

## Article

# Local muscle endurance and strength are the best predictors of Crossfit open 2020 in amateur athletes

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**Abstract:** This study analyzed the relationship between anthropometric measures, cardiorespiratory capacity, strength, power and local muscle endurance with performance in the CrossFit® Open 2020. For this, 17 volunteers (6 women) ( $29.0 \pm 7.2$  years;  $70.5 \pm 9.8$  kg) completed, on separate weeks, body composition (dual-energy x-ray absorptiometry), maximal oxygen consumption (2km row test), muscle strength (1RM back and front squat, isometric peak torque), and muscle power (1RM snatch and clean & jerk), and muscle endurance (Tibana test), which were compared with performance during the CrossFit® Open 2020. Multiple linear regression showed that for the CrossFit Open 2020.1 and 2020.2 workouts, the score in the Tibana test was the only variable that explained the outcomes (Beta = -0.78,  $p < 0.01$  for 2020.1 workout and Beta = 0.82,  $p < 0.01$  for 2020.2 workout). Performance in the CrossFit Open 2020.3 and 2020.4 workouts were explained through the relative strength (Beta = 0.58,  $p = 0.02$  for 2020.3 workout and Beta = 0.50,  $p = 0.04$  for 2020.4 workout). Lastly, Tibana test had the greatest influence on CrossFit Open 2020.5 workout (Beta = -0.75,  $p < 0.01$ ). A local muscle endurance and muscle strength may be used to predict CrossFit® open workout performance.

**Keywords:** Functional fitness training; athletic performance; exercise testing

## 1. Introduction

Competitive CrossFit often consists of two stages, the online qualifier (multiple unfamiliar workout challenges that are completed over the course of some weeks) from which the competitors with the best online results qualify for regional events (South America, North America, Africa, Asia etc.). The CrossFit Open is an online competition officially managed by CrossFit Inc, being one of the largest sports events in the world, with more than 239,106 participants in the 2020 event.

Despite the increase in popularity, there is a paucity of literature on the topic of CrossFit performance. Previous research has investigated the relationship between non-specific tests such as anthropometric profile [1], cardiorespiratory capacity [2], muscle strength [2], and muscle power [2], with performance in practitioners and athletes of CrossFit. For example, Martínez-Gómez et al. [2] evaluated the relationship between muscle strength (Full-Squat) and performance at the CrossFit Open 2017. The authors showed that strength and power indices measured in a squat test were positively associated with CrossFit performance. However, according to Butcher et al. [3], performance in CrossFit

is different from most sports where it is possible to predict and evaluate the performance of an athlete with tests of muscular strength, physiological variables, and aerobic and anaerobic powers (test on treadmill and Wingate, respectively). In CrossFit, although the tests are partially associated with performance in some tests (CrossFit open and benchmarks), these tests have no specificity with the variety of movements and repetitions during the workouts (calisthenics, strength, and endurance).

The workouts in the previous year (2019) had no characteristics of muscle strength or cardiovascular capacity. On the other hand, the athletes performed several repetitions of specific exercises, such as a gymnastic component (e.g., burpees, strict handstand push-ups or walks, bar or ring muscle-ups, chest to bar pull-ups, toes-to-bar, rope climb, pistols) with relatively light resistance exercises (e.g., wall ball, thruster, clean, snatch, deadlift, front squat). However, it is unknown whether a specific test of local muscle endurance is associated with performance in the CrossFit® Open. Prior physical performance screening might provide efficient data for analysis and important feedback to athletes and coaches to determine key performance predictors in a particular competition. This information could be valuable for evidence-based strategies during competitions and to identify possible deficient performance.

Therefore, the current study aimed to analyze the relationship between anthropometric measures, cardiorespiratory capacity, and the variables of strength, power, and a specific test of muscular endurance with performance in the CrossFit® Open 2020. We hypothesized that significant correlations would be found between the variables analyzed and performance in the CrossFit® Open 2020.

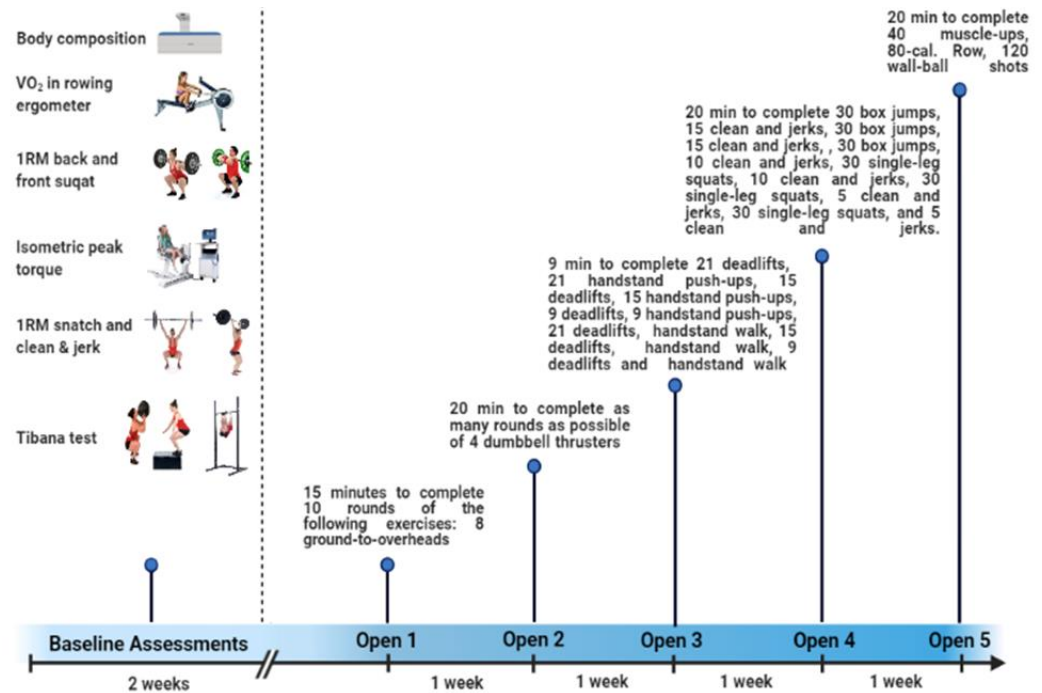
## 2. Materials and Methods

### 2.1 Participants

In total, 17 volunteers (6 women) ( $26.6 \pm 5.7$  years;  $70.5 \pm 9.8$  kg;  $11.9 \pm 6.0\%$  of body fat;  $48.7 \pm 4.4$  ml/kg/min<sup>-1</sup>;  $1.8 \pm 0.3$  of relative back squat muscle strength) were recruited. All subjects were free of injury or known illnesses, were not using performance enhancing drugs, and had a minimum of 6 months of CrossFit experience. Participants were advised to sleep six to eight hours the night before the tests, maintain regular nutritional and hydration habits, avoid intense exercise 48h prior to the sessions, and avoid smoking, alcohol, and caffeine consumption 24h before a session. All subjects provided informed consent, and the study was approved by the University Research Ethics Committee for Human Use (2.698.225/Universidade Estácio de Sá/UNESA/RJ) and conformed to the principles of the Helsinki Declaration on the use of human participants for research.

### 2.2 Experimental Design

The present study followed a cross-sectional design. All participants performed the baseline assessments two weeks prior to the CrossFit Games Open 2020 (five Workouts for 5 weeks) (October – November / 2019). Figure 1 shows schematic illustration of the methodological steps in the following study.



**Figure 1.** Description of study timeline.

### 2.3 Baseline Assessments

The participants performed, on separate weeks, body composition (dual-energy x-ray absorptiometry), maximal oxygen consumption (2km row test), muscle strength (1RM back squat, 1RM front squat and isometric peak torque, Biodex System 3), and muscle power measures (1RM snatch and 1RM clean & jerk), as well as a specific test of muscle endurance (Tibana test). Baseline Assessments were performed two weeks before the CrossFit® Open 2020.

### 2.4 Body composition

Body composition analysis (percentage body fat and fat-free mass) was conducted using dual energy x-ray absorptiometry (General Electric-GE model 8548 BX1L, year 2005, Lunar DPX type, software Encore 2005; Rommelsdorf, Germany) with an in vivo variation coefficient of 0.9%–1.1%. Briefly, the tests included a complete body scan of the volunteers in a supine position. The apparatus was continuously regulated and operated by a technically trained professional. Legs were secured by nonelastic straps at the knees and ankles, and the arms were aligned along the trunk with the palms facing the thighs. The following variables were evaluated: body mass, fat free mass, body fat mass, and percentage of body fat mass.

### 2.5 Maximal oxygen consumption

The 2k row test was performed as previously described by Jensen et al. [4]. All exercise tests were performed on the same rowing ergometer (model E; Concept2, Morrisville, VT). The subjects individually adapted their preferred stroke rate and drag factor in both tests and during the warm-up protocol. The standardized warm-up for the 2k time trial was 4 minutes of easy rowing; 4 × 1 minute with 10, 15, 20, and 10 hard strokes for each

minute; and 2 minutes of easy rowing. After a short rest while the oxygen uptake equipment was mounted, the 2k all-out time trial was performed.

Before and during the test period, athletes were monitored by ECG (Digital Electrocardiogram, Micromed Brazil) to detect possible anomalies that would make it impossible for the volunteers to continue the test or study. Heart rate (HR) was measured with a Polar H10 (Polar Electro Oy, Kempele, Finland). The gases were analyzed using the ERGOPc ELITE / Metasofit 3 device. The  $\text{VO}_2$  peak and HR values adopted were the highest achieved during the test. All procedures were followed by a cardiologist.

### *2.6 Muscle strength and power measures*

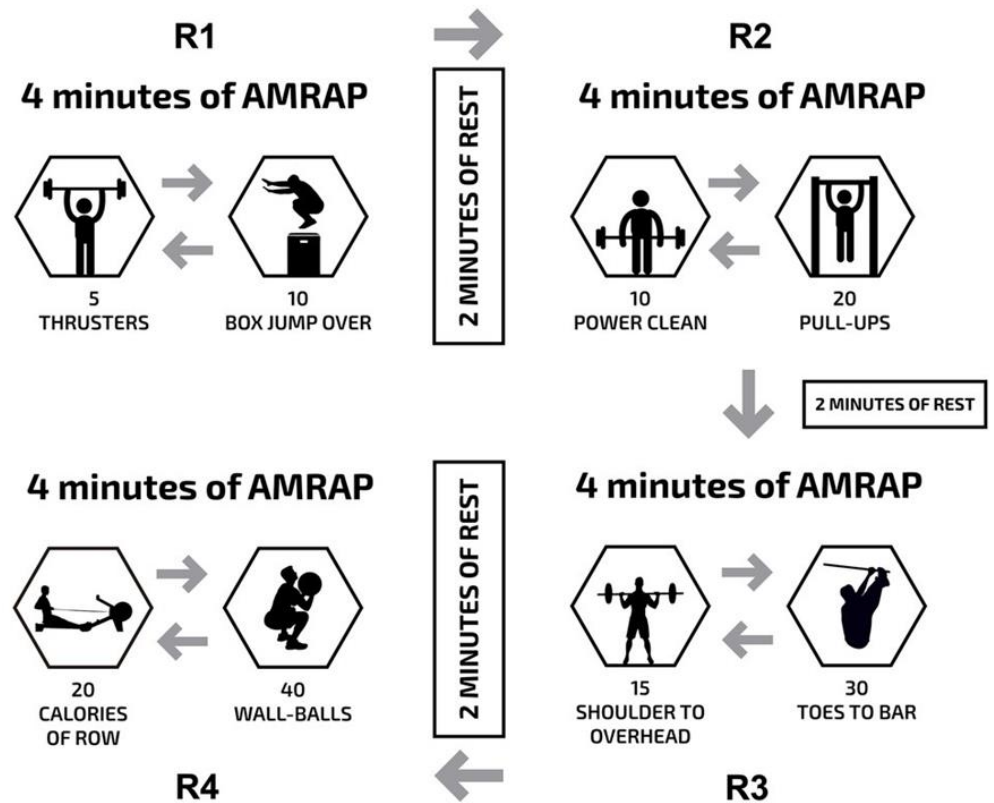
Participants performed one 1RM test for back squat, front squat, snatch, and clean & jerk according to procedures recommended by the National Strength and Conditioning Association [5,6] with 48-h rest intervals between sessions to minimize the effects of muscle fatigue and pain. All randomized tests were performed with a barbell (20/15 kg) and weights (1-25 kg) (Pood Fitness®). The protocol consisted of a brief general warm-up on a bike or indoor rowing ergometer, followed by eight repetitions at 50% of estimated 1-RM (according to the previous loads used by participants in their training routines). After a 1-min rest, they performed three repetitions at 70% of estimated 1-RM. Then, the participants completed three to five attempts with 3 to 5-min rest intervals between each attempt, with progressively heavier weights until the 1-RM was determined. Both testing sessions took place between 2 p.m. and 3 p.m. after lunch and under a controlled standardized temperature. During this period, standard instructions and explanations regarding the procedures of the test protocols and the proper execution of the exercise technique were provided by a qualified and experienced investigator.

### *2.7 Isometric strength*

Upon arrival at the laboratory, subjects were seated in a knee extension chair that allowed for isometric force testing. Subjects were restrained in the chair with straps secured around their chest, abdomen, and hips. Their arms remained crossed throughout testing. Three maximal isometric contractions of knee extension were performed on the isokinetic dynamometer (Biodex System 3, Biodex Medical Systems, Shirley, NY, USA). The knee joint was fixed at 60 ° for performance of the isometric contraction for a period of 5s, with the subject seated and hips fixed at a 90 ° angle [7]. A 3-min recovery period was provided between isometric contractions. The highest value was considered as the maximum isometric torque index [7].

### *2.8 Local Muscle Endurance*

The local muscle endurance test used was the Tibana test, which involved the completion of four different rounds of work, each separated by 2 min of rest (Figure 2). The rounds consisted of 4 min of as many rounds as possible (AMRAP) of five thrusters (60 kg for men and 43 kg for women) and 10 box jumps over (round 1); 4 min of AMRAP of 10 power clean (60 kg for men and 43 kg for women) and 20 pull-ups (round 2); 4 min of AMRAP of 15 shoulder to overhead (60 kg for men and 43 kg for women) and 30 toes to bar (round 3); and 4 min of AMRAP of 20 calories of rowing and 40 wall ball (9 kg for men and 6 kg for women) (round 4) [8,9].



**Figure 2.** Description of the local muscle endurance test (Tibana Test): 4 min of as many rounds as possible (AMRAP) of five thrusters, and 10 box jump over (round 1); 2 min of rest; 4 min of AMRAP of 10 power clean, and 20 pull-ups (round 2); 2 min of rest; 4 min of AMRAP of 15 shoulder to overhead, and 30 toes to bar (round 3); 2 min of rest; and 4 min of AMRAP of 20 calories of row, and 40 wall ball (round 4).

### 2.9 CrossFit Open 2020

The specific details of the five WODs used in this study, known as 20.1, 20.2, 20.3, 20.4, and 20.5, are briefly explained below:

- 20.1: Participants had 15 minutes to complete 10 rounds of the following exercises: 8 ground-to-overheads (95 lb men; 65 lb women) and 10 bar-facing burpees.
- 20.2: Participants had 20 min to complete as many rounds as possible of 4 dumbbell thrusters (50-lb for men and 35-lb for women - Dumbbells), 6 toes-to-bars, and 24 double-unders.
- 20.3: Participants had 9 min to complete 21 deadlifts, 225/155 lb., 21 handstand push-ups. 15 deadlifts, 225/155 lb., 15 handstand push-ups, 9 deadlifts, 225/155 lb., 9 handstand push-ups, 21 deadlifts, 315/205 lb., 50-ft. handstand walk, 15 deadlifts, 315/205 lb., 50-ft. handstand walk, 9 deadlifts, 315/205 lb., and 50-ft. handstand walk
- 20.4: Participants had 20 min to complete 30 box jumps, 24/20 in., 15 clean and jerks, 95/65 lb., 30 box jumps, 24/20 in., 15 clean and jerks, 135/85 lb., 30 box jumps, 24/20 in., 10 clean and jerks, 185/115 lb., 30 single-leg squats, 10 clean and jerks, 225/145 lb., 30 single-leg squats, 5 clean and jerks, 275/175 lb., 30 single-leg squats, and 5 clean and jerks, 315/205 lb.

- 20.5: Participants had 20 min to complete 40 muscle-ups, 80-cal. row, 120 wall-ball shots, (20-lb. ball to 10 ft/14-lb. ball to 9 ft.).

### 2.10 Statistical analysis

The data are expressed as mean value  $\pm$  standard deviation (SD). The Shapiro–Wilk test was used to check for parametric distribution of study variables. Simple Pearson’s  $r$  correlations were used to determine the associations between the results of CrossFit Open 2020 benchmarks and anthropometric, strength, cardiorespiratory, and performance measures. The magnitude of the correlations was classified as:  $r \leq 0.1$  trivial;  $0.1 < r \leq 0.3$  small;  $0.3 < r \leq 0.5$  moderate;  $0.5 < r \leq 0.7$  large;  $0.7 < r \leq 0.9$  very large;  $r > 0.9$  almost perfect [10]. For each of the dependent CrossFit Open 2020 benchmarks, a forward stepwise linear regression model was created using the significant relative data. The probability of  $F$  used for variables to enter the model was less than or equal to 0.05, and to remove variables was greater than or equal to 0.10. Multicollinearity was assessed by examining each significant variable in an independent regression model. The level of significance was  $p \leq 0.05$  and SPSS version 20.0 (Somers, NY, USA) software was used.

## 3. Results

### 3.1 Anthropometric, strength, cardiorespiratory, and performance data presentation

The anthropometric and cardiorespiratory measurements are shown in table 1 and the strength measurements are shown in table 2. The participants achieved  $252.3 \pm 31.7$  repetitions (men) and  $257.7 \pm 36.0$  repetitions (women) during the Tibana test.

**Table 1.** Mean  $\pm$  SD of anthropometric and cardiorespiratory measurements of the participants

	All (n = 17)	Men (n = 11)	Women (n = 6)
Age, yr.	29.0 $\pm$ 7.2	26.63 $\pm$ 5.7	33.3 $\pm$ 8.1
Body weight, kg	70.5 $\pm$ 9.8	77.0 $\pm$ 3.6	58.6 $\pm$ 4.2
Body fat, %	11.9 $\pm$ 6.0	8.8 $\pm$ 5.0	17.1 $\pm$ 3.3
Lean mass, kg	61.6 $\pm$ 11.1	69.5 $\pm$ 4.1	48.5 $\pm$ 2.9
VO <sub>2max</sub> , mL.(kg.min) <sup>-1</sup>	48.7 $\pm$ 4.4	49.7 $\pm$ 4.6	45.9 $\pm$ 2.1
VO <sub>2max</sub> , maximal oxygen consumption			

**Table 2.** Mean  $\pm$  SD of strength measurements of the participants

	All (n = 17)	Men (n = 11)	Women (n = 6)
Back squat, kg	129.4 $\pm$ 30.0	145.5 $\pm$ 23.2	100.0 $\pm$ 13.7
Back squat, relative to body weight	1.8 $\pm$ 0.3	1.9 $\pm$ 0.3	1.7 $\pm$ 0.3
Front squat, kg	113.8 $\pm$ 27.0	129.5 $\pm$ 17.0	85.0 $\pm$ 14.5
Front squat, relative to body weight	1.6 $\pm$ 0.3	1.7 $\pm$ 0.3	1.5 $\pm$ 0.3
Snatch, kg	76.9 $\pm$ 23.8	91.3 $\pm$ 13.0	50.5 $\pm$ 14.0
Snatch, relative to body weight	1.1 $\pm$ 0.3	1.2 $\pm$ 0.2	0.9 $\pm$ 0.2
Clean and Jerk, kg	95.5 $\pm$ 26.2	110.6 $\pm$ 17.0	67.7 $\pm$ 13.9

Clean and Jerk, relative to body weight	1.3 ± 0.3	1.4 ± 0.3	1.2 ± 0.2
Total strength, kg	415.6 ± 104.4	476.9 ± 67.1	303.2 ± 49.5
Total strength, relative to body weight	5.9 ± 1.1	6.2 ± 1.0	5.2 ± 0.9
Isometric strength, kg	268.0 ± 56.4	303.6 ± 25.5	202.6 ± 30.6
Isometric strength, relative to body weight	3.8 ± 0.5	4.0 ± 0.4	3.5 ± 0.6

### 3.2 CrossFit Open 2020 data and correlations

There was a statistically significant correlation between age and CrossFit Open 2020.1 ( $r = 0.95$ ;  $p < 0.01$ ), CrossFit Open 2020.2 ( $r = -0.98$ ;  $p < 0.01$ ), and CrossFit Open 2020.4 ( $r = -0.85$ ;  $p = 0.03$ ) for women. No correlations were observed between age and CrossFit Open 2020 benchmarks for men. There were no significant associations between anthropometric measures and CrossFit Open 2020 for men or women. The correlations between CrossFit Open 2020 benchmarks and the strength, cardiorespiratory, and performance measures for men and women are shown in tables 3 and 4, respectively.

**Table 3.** Correlations between CrossFit Open 2020 benchmarks and strength, cardiorespiratory, and performance measures in men ( $n = 11$ )

	2020.1	2020.2	2020.3	2020.4	2020.5
VO <sub>2max</sub> , mL.(kg.min) <sup>-1</sup>	$r = -0.54$ ; $p = 0.09$	$r = 0.16$ ; $p = 0.66$	$r = -0.19$ ; $p = 0.62$	$r = 0.06$ ; $p = 0.85$	$r = -0.30$ ; $p = 0.39$
BS, kg	$r = -0.28$ ; $p = 0.40$	$r = 0.36$ ; $p = 0.31$	$r = 0.59$ ; $p = 0.09$	$r = 0.79$ ; $p < 0.01^*$	$r = -0.37$ ; $p = 0.26$
BS, rbw	$r = -0.31$ ; $p = 0.36$	$r = 0.39$ ; $p = 0.27$	$r = 0.62$ ; $p = 0.08$	$r = 0.81$ ; $p < 0.01^*$	$r = -0.40$ ; $p = 0.25$
FS, kg	$r = -0.31$ ; $p = 0.35$	$r = 0.50$ ; $p = 0.14$	$r = 0.72$ ; $p = 0.03^*$	$r = 0.82$ ; $p < 0.01^*$	$r = -0.46$ ; $p = 0.19$
FS, rbw	$r = -0.33$ ; $p = 0.32$	$r = 0.51$ ; $p = 0.14$	$r = 0.72$ ; $p = 0.03^*$	$r = 0.85$ ; $p < 0.01^*$	$r = -0.48$ ; $p = 0.16$
Snatch, kg	$r = -0.43$ ; $p = 0.19$	$r = 0.47$ ; $p = 0.17$	$r = 0.60$ ; $p = 0.09$	$r = 0.78$ ; $p = 0.01^*$	$r = -0.55$ ; $p = 0.10$
Snatch, rbw	$r = -0.43$ ; $p = 0.19$	$r = 0.48$ ; $p = 0.16$	$r = 0.62$ ; $p = 0.08$	$r = 0.81$ ; $p < 0.01^*$	$r = -0.56$ ; $p = 0.09$
C&J, kg	$r = -0.50$ ; $p = 0.12$	$r = 0.77$ ; $p = 0.01^*$	$r = 0.87$ ; $p < 0.01^*$	$r = 0.90$ ; $p < 0.01^*$	$r = -0.61$ ; $p = 0.06$
C&J, rbw	$r = -0.49$ ; $p = 0.13$	$r = 0.75$ ; $p = 0.01^*$	$r = 0.86$ ; $p < 0.01^*$	$r = 0.92$ ; $p < 0.01^*$	$r = -0.61$ ; $p = 0.06$
TS, kg	$r = -0.39$ ; $p = 0.24$	$r = 0.54$ ; $p = 0.11$	$r = 0.72$ ; $p = 0.03^*$	$r = 0.86$ ; $p < 0.01^*$	$r = -0.50$ ; $p = 0.14$

TS, rbw	r = -0.39; p = 0.23	r = 0.54; p = 0.11	r = 0.72; p = 0.02*	r = 0.88; p < 0.01*	r = -0.51; p = 0.13
IS, kg	r = 0.20; p = 0.56	r = -0.56; p = 0.09	r = -0.58; p = 0.10	r = -0.25; p = 0.46	r = -0.03; p = 0.94
IS, rbw	r = 0.06; p = 0.86	r = -0.34; p = 0.33	r = -0.26; p = 0.50	r = 0.04; p = 0.92	r = -0.23; p = 0.52
Tibana test, rep	r = -0.73; p = 0.01*	r = 0.83; p < 0.01*	r = 0.74; p = 0.02*	r = 0.51; p = 0.11	r = -0.89; p < 0.01*

VO<sub>2max</sub>, maximal oxygen consumption; BS, back squat; FS, front squat; C&J, clean and jerk; TS, total strength; IS, isometric strength; rbw, relative to body weight

**Table 4.** Correlations between CrossFit Open 2020 benchmarks and strength, cardiorespiratory, and performance measures in women (n = 6)

	2020.1	2020.2	2020.3	2020.4	2020.5
VO <sub>2max</sub> , mL.(kg.min) <sup>-1</sup>	r = -0.88; p = 0.05	r = -0.88; p = 0.05*	r = -0.62; p = 0.26	r = -0.81; p = 0.10	r = 0.67; p = 0.33
BS, kg	r = -0.32; p = 0.54	r = 0.20; p = 0.71	r = 0.54; p = 0.27	r = 0.52; p = 0.30	r = -0.84; p = 0.17
BS, rbw	r = -0.20; p = 0.71	r = 0.12; p = 0.83	r = 0.62; p = 0.19	r = 0.35; p = 0.50	r = -0.89; p = 0.11
FS, kg	r = -0.66; p = 0.16	r = 0.59; p = 0.22	r = 0.82; p = 0.05*	r = 0.81; p = 0.05*	r = -0.95; p = 0.05*
FS, rbw	r = -0.57; p = 0.24	r = 0.52; p = 0.29	r = 0.90; p = 0.02*	r = 0.69; p = 0.13	r = -0.92; p = 0.08
Snatch, kg	r = -0.90; p = 0.02*	r = 0.90; p = 0.01*	r = 0.75; p = 0.09	r = 0.91; p = 0.01*	r = -0.88; p = 0.12
Snatch, rbw	r = -0.90; p = 0.02*	r = 0.92; p = 0.01*	r = 0.85; p = 0.03*	r = 0.89; p = 0.02*	r = -0.81; p = 0.19
C&J, kg	r = -0.89; p = 0.02*	r = 0.86; p = 0.03*	r = 0.72; p = 0.11	r = 0.93; p = 0.01*	r = -0.94; p = 0.06
C&J, rbw	r = -0.90; p = 0.01*	r = 0.89; p = 0.02*	r = 0.89; p = 0.02*	r = 0.92; p = 0.01*	r = -0.87; p = 0.13
TS, kg	r = -0.78; p = 0.07	r = 0.72; p = 0.11	r = 0.80; p = 0.06	r = 0.90; p = 0.01*	r = -0.96; p = 0.04*
TS, rbw	r = -0.71; p = 0.11	r = 0.68; p = 0.14	r = 0.93; p = 0.01*	r = 0.80; p = 0.06	r = -0.90; p = 0.10
IS, kg	r = 0.13; p = 0.81	r = 0.09; p = 0.87	r = 0.13; p = 0.81	r = -0.39; p = 0.44	r = 0.66; p = 0.34
IS, rbw	r = 0.12; p = 0.82	r = 0.09; p = 0.87	r = 0.30; p = 0.56	r = -0.37; p = 0.57	r = 0.48; p = 0.52



Tibana test, rep	r = -0.96; p < 0.01*	r = 0.98; p < 0.01*	r = 0.71; p = 0.11	r = 0.84; p = 0.04*	r = -0.63; p = 0.38
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VO<sub>2max</sub>, maximal oxygen consumption; BS, back squat; FS, front squat; C&J, clean and jerk; TS, total strength; IS, isometric strength; rbw, relative to body weight

### 3.3 CrossFit Open 2020 regression

Multiple linear regression analysis was undertaken to predict the performance in the CrossFit Open 2020 benchmarks. Multiple linear regression for CrossFit Open 2020.1 and 2020.2 workouts resulted in a significant model ( $R^2 = 0.71$ ,  $p < 0.01$  and  $R^2 = 0.79$ ,  $p < 0.01$ , respectively). The score in the Tibana Test was the only independent variable that explained the outcomes (Beta = -0.78,  $p < 0.01$  for 2020.1 workout and Beta = 0.82,  $p < 0.01$  for 2020.2 workout). Multiple linear regression for CrossFit Open 2020.3 and 2020.4 workouts also resulted in a significant model ( $R^2 = 0.74$ ,  $p = 0.01$  and  $R^2 = 0.68$ ,  $p < 0.01$ , respectively). The relative total strength was the only independent variable that explained the outcomes (Beta = 0.58,  $p = 0.02$  for 2020.3 workout and Beta = 0.50,  $p = 0.04$  for 2020.4 workout). Lastly, multiple linear regression for the CrossFit Open 2020.5 workout resulted in a significant model ( $R^2 = 0.83$ ,  $p = 0.01$ ). The score in the Tibana test had the greatest influence on the model (Beta = -0.75,  $p < 0.01$ ), followed by VO<sub>2max</sub> (Beta = -0.49,  $p < 0.01$ ) and age (Beta = -0.38,  $p = 0.04$ ), with relative total strength failing to attain significance (Beta = -0.35,  $p = 0.07$ ).

## 4. Discussion

This study aimed to analyze the relationship between anthropometric measures, cardiorespiratory capacity, and the variables of strength, power, and a specific test of muscular endurance with performance in the CrossFit® Open 2020. The score in the Tibana test was the only independent variable that explained the outcomes in CrossFit Open 2020.1 and 2020.2 workouts, while for performance in 2020.3 and 2020.4 workouts the relative total strength independent variable explained the outcomes.

Confirming the initial hypothesis, specific tests of localized muscular endurance and muscle strength had the strongest relationship with performance in the Open. On the other hand, contrary to previous studies the percentage of fat [1] and cardiorespiratory capacity [2] were not significantly correlated with CrossFit Open 2020 workout performance.

The result of local muscle endurance as one of the best predictors of athletic performance in the CrossFit open 2020 might be related to the test specificities used in the current study. The Tibana test consists of a variety of exercises and movements places greater stress on gymnastic component (pull-ups and toes-to-bar), resistance exercises (thruster, clean, shoulder to overhead and wall ball), which are requisites for almost all athletic endeavors and fitness components involved in CrossFit. Current data reinforce the use of the Tibana test or other specific test as a key tool for physical performance screening of practitioners of Functional fitness training.

In a prior review, Suchomel et al. [11] explained potential benefits of muscular strength in athletic performance. It is well established that greater muscular strength is associated with enhanced force-time characteristics, including rate of force development, external mechanical power, and magnitude of potentiation, besides general skill performance, such as jumping, sprinting, and change of direction [11]. These adaptations may clarify why relative total muscle strength can be vastly influential in improving an individual's overall performance during CrossFit® workouts. Furthermore, in some CrossFit Open workouts there are tests with strength characteristics which can be advantageous for stronger athletes.

An important characteristic in relation to CrossFit Open WODs is that they can vary in terms of intensity, duration, and skills, as well as physiological demands. For example, in workouts where total muscle strength was more related to performance (20.3 and 20.4), exercises (deadlift and clean & jerk) included high overload characteristics. On the other hand, in the other workouts, the most common characteristics were the large number of repetitions with a gymnastic component and lighter resistance exercises. Thus, it appears that the correlations in relation to localized muscle endurance, cardiovascular fitness, anthropometric profile, and muscle strength and power with CrossFit Open WODs are highly dependent on their characteristics and that the performance of single tests as performed in previous studies may not reflect the athletic profile of the volunteers. An effective alternative for athletes and coaches may be the holistic assessment model of athletes [5].

Accumulating evidence suggests that lower body fat can also have a beneficial effect on relevant fitness components, including endurance, strength, power, speed, balance, and agility [12-14]. The reason behind this is that additional weight creates more resistance during exercise and consequently the individual needs to work harder to maintain a certain level of performance. On the other hand, the individual may have a low body fat percentage, but show low strength levels [15]. An interesting finding of the current study is that body fat percentage displayed a low standard deviation (men  $11.9 \pm 6.0$ ; woman  $8.8 \pm 5.0$ ), which indicates that the athletes are not overweight. Possibly, athletic performance is more affected by excessive body fat percentage, as demonstrated in previous studies [16,17].

One of the essential aspects of the practical application of the present research is to highlight that organizers of face-to-face and online competitions know how to organize the workouts so that they really contemplate the different physical demands. For example, if a competition has a large number of events with high overloads it will favor the strongest athletes. Therefore, the competitions may not elicit the athletes with the best physical conditioning, but only the strongest athletes. Our findings will help coaches, exercise physiologists, and practitioners to assess their current training status and direct training to future competitions. For example, if the localized muscular resistance is much lower than the values of competitive athletes of the modality, training can be directed to improving localized muscular resistance and maintaining the other capacities (strength, power, and cardiovascular).

Despite the interesting findings of this study, some limitations need to be mentioned. First, the reduced number of volunteers. Second, the specific test does not include all gymnastics (e.g., ring and bar muscle-ups, rope climbs, pistols etc.), weightlifting (e.g., snatch) and powerlifting exercises (e.g., deadlift) that are usually performed at the CrossFit Open. Third, it should be noted, that these results should be considered only for amateur athletes. Therefore, our findings may not be directly transferable to elite athletes.

## 5. Conclusions

In conclusion, we report for the first time that a specific muscle endurance test may be used to predict CrossFit® open workout performance. In contrast to our hypothesis, we did not observe any correlation between anthropometric profile and cardiorespiratory capacity with CrossFit Open performance. From a practical perspective, coaches and practitioners can use these findings to assess physical fitness and organize the distribution of the training session based on less developed physical needs, in order to ensure an appropriate physiological adaptation for a given competition.

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