International Journal of EXERCISE SCIENCE

Original Research

The Relationship Between Physical Characteristics and Maximal Strength in Men Practicing the Back Squat, the Bench Press and the Deadlift

Pierre-Marc Ferland†[1,2], Alexander Pollock†[2], Ryan Swope‡[2], Mark Ryan‡[2], Michael Reeder‡[2], Kristin Heumann‡[2], and Alain Steve Comtois‡[1]

[1]Department of Physical Activity Sciences, University of Quebec-Montreal, Montreal, Quebec, CANADA; [2]Department of Kinesiology, Colorado Mesa University, Grand Junction, CO, USA

†Denotes graduate student author, ‡Denotes professional author

ABSTRACT

International Journal of Exercise Science 13(4): 281-297, 2020. This study was designed to quantify the relationships between physical characteristics and maximal strength in the back squat, the bench press and the deadlift on powerlifters and football players. Eighteen male junior drug-tested classic powerlifters and seventeen NCAA Division II American football players' anthropometric measurements were taken to compare them with maximal strength results from either a powerlifting meet or testing from their supervised strength and conditioning program. Pearson's bivariate correlations analysis revealed (statistical significance was set at $p<0.05$) that individuals with a greater (Wilks points) back squat, generally presented a higher Bodyweight (BW) (r=0.37), Body Mass Index (BMI) (r=0.45), Bodyfat Percentage (BF%) (r=0.36), Hip (r=0.41), Waist (r=0.35) and Torso (r=0.41) Circumference (C), Hip C/Height (r=0.46), Waist C/Height (r=0.39) and Torso C/Height (r=0.45) ratios. The individuals with a greater bench press generally presented a higher BMI (r=0.37), Lean Body Weight (LBW) (r=0.36), Hip C (r=0.39) and Hip C/Height ratio (r=0.39). On the other hand, individuals with a greater deadlift were generally older (r=0.34), shorter (r=-0.41), had shorter thighs (r=-0.52) and trunks (r=-0.36), smaller Thigh Length (L)/Height ratio (r=-0.44), Waist C/Hip C (r=-0.41) and Thigh L/Lower Leg L (r=-0.53) ratios, but a higher Lower Leg L/Height ratio (r=-046). The results of this study should be utilized by strength and conditioning coaches to deepen their comprehension of their athletes' physical characteristics in order to help them develop strength through their advantages. Further research should focus on evaluating how physical characteristics affect performance in different squat, bench, and deadlift stances.

KEY WORDS: Body composition; anthropometry; conventional deadlift; sumo deadlift

INTRODUCTION

Maximal strength is the principal physical asset that modern day North-American strength and conditioning coaches are known to be developing. It has shown to be related to jump (27, 39) and sprint (24, 39) performance as well as improving initial concentric muscle power production (7), rate of force development (10, 12, 34), vertical jump performance (2), economy in aerobic sports (12, 13, 18, 28, 36) and also reducing injury rates (35).

Since powerlifting is the sport of maximal strength (8), it is common practice for strength and conditioning coaches to utilize the big three: i.e., the back squat, the bench press and the deadlift, to test their athlete's strength. Over the years, multiple studies have demonstrated that physical characteristics, anthropometry (17, 19, 23), fat free mass (3), skeletal muscle mass (40) and bone mass (9) were related to powerlifting performance and therefore, maximal strength. Furthermore, other studies have evaluated the relationship between anthropometry and strength in the bench press (11, 20, 22, 30, 32, 33) and in the big three (21) on non-powerlifter populations. Nonetheless, only one of these studies had been directed on sanctioned drug-tested classic powerlifting.

The purpose of this study was to quantify the relationships between physical characteristics (anthropometry, physical proportions and body composition) and maximal strength in the big three on classic drug-tested powerlifters and football players. The hypothesis of this investigation was that various physical characteristics of powerlifters and football players would be related to maximal strength measures, since the protocol from this study includes anthropometrical measurements that were utilised to build ratios in order to outline what physical proportions help performance in each of the powerlifting movements.

It was expected that these results would complete the ones from the first author's other study directed on powerlifters and make results generalizable to collegiate athletes practicing the squat, bench and deadlift on a regular basis. Results from this study could be useful for strength and conditioning coaches working with athletes as they utilize the back squat, the bench press, and the deadlift to help build their strength. The information present in this article will help practitioners understand better their trainees' physical characteristics in order to help them develop strength through their physical advantages as well as compensate their areas where they are at a physical disadvantage.

METHODS

Participants

Ethical approval was obtained on August 2nd, 2018 through the University of Quebec at Montreal's (UQÀM) institutional review board committee (IRB 2790_e_2018) and a second ethical approval was also obtained on April 8th, 2019 through the Colorado Mesa University' (CMU) institutional review board committee (IRB 19-30) as the first part of the data collection was conducted in Canada and the second part of the data collection was conducted in the United-States of America (USA). This research was carried out fully in accordance to the ethical standards of the International Journal of Exercise Science (25).

Participants were either male junior (18 to 23 yrs. old) drug-tested (4, 38) classic (raw) powerlifters members of the Quebec Powerlifting Federation (QPF) or Colorado Mesa University NCAA Division II (6) American football players. All participants had no physical limitation that could affect their performance in all three maximal strength tests (back squat, bench press and deadlift). The QPF (29) falls under the Canadian Powerlifting Union (CPU) (5) and International Powerlifting Federation (IPF) (14). The Colorado Mesa University (6) football

team were conference champions 3 of their last 4 years in the Rocky Mountain Athletic Conference (RMAC) (31). Colorado Mesa University football players were selected to be compared to powerlifters as they follow a well-supervised strength and conditioning program which includes execution of all three powerlifting lifts on a weekly basis. Utilizing this group would insure a maximum of training experience and technical abilities as well as have both groups tested under circumstances of high arousal. Participants from both data collections were first asked to read and sign two copies of the consent form, before proceeding into data collection.

Protocol

The experimental approach of this descriptive quantitative study consisted of measuring various physical characteristics of powerlifters and football players and to compare them to maximal strength results from either a powerlifting meet or maximal strength testing component of their athletic program. The rationale behind this experimental approach is to compare results from both groups with similar characteristics and strength levels (view tables 1 and 2) and then combine the data for further analysis to help generalize results to all populations practicing the squat, bench, and deadlift in their weekly training routine.

The research team was present at the official weigh-ins of the powerlifting competition on November 10th and 11th, 2018 and in the Monfort Family Human Performance Lab during football testing week between April 29th and May 3rd, 2019 to collect both group's physical characteristics.

Physical characteristics data collection started by having participants stand still in their underwear. Hip circumference was measured at its largest point, having the subject relax, with his arms to his sides. Waist circumference was measured at its largest point, having the subject relax, with his arms to his sides. Chest circumference was measured at its largest point (without the shoulders), having the subject relax, with his arms to his sides. Arm length was measured from the lateral posterior apex of the acromion to apex of the olecranon, having the subject relax, with his arms to his sides and his hands in a neutral position. Forearm length was measured from the apex of the olecranon to the styloid process of the ulna, having the subject relax, with his arms to his sides and his hands in a neutral position. Thigh length was measured from the lateral apex of the greater trochanter to lateral epicondyle space of the knee. Lower leg length was measured from the lateral epicondyle space of the knee to the lateral apex of the malleolus. Trunk length was measured from the center of the belly-button to the top of the sternal extremity of the collarbone. Reach (wingspan) was measured from tip the middle finger to tip of the middle finger, having the subject's palms facing forward and stretching as much as he could. Height was measured with a stadiometer (Seca, CA, USA) having subjects place their feet together with their heels against the wall, chin slightly tucked with lungs full of air. These measurements were taken on the right side of the subject with a non-stretchable 3 m measuring tape to the nearest 0.1 cm as recommended by the ACSM (1). The anatomical landmark's selection of the anthropometric measurements was based on simplicity of identification allowing the investigators to take measurements quickly and not interrupt the competition schedule as well as for the coaches to be able to reproduce these measurements and calculate

their athlete's ratios. Additionally, the anatomical landmarks selection was based on Frank H. Netter's Atlas of human anatomy (26) and the ACSM's guidelines for exercise testing and prescription (1) in order to measure limb lengths in the straightest lines possible. All measurements were taken by the same investigator for both groups as he was giving verbal instructions to the subjects and was being assisted by one of the co-authors.

After anthropometric measurements were taken, subjects stood on the bio-impedance scale (In-Body 270, Seoul, Korea for the powerlifters and Tanita TBF-300 WA, Japan for the football players) where their age was asked verbally before starting the body composition analysis. Since bio-impedance (BIA) of the powerlifters was done without them receiving preliminary instructions as it was during competition official weigh-in, football players did not receive any instructions for their BIA analysis either. Hydration status and weight loss procedures were not monitored, and bio-impedance analyses were conducted with two different devices. These are considered as study methodology limitations and were done because researchers did not want to interfere with the powerlifting competition results and because data collection was conducted in two different countries (Canada for the powerlifters and USA for the football players) and the same model of bio-impedance scale was not available. Participants' anthropometric measurements and bio-impedance body composition analysis were executed within a 4-minute time frame.

Absolute maximal strength was tested with the back squat, the bench press and the deadlift during the powerlifting competition and a regular strength and conditioning testing session. Football players' strength was tested in the strength and conditioning facility with players executing a mandatory 15 to 20 minutes dynamic warm up with emphasis on the movement patterns/muscle groups that would be tested that day. In lower body movements (squat, deadlift) there would be a short involvement of lower body plyometric movements to prime the nervous system and to prepare the muscle tissue for forceful contractions.

The testing schedule had players test their bench press on Monday, back squat on Tuesday and conventional deadlift on Thursday with a rep scheme of 6-4-2-1-1-1-1 for each of the 3 lifts. Players were placed in teams of 4 to 5 allowing a work to rest ratio of at least 1:6 as they would need to load the bar in between sets and attempts. All football players testing sessions were supervised by certified strength and conditioning coaches.

Statistical Analysis

Participants' total (in kg) was calculated using his best completed attempt of each lift similar to a regular powerlifting meet. Relative maximal strength was calculated with Wilks coefficient in order to compare maximal strength regardless of bodyweight. First, total Wilks points was calculated, then individual lift's Wilks points were calculated by multiplying the proportion of the lift on the total with total Wilks points (ex: % of the Squat on the Total * Total Wilks points = Squat Wilks points). The Wilks Formula was utilised to calculate participants' relative strength as it was the formula utilized during the powerlifting competition and had previously been validated (37). At the time the results of this study were going under their submission process, the International Powerlifting Federation (IPF) (14) had come out with a new formula (15, 16),

but it had not been validated and was not the one utilised at the time the competition occurred. Therefore, authors decided to proceed with the Wilks, as it had been established for many years, validated and utilized during the sanctioned powerlifting competitions (5, 14, 16, 29). Percentage of each lift on the total was calculated by dividing the lift by the total and multiplying it by 100 (lift / total * 100).

All values are reported as means ± SD. Correlations between physical characteristics and maximal strength measures were calculated with Pearson's bivariate correlations analysis. A stepwise regression analysis was performed with a forward linear regression approach for each of the maximal strength measures to determine the ability of each physical characteristic to predict outcome in each of these measures. Power calculation was not performed, since the number of participants was established by samples of convenience. Significance was set at $p \leq 0.05$ for both analyses. All statistical analyses were conducted using IBM SPSS Statistics for Windows (version 25).

RESULTS

Participants' physical characteristics and maximal strength measures for both groups are presented as means ± standard deviations in Tables 1 and 2, respectively.

Table 1. Participants' physical characteristics.

Measure	Powerlifters (n=18)	Football Players (n=17)
	Mean ± SD	Mean ± SD
Age	21.2 ± 1.2*	20.3 ± 1.2
Height	174.1 ± 7.0*	185.4 ± 8.1
BW	83.2 ± 12.4*	111.8 ± 23.0
BMI	27.4 ± 3.5*	32.3 ± 5.5
BF%	17.5 ± 6.7	19.6 ± 6.9
LBW	68.3 ± 9.1*	88.7 ± 13.1
Hip C	99.5 ± 6.9*	112.1 ± 11.3
Waist C	84.6 ± 7.6*	103.4 ± 15.7
Torso C	104.3 ± 6.2*	115.4 ± 12.0
Arm L	33.9 ± 1.7	34.6 ± 2.8
Forearm L	26.7 ± 1.2*	28.7 ± 1.7
Thigh L	41.7 ± 1.8*	47.1 ± 3.7
Lower Leg L	42.5 ± 1.9*	43.0 ± 2.6
Trunk L	38.9 ± 2.8*	42.5 ± 3.5
Reach	180.2 ± 7.2*	193.2 ± 10.3
Hip C/Height	.57 ± .04*	.60 ± .05
Waist C/Height	.49 ± .05*	.56 ± .07
Torso C/Height	.60 ± .04	.62 ± .05
Trunk L/Height	.22 ± .01	.23 ± .01
Thigh L/Height	.24 ± .01*	.25 ± .01
Lower Leg L/Height	.24 ± .01*	.23 ± .01
Reach/Height	1.04 ± .02	1.04 ± .03
Waist C/Hip C	.85 ± .04*	.92 ± .06
Forearm L/Reach	.15 ± .01	.15 ± .01
Forearm L/Torso L	.26 ± .02	.25 ± .02
Forearm L/Height	.15 ± .01	.15 ± .01
Forearm L/Arm L	.79 ± .04*	.83 ± .06
Thigh L/Lower Leg L	.98 ± .04	1.10 ± .08
Trunk L/Thigh L	.93 ± .06*	.90 ± .06

Means ± SD. * Significantly different to Football Players, significance was set at $p<0.05$
BW: Body Weight; BMI: Body Mass Index; BF%: Body Fat Percentage; LBW: Lean Body Weight, C: Circumference, L: Length

Table 2. Participants' maximal strength measures.

	Powerlifters (n=18)	Football Players (n=17)
Measure	Mean ± SD	Mean ± SD
Squat kg	199.9 ± 32.8*	229.6 ± 29.8
Bench kg	126.94 ± 20.3*	148.0 ± 21.0
Deadlift kg	229.6 ± 33.3	224.9 ± 28.5
Total kg	556.4 ± 83.0	602.5 ± 69.7
Squat Wilks	134.4 ± 14.6	137.1 ± 12.3
Bench Wilks	85.4 ± 9.2	88.3 ± 9.2
Deadlift Wilks	154.6 ± 13.6*	134.6 ± 13.9
Total Wilks	374.4 ± 33.5	360.1 ± 27.4
% Squat	35.9 ± 1.8*	38.1 ± 01.7
% Bench	22.8 ± 1.6*	24.6 ± 02.1
% Deadlift	41.3 ± 1.1*	37.4 ± 02.2

Means ± SD. * Significantly different to Football Players, significance was set at $p<0.05$

The two-tailed Pearson correlation analysis revealed multiple significant relationships between physical characteristics and maximal strength measures (Tables 3 to 5).

Significant correlations ($p<0.05$) between absolute maximal strength (kg) in the squat and Bodyweight (BW) (r=0.81 and 0.78), Body Mass Index (BMI) (r=0.64 and 0.87), Lean Body Weight (LBW) (r=0.72 and 0.60), Hip Circumference (C) (r=0.73 and 0.83) and Torso C (r=0.69 and 0.83); between bench press kg and BW (r=0.77 and 0.62), BMI (r=0.60 and 0.69) and Hip C (r=0.73 and 0.69); between deadlift kg and BMI (r=0.66 and 0.60), Hip C (r=0.74 and 0.64) and Torso C (r=0.81 and 0.61); between Total kg and BW (r=0.84 and 0.74), BMI (r=0.66 and 0.83), LBW (r=0.78 and 0.62), Hip C (r=0.76 and 0.82), Waist C (r=0.61 and 0.75) and Torso C (r=0.78 and 0.77) were found in all three Pearson's bivariate correlations analyses.

When combining both groups for the correlation analysis, the individual with the highest absolute maximal strength practicing the powerlifting movements is taller and heavier, has a higher BMI, Bodyfat Percentage (BF%) and LBW; also a greater hip, waist and torso C, longer arms, forearms, thighs, trunk and reach; higher Hip C/Height, Waist C/Height, Torso C/Height, Trunk L/Height, Waist C/Hip C, and Thigh L/Lower Leg L ratios, but a smaller Forearm L/Torso C ratios.

Table 3. Relationships between physical characteristics and maximal strength in junior powerlifters (n=18).

	S	B	D	T	SW	BW	DW	TW	%S	%B	%D
Age	.20	**.48**	.39	.35	-.05	.39	.22	.17	-.47	.39	.18
Height	.39	.41	.38	.41	.27	.31	.23	.29	.06	.10	-.24
BW	**.81**	**.77**	**.82**	**.84**	**.48**	.41	.45	**.50**	.15	-.02	-.21
BMI	**.64**	**.60**	**.66**	**.66**	.34	.26	.33	.36	.12	-.07	-.10
BF%	.32	.20	.27	.28	.16	-.05	.03	.07	.24	-.18	-.13
LBW	**.72**	**.75**	**.77**	**.78**	.46	**.50**	**.51**	**.54**	.03	.08	-.15
Hip C	**.73**	**.73**	**.74**	**.76**	.42	.40	.37	.44	.13	.04	-.27
Waist C	**.59**	**.54**	**.62**	**.61**	.27	.17	.25	.27	.12	-.09	-.06
Torso C	**.69**	**.76**	**.81**	**.78**	.37	.46	**.51**	.49	-.09	.06	.06
Arm L	.37	**.48**	.40	.43	.27	.45	.31	.37	-.08	.23	-.20
Forearm L	**.50**	.35	.46	.47	.43	.20	.36	.39	.25	-.20	-.12
Thigh L	.27	.22	.28	.27	.09	.01	.07	.07	.06	-.07	.01
Lower Leg L	.42	.41	**.48**	.46	.36	.33	.44	.43	.02	-.04	.03
Trunk L	.41	.46	.38	.43	.18	.26	.09	.19	.08	.17	-.36
Reach	.42	.46	**.48**	**.47**	.31	.38	.40	.40	-.06	.07	-.01
Hip C/Height	**.50**	**.49**	**.51**	**.52**	.25	.22	.23	.26	.09	-.01	-.13
Waist C/Height	.37	.32	.40	.39	.13	.03	.13	.11	.08	-.12	.05
Torso C/Height	.38	.43	**.50**	.46	.16	.22	.32	.26	-.13	-.00	.21
Trunk L/Height	.27	.33	.23	.28	.04	.13	-.07	.02	.06	.17	-.34
Thigh L/Height	-.14	-.24	-.10	-.16	-.25	-.41	-.21	-.31	.00	-.25	.35
Lower Leg L/Height	.09	.05	.19	.12	.16	.08	.33	.23	-.06	-.18	.37
Reach/Height	.02	.07	.16	.09	.05	.12	.30	.18	-.22	-.05	.41
Waist C/Hip C	.07	-.05	.12	.06	-.09	-.28	-.05	-.14	.05	-.27	.31
Forearm L/Reach	.21	-.05	.08	.10	.24	-.17	.03	.07	.42	-.36	-.15
Forearm L/Torso L	-.28	-.44	-.41	-.39	-.05	-.28	-.21	-.18	.25	-.19	-.12
Forearm L/Height	.19	-.00	.17	.14	.24	-.07	.21	.17	.24	-.35	.11
Forearm L/Arm L	.09	-.18	.03	.00	.13	-.29	.03	-.01	.33	-.46	.13
Thigh L/Lower Leg L	-.17	-.21	-.22	-.21	-.31	-.37	-.42	-.41	.06	-.04	-.03
Trunk L/Thigh L	.29	.38	.24	.30	.15	.31	.05	.17	.04	.26	-.44

Bold indicates significant correlations at $p<0.05$

S: Squat, B: Bench, D: Deadlift, T: Total, SW: Squat Wilks, BW: Bench Wilks, DW: Deadlift Wilks, TW: Total Wilks, %S: Percentage of the Squat on the total, %B: Percentage of the Bench on the total, %D: Percentage or the Deadlift of the total, BW: Body Weight, BMI: Body Mass Index, BF%: Bodyfat Percentage, LBW: Lean Body Weight, C: Circumference, L: Length

The individuals with a greater squat regardless of bodyweight (Wilks) generally presented a higher BW, BMI, BF%, Hip, waist and torso C, Hip C/Height, Waist C/Height and Torso C/Height ratios. The individuals with a greater bench press generally presented a higher BMI, LBW, Hip C and Hip C/Height ratio. The individuals with a greater deadlift Wilks were older, shorter, had shorter thighs and trunks, smaller Thigh L/Height ratio, Waist C/Hip C and Thigh L/Lower Leg L ratios, but a higher Lower Leg L/Height ratio.

The individuals having a higher % of their squat on their total were older, taller, heavier, had a higher BMI, BF%, LBW, had a higher Waist, Hip and Torso C, longer forearm and thighs, higher Hip C/Height and Waist C/Height Waist C/Hip C and Thigh L/Lower Leg L, but smaller Lower Leg L/Height. The individuals having a higher bench % on their total were taller, had more LBW, had longer thighs, trunk and reach, higher Thigh L/Height and Thigh L/Lower Leg L. The individuals having a higher % of their deadlift on their total were shorter, lighter, had a smaller BMI, LBW, Hip, Waist and Torso C, Shorter Forearm and Thighs, shorter trunk and reach, Hip C/Height Waist C/Height Trunk L/Height Thigh L/Height Waist C/Hip C Forearm L/Arm L Thigh L/Lower Leg L.

Table 4. Relationships between physical characteristics and maximal strength in college football players (n=17).

	S	B	D	T	SW	BW	DW	TW	%S	%B	%D
Age	**.51**	**.52**	.37	**.53**	.37	.42	.14	.38	.10	.18	-.24
Height	.18	.22	.14	.20	-.29	-.13	-.33	-.34	-.03	.17	-.13
BW	**.78**	**.62**	**.55**	**.74**	.38	.24	.02	.26	.31	.06	-.29
BMI	**.87**	**.69**	**.60**	**.83**	**.60**	.39	.17	**.49**	.37	.03	-.32
BF%	**.84**	**.53**	**.57**	**.75**	**.59**	.23	.18	.43	.44	-.10	-.24
LBW	**.60**	**.59**	.46	**.62**	.15	.24	-.06	.12	.11	.19	-.25
Hip C	**.83**	**.69**	**.64**	**.82**	.48	.36	.16	.42	.26	.06	-.25
Waist C	**.83**	**.58**	**.55**	**.75**	.48	.21	.05	.31	.41	-.02	-.31
Torso C	**.83**	**.54**	**.61**	**.77**	**.50**	.18	.14	.36	.39	-.11	-.21
Arm L	.31	.28	.21	.31	-.11	-.04	-.22	-.17	.06	.13	-.16
Forearm L	.38	.48	.23	.40	.06	.27	-.16	.04	.05	.30	-.31
Thigh L	.30	**.49**	.10	.32	-.06	.26	-.31	-.10	.01	.41	-.38
Lower Leg L	.12	.15	.06	.12	-.27	-.12	-.32	-.32	.01	.16	-.15
Trunk L	.40	.47	.24	.41	-.00	.18	-.22	-.05	.07	.28	-.31
Reach	.32	.36	.25	.35	-.09	.07	-.19	-.11	-.02	.20	-.17
Hip C/Height	**.86**	**.69**	**.66**	**.84**	**.68**	.48	.33	**.63**	.30	.00	-.23
Waist C/Height	**.90**	**.61**	**.59**	**.81**	**.64**	.30	.16	.46	**.48**	-.06	-.32
Torso C/Height	**.91**	**.55**	**.67**	**.83**	**.73**	.28	.33	**.59**	.48	-.19	-.19
Trunk L/Height	**.49**	**.58**	.27	**.49**	.24	.41	-.09	.20	.14	.31	-.40
Thigh L/Height	.29	**.51**	.04	.29	.15	.46	-.17	.14	.04	.43	-.42
Lower Leg L/Height	-.02	.00	-.07	-.04	-.11	-.05	-.17	-.15	.05	.09	-.11
Reach/Height	.36	.40	.29	.39	.28	.37	.16	.33	.00	.15	-.14
Waist C/Hip C	**.64**	.32	.30	**.49**	.34	-.02	-.12	.09	**.52**	-.09	-.32
Forearm L/Reach	.16	.26	.01	.15	.24	.35	.02	.23	.10	.20	-.26
Forearm L/Torso L	**-.71**	-.32	**-.57**	**-.64**	**-.53**	-.03	-.28	-.39	-.41	.32	.02
Forearm L/Height	.36	.48	.19	.37	.38	**.54**	.11	.41	.09	.27	-.32
Forearm L/Arm L	-.04	.09	-.06	-.02	.18	.30	.13	.25	-.03	.12	-.08
Thigh L/Lower Leg L	.25	.42	.06	.26	.18	.40	-.07	.18	.02	.32	-.31
Trunk L/Thigh L	.14	.00	.18	.14	.04	-.11	.07	.02	.08	-.14	.07

Bold indicates significant correlations at $p<0.05$

S: Squat, B: Bench, D: Deadlift, T: Total, SW: Squat Wilks, BW: Bench Wilks, DW: Deadlift Wilks, TW: Total Wilks, %S: Percentage of the Squat on the total, %B: Percentage of the Bench on the total, %D: Percentage or the Deadlift of the total, BW: Body Weight, BMI: Body Mass Index, BF%: Bodyfat Percentage, LBW: Lean Body Weight, C: Circumference, L: Length

Table 5. Relationships between physical characteristics and maximal strength for all subjects (n=35).

	S	B	D	T	SW	BW	DW	TW	%S	%B	%D
Age	.14	.25	**.38**	.28	.09	.32	**.34**	.32	**-.34**	.08	.21
Height	**.47**	**.50**	.16	**.41**	.07	.16	**-.41**	-.15	**.34**	**.37**	**-.55**
BW	**.80**	**.74**	**.43**	**.73**	**.37**	.32	-.27	.11	**.50**	.30	**-.61**
BMI	**.80**	**.72**	**.49**	**.75**	**.45**	**.37**	-.13	.23	**.46**	.21	**-.52**
BF%	**.56**	**.39**	**.38**	**.51**	**.36**	.11	-.01	.18	**.36**	-.05	-.24
LBW	**.72**	**.74**	**.37**	**.67**	.28	**.36**	-.31	.06	**.41**	**.39**	**-.62**
Hip C	**.81**	**.76**	**.49**	**.76**	**.41**	**.39**	-.19	.19	**.45**	.29	**-.57**
Waist C	**.76**	**.66**	**.36**	**.66**	**.35**	.24	-.30	.06	**.53**	.24	**-.60**
Torso C	**.79**	**.69**	**.50**	**.74**	**.41**	.30	-.13	.19	**.43**	.19	**-.48**
Arm L	**.36**	**.38**	.26	**.37**	.07	.17	-.11	.02	.09	.21	-.23
Forearm L	**.57**	**.57**	.23	**.50**	.25	.29	-.30	.03	**.40**	.33	**-.57**
Thigh L	**.48**	**.57**	.06	**.39**	.07	.23	**-.52**	-.19	**.40**	**.48**	**-.67**
Lower Leg L	.27	.28	.24	.29	.04	.10	-.06	.02	.07	.12	-.14
Trunk L	**.53**	**.59**	.22	**.49**	.13	.27	**-.36**	-.06	.33	**.40**	**-.56**
Reach	**.52**	**.56**	.23	**.48**	.14	.26	-.32	-.04	.31	**.37**	**-.52**
Hip C/Height	**.72**	**.65**	**.51**	**.70**	**.46**	**.39**	.01	.32	**.35**	.14	**-.38**
Waist C/Height	**.73**	**.60**	**.38**	**.64**	**.39**	.24	-.21	.12	**.50**	.16	**-.51**
Torso C/Height	**.68**	**.54**	**.54**	**.66**	**.45**	.28	.10	**.33**	.30	.00	-.24
Trunk L/Height	**.43**	**.51**	.22	**.42**	.15	.30	-.21	.04	.21	.32	**-.41**
Thigh L/Height	.33	**.44**	-.05	.25	.05	.21	**-.44**	-.16	.32	**.41**	**-.56**
Lower Leg L/Height	-.27	-.29	.11	-.16	-.04	-.09	**.46**	.21	**-.37**	-.32	.54
Reach/Height	.22	.27	.21	.25	.17	.26	.10	.21	-.02	.11	-.07
Waist C/Hip C	**.54**	**.40**	.12	**.40**	.18	.00	**-.41**	-.15	**.54**	.15	**-.54**
Forearm L/Reach	.19	.12	.04	.13	.24	.10	-.01	.13	.25	-.02	-.18
Forearm L/Torso L	**-.51**	**-.40**	**-.46**	**-.52**	-.29	-.17	-.10	-.23	-.17	.03	.12
Forearm L/Height	.30	.27	.16	.27	.31	.25	.06	.24	.20	.05	-.20
Forearm L/Arm L	.20	.19	-.05	.12	.18	.12	-.19	.01	.32	.12	**-.34**
Thigh L/Lower Leg L	**.37**	**.45**	-.08	.26	.07	.21	**-.53**	-.20	**.41**	**.44**	**-.65**
Trunk L/Thigh L	.07	.04	.23	.13	.07	.06	.21	.16	-.10	-.09	.15

Bold indicates significant correlations at $p<0.05$

S: Squat, B: Bench, D: Deadlift, T: Total, SW: Squat Wilks, BW: Bench Wilks, DW: Deadlift Wilks, TW: Total Wilks, %S: Percentage of the Squat on the total, %B: Percentage of the Bench on the total, %D: Percentage or the Deadlift of the total, BW: Body Weight, BMI: Body Mass Index, BF%: Bodyfat Percentage, LBW: Lean Body Weight, C: Circumference, L: Length

The forward stepwise linear regression analysis revealed that different physical characteristics can predict different maximal strength measures (Table 6). Results show that the absolute hip circumference (Hip C) significantly predicted ($p<0.05$) and positively affected absolute maximal strength (kg) in the squat, the bench press and the total and that relative hip circumference (Hip C/Height) significantly predicted ($p<0.05$) and positively affected relative maximal strength (Wilks) in the squat and bench press. Results also show that Torso L/Height significantly predicted ($p<0.05$) and positively affected deadlift kg, Wilks and total Wilks. Finally, the Waist

C/Hip C ratio significantly predicted ($p<0.05$) and positively affected the % of the squat on the total, but negatively affected the deadlift kg, deadlift Wilks and the total Wilks. For more detailed results, please refer to result tables 3 to 6.

Table 6. Stepwise linear regression analysis results of all subjects (n=35).

Performance Measures	Characteristics	R^2	B	β	P-Value
Squat kg		0.655			<0.001
	Hip C		2.495	0.809	<0.001
Bench kg		0.584			<0.001
	Hip C		1.573	0.764	<0.001
Deadlift kg		0.567			<0.001
	Torso L/Height		647.407	0.992	<0.001
	Waist C/Hip C		-328.974	-0.643	0.001
	Lower Leg L		6.568	0.476	0.001
Total kg		0.579			<0.001
	Hip C		5.403	0.761	<0.001
Squat Wilks		0.216			0.005
	Hip C/Height		128.163	0.464	0.005
Bench Wilks		0.152			0.021
	Hip C/Height		73.335	0.389	0.021
Deadlift Wilks		0.521			<0.001
	Thigh L/Lower Leg L		-79.952	-0.395	0.013
	Torso L/Height		225.466	0.626	0.001
	Waist C/Hip C		-170.317	-0.603	0.003
Total Wilks		0.346			0.001
	Torso L/Height		497.462	0.752	<0.001
	Waist C/Hip C		-331.300	-0.639	0.002
% Squat		0.416			<0.001
	Waist C/Hip C		0.187	0.546	<0.001
	Age		-0.006	-0.352	0.014
% Bench		0.225			0.004
	Thigh L		0.002	0.475	0.004
% Deadlift		0.513			<0.001
	Thigh L		-0.004	-0.537	0.001
	Lower Leg L/Height		0.789	0.285	0.049

Significance was set at $p<0.05$ level; C: Circumference, L: Length

DISCUSSION

The main finding of the present study is that several strong significant relationships ($r \geq 0.6$, $p<0.05$) were established between physical characteristics and maximal strength measures in both groups of athletes: powerlifters and football players. As well, significant correlations between absolute strength (kg) in the squat, the bench press, the deadlift and the total can be

generalized to populations practicing the big three on a regular basis at the level of technique routinely observed in local competitive powerlifting clubs and among collegiate strength and conditioning programs.

Specifically, the results of this study indicate that the taller, the heavier, with more bodyfat, the more muscular and the bigger built (based on anthropometric measurements) individuals were generally stronger. These results are similar to previous studies that presented multiple significant correlations between classic powerlifting and lean body tissue (9), equipped powerlifting performance and muscle thickness (3) and equipped powerlifting performance and skeletal muscle mass (40). In addition, other studies illustrated similar results, with the stronger equipped powerlifters having significantly larger proportional muscle mass and muscle to bone mass ratio (19) and significantly greater muscle mass and larger muscle girths (17). Furthermore, a study by Mayhew et al. showed that body size was the major determinant of powerlifting performance in adolescent male athletes (23).

In addition, our results indicate that a bigger, wider and thicker individual is at a greater advantage in the squat and the bench press (Wilks points). On the other hand, individuals with a greater deadlift were built shorter, thinner, had shorter thighs and trunks, but longer lower legs (shins). These results could be related to the bar placement as the bar is over the body for squat and bench, making a thicker individual advantaged in both lifts, as a thicker body would help stabilise the bar in the squat and reduce the stroke distance in the bench press but disadvantaged in the deadlift as the bar is in front of the body, making it harder for a thicker individual to get into a proper position. The study directed on equipped male powerlifters showed similar results with skeletal muscle mass being negatively correlated with deadlift performance ($r=-0.47$, $p<0.05$).

By looking at the characteristics of the individuals having a higher % of their squat and bench press on their total and comparing them to the physical characteristics that differentiated both groups of lifters (powerlifters vs football players), one could hypothesize that these correlations are describing mostly the football players as they presented these physical characteristics and a higher squat and bench Wilks. This could also mean that football players put less training emphasis on the deadlift (40).

Individuals having a higher % of their deadlift on their total being shorter, lighter, having a smaller BMI, LBW, Hip, Waist and Torso C, Shorter Forearm and Thighs, shorter trunk and reach, Hip C/Height Waist C/Height Trunk L/Height Thigh L/Height Waist C/Hip C Forearm L/Arm L Thigh L/Lower Leg L could perhaps mean that these physical characteristics are not the ones typically associated with a good powerlifter as a higher percentage of the deadlift on the total could imply that they are weaker at the squat and bench press.

The forward stepwise linear regression analysis results showing that absolute and relative hip circumference significantly predicts and positively affects squat and bench press performance (kg and Wilks points) may indicate that individuals with a larger hip circumference perform better in these movements, since being thicker places their hip/trunk muscles at a greater

mechanical advantage by increasing the length of their levers (increased muscle thickness and distance from the muscle center of mass and the spine). Results showing that Torso L/Height significantly predicted, and positively affected deadlift kg, Wilks and total Wilks may indicate that a shorter torso relative to height puts the lifter in a mechanically advantaged position in the deadlift as the hips can be placed closer to the barbell which reduces the length of the moment arm when measured from the center of the hips to the center of the barbell. Finally, the Waist C/Hip C ratio significantly predicted and positively affected the % of the squat on the total, but negatively affected the deadlift kg, deadlift Wilks points. This could mean that thicker individuals are better at the squat but may have a harder time getting into a good position in the deadlift as their thicker torso becomes a technical limitation and enables them to place their hips closer to the barbell.

Likewise, other studies have questioned whether variables such as anthropometric dimensions and body composition help predict maximal strength. Some studies reported that adding these variables does not significantly improve the accuracy of the 1RM prediction equation in various populations (22, 30, 32), while others found that adding anthropometric dimension does improve the accuracy. According to Mayhew et al. (20), short arms do not make a significant difference in bench press performance among college men, while a thicker chest (measured by drop from the bar to the chest) accounted for over 50% of the variance. However, more recently, Hetzler et al. (11) found that arm circumference and length do improve the accuracy of a 1RM predictive equation. A predictive formula taking into account arm circumference and length may help predict 1RM based on performance in the NFL-225 test, but it is not as accurate as real 1RM testing where the coefficient of determination (R^2) was of 0.87 with the NFL-225 test alone, and increased to 0.90 when adding arm circumference and length (11). Furthermore, another study by Mayhew et al. (21) found that body composition and anthropometric measures were significantly correlated to maximum strength in highly trained football players, and that the more joints involved in a movement, the less relationship there was with maximal strength (the lesser the prediction of strength based on physical dimensions was accurate).

Ultimately, strength and conditioning coaches should take into account the previously mentioned physical characteristics in order to identify and differentiate their trainees that are better built for the squat and bench press to the ones that are better built for the deadlift in order to design strength and conditioning programs according to their trainees' physical advantages and disadvantages.

Although results were statistically significant, the methodology utilised in this study presents certain limitations. Limits to this study include that the bio-impedance analyses were conducted with two different devices, the anatomical landmark's selection of the anthropometric measurements had not been previously validated and that the maximal strength test results for the football group setting was not tested during a sanctioned, drug-tested powerlifting competition. Thus, the current study appears to confirm that anthropometric dimensions relate to maximum performance. Nonetheless, this topic should be further investigated to establish a more precise prediction model.

Conclusion: Finally, the results of the current study investigated the differences between anthropometric measurements in two different groups of strength athletes using the big three used in strength and conditioning. This furthers our knowledge on various associations between anthropometric dimensions and performance, adding to the body of literature regarding physical characteristics related to strength. The various associations reported herein may contribute to differentiating the weaker and the stronger powerlifters, as has been reported in previous studies that were directed on classic (9), equipped (3, 17, 19, 40) and unsanctioned powerlifting (23).

Moreover, this descriptive quantitative research quantified the relationships between physical characteristics and maximal strength in the big three on powerlifters and football players. The hypothesis of this research project was confirmed. There are multiple physical characteristics of powerlifters and football players which related to maximal strength measures.

The results of this study should be utilized by strength and conditioning coaches to deepen their comprehension of their athlete's physical characteristics and build strength accordingly, as previous surveys have not shown that this was common practice in the strength and conditioning programs of four of the major professional North-American sports associations. Further research should classify back squat, bench press, and deadlift stances and evaluate how physical characteristics affect performance in each one of those particular movements.

ACKNOWLEDGEMENTS

The first author of this study would like to thank the Colorado Mesa University Department of Kinesiology, the Monfort Family Human Performance Lab, the Colorado Mesa University Strength & Conditioning staff, the Colorado Mesa University football team and the Quebec Powerlifting Federation. This research was partly funded by the Quebec Ministry of Education's International Mobility Scholarship program and the Mitacs Globalink Research Award which both allow students to conduct research projects in universities from other countries. This article is part of the first author's PhD thesis.

REFERENCES

1. American College of Sports Medecine. Acsm's guidelines for exercise testing and prescription 9th ed. Philadelphia: Wolters Kluwer; 2014.

2. Baker D. Improving vertical jump performance through general, special, and specific strength training. J Strength Cond Res 10(2): 131-136, 1996.

3. Brechue WF, Abe T. The role of ffm accumulation and skeletal muscle architecture in powerlifting performance. Eur J Appl Physiol 86(4): 327-336, 2002.

4. Canadian Center for Ethics in Sports. Anti-Doping. Available at: https://cces.ca/anti-doping; 2018.

5. Canadian Powerlifting Union. Canadian powerlifting union. Available at: http://www.powerlifting.ca/cpu/; 2019.

6. Colorado Mesa University. The official website of Colorado Mesa University athletics. Available at: https://cmumavericks.com/; 2019.

7. Cronin JB, McNair PJ, Marshall RN. The role of maximal strength and load on initial power production. Med Sci Sports Exerc 32(10): 1763-1769, 2000.

8. Ferland P-M, Comtois AS. Classic powerlifting performance: a systematic review. J Strength Cond Res 33(Suppl. 1): S194-S201, 2019.

9. Ferland P-M, St-Jean Miron F, Laurier A, Comtois AS. The relationship between body composition measured by dual-energy x-ray absorptiometry (dexa) and maximal strength in classic powerlifting. J Sport Med Phys Fitness Epub doi: 10.23736/S0022-4707.19.09996-1, 2019.

10. Heggelund J, Fimland MS, Helgerud J, Hoff J. Maximal strength training improves work economy, rate of force development and maximal strength more than conventional strength training. Eur J Appl Physiol 113(6): 1565-1573, 2013.

11. Hetzler RK, Schroeder BL, Wages JJ, Stickley CD, Kimura IF. Anthropometry increases 1 repetition maximum predictive ability of NFL-225 test for division ia college football players. J Strength Cond Res 24(6): 1429-1439, 2010.

12. Hoff J, Gran A, Helgerud J. Maximal strength training improves aerobic endurance performance. Scand J Med Sci Sports 12(5): 288-295, 2002.

13. Hoff J, Helgerud J, Wisløff U. Maximal strength training improves work economy in trained female cross-country skiers. Med Sci Sports Exerc 31(6): 870-877, 1999.

14. International Powerlifting Federation. International powerlifting federation. Available at: https://www.powerlifting.sport/; 2019.

15. International Powerlifting Federation. IPF formula. https://www.powerlifting.sport/rulescodesinfo/ipf-formula.html; 2019.

16. International Powerlifting Federation. Technical rules. Available at : https://www.powerlifting.sport/rulescodesinfo/technical-rules.html; 2019

17. Keogh JW, Hume PA, Pearson SN, Mellow PJ. Can absolute and proportional anthropometric characteristics distinguish stronger and weaker powerlifters? J Strength Cond Res 23(8): 2256-2265, 2009.

18. Loveless DJ, Weber CL, Hhaseler LJ, Schneider DA. Maximal leg-strength training improves cycling economy in previously untrained men. Med Sci Sports Exerc 37(7): 1231-1236, 2005.

19. Lovera M, Keogh J. Anthropometric profile of powerlifters: Differences as a function of bodyweight class and competitive success. J Sports Med Phys Fitness 55(5): 478-487, 2015.

20. Mayhew J, Ball T, Ward T, Hart C, Arnold M. Relationships of structural dimensions to bench press strength in college males. J Sports Med Phys Fitness 31(2): 135-141, 1991.

21. Mayhew J, Piper F, Ware J. Anthropometric correlates with strength performance among resistance trained athletes. J Sports Med Phys Fitness 33(2): 159-165, 1993.

22. Mayhew JL, Jacques JA, Ware JS, Chapman PP, Bemben MG, Ward TE, Slovak JP. Anthropometric dimensions do not enhance one repetition maximum prediction from the NFL-225 test in college football players. J Strength Cond Res 18(3): 572-578, 2004.

23. Mayhew JL, McCormick TP, Piper FC, Kurth AL, Arnold MD. Relationships of body dimensions to strength performance in novice adolescent male powerlifters. Pediatr Exerc Sci 5(4): 347-356, 1993.

24. McBride JM, Blow D, Kirby TJ, Haines TL, Dayne AM, Triplett NT. Relationship between maximal squat strength and five, ten, and forty yard sprint times. J Strength Cond Res 23(6): 1633-1636, 2009.

25. Navalta JW, Stone WJ, Lyons S. Ethical issues relating to scientific discovery in exercise science. Int J Exerc Sci 12(1): 1-8, 2019.

26. Netter FH. Atlas of human anatomy. 6th ed. Philadelphia: Elsevier; 2019.

27. Nuzzo JL, McBride JM, Cormie P, McCaulley GO. Relationship between countermovement jump performance and multijoint isometric and dynamic tests of strength. J Strength Cond Res 22(3): 699-707, 2008.

28. Østerås H, Helgerud J, Hoff J. Maximal strength-training effects on force-velocity and force-power relationships explain increases in aerobic performance in humans. Eur J Appl Physiol 88(3): 255-263, 2002.

29. Quebec Powerlifting Federation. The official website of the Quebec powerlifting federation. Available at: http://www.fqd-quebec.com/; 2019.

30. Reynolds JM, Gordon TJ, Robergs RA. Prediction of one repetition maximum strength from multiple repetition maximum testing and anthropometry. J Strength Cond Res 20(3): 584-592, 2006.

31. Rocky Mountain Athletic Conference. Rocky Mountain athletic conference. Available at: https://rmacsports.org/; 2019.

32. Scanlan J, Ballmann K, Mayhew J, Lantz CD. Anthropometric dimensions to predict 1-rm bench press in untrained females. J Sports Med Phys Fitness 39(1): 54-60, 1999.

33. Schumacher RM, Arabas JL, Mayhew JL, Brechue WF. Inter-investigator reliability of anthropometric prediction of 1rm bench press in college football players. Int J Exerc Sci 9(4): 427-436, 2016.

34. Strass D. Effects of maximal strength training on sprint performance of competitive swimmers. Swimming Science V (International Series of Sport Sciences) 18: 149-156, 1988.

35. Suchomel TJ, Nimphius S, Stone MH. The importance of muscular strength in athletic performance. Sports Med 46(10): 1419-1449, 2016.

36. Sunde A, Støren Ø, Bjerkaas M, Larsen MH, Hoff J, Helgerud J. Maximal strength training improves cycling economy in competitive cyclists. J Strength Cond Res 24(8): 2157-2165, 2010.

37. Vanderburgh P, Batterham A. Validation of the wilks powerlifting formula. Med Sci Sports Exerc 31(12): 1869-1875, 1999.

38. World Anti-Doping Agency. World anti-doping agency. Available at: https://www.wada-ama.org/en; 2018.

39. Wisløff U, Castagna C, Helgerud J, Jones R, Hoff J. Strong correlation of maximal squat strength with sprint performance and vertical jump height in elite soccer players. Br J Sports Med 38(3): 285-288, 2004.

40. Ye X, Loenneke JP, Fahs CA, Rossow LM, Thiebaud RS, Kim D, Bemben MG, Abe T. Relationship between lifting performance and skeletal muscle mass in elite powerlifters. J Sports Med Phys Fitness 53(4): 409-414, 2013.