



Analysis of Morphofunctional Variables Associated with Performance in Crossfit® Competitors

by

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CrossFit® is a competitive sport and fitness modality characterized by multiple physical capabilities and multi-joint movements. This study aimed to analyse and classify variables related to CrossFit® competitors' specific performance. Fifteen male CrossFit® competitors were selected ($n = 15$; 30.57 ± 5.5 years; 1.76 ± 0.06 m; 78.55 ± 9.12 kg). Mean values were obtained for body mass index (25.3 ± 2.14 kg/m²), 4 skinfolds, 1 repetition maximum in the squat (137.60 ± 19.65 kg) and the bench press (101.67 ± 10.64 kg), maximum pull-ups (18.87 ± 5.05), sit-ups in 60 s (46.60 ± 4.22), peak power in the countermovement jump (3908.04 ± 423.68 W), VO₂max with a shuttle run test (47.70 ± 4.79 ml kg⁻¹·min⁻¹), and time in the Workout of the Day (WOD) "Fran" (337.13 ± 119.19 s) and "Donkey Kong" (417.47 ± 98.44 s) components. Principal component analysis was conducted to classify variables and to select those most related to each new component ("strength and muscle mass", "adiposity" and "aerobic capacity"). The correlation matrix was analysed, indicating significant correlations between "Donkey Kong" and VO₂max ($r = -.675$; $p < .01$), suprailiac skinfold ($r = .713$; $p < .01$) and sit-ups ($r = -.563$; $p < .05$); and between "Fran" and squat ($r = -.528$; $p < .05$). Three important components characterizing CrossFit® competitors were identified: "strength and muscle mass", low "adiposity" and "aerobic capacity". Significant relationships between morphofunctional variables and Crossfit® performance were found in Crossfit® competitors.

Key words: high intensity interval training, power, principal component analysis, Crossfit, performance.

Introduction

CrossFit has grown significantly as a fitness modality and competitive sport in recent years. CrossFit is characterized by the high intensity of its workouts, the execution of a large number of varied movements, and different expressions of physical fitness, particularly strength and endurance. This research seeks answers to questions related to CrossFit's benefits, risks, and potential improvements in the training process and subsequent performance.

According to the American College of Sports Medicine, high-intensity interval training (HIIT) is currently the leading trend in fitness worldwide, ranking first since 2014 (Thompson, 2017). CrossFit is probably the HIIT-based exercise program with the highest growth over the last 10 years; the CrossFit.com website states

that there were 11,677 CrossFit gyms worldwide in 2015 and 324,307 participants from 175 countries took part in the CrossFit Games Open 2016.

CrossFit training programs are characterized by constantly varied multi-joint movements, including weight-lifting and body-weight exercises, performed at submaximal intensities. The main unit of training is the workout of the day (WOD), in which as many rounds as possible of the exercise are completed within a certain time (as many repetitions as possible - AMRAP). Alternatively, the workout is not timed and focuses on a single, complex skill, which is not yet adequate for efficient inclusion in a timed workout. WODs combine traditional cardiovascular exercises such as running, cycling or rowing, with movements from the fields of

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Weightlifting, Powerlifting, Strongman and Gymnastics (Glassman, 2003, 2017).

CrossFit sessions are usually scored and recorded, allowing individuals to track their performance and thus compare the weight lifted, the number of repetitions completed in a given time, or the time spent performing a set of exercises. Recent research on the motivation of CrossFit practitioners (Sibley and Bergman, 2017) suggests that the group and its competitive environment can easily lead participants to focus on the social recognition of competition rather than motivations related to health, potentially creating situations that could lead to overtraining or other unhealthy behaviours. However, publishing records can also allow practitioners to evaluate their progression, thus improving their sense of competence (Sibley and Bergman, 2017).

Montalvo et al. (2017) indicate that WODs usually mix aerobic and anaerobic exercises with movements of high technical complexity performed under conditions of cardiovascular and muscular fatigue, contrasting with the principles of traditional training, which promote the execution of multiarticular power movements first, to maximize the load and preserve technique. They also point out that fatigue associated with high-intensity anaerobic exercise can cause loss of concentration and affect technique, so that injuries may occur (Montalvo et al., 2017). The harmful potential of CrossFit is currently being studied from several perspectives (Meyer et al., 2017).

The rapid and widespread growth of CrossFit as a fitness modality and sport, combined with its competitive nature and its harmful potential, requires parallel analysis of the physical and physiological characteristics that may allow for the improvement of training systems.

Very few studies exist (Claudino et al., 2018) that evaluate and describe the physical capacities of CrossFit competitors (Bellar et al., 2015; Butcher et al., 2015; Eremin et al., 2014). Aerobic and anaerobic capacities are the most studied variables to date; improvements are associated with higher performance in WODs (Bellar et al., 2015), although Butcher et al. (2015) found that only whole-body strength can partially explain performance in the WODs "Grace" and "Fran". Eremin et al. (2014), in a study of the elite

Russian CrossFit competitors, found that their participants exhibited substantial myocardial growth and increased stroke volume.

In relation to physical characteristics, there are also little data describing CrossFit competitors; Tibana (2018) found body fat levels of between 12-14% in male CrossFit competitors and a Body Mass Index (BMI) of around 26 kg/m².

To improve the training process it is essential to obtain more data about the most important variables associated with performance.

Therefore, the aims of this study were to analyse CrossFit competitors' physical capacities (maximum strength, strength endurance and aerobic capacity) and morphological characteristics (subcutaneous fat and Body Mass Index (BMI)) as well as to determine their relationship with specific performance.

Methods

Participants

The sample consisted of 15 experienced male CrossFit practitioners (age: 30.57 ± 5.5 years, body height: 1.76 ± 0.06 m, body mass: 78.55 ± 9.12 kg; BMI: 25.30 ± 2.14 kg/m²; mean ± SD) who participated in amateur competitions, in the *Scaled* category (an easier adaptation of the highest category, *Rx*). Participants signed a letter of consent agreeing to take part in the study voluntarily, and were informed of the risks and benefits of the study. The study complied with the regulations of the Research Ethics Committee of the Pablo de Olavide University, following the principles outlined in the Declaration of Helsinki.

Participants were selected by a Level 1 CrossFit Coach, and all belonged to the Feel CrossFit training box. The inclusion criteria established were: no muscle-tendon and/or osteoarticular lesions that could be aggravated by the performance of the tests, no other type of physical training in addition to CrossFit, a minimum of 2 years of CrossFit experience, and a training frequency of 4-5 days a week.

Instruments

Maximal isometric hand grip strength was measured with a Takei 5001 dynamometer (Takei Scientific Instruments, Tokyo, Japan). Morphological data were obtained using a Tanita digital scale (HD-313 Tanita, Tokyo, Japan) with 100 g precision, and a portable stadiometer with 1

mm precision and a Slim Guide calliper. For maximal strength tests, a 20 kg Xenios bar and Eleiko XF discs (1.25 -20 kg) were used; the CMJ was evaluated using the Optojump Next device (Optojump-next, Microgate, Bolzano, Italy).

Design

This was a descriptive and correlational study, where the selected variables were not manipulated, so they were not strictly independent or dependent variables. To explain the possible associations, we established independent variables based on the morphological and functional characteristics of athletes, and as a dependent variable we used the time taken for the WODs as a measure of performance.

First, a descriptive analysis of all variables was made; then a factorial analysis was applied using Principal Component Analysis (PCA) of the morphofunctional variables, in order to group them into a new, reduced set of factors, and to identify the variables most associated with the extracted components. Finally, a correlational analysis was carried out between the morphofunctional variables and the performance shown in the WODs. The independent and dependent variables are listed below.

Independent variables: peak power (W) in the countermovement jump (CMJ) obtained using the formula of Sayers et al. (1999); hand grip strength (kg) (dynamometry); maximum number of pull-ups and maximum number of sit-ups in 60 s; 1 RM for the deep squat and the bench press (kg); maximum aerobic capacity (VO_{2max} , $ml \cdot kg^{-1} \cdot min^{-1}$) evaluated using the shuttle run test (SRT); body mass index (BMI, in kg/m^2); and triceps, subscapular, suprailiac, thigh and calf skin folds (mm).

Dependent variables: time taken to complete the WOD called "Fran" (WOD1_Fran) and the WOD "Donkey Kong" (WOD2_DK). These WODs were selected because they are characteristic of CrossFit (Claudino et al., 2018) and include different modes of exercise.

Procedures

Measurements were obtained at the Feel CrossFit training box on non-consecutive days, leaving 48 hours of recovery between tests. All sessions started with a general 15-min warm-up with continuous running, jumps, rowing and joint mobility, followed by a specific warm-up for each

test. Before beginning each test, the protocols were thoroughly explained, and supervised by the researchers to ensure correct execution.

Peak power. All subjects performed CMJ tests for 4 min, with a 30 s rest interval between each jump according to the protocol. Subsequently, 3 valid attempts were made per participant, with 40 s rest intervals between each jump. The best result was selected to calculate peak power (Sayers et al., 1999).

Maximum number of pull-ups. The test consisted of performing the maximum number of pull-ups without swinging, to fatigue, counting only the repetitions in which the chin came above the horizontal edge of the grip bar.

Maximum number of sit-ups. An assistant held the participant's ankles to prevent him from swinging with his feet. The maximum number of trunk lifts from the horizontal to the knees was determined over a period of 60 s.

Hand dynamometry. Maximum grip strength in both hands was assessed alternately using three valid attempts, following the protocol of España-Romero et al. (2010). A pre-adjustment of the grip of the dynamometer was made depending on the size of the participant's hand.

Squat and bench press. Strength was assessed using 5 maximal repetitions (5RM) in the full squat and bench press (Gail et al., 2015). After carrying out the general warm-up, athletes performed a set of 10 repetitions at 50% of 1RM, then two further sets, one of 7 repetitions at 70% of 1RM and another of 6 repetitions at 80% of 1RM. Finally, they performed the search phase of the 5RM. In this phase the weight was increased to determine the 5RM. Rest intervals between sets were set at 4-5 minutes to allow complete recovery and achieve the 5 RM in less than 5 attempts, before the onset of fatigue. From the 5RM, 1RM was estimated (Reynolds et al., 2006).

VO_{2max} . Maximum aerobic capacity was evaluated using the shuttle run test (SRT), given the validity and reliability shown in published studies (Mayorga-Vega et al., 2015).

WOD1_Fran. This WOD was composed of 3 rounds, each with 21, 15 and 9 repetitions, respectively, of two exercises performed one after another: thrusters with 43 kg (exercise that requires performing a full squat followed by a shoulder press) and pull-ups, valid with any type of technique (kipping, butterfly or strict). Kipping

and butterfly pull-ups use the swinging momentum of the whole body to assist with elevation of the body toward the pull-up bar (Dinunzio et al., 2018). After being given a start signal, the participant tried to complete all the repetitions in the shortest possible time.

WOD2_DK. The procedure in the WOD "Donkey Kong" also followed the sequence of 21-15-9 in three rounds, but with three consecutive exercises: burpees, kettlebell swings with 24 kg, and jumps onto a 24-inch box, all in the shortest possible time.

These WODs were selected because they are characteristic of CrossFit and have been used in previous studies (Babiash et al., 2013; Butcher et al., 2015).

All morphological measurements were made in accordance with the recommendations of the International Society for Advancement in Kinanthropometry. The body mass index (BMI, kg/m²) was obtained using these measures. Each skin fold was measured 3 times, taking the average value as the final data.

Statistical analysis

Following the recommendations proposed by Hopkins (2000) to control reliability between repeated measurements, the Intraclass Correlation Coefficient (ICC) and the Technical Error of Measurement (ETM) were evaluated. In the CMJ and dynamometry, the lowest measure was discarded, the other two were compared and the highest value was selected; the ICCs obtained were > .9 for the CMJ, > .98 for skinfolds and > .92 for dynamometry. The coefficient of variation of the ETM was below 1.5% for the skinfolds and dynamometry, and below 3% for the CMJ.

For descriptive analysis of variables, the mean (\bar{X}) and standard deviation (SD) were calculated and checked for normal distribution (Shapiro-Wilk test).

Given the small number of participants, it was essential to statistically verify all conditions to apply to the PCA. Scientific knowledge about the variables should be included (Hair et al., 2009) to select which are appropriate for inclusion in a PCA. To ensure the relevance of each selected variable we analysed the anti-image matrix of correlation coefficients excluding the dependent variables for a later analysis. We evaluated possible problems of multicollinearity, and variables with a value lower than 0.5 on the

diagonal were removed, which yielded a reduced and appropriate number of factors. The factorial analysis was considered adequate with a value in the determinant of .009 in the correlation matrix. The null hypothesis in the Bartlett sphericity test was also rejected ($p = .007$) and we confirmed the sample adequacy with the Kaiser-Meyer-Olkin test (KMO = .626).

The anti-image matrix of the correlation matrix was analysed to identify the variables with the lowest coefficient of adequacy and eliminate them from the final analysis. The number of initial components to be extracted was chosen using the Cattell test. To improve the meaning and interpretation of the factors obtained, an orthogonal rotation (varimax) was applied. Variables with a correlation above .700 were considered for inclusion (Hair et al., 2009).

Relationships between variables were analysed using Pearson correlation coefficients.

SPSS v.24 was used for the entire statistical analysis.

Results

The results presented include the descriptive analysis of the variables, the correlations observed among them with the WODs and the principal extracted components.

The descriptive data ($\bar{X} \pm SD$) for all analysed variables and their units of measurement, obtained by CrossFit practitioners, are presented in Table 1.

For the principal components analysis (Table 2), 8 variables were chosen after discarding those that did not meet the statistical requirements. Each of them had a correlation > .700, and was representative of each of the 3 main components extracted.

Components 1, 2 and 3 explained 36.51, 31.1 and 12.7% of the total variance, respectively, with a cumulative percentage of 80.31% of total variance.

Analysing each component and its association with the variables marked with an asterisk (Table 3) resulted in the naming of three groups described as "Strength-body mass", "Adiposity" and "Aerobic Capacity", corresponding to components 1, 2 and 3, respectively.

The Pearson correlation coefficients for the 15 variables analysed (Table 3) showed numerous

correlations greater than .300, and there were few highly correlated variables ($r > .800$). Both

conditions were necessary for the application of the PCA.

Table 1*Descriptive results for the variables analysed.*

Variable	Mean \pm SD		
BMI (kg/m ²)	25.30	\pm	2.14
Triceps (mm)	8.47	\pm	2.56
Subscapular (mm)	9.93	\pm	3.06
Thigh (mm)	10.13	\pm	3.04
Suprailiac (mm)	7.67	\pm	2.26
Calf (mm)	7.33	\pm	2.66
Bench Press (kg)	101.67	\pm	10.64
Dynamometry (kg)	54.10	\pm	6.50
Squat (kg)	137.60	\pm	19.65
Peak Power (W)	3908.04	\pm	423.68
VO _{2max} (ml·kg ⁻¹ ·min ⁻¹)	47.70	\pm	4.79
Sit-ups (number of reps)	46.60	\pm	4.22
Pull-ups (number of reps)	18.87	\pm	5.05
WOD1_Fran (s)	337.13	\pm	119.19
WOD2_DK (s)	417.47	\pm	98.44

Table 2*Results of Principal Component Analysis.*

	Component		
	1	2	3
Accumulated explained variance	36.51%	67.61%	80.31%
BMI	.907*	.295	-.064
Triceps	-.114	.897*	-.263
Thigh	.035	.917*	-.076
Bench Press	.792*	-.345	-.104
Squat	.832*	-.213	.082
VO _{2max}	-.028	-.031	.922*
Sit-ups	-.163	-.420	.721*
Peak Power	.806*	.145	-.171

* Values indicate the variables to which each component was most strongly related

Table 3

Correlation coefficients between variables.

	Triceps	Subscapular	Suprailiac	Thigh	Calf	Bench Press	Squat	Dynamometry	VO2max	Sit-ups	Pull-ups	Peak Power	WOD1_Fran	WOD2_DK
BMI	.178	.528*	.249	.262	.266	.597*	.612*	.393	-.106	-.290	-.388	.797**	.186	-.009
Triceps	1	.725**	.499	.771**	.625*	-.298	-.342	.038	-.266	-.504	-.414	.074	.337	.414
Subscapular		1	.473	.546*	.406	.145	-.048	.214	-.248	-.522*	-.292	.501	.455	.376
Suprailiac			1	.506	.495	-.001	.078	-.297	-.294	-.637*	-.167	-.067	.283	.713**
Thigh				1	.708**	-.252	-.060	.252	-.170	-.401	-.482	.070	.140	.305
Calf					1	-.016	.235	.000	-.288	-.514*	-.294	.161	-.199	.264
Bench Press						1	.674**	.309	-.061	-.086	.155	.455	-.236	-.242
Squat							1	.260	.011	-.003	.101	.482	-.528*	-.239
Dynamometry								1	.354	.086	-.304	.424	-.219	-.506
VO2max									1	.494	.173	-.195	-.293	-.675**
Sit-ups										1	.332	-.249	-.233	-.563*
Pull-ups											1	-.479	-.333	-.289
Peak Power												1	.115	-.043
WOD1_Fran													1	.581*
WOD2_DK														1

*. Significant Correlation $p < 0.05$ **. Significant Correlation $p < 0.01$

Discussion

Due to the growth of CrossFit as competitive sport, and the absence of scientific literature on its morphofunctional characteristics and factors influencing performance, this study sought to investigate variables associated with performance, with the aim of grouping factors to make analysis simpler.

CrossFit is still very young, both as a competitive sport and as a fitness modality; thus it was difficult to gather a representative sample that met the established inclusion criteria. The sample was small, yet the 15 selected athletes had a minimum of 2 year experience in this sport, in addition to at least 4 days of training per week. It

was therefore reasonable to expect that their morphofunctional characteristics were conditioned by the exclusive practice of CrossFit.

As mentioned, CrossFit combines gymnastic exercises with body weight, lifting of maximum and submaximal weights (with Olympic movements, Powerlifting exercises, and Strongman) along with classic cardiovascular exercises (rowing, cycling, running or swimming). Reference data for related sports specialties were chosen to characterize and classify CrossFit.

The data obtained on body composition in CrossFit practitioners gave an average BMI of 25.30 kg/m², similar to that obtained by Tibana et al. (2018) in CrossFit practitioners. This value is

higher than that found in adult male gymnasts (23-24 kg/m²; João and Filho, 2015), but lower than that seen in powerlifters (29-31 kg/m², Keogh et al., 2007). Skinfold measurements followed the same pattern; they were somewhat higher than the average values measured in male adult gymnasts (João and Filho, 2015) and lower than those measured in powerlifters (Keogh et al., 2007). The results concur with the fact that CrossFit practitioners need significant muscular mass to lift heavy external loads, without an excessive total body mass that may cause difficulties in gymnastic movements executed with their own weight; in parallel, a low adipose tissue ratio will favour a decrease in the total weight and an increase in the percentage of lean mass.

PCA was applied to extract a reduced number of factors or components that explained the majority of the variance observed. To select a coherent model suitable to the statistical process proposed, variables were eliminated, avoiding multicollinearity and ensuring statistically acceptable sample adequacy. All variables analysed were reduced to 3 components that explained 80.31% of the total variance. The first was called "Strength-body mass" and was characterized by a higher body mass and better results in absolute strength tests, as well as higher values in peak power (IMC .907, bench press .792, squat .832 and peak power .806); this explained 36.51% of the variance. The second component, "Adiposity", represented greater thickness in skin folds (Triceps .897 and Thigh .917), and explained 31.1% of the variance. The third component, "Aerobic capacity", was clearly associated with better results in the SRT (higher VO₂max), in addition to better results in the sit-ups test (VO₂max .922 and sit-ups .721), and explained 12.7% of the variance.

In the correlational analysis with performance, special attention was given to the variables most strongly related to each component extracted from the PCA (Colyer et al., 2017).

Higher values in VO₂max (third component = .922) were associated with better performance in WOD2_DK, as could be expected from the characteristics of this WOD; it had an average duration of almost 7 minutes (approximately 1 min 30 s longer than WOD1_Fran), and included global exercises

involving high oxygen uptake, such as box jumps, burpees (Ratamess et al., 2015) and kettlebell swings (Hulsey et al., 2012). These features suggest the importance of aerobic capacity, as indicated by our results. These results reinforce in part the improvements observed in VO₂max after the practice of high-intensity interval training in the form of HIIT or HIPT (Milanović et al., 2015). No significant associations were found between VO₂max and WOD1_Fran, coinciding with the results of Butcher et al. (2015), probably due to the lower number of exercises and thus shorter duration: 90 repetitions in total (45 pull-ups and 45 thrusters). In addition, the pull-up involves low oxygen uptake and is characterized by a pulling movement of the upper limbs with relatively little involvement of the rest of the body (Dickie et al., 2017).

Greater numbers of movements made using the participant's own weight (sit-ups and pull-ups) also showed associations with less time needed to complete WODs, although the value of *r* was low ($r \leq .300$) except in sit-ups (third component = .721) / WOD2_DK ($r = -.563$; $p < .05$). This is of interest given the constant abdominal involvement in trunk flexion movements in box jumps, its incorporation in burpees and its synergistic action during kettlebell swings (Andersen et al., 2016). An unexpected result was the low value of *r* in the association with pull-ups/WOD1_Fran ($r = -.333$); a possible explanation may be that the pull-up technique used by athletes during the execution of the WOD (all using the butterfly or kipping technique) was different from the protocol requirements in the pull-ups test (where swinging movements or help kicks are not allowed). The pull-up values obtained in our CrossFit competitors were very high (18.87 ± 5.05) in comparison with soldiers who had completed a physical training program (9.2 ± 5.4) (Lester et al., 2014).

Greater results in absolute strength tests (squat, dynamometry and bench press) were associated with better performance (shorter time in the WODs), showing significant values of $r > .500$ in squat/WOD1_Fran ($r = .528$; $p < .05$) and hand dynamometry/WOD2_DK ($r = .506$; $p = .055$); both results are in line with the content of the evaluated WODs, as they are characteristic of the squat movement (first component = .832) during the execution of thrusters (WOD1_Fran),

and the kettlebell swing movement (WOD2_DK), since the kettlebell remains gripped by the hands during a downward and upward arc, until its momentum is exhausted (Lake and Lauder, 2012).

Greater skinfold thicknesses were directly associated with a slower execution of the two WODs evaluated, although with low or very low r values ($r < .300$), only appearing with $p < .01$ and $r = .713$ in the correlation between suprailiac and WOD2_DK. These results were expected considering the homogeneity of the sample, with its low skinfold values, and suggest a negative influence of greater adiposity on performance.

The use of PCA helps in the analysis of the large amount of information obtained from the measurement of many variables in attempts to find possible relationships with sports performance (Colyer et al., 2017), but attention must be paid to the conditions of application of statistical procedures. To continue with the determination of predictive variables of performance in CrossFit, it would be necessary to include new variables or more specific tests and new capacities (e.g. anaerobic power), as well as a

larger and more varied number of WODs to represent the enormous variety of CrossFit exercises. It would also be very important to increase the sample size in order to gain statistical accuracy.

In conclusion, within the limitations of our study, we observed important components that characterized the CrossFit competitor: strength and muscle mass, low adiposity and aerobic capacity. In addition, significant relationships were found between morphofunctional variables and performance in Crossfit WODs: VO2max, suprailiac skinfold and sit-ups in "Donkey Kong", and squat in "Fran". It is very important to identify and reduce the number of influential variables in sports performance to facilitate analysis, particularly in sports such as CrossFit, which presents multiple different physical demands. These results should help develop CrossFit programs and train relevant physical abilities together with the specific movement characteristics of the discipline.

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