. Pairwise post hoc comparisons indicated a decrease in VJH of 10.33% (*g* (*moderate*) = 0.732), PV of 3.10% (*g* (*large*) = 1.17), RSImod of 13.8% (*g* (*moderate*) = 0.577) and PPP of 6.00% (*g* (*large*) = 1.02). In contrast, there as an increase from post to post+2 of 13.06% in VJ (*g* (*large*) = 0.981), 4.12% for PV (*g* (*large*) = 1.08), 14.0% for RSImod (*g* (*moderate*) = 0.580), and PPP of 4.66% (*g* (*moderate*) = 0.638). Similarly, there was an increase from post to post+2 of 10.8% in VJ (*g* (*moderate*) = 0.741), 3.1% for PV (*g* (*moderate*) = 0.678), 14.0% for RSImod (*g* (*moderate*) = 0.789), and PPP of 3.0% (*g* (*small*) = 0.136) (Figure 1). The repeated-measures ANOVA showed no statistically significant differences on any of the other kinetic (Table 4) and kinematic variables (Table 5) (p < .05), although a practically relevant trend was observed whereby kinetic and kinematic performance parameters were consistently the weakest for the post-test, with subjects performing better at pre, post+2- and post+4 timepoints.



*Note. *Indicates significant post-hoc pairwise comparisons.*

Figure 1. Boxplot of (A) vertical jump height (cm), (B) peak velocity (m/s), (C) peak propulsive power (w), and (D) Reactive Strength Index modified (RSImod) at the different study timepoints.

Table 4. Mean, standard deviation (SD), and 95% confidence interval (CI) of the kinetic variables of the CMJ at the different study timepoints.

	Mean	SD	95% CI	Mean	SD	95% CI	Mean	SD	95% CI	Mean	SD	95% CI
Peak propulsive force (N·kg−1)	1853.57	568.99	1633.39-2279.35	1826.81	484.66	1609.72-2140	1897.15	547.03	1643.46-2253.38	1872.99	575.88	1618.02-2273.23
Rate of concentric force development (N·s−1·kg−1)	5791.80	4818.53	3846.34-9152.19	8984.43	5937.05	6363.93-12643.9	7097.75	4692.01	4931.45-9796.25	5087.00	4574.03	3249.57-8235.64
Force at zero velocity (N·kg−1)	1722.32	513.15	1509.65-2104.60	1690.15	458.51	1487.53-1992.94	1765.50	489.52	1559.96-2059.44	1723.90	515.34	1491.08-2050.39
Peak propulsive power (W·kg−1) †	3324.00	736.50	2937.99-3700.94	3195.86	686.43	2816.32-3538.51	3313.52	787.34	2931.31-3777.76	3293.15	678.98	2963.71-3621.55
Rate of power development (W·s−1·kg−1)	66810.17	23375.82	50077.90-75572.30	59053.59	35735.65	38567.30-74989.3	80595.08	22443.15	70530.50-93951.6	74182.62	21027.03	65193.00-87797.7
Total impulse (N·s−1)	1596.55	287.04	1436.02-1735.85	1617.76	323.10	1461.60-1795.87	1650.96	309.85	1494.13-1816.74	1591.45	286.19	1449.85-1737.18
Relative net impulse (N·s·kg−1)	2.71	0.28	2.56-2.86	2.71	0.31	2.55-2.87	2.78	0.23	2.67-2.91	2.66	0.13	2.59-2.72

Note. † Indicates a main effect of time through the repeated-measures ANOVA (p < .001).

Table 5. Mean, standard deviation (SD), and 95% confidence interval (CI) of the kinematic variables of the CMJ at the different study timepoints.

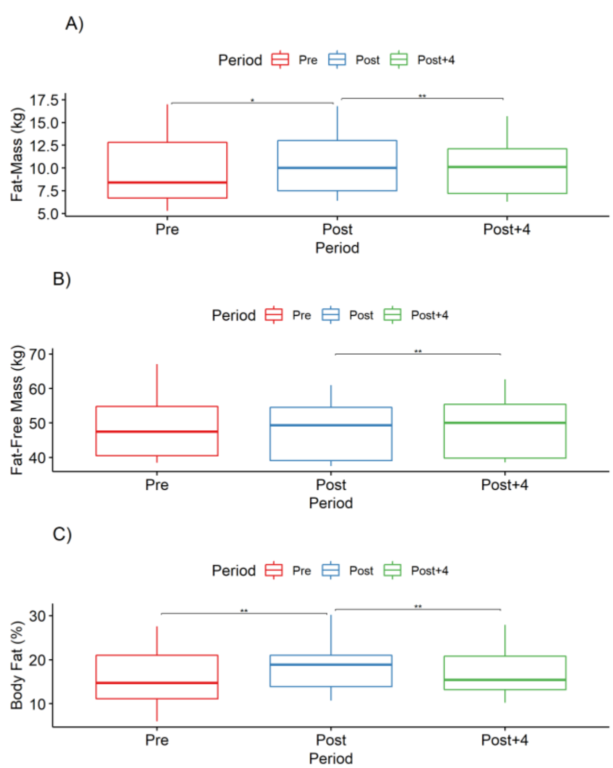
	Mean	SD	95% CI	Mean	SD	95% CI	Mean	SD	95% CI	Mean	SD	95% CI
Jump height (cm)†	38.98	6.55	35.77-42.41	35.33	6.79	31.58-38.33	40.59	7.16	37.11-44.62	39.15	6.01	36.08-42.07
Peak velocity (m/s) †	2.99	0.22	2.88-3.09	2.90	0.20	2.81-3.00	2.99	0.25	2.86-3.12	2.96	0.21	2.86-3.06
Contraction time (s)	0.82	0.09	0.77-0.86	0.84	0.13	0.79-0.94	0.83	0.15	0.77-0.94	0.78	0.08	0.75-0.83
Eccentric duration (s)	0.34	0.04	0.32-0.36	0.35	0.06	0.31-0.38	0.34	0.04	0.32-0.36	0.35	0.05	0.32-0.37
Concentric duration (s)	0.27	0.03	0.26-0.28	0.28	0.04	0.26-0.3	0.26	0.02	0.25-0.28	0.26	0.02	0.25-0.27
Time to peak force (s)	0.52	0.07	0.48-0.56	0.54	0.11	0.49-0.61	0.54	0.15	0.48-0.66	0.49	0.06	0.45-0.52
Time to peak power (s)	0.21	0.03	0.19-0.22	0.21	0.03	0.19-0.22	0.20	0.02	0.19-0.21	0.20	0.02	0.19-0.21
RSImod†	0.49	0.11	0.43-0.54	0.43	0.12	0.37-0.49	0.50	0.11	0.44-0.56	0.50	0.08	0.46-0.55

Note. † Indicates a main effect of time through the repeated-measures ANOVA (p < .001).

Table 6. Subjects' body composition descriptors before COVID-19 lockdown, immediately after lock down (post) and four weeks post lockdown (post+4). Data is presented as mean ± SD.

	Pre	Post	Post+4
All Subjects			
Age (yrs.)	21.76 ± 2.63	-	-
Height (m)	1.63 ± 0.07	-	-
Weight (kg)	59.25 ± 8.90	59.50 ± 8.50	59.78 ± 8.47
BMI (kg/m2)	22.20 ± 2.28	22.30 ± 2.11	22.40 ± 2.02
FM (kg)	9.82 ± 3.89*	11.03 ± 3.51	10.19 ± 3.18*
FFM (kg)	50.03 ± 9.93	48.52 ± 8.38	49.52 ± 8.70
BF (%)	16.40 ± 6.97*	18.70 ± 5.96	17.28 ± 5.65*
Male Participants			
Age (yrs.)	22.5 ± 3.08	-	-
Height (m)	1.67 ± 0.06	-	-
Weight (kg)	63.80 ± 7.52	63.41 ± 7.01	64.06 ± 7.03
BMI (kg/m2)	22.80 ± 2.24	22.48 ± 1.68	22.85 ± 1.80
FM (kg)	8.90 ± 3.11	9.48 ± 2.76	8.89 ± 2.45
FFM (kg)	55.50 ± 6.74	53.94 ± 5.41	55.18 ± 5.54
BF (%)	13.50 ± 4.34	14.80 ± 3.28	13.76 ± 2.84
Female Participants			
Age (yrs.)	21.22 ± 1.41	-	-
Height (m)	1.56 ± 0.04	-	-
Weight (kg)	53.00 ± 6.21	52.94 ± 6.06	52.94 ± 5.77
BMI (kg/m2)	21.71 ± 2.52	21.68 ± 2.36	21.68 ± 2.36
FM (kg)	12.46 ± 3.87	13.14 ± 3.56	12.28 ± 3.30*
FFM (kg)	40.54 ± 2.61	39.94 ± 3.39	40.48 ± 2.67
BF (%)	23.08 ± 4.78	24.48 ± 4.35	22.90 ± 4.19*

*Note. *Indicates significant differences compared to post-test measurement. BMI = body mass index, FM = fat mass, FFM = fat free mass, BF = body fat.*



*Note. *Indicates significant post-hoc pairwise comparisons.*

Figure 2. Boxplot of (A) Fat Mass (kg), (B) Fat-Free Mass (kg), and (C) Body Fat (%) at the different study timepoints.

The repeated-measures ANOVA showed a small main effect of time in fat-free mass (FFM) [F (2,24) = 5.586, p < .01, η^2 = 0.022], fat-mass (FM) [F (2,24) = 5.586, p < .01, η^2 = 0.022], and body fat percentage (BF%) [F (2,24) = 8.795, p < .001, η^2 = 0.025], but no for bodyweight and BMI (p > .05). For BF (%), the post-hoc pairwise analysis showed an increase of 13% from pre to post (*g* (*large*) = 0.902) and decrease of 11% from post to post+4 (g (*large*) = 1.09), and no differences between pre and post+4 (p > .05). Similarly, FM increased 11% from pre to post (g (*moderate*) = 0.687), and a decreased 8% from post to post+4 (*g* (large) = 0.897), and there were no differences between pre and post+4 in FM. Finally, there was an increase of FFM increased 8% from post to post+4 (g (*moderate*) = 0.687), but no differences between pre to post, or pre to post+4 (Table 6 and Figure 2).

The repeated measures correlation showed a moderate association between FFM and VJH (RMC = 0.47) for all time periods; the Pearson's association indicated a very large association (R = 0.81) at Pre, large association (R = 0.63) at Post, and very large association (R = 0.83) at Post+4 (Figure 3). Similarly, there was a moderate association between FFM and PPP (RMC = 0.47) for all time periods, and individual nearly perfect association (R = 0.93) at Pre, large association (R = 0.97) at Post, and very large association (R = 0.98) at Post+4. In addition, there was also a moderate association between FFM and PV (RMC = 0.47) for all time periods, and individual very large associations (R = 0.86) at Pre, large association (R = 0.81) at Post, and very large association (R = 0.84) at Post+4. Moreover, there was moderate negative association (RMC = -0.42) for all time periods, and moderate negative individual association for Pre (R = -0.42), Post (R = -0.40), and Post+4 (P = - 0.53) between FM and PV. Finally, there was also a moderate negative association between BF% and PV (RMC = -0.42) for all time periods, and large negative individual association for Pre (R = -0.64), Post (R = -0.69), and Post+4 (p = - .79) (*see figures 2s-7s in supplemental materials*).

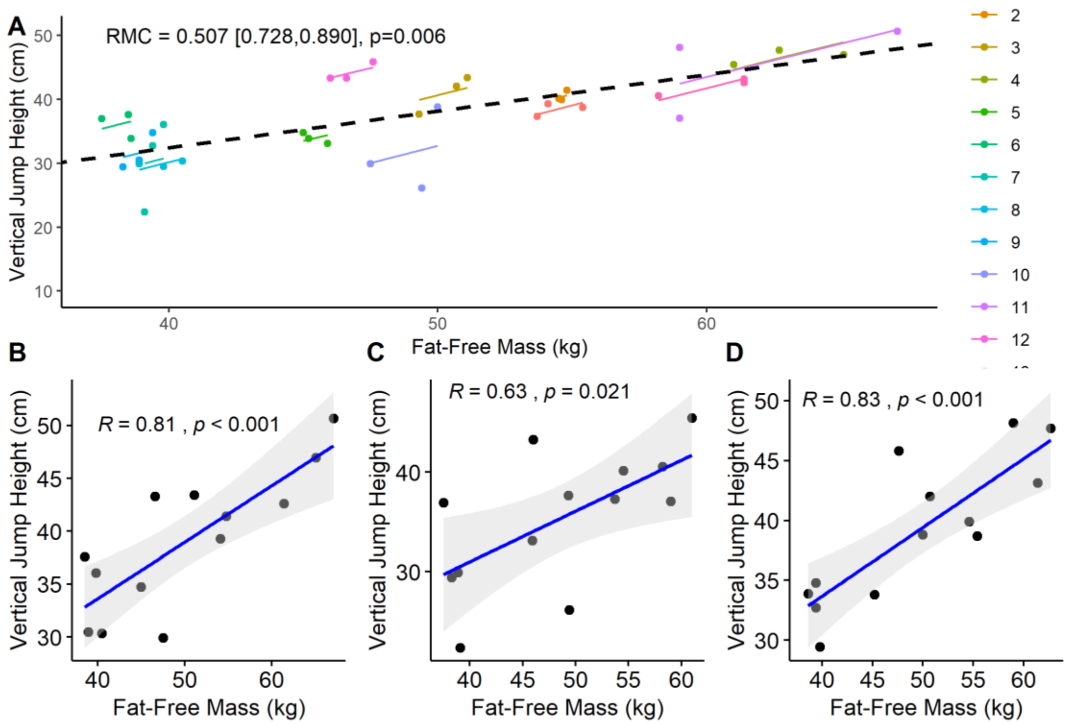


Figure 3. Repeated measures correlation (A) and individual Pearson's correlation (B = Pre, C = Post, and D = Post+4) with regression lines between Fat-Free Mass (kg) and Vertical Jump Height (cm).

DISCUSSION

The purpose of this study was to analyse the effects of the COVID-19 lockdown on body composition and the kinetic and kinematic variables of the vertical jump in world-class martial art athletes. Results showed a significant detriment to VJH performance following the 16-week lockdown period, during which an altered home-based strength and conditioning program was adopted. Analyses of the CMJ performance variables indicated that the decreased jump performance was due to an impaired ability to produce PV and PPP. At post measurements, while vertical jump force was slightly reduced, although not statistically significantly, additional time was taken by the athlete to complete the jump, thus reducing both PV and PPP. This increase in time appears to have occurred during the braking phase and take-off phases of the vertical jump. Furthermore, post-COVID-19 lockdown training was focused on retraining neuromuscular components (motor unit recruitment, firing rate, stretch-shortening cycle) by increasing the training load from the at-home lockdown training to 70% of pre-lockdown load. Increases in lower body power, as facilitated by neuromuscular adaptations, have been reported after a period of intensive strength training (alterations in movement speed and volume). Therefore, as supported by prior research (Brown et al., 2017), retraining likely contributed neuromuscular adaptations resulting in the rise of peak velocity and peak propulsive power seen at post+2 and post+4 assessments compared to post. These findings corroborate a recent report, which highlighted that the ability to achieve higher VJH during the CMJ is determined by the ability to produce PV (Perez-Castilla et al., 2019). Surprisingly, although other kinetic variables such as force, rate of force development, and power were reduced from pre- to post-test, these were not statistically significant. Previous work has shown that net vertical impulse and peak power can accurately predict VJH (McBride et al., 2010). However, in the present study, those variables were not sufficiently affected by the detraining or retraining to reach statistically significant differences.

A second important finding of the current study was that subjects returned to pre-lockdown levels of VJH performance within two to four weeks after engaging in a progressive retraining period through the training facility-based strength and conditioning sessions. The improvements in VJH are attributed to the training program, as the loads experienced during Wushu practice remained constant. Prior literature corroborates this finding with athletes exhibiting improvements in athletic performance measures attributed to resistance training program participation despite regular sport practice engagement (Loturco et al., 2017). Moreover, study findings are consistent with the detraining and retraining literature. For example, previous work with soccer players showed that performance measures following a short period of detraining (two weeks) were recovered after three-weeks of retraining (Joo, 2018). However, the novel approach of the current study in comparison to other detraining and retraining studies is that the detraining period was longer (16 weeks) and was due to an external uncontrollable factor. Furthermore, subjects in the present study did not aim to detrain, in fact attempted to maintain their physical performance through home-based bodyweight strength training sessions.

Recent research indicates that a short training period can positively impact combat performance variables such as punch impact force across various punching styles (Loturco et al., 2019). For example, after only one-week of training there was a marked increase in jab punch impact (Cohen’s d = 0.36) and cross punch impact (Cohen’s d = 0.39) in elite boxers (Loturco et al., 2019). The rapid improvements associated with the retraining period may be attributed to the specificity of programming and exercises included, which may have affected neuromuscular training adaptations resulting in augmented jump kinetic performance. Certainly, lower body kinetics play a paramount role in punching with the capacity to transfer large amounts of force at high velocities from the lower body to the upper body, which have been shown vital in producing high punch impact forces (Lenetsky et al., 2013). Consequently, coaches desiring to improve punching performance are encouraged to implement lower-body explosive exercises resulting in enhanced jumping kinetic performance in their training programs. Moreover, the current results highlight the quality differences of training facility-based strength and conditioning sessions in comparison with home-based training sessions. The subjects in this study were world class martial art athletes with high levels of motivation to maintain their functional performance during the 16-week lockdown. Nonetheless, the current results indicate that the home-based exercise program was not effective enough to sustain pre-lockdown CMJ performance. At the same time, the current findings indicate that these elite athletes were able to regain their original CMJ performance in only a few weeks after returning to their training facility. It is hypothesized that if athletes spent the 16-week lockdown period with passive rest, their CMJ performance decrements would have been substantially greater and a longer retraining period would have been needed to regain pre-lockdown performance levels.

Altogether, the current results indicate that the 16-week home-based training program was insufficient to sustain the kinematic performance for the CMJ, but adequately sustained the kinetic parameters, such as force, rate of force development, power, and impulse production during the CMJ. This is a novel and relevant finding given the strong connection between vertical jump kinetic performance and both impact and speed of combat actions (Loturco et al., 2014; Loturco et al., 2019). In karate athletes, mean propulsive power during the squat jump demonstrated a strong association with maximal punching speed ($r = 0.765$) and impact ($r = 0.789$). Similarly, VJH displayed a strong relationship with both punching speed ($r = 0.729$) and impact ($r = 0.707$) (Loturco et al., 2014). In fact, lower body explosiveness has been shown to play an critical role in total punch impact in competitive boxers (Filimonov et al., 1985). Other studies highlighted that leg drive meaningfully affects hand velocity during maximal punching (Lenetsky et al., 2013; Turner et al., 2011). Therefore, lower-body training appears to be a plausible training program aiming to maintain vital kinetic measures associated with combat actions. Considering that the home-based bodyweight exercises were performed at a controlled and slow pace, it seems logical that the velocity of the movement during CMJ was affected, thus, the ability to produce movement velocity was the most drastically detrained parameter during the lockdown period. Future studies may focus on replicating the application of an extensive home-based program but using an experimental controlled study design to determine if the rate of detraining is dependent on the type of activity performed during the detraining period.

An additional element in the current study is the observation of an increase in the subjects' body weight from pre- to post-test. The subjects' nutritional intake was not controlled during the lockdown period, but the subjects generally aimed to stay active and eat healthy to best maintain their sports performance. At the same time, training volume was decreased substantially resulting in a probable reduction in caloric expenditure. These factors may have contributed to the observed increase in body weight. A previous study on anthropometrics in martial art athletes revealed that body fat and body weight can predict vertical jump height, with increases on each of these variables negatively affecting VJH (Abidin & Adam, 2013). Hence, the increased BF (%) and FM observed during post testing contributed to the reduction in VJH achieved by the subjects. The increase in BF (%) and FM could be attributed to the decreased training volume and lack of nutritional follow-up during the COVID-19 lockdown. Figure 3 displays the changes in body composition across time and Figure 3B the relationship between fat-free mass and vertical jump height across the three time points. Both figures suggest that alterations in body composition impacted vertical jump performance. Consequently, the retraining period which resulted in improved body composition potentially contributed to enhancement of vertical jump height, peak propulsive power, peak velocity, and RSImod. Certainly, research reports a concurrent increase in vertical jump height with increases in fat-free mass (Nikolaidis, 2014), like those reported in the present study (Figure 3B). Future studies may seek to assess the effects of body weight and body composition changes on different kinetic and kinematic parameters of vertical jump performance in elite athletes using a controlled design for both training and diet programming.

The current study is not without limitations. First, the experimental study design lacked a control group. Developing a study with a control-group experimental design was not feasible given the medical considerations and the sudden unexpected impact of the pandemic. Yet, the repeated-measures within-subjects ANOVA design allowed the subjects to serve as their own controls, which increased the statistical power of the analysis. Additionally, we were unable to provide reliability scores for body composition measures obtained through the InBody BIA device; however, this instrument has demonstrated excellent reliability in a previous study (McLester et al., 2020). Another limitation is the absence of muscle activation, muscle quality, and muscle fibre type measures, thus the relationship between changes in muscle activation or structure and vertical jump performance remains to be unknown. Moreover, we were unable to assess for maximal squat test (1-RM) at any of the post-test periods. It has been previously reported that changes in maximal strength (1-RM) can have an effect on kinetic and kinematic components in vertical jump performance (Nuzzo et al., 2008). However, given the current guidelines, we were unable to provide any "*spotting*" during the lifts, thus, it has decided to avoid any 1-RM testing due to safety concerns. Lastly, the present study employed the analysis of CMJ as the most practically relevant assessment for elite martial art athletes. It is possible that other tests where kinetic and kinematic parameters show more sensitivity may have led to more pronounced results. Future literature may desire to incorporate additional tests when exploring the impact of a period of detraining in elite athletes.

CONCLUSION

Through the tracking of a group of elite martial art athletes in the present study, it appears that vertical jump performance can be negatively impacted due to a decreased ability to produce peak velocity and peak propulsive power in combination with an increased BF (%) and FM during an extended detraining period. At the same time, it appears that a home-based bodyweight training program implementation may retain force and impulse production for vertical jumping. Generation and transfer of lower-body forces to the upper-body play a paramount role in the athlete's ability to attain high punch impact forces and speed. Provided the strong connection with lower-body explosiveness, as observed with jumping and combat actions in Wushu, regaining pre-lockdown vertical jump performance levels is of interest to coaches training combat athletes. Moreover, jump height, RSImod, peak velocity and peak propulsive power are rapidly restored to pre detraining levels following programming presented in this study. Consequently, practitioners may desire to implement a post-lockdown training (or post-detraining) program similar to that described in the present study, which may result in the relatively quick retraining needed after a prolonged lockdown/detraining period.

AUTHOR CONTRIBUTIONS

Erik Tan: conceptualization, methodology, investigation, resources, data curation, writing and, supervision. Samuel Montalvo: conceptualization, methodology, data curation, formal analysis, supervision and, writing. Matthew P. Gonzalez: writing. Martin Dietze-Hermosa: writing. See Min: investigation and, data curation. Sandor Dorgo: supervision and, writing.

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DISCLOSURE STATEMENT

No potential conflict of interest was reported by the authors.

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ANNEXE 1. SUPPLEMENTAL MATERIALS.

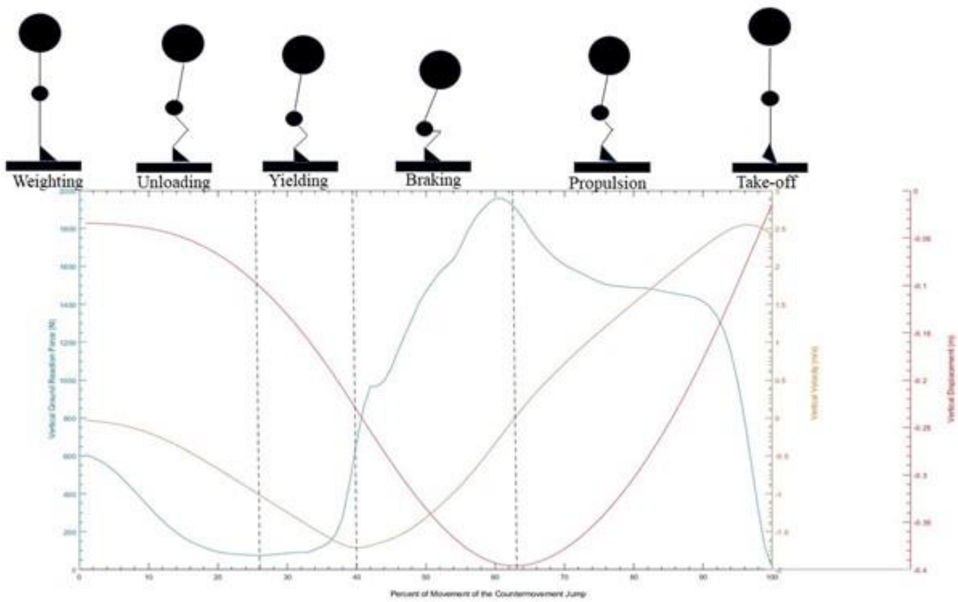

Figure 1s. Determinants of Kinetic and Kinematic parameters of the vertical jump; y-blue axis) Vertical ground reaction force (n), y-gold axis) Vertical velocity (m/s), y-red axis) Vertical displacement of the centre of mass (m).

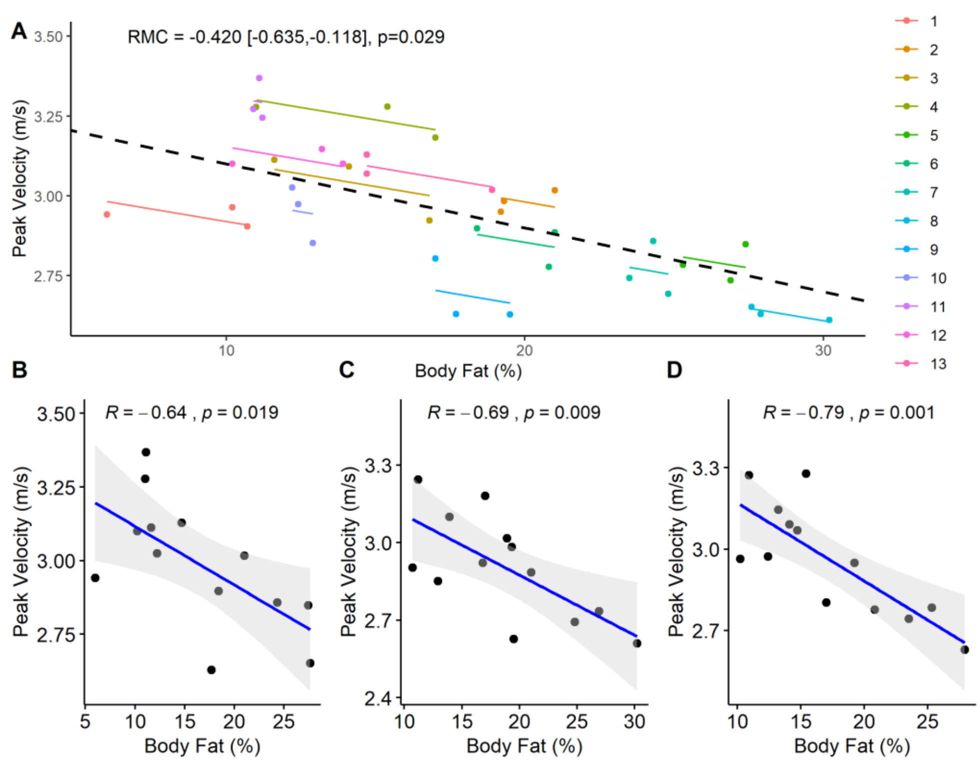

Figure 2s. Repeated measures correlation (A) and individual Pearson's correlation (B = Pre, C = Post, and D = Post+4) with regression lines between Body fat (%) and Peak Velocity (m/s).

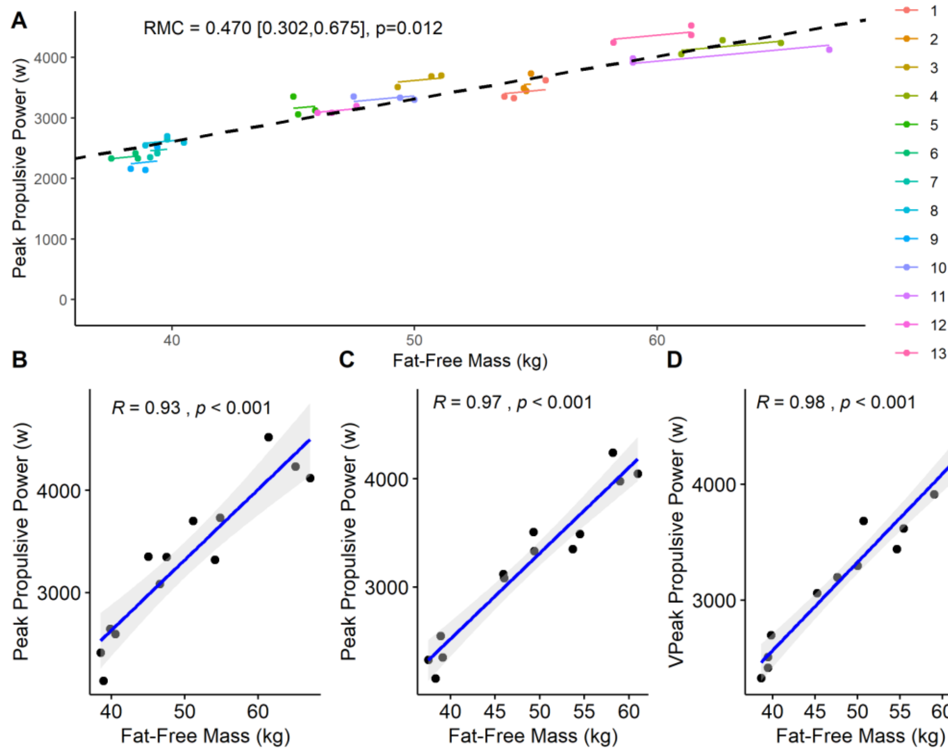

Figure 3s. Repeated measures correlation (A) and individual Pearson's correlation (B = Pre, C = Post, and D = Post+4) with regression lines between Fat-Free Mass (kg) and Peak Propulsive Power (w).

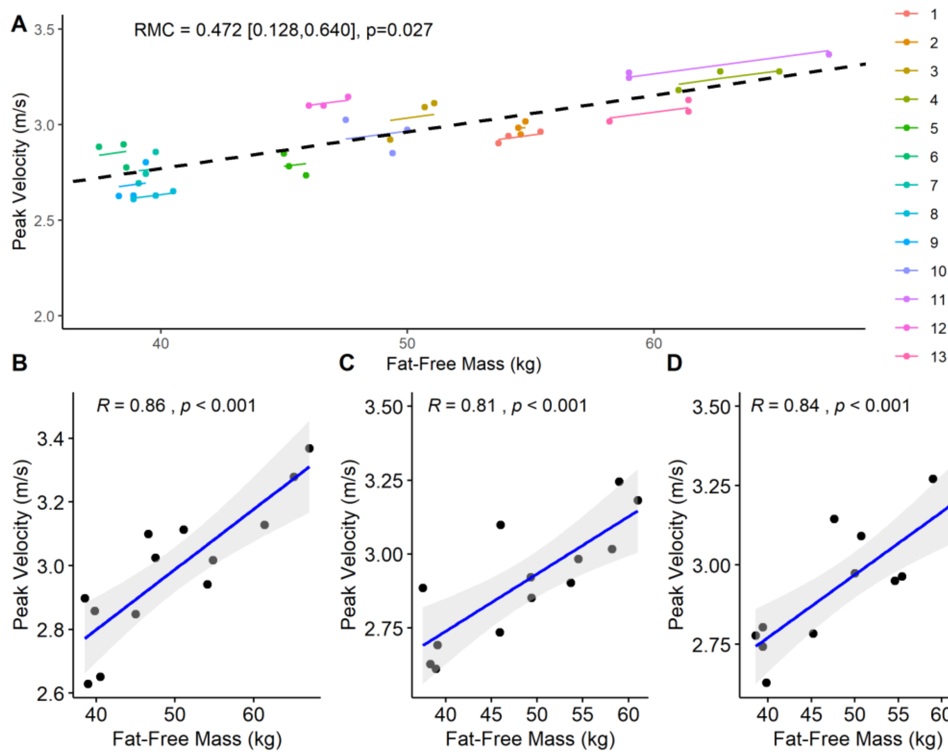

Figure 4s. Repeated measures correlation (A) and individual Pearson's correlation (B = Pre, C = Post, and D = Post+4) with regression lines between Fat-Free Mass (kg) and Peak Velocity (m/s).

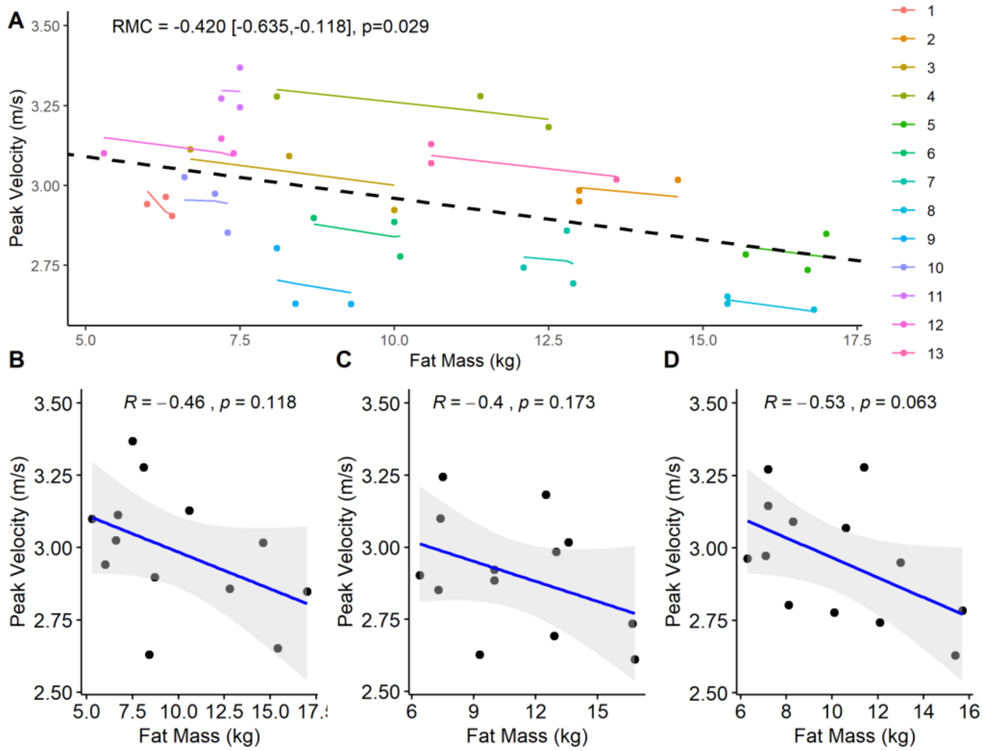

Figure 7. Repeated measures correlation (A) and individual Pearson's correlation (B = Pre, C = Post, and D = Post+4) with regression lines between Fat-Free Mass (kg) and Peak Velocity (m/s).