Baltic Journal of Health and Physical Activity

Volume 15 | Issue 1 Article 5

2023

Force–velocity profiles in CrossFit athletes: A cross-sectional study considering sex, age, and training frequency

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Recommended Citation

Parraga-Montilla JA, Cabrera Linares JC, Jimenez Reyes P, Moyano Lopez M, Serrano Huete V, Morcillo Losa JA, Latorre Roman PA. Force–velocity profiles in CrossFit athletes: A cross-sectional study considering sex, age, and training frequency. Balt J Health Phys Act. 2023;15(1):Article5. https://doi.org/10.29359/BJHPA.15.1.05

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Abstract

Introduction: The force–velocity profile has been analysed previously in different sports modalities; nevertheless, it has not been analysed in CrossFit. Objective: The aim of this study was to report neuromuscular characteristics of CrossFit athletes using their individual force-velocity profile, investigating differences according to sex, age, and training frequency. Materials and Methods: 72 males (33.17 ± 6.86 years; BMI: 25.93 ± 3.64 kg/m^2) and 18 females (30.11 ± 6.92 years; BMI: 23.53 ± 3.98 kg/m^2) participated in this study. The force-velocity profile was calculated using Samozino's method. Furthermore, neuromuscular characterization was completed with a squat jump and three drop jumps (20, 30, and 40 cm). Results: Regarding sex, significant differences in all analysed mechanical variables ($p < 0.001$) were found except for the theoretical maximal force ($p = 0.944$). No significant differences were found between age groups. Considering training frequency, athletes who train more than 5 days per week showed higher performance in all analysed mechanical variables ($p < 0.05$). Conclusion: CrossFit athletes have a force-velocity profile more oriented towards velocity than force. Males and females have different neuromuscular characteristics, also neuromuscular improvements can be achieved at any age. Moreover, higher neuromuscular performance is developed with a training frequency of 5 days or more per week.

Keywords

squat jump, countermovement jump, CrossFit, force–velocity profile, neuromuscular characterization

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The authors appreciate the selfless participation of the athletes in this research.

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Baltic Journal
of Health and Physical Activity

e-ISSN 2080-9999

Article

Force–velocity profiles in CrossFit athletes: A cross-sectional study considering sex, age, and training frequency

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Citation: Parraga-Montilla JA, Cabrera Linares JC, Jimenez Reyes P, Moyano Lopez M, Serrano Huete V, Morcillo Losa JA, Latorre Roman PA. Force–velocity profiles in CrossFit athletes: A cross-sectional study considering sex, age, and training frequency. Balt J Health Phys Act. 2023;15(1):Article5. https://doi.org/10.29359/BJHPA.15.1.05

Academic Editor:
Agnieszka Maciejewska-Skrendo

Received: January 2022
Accepted: December 2022
Published: March 2023

Abstract: Introduction: The force–velocity profile has been analysed previously in different sports modalities; nevertheless, it has not been analysed in CrossFit. Objective: The aim of this study was to report neuromuscular characteristics of CrossFit athletes using their individual force-velocity profile, investigating differences according to sex, age, and training frequency. Materials and Methods: 72 males (33.17 ± 6.86 years; BMI: 25.93 ± 3.64 kg/m^2) and 18 females (30.11 ± 6.92 years; BMI: 23.53 ± 3.98 kg/m^2) participated in this study. The force-velocity profile was calculated using Samozino's method. Furthermore, neuromuscular characterization was completed with a squat jump and three drop jumps (20, 30, and 40 cm). Results: Regarding sex, significant differences in all analysed mechanical variables ($p < 0.001$) were found except for the theoretical maximal force ($p = 0.944$). No significant differences were found between age groups. Considering training frequency, athletes who train more than 5 days per week showed higher performance in all analysed mechanical variables ($p < 0.05$). Conclusion: CrossFit athletes have a force-velocity profile more oriented towards velocity than force. Males and females have different neuromuscular characteristics, also neuromuscular improvements can be achieved at any age. Moreover, higher neuromuscular performance is developed with a training frequency of 5 days or more per week.

Keywords: squat jump, countermovement jump, CrossFit, force–velocity profile, neuromuscular characterization.

1. Introduction

High intensity interval training (HIIT) is an alternative to traditional training programmes, causing important physiological adaptations and eliciting improvements in fitness, and health [1]. HIIT is distinguished from other training programmes because sessions consist of relatively brief bursts of vigorous activity (i.e. approximately 90% of maximal aerobic power for brief intervals), interspersed with short rest periods or low-intensity physical activity for recovery between the exercises [2]. Likewise, HIIT shows a greater adherence of participants, since it is a time-efficient alternative due to the shorter required training time [3]. This specific characteristic of HIIT (time-efficiency) avoids one of the highest barriers to engaging in a regular physical programme, the "lack of time" [4]. Recently, different modalities of HIIT have become more popular, such as high intensity functional training (HIFT), high intensity endurance training (HIET), and high intensity power training (HIPT). The main difference between HIPT and HIIT is that in a HIPT programme there is no prescribed rest period, so the participants maintain a high-power output throughout the session. Moreover, HIPT incorporates high-intensity resistance training using a wide variety of multiple-joint movements, with CrossFit (CF) included in this sport modality [5].

The objective of CF is to prepare the participants for any physical contingency by preparing them for the unknown and for the unknowable. The idea behind this is to prepare participants for all kinds of physical needs that may arise in their daily lives [6]. It has been shown that CF improves cardiovascular/respiratory endurance, stamina, strength, flexibility, power, and balance [7]. However, contrary to the idea that CF carries a higher risk of participant injury, previous studies have shown an injury rate similar to other training programmes [8].

CF sessions are carried out in a “CF box” (i.e., a CF gym with the bare necessities to perform the workout), and so-called “workouts of the day” (WOD) are used. These can include functional lifts (i.e., squat, deadlift, snatch, and overhead press) and basic gymnastic exercises (e.g., use of rings, hand-stands, and parallel bars) [5, 6]. Independently of the selected WOD, athletes must overcome resistance with a wide range of magnitude and execute the exercise as quickly as possible. Among other movements, CF uses Olympic-style weightlifting, which has been shown to produce the highest average human power outputs of all resistance training exercises [9]. Power can be defined as the amount of work done over a unit of time, or as the product of force and velocity [10]. It is important to note that the same maximal power can be achieved from different combinations of F0 and V0 ($Pmax = F_0 \cdot V_0/4$), with F0 being the theoretical maximal force that the lower limbs can produce at null velocity (extrapolated intercept with force-axis, in $N \cdot kg^{-1}$), and V0 being the theoretical maximal velocity at which lower limbs can extend under zero load (extrapolated intercept with velocity-axis, in $m \cdot s^{-1}$) [11]. In this way, it is important to understand the relationship between the capacity to apply force and the velocity at which the movement is carried out. The force-velocity (F-v) profile has been shown to be a high-reliability method for assessing this relationship [12].

According to new perspectives in training and quantification of athlete force, a new testing methodology based on the F-v relationship has recently emerged, with the expectation of providing more meaningful data to implement individualised training programmes [13]. Consequently, it is important to know the relationship between force and velocity, since previous research has concluded that as the velocity of movements increases, the ability to produce force decreases. Hence, maximum power is achieved at a compromised level of maximal force and velocity [14]. Samozino et al. [12] proposed a mathematical expression for calculating the F-v profile. This can be considered as a “field method” since it is economical and easily performed by athletes, and relatively easily assessed by coaches. Furthermore, Samozino’s method has shown greater reliability compared to the gold standard devices, such as the force platform or lineal transducer [15].

To determinate the vertical F-v profile, the body mass, vertical push-off distance determined by the extension range of the lower extremities (hpo) [12], starting height, and jump height [13] need to be known. Consequently, the four main variables obtained from the linear F-v relationship are the theoretical maximal force (F_0), the theoretical maximal velocity (V_0), the slope of the F-v relationship (Sfv), and the theoretical maximal power (Pmax). Therefore, F_0, V_0, and Pmax represent the external mechanical limits of the entire neuromuscular system to produce force, velocity, and power, respectively [11]. Regarding the F-v profile, previous research has concluded that each athlete has an individual F-v profile (Sfv) and demonstrated the importance of reaching the F-v optimal (Sfv_{opt}), which represents the optimal balance between force and velocity capabilities. Considering that Samozino's method allows focusing of the training programme at an individual level, it is possible to obtain a better improvement in the athlete's performance, regardless of their physical level, using a reduction of the Sfv and Sfv_{opt} (FV_{imb} %) [16].

Previous studies have analysed the F-v profile in different sports [17]. So far, however, there has been little discussion of the neuromuscular parameters that influence athletes' performance in CF. To date, most of the studies in CF have focused on observing a physiological response to a session [18] or the nature and prevalence of injuries in this sport modality [19]. Nevertheless, only a few studies have shown a high level of evidence and a low level of bias [20].

Therefore, the aim of this study was to report the neuromuscular characteristics of CF athletes using their individual F-v profile and to investigate the differences according to sex, age, and training frequency. The main hypothesis is that CF athletes will have a F-v profile more oriented towards velocity than force, independently of sex, age, or training frequency.

2. Materials and Methods

2.1. Participants

Ninety athletes participated in this study, 72 males (33.17 ± 6.86 years; BMI: 25.93 ± 3.64 kg/m^2) and 18 females (30.11 ± 6.92 years; BMI: 23.53 ± 3.98 kg/m^2). The participants attend a CF box at least 3 days per week. To avoid neuromuscular fatigue during the testing session, no physical activity was allowed for 24 hours prior to the assessment. Inclusion criteria were: a) older than 18 years, b) 6 months or more of experience in a CF box, c) free of injuries in the last 6 months, and d) attendance of three or more sessions weekly. The exclusion criteria were: a) any problem in the lower limbs or upper body that did not allow completion of the test, and b) missing two or more sessions in the last month.

All participants gave written informed consent to join this study. The ethical recommendations approved in the Declaration of Helsinki (2013) were followed. Moreover, the directives of the European Union on Good Clinical Practice (111/3976/88 of July 1990), as specified in a national legal framework for human clinical research (Royal Decree 561/1993 on clinical essays) were followed. The study was approved by the local Ethics Committee (Ref.: MAR.17/1).

2.2. Study Design

To assess the participants, the protocol proposed by Samozino et al. [12] was followed. The height was measured using a Seca 222 tallimeter (Hamburg, Germany). Body mass, and lean body mass were measured using an Inbody 270 body mass bioimpedance tetrapolar balance, which has been used in previous studies [21]. Moreover, a metric tape (Lufkin W606PM, Merylan, USA) was used to measure the vertical distance between the floor surface and the trochanter of the right leg in a sitting position (knee 90°), and the distance from the top to the tip of the foot under extension (lying supine).

SJ, CMJ, and Drop Jump (DJ) height: To measure the height of the jump, the previously utilised [15] OptoGait system (Optogait® Microgate, Bolzano, Italia) was used. The OptoGait system it is an optical data acquisition system composed of a transmitter and a receiver bar. Each 1 m bar contains 96 Infrared LEDs (1.041 cm resolution) and is located on the transmitter bar, continuously communicating with the LEDs located on the receiver bar. The bars measure flight and contact times during execution with an accuracy of 1 millisecond. This device has shown high concurrent reliability [22].

Loaded jump condition: To assess CMJ in a loaded condition, an Olympic barbell (15 kg for females and 20 kg for males) was used. Furthermore, extra weight (0.5 kg, 2 kg and 5 kg) was added to the loaded condition jumps (Ruster®, Spain).

Mechanical variables: To assess lower limb strength and neuromuscular parameters, Samozino's method [13] was followed. Consequently, the obtained mechanical variables were: a) theoretical maximum force (F_0) (N/kg); b) theoretical maximal velocity (V_0) (m/s); c) maximal mechanical power output (Pmax) (w/kg); d) slope of the linear F-v relationship (S*fv*); e) optimal slope of the linear F-v relationship (Sfv_{opt}); f) F-v imbalance [FV_{imb} (%)]; g) maximum jump height (hmax).

2.3. Procedures

A cross sectional study was conducted. The evaluation of the participants was carried out in the CF box in which they usually perform their WOD. This allowed collecting the data in a more natural way, since previous research has shown that the collected data can be influenced by the location of the evaluation [23]. The vertical jump test with SJ, and CMJ was conducted to collect neuromuscular data; these are the most commonly used tests for evaluating the maximal mechanical capabilities of the lower limbs [24]. In addition, neuromuscular characterization was completed with a DJ test. Different tests were conducted in order to clarify and determine the neuromuscular parameters, since previous studies concluded that a single test does not predict the final results of a benchmark WOD in CF [25].

The testing session was carried out in one week from Monday to Friday, with participants attending separately. Prior to the testing sessions, anthropometric data were collected from the participants (body mass, height, and height push off – hpo). Then, the athletes performed a standard warm-up, consisting of ten minutes of jogging on a treadmill and dynamic stretching. Subsequently, they performed the same movement that they were planning to do during the testing session (i.e., SJ, CMJ, and DJ) three times to avoid any risk of injury. These movements are part of the athletes' daily routine; therefore, they did not need a familiarisation session. Afterwards, the testing session started.

To determinate the individual F-v profile, each participant performed four CMJ in different load conditions: the first one without a load (CMJ) and the others with additional loads: 25% (CMJ1), 50% (CMJ2), and 75% (CMJ3) of their body mass, respectively. Before each jump, the evaluators carefully explained how to execute the test. The participants started in a standing position with their hands on their hips (unloaded condition) or on the bar (loaded jumps), maintaining the same hand position during the movement. To perform the CMJ, they started from the standing position and began to descend until a crouching position with a knee angle of approximately 90°, immediately followed by a jump to reach a maximal height. The athletes were asked to touch down with the same leg position as the moment of take-off (extended leg with foot plantar flexion). They performed two valid trials for each load, and 2 min recovery was allowed between trials, with 4–5 min recovery time between load conditions. The neuromuscular characterisation was completed with a SJ, and three DJ executed at 20 cm (DJ1), 30 cm (DJ2), and 40 cm (DJ3). To execute the SJ, countermovement was prohibited by having to hold the crouched position at a 90° knee angle for at least 2 seconds [26].

2.4. Statistical Analysis

Data were analysed using SPSS, v.19.0 for Windows (SPSS Inc, Chicago, USA). The data are shown as descriptive statistics, using the mean and standard deviation (SD). Kolmogorov-Smirnov and Levene's tests were conducted in order to confirm the normal distribution and homogeneity of the data. Differences between sex and age groups were analysed using analysis of variance (ANOVA), adjusted with the Bonferroni test. Furthermore, eta squared (η^2_p) was calculated for the ANOVA tests. The thresholds for the effect sizes (ES) were < 0.01 (small), 0.01–0.06 (medium) and > 0.14 (large) [27]. The significance level was set at $p < 0.05$.

3. Results

Table 1 shows mean values and standard deviations (SD) of all mechanical variables that determine the F-v profile, according to the participants' sex. Significant differences were found in all analysed variables except for F_0, which showed similar values for males and females.

Table 1. Mechanical parameters determining the F-v profile.

	Total (n = 90)		Male (n = 72)		Female (n = 18)		*p*-value
	Mean (SD)	VC%	Mean (SD)	VC%	Mean (SD)	VC%	
Weight (kg)	77.11 (14.72)	19.09	81.35 (12.71)	15.62	60.18 (8.97)	14.90	0.607
F_0 (N/kg)	29.52 (4.78)	16.21	29.54 (4.69)	15.89	29.45 (5.27)	17.89	0.944
V_0 (m/s)	4.23 (1.73)	40.80	4.50 (1.76)	39.12	3.14 (1.04)	33.05	0.002
P_{max} (W/kg)	30.29 (10.36)	34.22	32.28 (10.42)	32.29	22.32 (4.95)	22.18	< 0.001
S_{fv} (N · s/m/kg)	-8.09 (3.44)	-42.56	-7.50 (3.01)	-40.13	-10.46 (4.10)	-39.20	0.001
$\underline{FV}_{imb}$ (%)	52.54 (22.02)	41.92	49.47 (20.37)	41.19	64.82 (24.60)	37.96	0.007
h_{max} (m)	0.33 (0.07)	21.39	0.35 (0.06)	18.00	0.25 (0.04)	14.30	< 0.001

SD: standard deviation; VC: variation coefficient; F_0 = maximal theoretical force; V_0 = maximal extension velocity of the athlete's lower limbs; P_{max} = maximal power output capability of the athlete's lower-limb neuromuscular system; S_{fv} = Index of the athlete's individual balance between force and velocity capabilities; FV_{imb} = magnitude of the difference between actual and optimal F-V profile; h_{max} = maximal jump height.

Figure 1 shows the current and optimal F-v profile for all the participants, and F-v profile adjust by age groups.

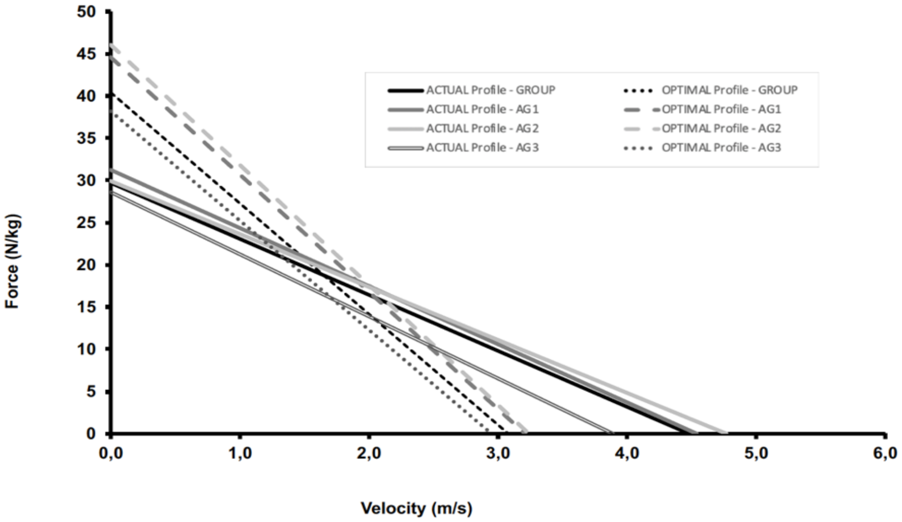


Fig. 1. Actual and optimal F-V profile for all the participants, and F-V profile (actual and optimal) by age groups. AG1: 18 to 25 years old; AG2: 26 to 35 years old; AG3: 36 to 45 years old.

In order to conduct inter-group analysis, different groups were established according to the participants' age, training frequency, and sex. Consequently, the participants were divided as follows: a) age group (AG), divided into AG1 (18 to 25 years old); AG2 (26 to 35 years old), and AG3 (36 to 45 years old) (Table 2); b) weekly training frequency (TF): TF1 (3 days per week); TF2 (4 days per week), and TF3 (5 days or more per week) (Table 3); and c) sex: males (M), or females (F) (Table 4). the inter-group correction (age, weekly training frequency, and sex) was conducted based on previous studies [28–34].

Regarding the age groups, AG1 obtained the highest values in all jumps performed. However, significant differences were not found among the age groups (Table 2).

Table 2. Comparison of results of jump tests by age groups.

	Total (n = 86)	AG1 (n = 13)	AG2 (n = 51)	AG3 (n = 22)	*p*-value	*η*
	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)		
CMJ (cm)	33.45 (7.05)	35.31 (8.04)	34.14 (7.62)	30.77 (3,93)	0.102	0.54
SJ (cm)	31.28 (6.74)	32.89 (7.73)	31.57 (7.23)	29.67 (4,58)	0.357	0.25
CMJ1 (cm)	23.53 (5.92)	24.76 (6.82)	24.20 (6.35)	21.25 (3,46)	0.105	0.53
CMJ2 (cm)	20.19 (5.01)	21.06 (5.79)	20.81 (5.48)	18.25 (2,35)	0.106	0.53
CMJ3 (cm)	18.83 (5.09)	19.83 (5.96)	19.36 (5.53)	17.01 (2,62)	0.144	0.46
DJ1 (cm)	33.04 (7.09)	34.57 (8.37)	33.64 (7.42)	30.72 (4,93)	0.190	0.39
DJ2 (cm)	33.73 (7.39)	34.66 (8.98)	34.19 (7.90)	32.11 (4,76)	0.488	0.17
DJ3 (cm)	33.70 (7.61)	34.77 (9.40)	34.27 (8.18)	31.75 (4,40)	0.375	0.23
F_0 (N/kg)	29.64 (4.81)	30.45 (3.97)	29.90 (5.28)	28.59 (4.07)	0.463	
V_0 (m/s)	4.22 (1.71)	4.16 (1.19)	4.38 (2.02)	3.89 (1.11)	0.543	
P_{max} (w/kg)	30.37 (10.35)	31.30 (8.06)	31.58 (12.13)	27.01 (5.49)	0.211	
S_{fv} (N·s/m/kg)	-8.12 (3.44)	-7.99 (2.74)	-8.11 (3.64)	-8.22 (3.47)	0.982	
Fv_{imb} (%)	52.80 (21.97)	51.24 (17.56)	52.65 (22.90)	54.08 (22.92)	0.933	
h_{max} (m)	0.33 (0.07)	0.35 (0.08)	0.34 (0.07)	0.30 (0.03)	0.102	

CMJ = countermovement jump; SJ = squat jump; CMJ1 = countermovement jump (25% body weight); CMJ2 = countermovement jump (50% body weight); CMJ3 = countermovement jump (75% body weight); DJ1 = drop jump (20cm); DJ2= drop jump (30cm); DJ3 = drop jump (40cm); AG1: 18 – 25 years; AG2: 26 – 35 years; AG3: 36 – 45 years; SD= standard deviation; *p* = *p*-value**;** *η*= eta square; cm = centimetres.

For training frequency, significant differences between groups were found. Specifically, differences were found between TF1 and TF3, whereas no differences between TF1 and TF2 were found (Table 3).

Table 3. Results of jump tests according to frequency training.

	Total (n = 90)	TF1 (n = 33) a	TF2 (n = 33) b	TF3 (n = 24) c	p-value	η	Post hoc
	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)			
CMJ (cm)	33.18 (7.11)	31.18 (5.42)	32.91 (5.27)	36.29 (10)	0.025	0.08	a<c*
CMJ1 (cm)	23.37 (5.89)	21.37 (4.20)	23.23 (4.13)	26.29 (8.44)	0.007	0.10	a<c**
CMJ2 (cm)	20.03 (5.01)	18.26 (3.37)	19.82 (3.76)	22.73 (7.05)	0.003	0.12	a<c**
CMJ3 (cm)	18.66 (5.07)	17.05 (3.22)	18.25 (3.69)	21.44 (7.35)	0.004	0.12	a<c**
SJ (cm)	31.13 (6.73)	29.70 (5.67)	30.80 (5.28)	33.55 (9.09)	0.960	0.05	
DJ1 (cm)	32.67 (7.24)	30.81 (5.55)	32.36 (5.70)	35.64 (10.03)	0.042	0.07	b<c*
DJ2 (cm)	33.23 (7.70)	31.06 (6.17)	33.36 (6.23)	36.03 (10.37)	0.053	0.06	a<c*
DJ3 (cm)	33.32 (7.69)	31.13 (5.86)	33.67 (6.19)	35.86 (10.69)	0.067	0.06	
F_0 (N/kg)	29.52 (4.78)	28.82 (4.11)	29.19 (4.14)	30.92 (6.17)	0.233		
V_0 (m/s)	4.23 (1.72)	4.14 (1.68)	4.14 (1.69)	4.47 (1.86)	0.731		
P_{max} (w/kg)	30.28 (10.36)	28.85 (9.78)	29.39 (9.82)	33.48 (11.54)	0.207		
S_{fv} (N · s/m/kg)	-8.09 (3.44)	-8.18 (3.7)	-8.02 (3.16)	-8.05 (3.59)	0.981		
Fv_{imb} (%)	52.53 (22.02)	52.86 (23.3)	52.85 (20.65)	51.64 (22.92)	0.974		
h_{max} (m)	0.33 (0.07)	0.31 (0.05)	0.32 (0.05)	0.36 (0.1)	0.025		

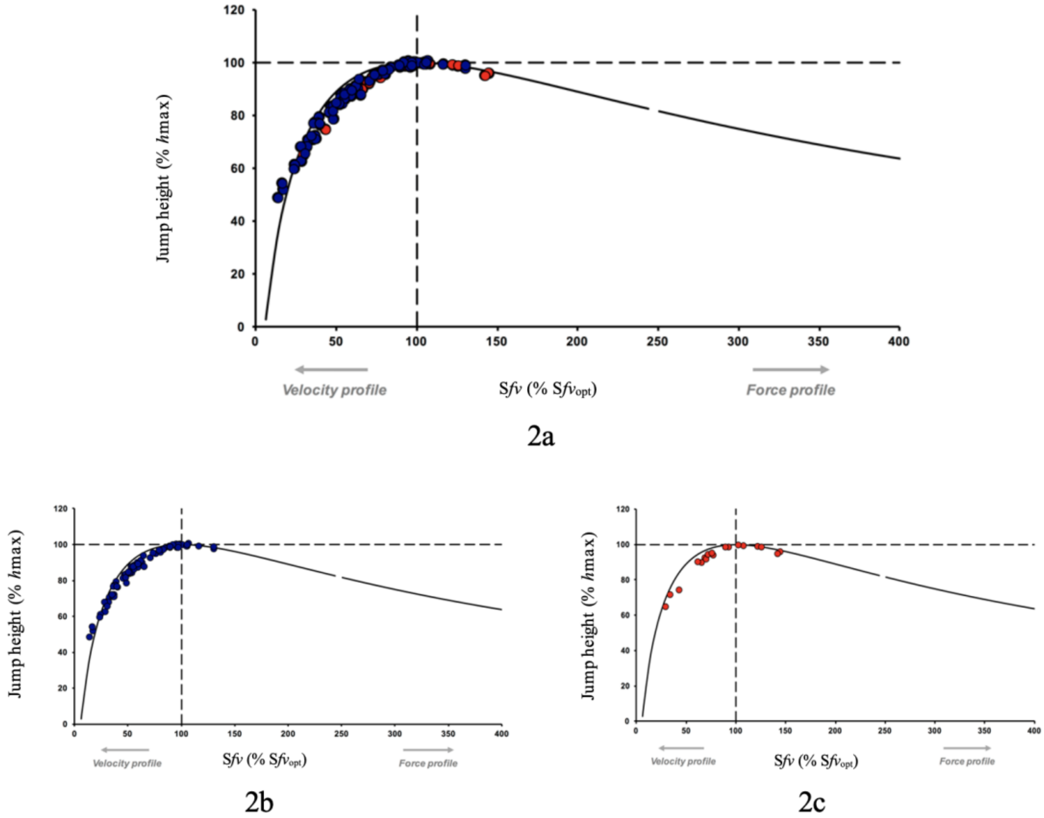
CMJ = countermovement jump; SJ = squat jump; CMJ1 = countermovement jump (25% body weight); CMJ2 = countermovement jump (50% body weight); CMJ3 = countermovement jump (75% body weight); DJ1 = drop jump (20 cm); DJ2 = drop jump (30cm); DJ3 = drop jump (40 cm); TF1: training frequency (3 days per week); TF2: training frequency (4 days per week); TF3: training frequency (5 days or more per week); SD = standard deviation; p = p-value (set at 0,05); η = eta square; cm = centimetres. *$p < 0{,}05$; ** $p < 0{,}001$; Lower case letters mean significant differences among groups (i.e., a, b, c).

Table 4 shows the jump height values adjusted by sex. Taking into account sex differences, males showed higher results than females in all jump tests. Significant differences were found in all variables assessed apart from F_0, which showed similar values for males and females.

Table 4. Comparison of results of jump tests by sex.

	Total (n = 90)	Males (n = 72)	Female (n = 18)	*p*	*η*
	Mean (SD)	Mean (SD)	Mean (SD)		
CMJ (cm)	33.18 (7.11)	35.17 (6.33)	25.22 (3.63)	< 0.001	1.7
SJ (cm)	31.13 (6.73)	32.89 (6.03)	24.07 (4.43)	< 0.001	1.54
CMJ1 (cm)	23.37 (5.89)	24.86 (5.42)	17.41 (3.43)	< 0.001	1.47
CMJ2 (cm)	20.03 (5.01)	21.04 (4.96)	15.96 (2.64)	< 0.001	1.11
CMJ3 (cm)	18.66 (5.07)	19.72 (4.99)	14.43 (2.64)	< 0.001	1.15
DJ1 (cm)	32.67 (7.24)	34.62 (6.49)	24.83 (4.22)	< 0.001	1.61
DJ2 (cm)	33.23 (7.70)	35.49 (6.54)	24.20 (4.88)	< 0.001	1.82
DJ3 (cm)	33.32 (7.69)	35.50 (6.65)	24.61 (4.99)	< 0.001	1.84
F_0 (N/kg)	29.52 (4.78)	29.53 (4.69)	29.44 (5.26)	0.944	
V_0 (m/s)	4.23 (1.72)	4.50 (1.76)	3.14 (1.04)	0.002	
P_{max} (W/kg)	30.28 (10.36)	32.27 (10.42)	22.32 (4.95)	< 0.001	
S_{fv} (N · s/m/kg)	-8.09 (3.44)	-7.49 (3.00)	-10.46 (4.10)	0.001	
Fv_{imb} (%)	52.53 (22.02)	49.46 (20.37)	64.81 (24.60)	0.007	
h_{max} (m)	0.33 (0.07)	0.35 (0.06)	0.25 (0.03)	< 0.001	

CMJ = countermovement jump; SJ = squat jump; CMJ1 = countermovement jump (25% body weight); CMJ2 = countermovement jump (50% body weight); CMJ3 = countermovement jump (75% body weight); DJ1 = drop jump (20 cm); DJ2 = drop jump (30 cm); DJ3 = drop jump (40cm); SD = standard deviation; *p* = p-value**;** η = eta square; cm= centimetres.



2a

2b

2c

Fig. 2. (a) Value of height jump reached in unloaded (SJ) and loaded condition (CMJ) expressed for males (blue) and females (red). It is shown relatively to the theoretical h_{max} (h expressed relatively to h_{max}). According to F-v profile (S*fv* expressed relatively to their personal S*fv$_{opt}$*). Each point represents a participant. The solid line represents theoretical changes predicted by the model (equation 5 in Samozino et al., 2013) with h_{PO} and P_{max} values arbitrarily set to the average values for the entire group; Figures (b) and (c) show the same values for males and females, respectively.

4. Discussion

The aim of this study was to report the neuromuscular characteristics of CF athletes using their individual F-v profile, and the differences according to sex, age, and training frequency. The main hypothesis is that CF athletes will have an F-v profile more oriented towards velocity than force, independently of their sex, age, or training frequency. The main finding of this study is that the main hypothesis has been corroborated, since CF athletes have an F-v profile more oriented towards velocity than force, implying a force deficit in their F-v profile. In addition, significant differences have been found regarding the sex and training frequency, whereas there have been no significant differences regarding the participants' age.

In relation to the F-v profile, the participants showed a force deficit, implying a profile oriented towards velocity. One factor that could explain this difference is the structure of CF programmes. The daily WOD includes functional movements that have to be performed as quickly as possible, but also with high intensity [6]. Therefore, the nature of CF does not allow the completion of a WOD applying the maximal strength or the maximal power, given that most of the movements need to be performed in a high-velocity regime. Consequently, in CF, there is a strength and power shortage compared to other sports that apply high power levels (e.g. weightlifting) [9]. This requirement implies a force deficit in the athletes, using a power output lower than maximal due to the relationship between force and velocity [35]. In order to reach individual maximal power, previous research has concluded that it is necessary to perform specific training with a load higher than the usual workload used in a daily training. This allows athletes to improve their performance in specific exercises (i.e. clean, snatch, overhead press) and in the WOD [36].

Previous research related to CF has focused on physiological characteristics and the influence that they have on completion of a WOD [25, 34]. Nevertheless, there are no previous studies assessing the neuromuscular parameters or F-v profiles of CF athletes. Jimenez Reyes et al. [37] analysed F-v profiles of sprinters and high jumpers, showing similar V0 values to those obtained in this study, and bigger differences in F0 between SJ and CMJ. Given that each athlete has an individual F-v profile and that sport performance can be limited by the FV_{imb} (i.e. an unfavourable balance between force and velocity), it may be possible to improve performance in the jump height in the SJ and CMJ, since both tests are important performance predictors in CF [38]. In addition, a study conducted in rugby and football players concluded that an individualised training programme focused on FV_{imb} was more efficient for improving jumping performance than a traditional training programme [39]. Thus, it is possible to modify FV_{imb} through a specific programme that focuses on increasing strength and decreasing velocity, while maintaining the training intensity [35].

According to training frequency, the participants who attend the CF box 5 days or more in per week (TF3) showed a higher value in the CMJ (both loaded and unloaded conditions), DJ1, and DJ2, compared to those that complete a WOD less than three days per week. However, these differences were not found for the SJ. Traditionally, it has been suggested that a difference between SJ and CMJ implies a greater utilisation of the stretch-shortening cycle, although a recent systematic review concluded that a greater difference in these parameters is not better in all sports [40]. The differences between groups found in this study may be related to the frequency of training, since previous research has concluded that a greater training frequency induces greater muscle improvements [31, 41]. It is an important finding in this study because has been shown previously that athletes who perform a WOD less than three days a week and those who have less than six months of experience showed a greater injury risk [42].

Regarding mechanical variables analysed by age groups, the present results confirm that the participants' age does not influence CF performance. This is an important finding, since CF induces neuromuscular adaptations, even in adults [5]. Previous research concluded that around the age of 40, maximum muscle strength progressively decreases, a process which is more pronounced after the age of 50 [28]. Nevertheless, it is possible to maintain the neuromuscular adaptation with regular sports practice, independently of the participants' age. This is especially possible if the sports modality includes HIIT, resistance training exercises, or a mix of both, such as CF [2, 43, 44].

In relation to the participants' sex, significant differences were found between males and females in all mechanical variables except for F0. This may be explained by the neuromuscular differences between the sexes, which affect execution velocity. These results are contrary to previous studies, which concluded that males show greater force than females, although the researchers conducted one repetition maximum test (1RM) instead of the F-v profile method [21]. Previous research has compared F-v profiles between sexes in other sport modalities (soccer, futsal, rugby); nonetheless, this has not been done previously in CF. Therefore, the present results cannot be compared with previous studies. In spite of differences between sports, the present outcomes are partially similar to previous research that has compared F-v profiles between males and females. Jimenez Reyes et al. [17] reported significant differences between the sexes in F_0, V_0, and Pmax in most analysed sports, except for basketball, taekwondo, and weightlifting. It seems that similar values of F0 are found in males and females if the sport modality does not involve movements with horizontal acceleration (i.e., sprinting, changes of direction) as the main part of the sport performance. Since participants in this study have different sports levels and different target seasons, it cannot be affirmed if the similar outcomes in F_0 between males and females are a consequence of sex differences, CF characteristics, or participants' performance levels.

Limitations

An important limitation of this study is that it is a cross-sectional study, and no intervention was conducted. Furthermore, the participants were not ranked according to their individual target season or performance level. Thus, the results should be applied carefully, since the F-v profile can tend towards to force or velocity depending on the athlete's physical fitness. Nevertheless, to the authors' knowledge, there are not previous studies that describe neuromuscular characterisation and F-v profile in this sport modality, which is the main strength of this study.

5. Conclusions

To conclude, CF athletes have an F-v profile more oriented towards velocity than force. Although a training frequency of 3 days per week has the same efficiency as 4 days, a higher neuromuscular performance is developed if the training frequency is increased to 5 days or more. In addition, neuromuscular improvements can be obtained at any age, whereas there are sex differences in performance due to the different neuromuscular parameters in males and females.

Practical applications

Knowing the individual F-v profile of a CF athlete allows the coaches to optimise and individualise a training programme focused on the athlete's FV_{imb}. Therefore, athletes who have similar F-v imbalance can be included in the same training groups in order to reach their Sfv_{opt}. In addition, a better knowledge of the F-v profile reduces any risk of injuries, because the closer the athlete is to their Sfv_{opt}, the lower the risk of injury.

In this regard, CF athletes should train using specific movements that have a greater neuromuscular implication (i.e., snatch, clean and jerk, deadlift), with high loads near to their maximum levels, in order to improve strength levels. As a consequence, training using these exercises two or three days per week is recommended to improve individual performance in the WOD. In addition, neuromuscular training should be performed before starting a CF programme in order to improve the movement techniques and minimise injury risk.

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Author Contributions: Study Design, JPM, PJR, JCL, MML; Data Collection, PLR, JML, PJR, MML; Statistical Analysis, VSH, PJR, JPM; Data Interpretation, JPM, JCC, MML, PLR; Manuscript Preparation, JPM, PLR, JCL, PJR, JML; Literature Search, JPM, PJR, VSH, PLR, JML. All authors have read and agreed to the published version of the manuscript.

Acknowledgements: The authors appreciate the selfless participation of the athletes in this research.

Funding: This research received no specific grant from any funding agency in the public, commercial, or not-for-profit sectors.

Institutional Review Board Statement: The ethical recommendations approved in the Declaration of Helsinki (2013) were followed. Moreover, the directives of the European Union on Good Clinical Practice (111/3976/88 of July 1990), as specified in a national legal framework for human clinical research (Royal Decree 561/1993 on clinical essays) were followed. The study was approved by the local Ethics Committee (Ref.: MAR.17/1).

Informed Consent Statement: All participants gave written informed consent to join this study.

Data Availability Statement: Data available from the corresponding author on request.

Conflicts of Interest: The authors declare no conflict of interest.