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ORIGINAL ARTICLE

Physical fitness factors to predict male Olympic wrestling performance

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Abstract To determine differences in maximal strength and muscle power output of the arm and leg extensor muscles, peak and mean power during a modified standing crank-arm Wingate test, running speed, muscle extensibility, and anthropometric markers between elite and amateurs wrestlers according to the weight classes system; 92 male wrestlers were assigned into 6 groups according to their body mass (light, middle and heavy weight) and their competitive level (elite and amateur): Light Weight (body mass ranged between 55 and 68 kg) in elite (LW_E, $n = 18$) and amateur (LW_A, $n = 15$) level; Middle Weight (body mass ranged between 68 and 84 kg) in elite (MW_E, $n = 18$) and amateur (MW_A, $n = 19$) level; and Heavy Weight (body mass ranged between 84 and 100 kg) in elite (HW_E, $n = 10$) and amateur (HW_A, $n = 12$) level. Elite wrestlers were older (8–12%), had more training experience (25–37%), fat-free mass (3–5%), maximal strength in absolute and relative terms (8–25%), muscle power (14–30%), mean and peak power during crank-arm Wingate testing in absolute and relative terms (13–22%), jumping height (8–17%) as well as grip (6–19%) and back strength (7–20%) compared to amateur wrestlers. However, no differences were observed between elite and amateur groups in height, body mass index, percentage of body fat, hamstring extensibility and running speed. The present results suggest that the higher absolute and relative values of maximal strength, muscle power, and anaerobic metabolism, explained in part by the differences in lean mass and neural activation patterns, will give elite wrestlers a clear advantage during the most frequently used techniques in Olympic wrestling.

Keywords Greco-roman · Freestyle · Maximum strength · Maximum power · Wingate · Muscle extensibility

Introduction

Wrestling was an important part of the ancient Olympic Games and is still one of the more popular events of the modern Olympic Games. This combat sport is based on a weight class system which aims to balance out the physical characteristics between wrestlers and therefore increase the percentage of performance that depends on technical and psychological skills. Currently, in the Olympics two wrestling styles are included for men: Greco-Roman, a classic style in which only upper-body moves are allowed, and Freestyle, which includes upper and lower body wrestling. Following a great number of regulation changes during the last few decades, the winner of an official wrestling bout is decided by either a fall (i.e., when an opponent's two shoulders are held to the mat) or by a scoring system that quantifies which wrestler is most superior with respect to controlling their opponent during the match duration (Yoon 2002). The changes in regulation have promoted less passive wrestling, prioritizing scoring strategies, and winning on points, instead of decisive actions or falls (Horswill 1992; Horswill et al. 1992; Hübner-Woźniak et al. 2004). These changes also forced several

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modifications in the fitness requirements of successful wrestlers, which as a result caused an evolution in the training methods (Horswill 1992; Sharratt et al. 1986; Yoon 2002).

Wrestling has been described as an intermittent physical event which produces great strength and muscle power demands of both the upper and lower body, with a high anaerobic energy metabolism demand (Horswill 1992; Horswill et al. 1989, 1992; Hübner-Woźniak et al. 2004; Kraemer et al. 2001; Sharratt et al. 1986). Numerous researchers have also reported that, although aerobic performance may be a basic requirement for wrestlers, it cannot be considered as a critical component of success in this sport (Horswill 1992; Horswill et al. 1992; Sharratt et al. 1986; Stine et al. 1979; Yoon 2002).

During the 1980's a few studies examined fitness profiles for wrestlers at different competitive levels in order to identify physiological differences that may contribute to success (Cisar et al. 1987; Horswill et al. 1989; Song and Garvie 1980). However, a limited number of studies have examined differences in physical fitness characteristics related to success in modern wrestling performance following the aforementioned rule changes and evolution in training methods during the last 20 years. These changes include an overall increase in wrestling performance at the elite level, the struggle against illegal pharmacological interventions, an increase in the total number of competitions per year, as well as the evolution in training and assessment equipment. Furthermore, examination of fitness profiles in male wrestlers can be very helpful for optimizing strength, power, and endurance training programs to improve wrestling performance.

Therefore, the first aim of this study is to investigate which anthropometric, physiological, and neuromuscular factors are different between elite and amateur male wrestlers. If differences exist, this will indicate the importance of these performance parameters in the elite wrestlers. Our second aim is to examine the differences that a weight class system can generate in the anthropometric and fitness markers among wrestlers. It was hypothesized that, at all weight classes, elite wrestlers would have more favorable body composition as well as higher physiological and neuromuscular characteristics compared to amateur wrestlers, even when physical training experience and fat-free mass values are included as covariates by general linear model univariate analysis.

Methods

Subjects

Ninety-two male wrestlers, 53 Greco-Roman, and 39 Freestyle competitors, from five different countries were assigned into 6 groups according to their body mass (light, middle and heavy weight) and their competitive level (elite and amateur) as follows: Light Weight (body mass ranged between 55 and 68 kg) in elite (LW_E, $n = 18$) and amateur (LW_A, $n = 15$) level; Middle Weight (body mass ranged between 68 and 84 kg) in elite (MW_E, $n = 18$) and amateur (MW_A, $n = 19$) level; and Heavy Weight (body mass ranged between 84 and 100 kg) in elite (HW_E, $n = 10$) and amateur (HW_A, $n = 12$) level. To be placed in the elite groups (LW_E, MW_E and HW_E) wrestlers: (1) had at least three international participations representing their respective countries in FILA tournaments (i.e., European and/or World Championships) (2) had at least 6 years of regular training experience. Furthermore, 11 of them had won at least one medal during an international tournament. Amateur wrestlers (LW_A, MW_A, and HW_A) had been finalist at their respective national championship in the last season, although they had not taken part in any international competition. The physical characteristics and training background of the subjects are presented in Table 1.

Experimental design and approach to the problem

The results of this training camp were used by the selectors of the five different countries to elect their own national team members for an incoming international tournament.

Previous studies conducted with highly trained wrestlers (Yankanich et al. 1998) found that any type of severe dehydration associated to the weight loss approaches may produce significant physiological and performance declines. Therefore, this study was carried out during an international training camp placed in the final week of a pre-competitive mesocycle. Throughout this training phase, all wrestlers had an average of 9.6 training sessions per week distributed in combat sessions (60%), endurance training (14%), and resistance training (26%). None of these 92 wrestlers were involved in a weight cutting approach or under restricted water or food intakes. All the subjects followed the same dietary plans during the experiments. Not one of these subjects, including the heavy Weight wrestlers, increased or decreased their body weight more than 1% during the week of assessments.

The subjects and coaches were informed in detail about the experimental procedures and the possible risks and benefits of the project. The study, which complied with the Declaration of Helsinki, was approved by the Bioethics Commission of the University of Murcia, and written informed consent was obtained from athletes prior to participation.

Testing was completed for all wrestlers in the same laboratory facilities on three consecutive days: day 1—anthropometrics (7:00–8:30), sprint running (10:00–12:00) and crank-arm Wingate test (16:00–18:30); day 2—counter

Table 1 Subjects' characteristics of elite and amateur wrestlers in the three weight classes

	Light Weight		Middle Weight		Heavy Weight	
	LW_E ($n = 18$)	LW_A ($n = 15$)	MW_E ($n = 18$)	MW_A ($n = 19$)	HW_E ($n = 10$)	HW_A ($n = 12$)
Age (year)	17.5 ± 1.1	16.1 ± 1.0*	18.5 ± 1.5	17.1 ± 1.8*	19.6 ± 1.5[ab]	17.2 ± 1.7*
Body mass (kg)	60.9 ± 4.4	58.2 ± 5.4	73.1 ± 4.8[a]	70.5 ± 4.5	87.0 ± 4.3[ab]	88.1 ± 7.5
BMI (kg m^{-2})	21.8 ± 1.5	21.0 ± 1.5	24.2 ± 1.7[a]	23.5 ± 1.4	28.2 ± 2.2[ab]	27.7 ± 2.4
Height (cm)	167.2 ± 4.6	166.5 ± 5.9	173.9 ± 5.2[a]	173.3 ± 4.1	175.5 ± 5.0[a]	178.2 ± 4.5
Arm span (cm)	169.7 ± 6.2	168.5 ± 6.7	177.7 ± 5.3[a]	177.4 ± 4.8	179.7 ± 6.4[a]	177.9 ± 7.3
Body fat (%)	10.3 ± 2.2	10.3 ± 2.8	11.1 ± 2.5	11.5 ± 2.5	13.7 ± 2.7[a]	17.2 ± 4.4*
FFM (kg)	54.6 ± 3.6	52.2 ± 4.6	65.0 ± 3.5[a]	62.4 ± 3.2*	75.4 ± 3.3[ab]	72.8 ± 4.2*
Training experience (year)	7.6 ± 1.9	5.7 ± 2.4*	7.9 ± 2.6	5.0 ± 1.9*	8.6 ± 1.9	5.5 ± 2.9*

BMI body mass index, *FFM* fat-free mass

* Significant differences compared to Elite wrestlers

[a] Significant differences compared to Light Weight elite wrestlers

[b] Significant differences compared to Middle Weight elite wrestlers

movement jump (CMJ), one repetition maximum (1RM), strength and load-power relationship in squat and bench press (10:00–14:00); day 3—muscle extensibility (16:00–17:30), maximal hand grip and back strength (18:00–19:30). No strenuous exercise was undertaken 24 h before reporting to the laboratory for testing and no other physical activity sessions were performed during these 3 days. The same warm-up procedures and protocol for each type of test were repeated in subsequent occasions.

Physical characteristics

Anthropometric measurements included: standing height, arm span, body mass, and three location skinfold thickness measurement (triceps brachii, subscapular, and abdominal) which were performed in accordance with guidelines from the International Society for the Advancement of Kineanthropometry (ISAK). Height and arm span were measured to the nearest 0.1 cm and body mass to the nearest 0.1 kg using a calibrated scale (Seca 714, Hamburg, Germany); skinfold thickness was assessed using a skinfold caliper (Holtain Ltd., UK, accurate to 0.2 mm). Body density was predicted by the NCAA method (Lohman 1981) that had been previously cross validated on wrestlers (Clark et al. 2002) and body fat percentage was calculated by the Brozek et al. (1963) formula.

Sprint running test

After a standardized 15-min warm-up period (low-intensity running, several acceleration runs, and stretching exercises), the subjects undertook a sprint running test consisting of two maximal sprints of 10 m, with a 3 min rest period between each sprint. Subjects were instructed to begin from a stationary start position, with their preferred foot forward on a line marked on the floor. The running speed of the wrestlers was evaluated using dual-beam electronic timing gates (Polifemo, Microgate, Bolzano, Italy). Speed was measured to the nearest 0.01 s. In a previous pilot study performed with part of these subjects, for 10-m running times the test–retest coefficient of variation (CV) was 1.7% and the intraclass correlation coefficient (ICC) was 0.91. The recorded time for this test was the better of the two trials.

Crank-arm Wingate test

All tests were performed on an adjustable SRM Indoortrainer (Schoberer Rad Meßtechnik, Germany, 2% accuracy) which was specifically modified for standing arm cranking. Before each test, the SRM crankset was calibrated according to the manufacturer's recommended procedure. The accuracy, validity, and reliability of the SRM power meter were previously established by Gardner et al. (2004). The height of the arm ergometer's central axis and crank-arm length were adjusted according to the optimal proportions determined previously (crank length 12–12.5% of arm span and crank-axle height between 50 and 60% of the subject height) (Neville et al. 2010). Each wrestler completed a habituation warm-up to familiarize themselves with the laboratory environment and testing procedures. The crank-arm trials were 30 s in duration and participants were instructed to crank as powerfully as possible on each revolution throughout the trial and not to adopt any pacing strategy. Power and cranking rate were recorded using 1 s data averages. Peak Power (W_{peak}) was defined as the greatest power value recorded by the SRM power meter and minimum power (W_{min}) was defined as the smallest power value recorded. The average power (W_{mean}) of the 30 s was also established. Fatigue index was calculated as:

FI = W_{peak}/W_{min}. Earlobe blood samples were taken and immediately analyzed for the lactate concentration using a portable lactate analyzer (Lactate Pro, Arkray Inc., Kyoto, Japan). This was performed after each 30 s trial until the maximum lactate value ($[La^-]_{peak}$) was determined from post-exercise blood samples taken every 2 min.

Jumping test (CMJ)

Warm-up consisted of 5 min of low-intensity running at a self-selected pace, 5 min of static stretching and upper-body joint mobilization exercises, followed by one set of 5 repetitions of bench press and full squat with a fixed load of 20 kg. Participants were instructed to complete a standard countermovement vertical jump (CMJ) in which they squatted down into a self-selected depth prior to explosively performing the concentric action. Participants were instructed to keep their hands on their hips at all times and to maintain the same position at take-off and landing. Flight times were measured using a vertical jump mat (Ergojump, Rome, Italy). In a previous pilot study performed with part of these subjects, the test–retest intraclass correlation coefficients and the coefficient of variation were 0.94 and 3.3%, respectively. The recorded height for this test was the average of three trials. Absolute mechanical power during CMJ was calculated with the following formula: $CMJ_P = BM\ g\ (2\ g\ h)^{1/2}$ in which "BM" is body mass in kg, "g" the acceleration of gravity in m s^{-2}, and "h" the jumping height in meters.

1RM strength and load-power relationship

All the subjects performed a full squat strength test using a smith machine as well as a bench press strength test using a free weight barbell for the determination of the 1 repetition maximum (1RM) and the full load-power relationship. A dynamic measurement system (T-Force System, Ergotech, Murcia, Spain, 0.25% accuracy) automatically calculated the relevant kinematic and kinetic parameters of every repetition, provided real time information on screen and stored data on a disk for subsequent analysis. The detailed testing procedures, validity, and reliability of this system have recently been reported elsewhere (Sánchez-Medina et al. 2010). Each subject was carefully instructed to perform each concentric phase of both the squat and the bench press in an explosive manner. Strong verbal encouragement and velocity feedback in every repetition was provided in order to motivate the participants to give a maximal effort. For the bench press initial load was set at 20 kg for all subjects, and was progressively increased in 10 kg increments until the attained mean propulsive velocity (MPV) was lower than 0.4 m s^{-1}. Thereafter, load was adjusted with smaller increments (5–2.5 kg). The heaviest load that each subject could properly lift to the full extension of his elbows was considered to be his 1RM. For squat initial load was set at 50% of their own body mass, and was progressively increased to 75, 100, and 125% when it was feasible. When MPV was lower than 0.5 m s^{-1}, the load was adjusted with smaller increments (5–2.5 kg). The heaviest load that each subject could properly lift to the full extension of his knees was considered to be his 1RM. For comparisons, the relative strength ratio (i.e., 1RM value divided by fat-free mass), maximum muscle power attained during the incremental test as well as the percentage of 1RM that maximizes power output in both exercises (i.e., bench press and squat) were calculated. Furthermore, the percentage of body mass that maximizes power output during the incremental test in the squat exercise was calculated.

Muscle extensibility

Passive straight leg rise for dominant (SLR_D) and non-dominant (SLR_{ND}) legs and the sit and reach test were used to determine hamstring muscle extensibility. The detailed testing procedures, validity, and reliability (i.e., ICC = 0.90 and 0.97 of the SLR and Sit and reach measures, respectively) have recently been established elsewhere (López-Miñarro and Rodríguez-García 2010). Briefly, for the SLR test, each subject was placed supine on an examination table, and the axis of a universal goniometer was aligned with the axis of the hip joint. The tester placed the stationary arm in line with the trunk and positioned the moveable arm in line with the femur. The subject's leg was lifted passively by the tester into hip flexion until tightness was felt by both the subject and the tester. The criterion score of hamstring extensibility was the maximum angle (degrees) read from the goniometer at the point of maximum hip flexion (1 degree accuracy). No warm-up or stretching exercises were performed by the wrestlers before the test measurements. Two trials were performed for each leg, and the average of the 2 trials on each leg was used for subsequent analyses. The sit and reach scores were measured with a sit and reach box (Eveque, Sit and Reach bench, Cheshire, England). A centimeter scale was placed on the top surface of the box. A reach distance of 15 cm corresponded to the position of the feet against the box. The final position that the subject reached was the score for each test. The recorded score for this test was the average of two trials. Scores were recorded in centimeters to the nearest 1.0 cm.

Maximal hand grip and back strength tests

Each subject's grip strength was measured for dominant ($Grip_D$) and non-dominant ($Grip_{ND}$) hands with a Baseline

Hydraulic Dynamometer (Country Technology Inc; Gays Mills, Wis.) Participants were placed sitting with 0° of shoulder flexion, 90° of elbow flexion and the forearm in neutral. The average of two trials was recorded. Maximal back strength (BS) was measured using a back muscle dynamometer (Takei, model T.K.K.5402, Tokyo, Japan). The length of the handle chain was adjusted to fit each subject so that the angle of the subjects' knees was at 45°. The average of two trials was recorded. The detailed testing procedures have been reported elsewhere (Kraemer et al. 2001).

Statistical procedures

Standard statistical methods were used for the calculation of the mean and standard deviations (SD). The differences between elite and amateur groups as well as between the three elite groups (LW_E, MW_E, and HW_E) were determined using the one-way analysis of variance (ANOVA). When significant differences were found, Newman–Keuls post hoc comparisons were used. The independent contribution of each performance and anthropometric variables to wrestling performance were assessed by simultaneously including physical training experience and fat-free mass values as covariates by general linear model univariate analysis. A binomial logistic regression analysis was also carried out to assess the effect of various performance and anthropometric variables on the probability of wrestling success. The binary logistic regression analysis estimates the probability (or more correctly the odds) of a wrestler placed in the elite group using their training experience, fat-free mass, maximal strength, and peak power as predictors or independent variables. We chose as our dichotomous dependent variable, whether a wrestler was, or was not, in the elite group. All variables that were identified as significantly ($P < 0.05$) different between elite and amateur wrestlers in the ANOVA analysis were then entered into a series of discriminant function analyses. This identified the variables that best classified group membership. Then, the variables offering the least relationship to wrestling caliber were removed and another discriminant analysis was run. This was repeated in four separate analyses until the variables that explained the most variance in group membership were identified. In logistic regression, the dependent variable is transformed into a logit variable, i.e., the natural log of the odds of the dependent occurring or not. This transformation ensures that the estimated probabilities are between 0 and 1. A logit model is a form of the generalized linear model. Training experience, fat-free mass, and peak power attained during the crank-arm Wingate testing were considered as potential predictor variables for the probability of being in the elite wrestler group. $P < 0.05$ criterion was used for establishing statistical significance for all analyses.

Results

Physical characteristics and training experience

The physical characteristics and training experience of the wrestlers are presented in Table 1. Elite groups were significantly ($P < 0.05$) older, had increased training experience and FFM ($P = 0.07$ between LW_E and LW_A) values compared to the amateur groups. No significant differences were detected between elite and amateur groups for body mass, height, BMI, and body fat ($P < 0.05$ between HW_E and HW_A). When comparing the three elite groups age, body mass, BMI, and FFM were higher in HW_E ($P < 0.05$) than MW_E and LW_E (Table 1).

Crank-arm Wingate, sprint running, and jumping tests

Elite groups demonstrated higher mean and peak power values during the modified crank-arm Wingate test compared to the amateur groups (from 16.0 to 22.0%; $P < 0.05$) (Fig. 1; Table 2). Mean and peak power values in HW_E were higher than MW_E (12.1 and 13.4%, $P < 0.05$) and LW_E (19.4 and 19.3%, $P < 0.05$) (Table 2; Fig. 1). When mean and peak power values were expressed relative to kilogram of fat-free mass, all elite groups (LW_E, MW_E, and HW_E) had higher values compared to the amateur groups (from 13.0 to 19.4%, $P < 0.05$) (Fig. 1; Table 2). No significant differences were detected in mean and peak power relative to fat-free mass between any elite group (LW_E, MW_E, and HW_E) (Table 2; Fig. 1). Elite wrestlers demonstrated significant higher values for $[La\text{-}]_{peak}$ compared to the amateur group (from 14.0 to 20.1%, $P < 0.05$), whereas no significant differences were detected between any elite group. No differences were observed in the fatigue index between elite and amateur groups and also between the three elite groups (Table 2). When wrestling groups (i.e., elite vs. amateur) were compared with respect to crank-arm Wingate mean and peak power, the difference remained significant after adjustment for FFM ($P < 0.05$), but not when adjusted for age or physical training experience ($P > 0.1$).

The HW_A group had a slower 10 m sprint running time than the HW_E group (6.8%, $P < 0.05$), whereas no significant differences were detected between the lightest elite groups and their respective amateur group. No significant differences were detected between the three elite groups (Table 3).

Significantly higher values were detected in CMJ and CMJ_P in the three elite groups compared to the amateur

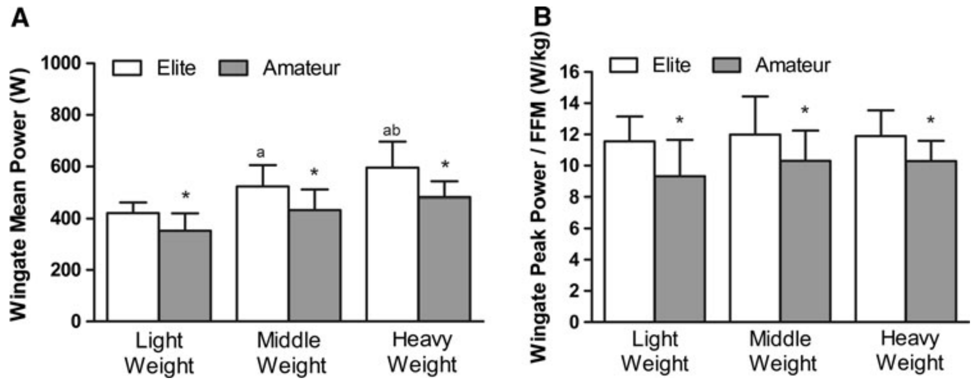

Fig. 1 Mean power (**a**) and peak power normalized to fat-free mass (**b**) during the 30 s crank-arm Wingate test according to weight class (Light Weight, Middle Weight and Heavy Weight) and performance level (Elite vs. Amateur). Data presented as mean ± SD. Significant differences *when compared to elite wrestlers; [a]when compared to Light Weight elite wrestlers; [b]when compared to Middle Weight elite wrestlers ($P < 0.05$)

Table 2 Mean power relative to fat-free mass, peak power, fatigue index, and peak blood lactate obtained in the 30 s Wingate test for elite and amateur wrestlers in the three weight classes

	Light Weight			Middle Weight			Heavy Weight		
	LW_E ($n = 18$)	LW_A ($n = 15$)	Elite–Amateur Dif. %	MW_E ($n = 18$)	MW_A ($n = 19$)	Elite–Amateur Dif. %	HW_E ($n = 10$)	HW_A ($n = 12$)	Elite–Amateur Dif. %
Mean power/FFM (W kg^{-1})	7.74 ± 0.86	6.74 ± 0.80*	13.0	8.07 ± 1.40	7.95 ± 1.08*	13.9	7.89 ± 1.07	6.62 ± 0.67*	16.0
Peak power (W)	630 ± 86	492 ± 146*	22.0	781 ± 154[a]	643 ± 140*	17.6	902 ± 151[ab]	750 ± 113*	16.8
Fatigue index	2.25 ± 0.45	1.98 ± 0.38	12.0	2.22 ± 0.39	2.29 ± 0.57	−3.1	2.37 ± 0.46	2.29 ± 0.50	3.4
$[La^-]_{peak}$	9.5 ± 1.6	7.6 ± 1.7*	20.1	10.7 ± 2.0	9.2 ± 1.9*	14.0	11.2 ± 1.4	9.6 ± 0.8*	14.3

Mean Power/FFM mean power relative to fat-free mass, *$[La^-]_{peak}$* peak blood lactate

* Significant differences compared to Elite wrestlers

[a] Significant differences compared to Light Weight elite wrestlers

[b] Significant differences compared to Middle Weight elite wrestlers

groups (from 7.6 to 16.6%, $P < 0.05$). The CMJ_P in HW_E was significantly higher than MW_E (16.4%, $P < 0.05$) and LW_E (16.4%, $P < 0.05$) (Table 3).

1RM strength and load-power relationship

Absolute and fat-free mass normalized 1RM strength values for squat and bench press exercises were significantly greater in all elite groups compared to the amateur groups (from 8.4 to 24.6%; $P < 0.05$) (Fig. 2). 1RM strength in squat and bench press for the HW_E group were higher than MW_E (14.7 and 15.5%, $P < 0.05$) and LW_E (23.0 and 17.6%, $P < 0.05$) (Fig. 2a, c). No significant differences were detected in fat-free mass normalized 1RM strength values in squat and bench press exercises between the three elite groups (Fig. 2b, d).

In elite groups, maximum muscle power output in squat and bench press were greater compared to the amateur groups (from 14.0 to 29.8%; $P < 0.05$) (Fig. 3). Maximum muscle power output in squat and bench press for the HW_E group were greater than MW_E (17.5 and 18.6%; $P < 0.05$) and LW_E (18.8 and 21.4%; $P < 0.05$) (Fig. 3). Significantly higher values were detected in the percentage of body mass that maximizes muscle power output in the squat between LW_E (90.3 ± 15.2%) and LW_A (78.3 ± 12.9%) and between MW_E (90.3 ± 12.2%) and MW_A (80.9 ± 14.1%) ($P < 0.05$). However, no significant differences ($P = 0.08$) were detected between heavy Weight wrestlers (88.9 ± 18.0%) and the amateur group (78.1 ± 7.4%). When wrestling groups (i.e., elite vs. amateur) were compared with respect to maximal strength and muscle power output, the difference remained significant after adjustment for FFM ($P < 0.05$), but not when adjusted for age or physical training experience ($P > 0.1$). Additionally, no significant differences were detected in the percentage of body mass that maximizes muscle power output

Table 3 Sprint running time, jump height and power, muscle extensibility, hand grip strength, and maximal back strength for elite and amateur wrestlers in the three weight classes

	Light Weight			Middle Weight			Heavy Weight		
	LW_E ($n = 18$)	LW_A ($n = 15$)	Elite–Amateur Dif. %	MW_E ($n = 18$)	MW_A ($n = 19$)	Elite–Amateur Dif. %	HW_E ($n = 10$)	HW_A ($n = 12$)	Elite–Amateur Dif. %
Time in 10 m (s)	1.80 ± 0.06	1.84 ± 0.10	−2.2	1.76 ± 0.06	1.81 ± 0.10	−2.8	1.76 ± 0.10	1.88 ± 0.11*	−6.8
CMJ (cm)	35.4 ± 6.7	31.0 ± 3.3*	12.4	35.0 ± 3.5	31.9 ± 3.8*	8.9	35.5 ± 4.4	29.6 ± 3.8*	16.6
CMJ_P (W)	1,568 ± 178	1,407 ± 158*	10.3	1,876 ± 141[a]	1,729 ± 168*	7.8	2,244 ± 177[ab]	2,074 ± 188*	7.6
Sit and Reach (cm)	21.6 ± 11.6	16.9 ± 7.5	21.9	20.7 ± 7.2	24.4 ± 7.1	−17.9	22.4 ± 9.1	18.0 ± 9.5	20.0
SLR_D (degrees)	91.4 ± 14.8	89.5 ± 9.1	2.2	88.3 ± 12.1	92.5 ± 9.9	−4.7	95.2 ± 9.8	87.4 ± 15.1	8.3
SLR_{ND} (degrees)	89.7 ± 16.6	84.7 ± 12.5	5.6	85.1 ± 12.2	89.7 ± 9.9	−5.6	91.4 ± 11.3	84.1 ± 13.6	8.0
$Grip_D$ (kg)	45.0 ± 6.5	39.7 ± 8.0*	11.8	53.1 ± 7.8[a]	46.5 ± 8.0*	12.4	55.6 ± 8.9[a]	52.1 ± 9.5	6.3
$Grip_{ND}$ (kg)	44.9 ± 7.3	36.4 ± 7.0*	18.9	49.1 ± 8.8	43.4 ± 7.9*	11.6	55.9 ± 6.7[a]	49.3 ± 11.1	11.8
BS (kg)	123.6 ± 14.6	98.3 ± 17.6*	20.5	136.3 ± 14.6[a]	121.8 ± 15.3*	10.6	148.1 ± 11.2[a]	134.4 ± 10.4*	9.3
BS/FFM	2.28 ± 0.29	1.88 ± 0.26*	17.5	2.10 ± 0.17[a]	1.96 ± 0.26*	6.9	1.81 ± 0.12[ab]	1.73 ± 0.17	4.2

CMJ counter movement jump height, *CMJ_P* counter movement jump power, *SLR_D and SLR_{ND}* straight leg rise for dominant and non-dominant leg, *$Grip_D$ and $Grip_{ND}$* grip strength for dominant and non-dominant hand, *BS* back strength, *BS/FFM* back strength relative to kilogram of fat-free mass

* Significant differences compared to Elite wrestlers

[a] Significant differences compared to Light Weight elite wrestlers

[b] Significant differences compared to Middle Weight elite wrestlers

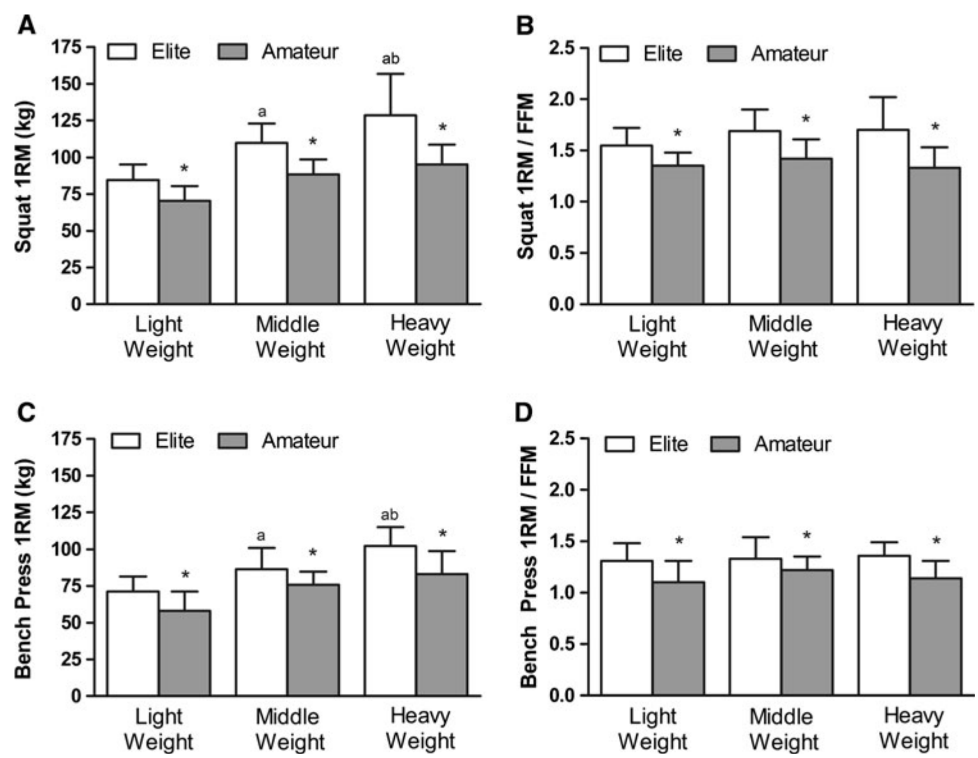

Fig. 2 One repetition maximum (**a**, **c**) and one repetition maximum normalized to fat-free mass (**b**, **d**) in the squat and bench press exercises according to weight class (Light Weight, Middle Weight and Heavy Weight) and performance level (Elite vs. Amateur). Data presented as mean ± SD. Significant differences *when compared to elite wrestlers; [a]when compared to Light Weight elite wrestlers; [b]when compared to Middle Weight elite wrestlers. ($P < 0.05$)

in squat between the three elite groups. No significant differences were detected in the percentage of 1RM that maximizes muscle power output in the squat and bench press between elite and amateur groups or between the three elite groups: LW_E (63.7 ± 6.5%; 36.9 ± 10.1%, respectively); MW_E (61.8 ± 6.7%; 35.4 ± 8.2%, respectively);

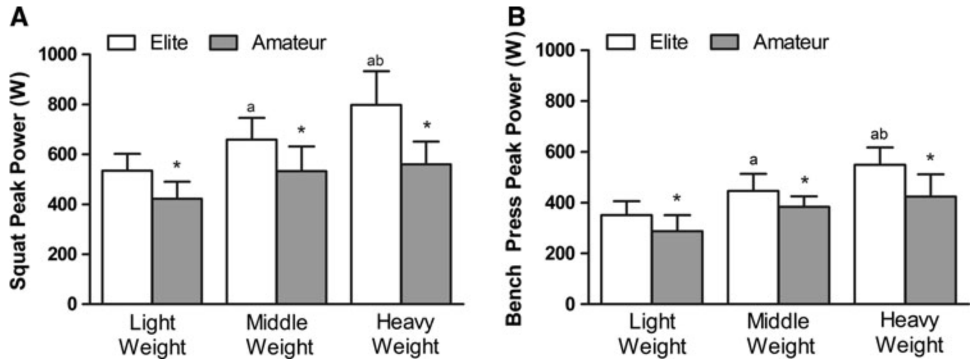

Fig. 3 Peak muscle power attained during the incremental test in squat (**a**) and bench press (**b**) exercises according to weight class (Light Weight, Middle Weight and Heavy Weight) and performance level (Elite vs. Amateur). Data presented as mean ± SD. Significant differences *when compared to elite wrestlers; [a]when compared to Light Weight elite wrestlers; [b]when compared to Middle Weight elite wrestlers ($P < 0.05$)

HW_E (62.1 ± 8.1%; 34.7 ± 7.8%, respectively); LW_A (62.9 ± 7.9%; 37.3 ± 8.1%, respectively); MW_A (64.5 ± 8.2%; 34.1 ± 11.7%, respectively); HW_E (61.8 ± 6.5%; 35.0 ± 11.1%, respectively).

Maximal hand grip and back strength tests

Grip strength for the dominant ($Grip_D$) and non-dominant ($Grip_{ND}$) hands demonstrated significantly higher values for the elite groups compared to the amateur groups in both light and middle weight classes (from 11.6 to 18.9%, $P < 0.05$), whereas no significant differences were detected in the heavy Weight class. HW_E demonstrated higher values in $Grip_D$ and $Grip_{ND}$ compared to LW_E (19.1 and 19.7%, $P < 0.05$) (Table 3). Maximal back strength (BS) in all elite groups was significantly greater (from 9.3 to 20.5%, $P < 0.05$) compared to the amateur groups. When back strength was normalized to kilograms of fat-free mass (BS/FFM), significantly greater values were detected for LW_E and MW_E compared to the amateur groups (17.5 and 6.9%, $P < 0.05$). MW_E and HW_E groups demonstrated higher values in BS compared to the LW_E group (9.3 and 16.5%, $P < 0.05$). LW_E had higher values in BS/FFM compared to MW_E (7.6%, $P < 0.05$) and HW_E (14.0%, $P < 0.05$) (Table 3).

Muscle extensibility

The straight leg rise for dominant (SLR_D) and non-dominant (SLR_{ND}) and the sit and reach test results are presented in Table 3. No differences were observed in any of three tests between the elite and amateur groups or the three elite groups.

Binary logistic regression

The binary logistic regression analyses identified that 7 of the 30 studied variables (i.e., training experience, FFM, 1RM strength and muscle power in bench press and full squat exercises, as well as Wingate peak power) predict the 89.1% of the probability of being in the elite wrestler group. Only training experience (odds ratio, exp (b) = 0.397, $P < 0.001$), FFM values (odds ratio, exp (b) = 1.53, $P < 0.001$), and crank-arm Wingate peak power (odds ratio, exp (b) = 0.987, $P < 0.001$) made significant contributions to the prediction of wrestling success.

Discussion

To our knowledge, this is the first reported case that simultaneously analyses and compares current anthropometric, physiological, neuromuscular, and speed and muscle extensibility characteristics for male wrestlers of different weight classes and performance levels. The primary findings of this investigation indicates that elite level wrestlers (LW_E, MW_E, HW_E) are characterized as older (8–12%), more training experience (25–37%), higher FFM (3–5%), 1RM strength (12–26%), maximum muscle power (14–30%), crank-arm Wingate mean and peak power (12–22%), Wingate peak blood lactate (14–20%), jumping height (8–17%) as well as maximal grip (6–19%) and back strength (7–20%) compared to the amateur groups (LW_A, MW_A, HW_A). However, height, BMI, body fat percentage, Wingate fatigue index, hamstring extensibility, and running speed were similar between elite and amateur groups. The predictive ability of maximal strength, muscle power, and crank-arm Wingate power to distinguish wrestling success remained significant after adjusting for fat-free mass, suggesting that lean body mass may contribute to the wrestling success, independent of age and years of training experience. When the results for the three elite groups (LW_E, MW_E, and HW_E) were compared, some anthropometric, neuromuscular, and physiological performance variables such as age, height, BMI, FFM, 1RM strength, and muscle power output, Wingate mean a peak power, as well as grip and back strength seem to be related to weight class. However, no differences were detected in training experience, body fat percentage, 1RM strength and muscle power output normalized to kilograms of fat-free mass, and crank-arm Wingate test. Although this study did not take into account other physiological factors related to success in the sport (i.e., aerobic power, reaction time, speed of movement, or the toleration of weight loss capabilities) based on the logistic regression analyses, years of training experience, fat-free mass, and crank-arm Wingate power were the most important factors of successful wrestling performance. These results may suggest that the higher absolute and normalized maximal strength, muscle power, and anaerobic metabolism, although explained in part by the differences in fat-free mass, will give elite wrestlers a clear advantage during Olympic wrestling compared to amateurs.

One of the major findings in the present study was that absolute and normalized to kilograms of fat-free mass maximal strength and power of the upper and lower extremity muscles were 7.7–29.9% higher in elite compared to the amateur wrestlers. In the wrestling group analyzed, the predictive ability of maximal strength, muscle power and crank-arm Wingate power to distinguish wrestling success remained significant after adjusting for fat-free mass, suggesting that the lean mass may contribute to the wrestling success, independent of training experience. Wrestling neuromuscular performance has been previously examined during isokinetic (Cisar et al. 1987; Kraemer et al. 2001; Sharratt et al. 1986; Song and Garvie 1980; Stine et al. 1979), isometric strength testing (Kraemer et al. 2001; Sharratt et al. 1986; Song and Garvie 1980; Utter et al. 2002) and even with highly specific exercises like the isometric "bear hug" designed to simulate many upper-body holds used by wrestlers (Kraemer et al. 2001). Unfortunately, a small number of researchers have examined dynamic muscle strength and muscle power profiles in exercises closely related to specific skills in wrestling (Mirzaei et al. 2009). In agreement with previous research, our results reveal greater strength and power output in elite versus novice wrestlers (Sharratt et al. 1986; Song and Garvie 1980; Stine et al. 1979), whereas no significant differences have been reported in isokinetic strength (Cisar et al. 1987). These neuromuscular performance differences will give elite wrestlers a clear advantage during the most frequently used takedown techniques (e.g., fireman's carry, olympic lift, duck under and double leg) and during the parterre wrestling moves (turk ride, gut wrench and cross ankle). This is mainly attributed to the fact that elite wrestlers have higher FFM levels and therefore total muscle mass that can generate force compared with amateur wrestlers. In addition, it was interesting to observe that maximal strength and power output in the elite wresting group was superior, not only in absolute, but also when it was normalized to kilograms of fat-free mass. This could be related to the fact that neural activation patterns and/or twitch tension per muscle mass under maximal and submaximal concentric actions were also diminished in amateur compared to elite wrestlers. These findings are in contrast to those reported in previous studies conducted with other sports (i.e., rowing and handball) where the differences detected in submaximal muscle power output between elite and sub-elite athletes diminish when these parameter were normalized to body mass (Gorostiaga et al. 2005; Granados et al. 2007; Izquierdo-Gabarren et al. 2010). One may speculate that these neuromuscular and muscle quality differences between novice and high-level counterparts may be explained in part by different technical skills and/or percentage of maximal strength and/or muscle power output involved during competition. It is also likely that the differences observed in maximal strength and muscle power output relative to FFM may also explained in part by possible differences in strength and conditioning programs utilized by elite vs. amateur wrestlers.

As expected the elite wrestlers in the higher weight classes demonstrated greater maximal strength and muscle power values compared to the wrestlers in the lighter weight classes. However, a unique finding of the present study was the absence of significant differences between elite wrestlers among the three weight classes for relative maximum muscle strength, as well as, the percentage of body mass that maximizes power output in the squat. It may be hypothesized that these results are due to neural activation patterns and/or twitch tension per muscle mass under maximal and submaximal concentric actions (Izquierdo et al. 2002) which are rather similar between the elite wrestlers, independent of the weight class. Also, the absence of differences between elite and amateur wrestlers and the three elite groups for the percentage of 1RM that maximizes muscle power output in the bench press and squat may suggest that independent of the subject's maximal strength, the load that optimized muscle power output is very close to 62–65% 1RM for squat and 34–37% 1RM for bench press. These results are similar to those described previously by Izquierdo et al. (2002, 2004) and Sánchez-Medina et al. (2010) where no significant differences were detected in the percentage of 1RM that maximizes muscle power output between groups with different relative strength. Moreover, the aforementioned differences in the percentage of 1RM that maximizes muscle power output between the two studied exercises (bench press and squat) indicate that each resistance exercise has its own load-power profile and the maximal power loads are attained at different %1RM in each exercise. These data are similar to those described earlier by Izquierdo et al. (2002) with highly trained weightlifters, handball players, road cyclists and middle distance runners, who showed that the percentage of 1RM that elicits maximal power was different between the upper (i.e., bench press) and lower (i.e., half squat) extremity actions. This type of information on different muscle groups and various resistance training exercises may also be useful to create optimal strength and/or power training programs for wrestlers with different strength and power levels.

Previous studies have reported that the isometric handgrip strength is one of the most critical predictors of wrestling success (Kraemer et al. 2001; Nilsson et al. 2002). In agreement with these previous findings, the three elite groups of this study demonstrated significantly higher isometric grip strength (6.3–18.9%) compared to the amateur group. Similarly, the significantly higher isometric back strength values detected in the three elite groups for absolute and relative values compared to the amateur group may suggest that this type of muscle test is a critical factor to success in this sport. Nevertheless, when back strength was expressed relative to fat-free mass, the lighter wrestlers had significantly higher values compared to the heavier wrestlers. These data indicate that the lighter weight classes have even greater ability to dominate and raise the opponent from the mat by using lower back muscles compared to the heavier wrestlers. These findings confirm the results from a pilot study conducted in our laboratory during a simulated international tournament with the same subjects (unpublished data) in which the elite lightweight wrestlers performed a greater number of rising actions against their opponent compared to heavier wrestlers.

The physical training experience has demonstrated to be one of the most critical factors for achieving success in wrestling. Indeed, the three elite groups had more years of training compared to the amateur groups, and most important, no significant differences were detected between the three elite groups. Additionally, none of the elite wrestlers which participated in this study (international tournament participations) had less than 6 years of regular and specific wrestling training background. These findings are similar to those described previously by some previous researchers that compared international and club level wrestlers (Karnincic et al. 2009) or Olympic competitors and national level wrestlers (Song and Garvie 1980). This may suggest that in addition to physical fitness performance, technical and competitive experience is of great importance in elite wresting performance.

It was also interesting to observe that heavy and middle Weight wrestlers (HW_E and MW_E) had significantly higher FFM compared to the amateur group. As it has been discussed previously, the differences in lean mass may, in part, explain the higher muscle strength and power values attained by the three elite groups compared to the amateur groups. Therefore, elite wrestles may have a clear advantage in creating frequent and forceful muscle contractions that are required during most of the combat techniques. However, no significant differences in % body fat were detected between the elite and amateur groups (except for HW). Thus, the present results may also highlight the importance of maximizing the lean mass and therefore reduce the % body fat levels within each weight class. In contrast with the present results, Horswill et al. (1989) reported that successful wrestlers had significantly lower body fat values compared to unsuccessful wrestlers. The discrepancy of these results may be explained by the large performance differences between the subjects of both studies. The amateur wrestlers in our study had approximately the same training experience (5.0–5.7 years) compared to the elite wrestlers in the study by Horswill et al. (1989). Therefore, it may be suggested that once the wrestlers reach national competitive level, body fat values appear similar to elite wrestlers. Several researchers have shown that the wrestlers' % body fat during competitive phases and following weight cutting can be reduced to 4–9% (Horswill 1992; Kraemer et al. 2001;Sharratt et al. 1986; Yoon 2002). This mainly depends on the wrestlers' weight class and the methodology used for the assessment (Mirzaei et al. 2009; Oppliger et al. 2006; Song and Garvie 1980; Utter and Hager 2008; Utter and Lambeth 2010). These results demonstrate the importance of lean body mass enhancement and reaching optimal body fat depots, independent of the weight class.

Sprint and extensibility tests have been traditionally used in wrestling performance assessment (Mirzaei et al. 2009; Sharratt et al. 1986; Song and Garvie 1980; Stine et al. 1979). No differences in sprint running and hamstring muscle extensibility were observed between elite and amateur wrestlers or between the three elite groups (LW_E, MW_E, and HW_E). These data suggest that these two fitness components are not fully related to wrestling performance. Similar to the current findings, some researchers found that there were no differences for muscle extensibility between successful and less successful wrestlers (Song and Garvie 1980; Stine et al. 1979) and also between different weight classes (Mirzaei et al. 2009; Song and Garvie 1980). In order to clarify this issue, it would be helpful to assess muscle extensibility in other muscle groups related to wrestling performance such psoas, latisimus dorsi and pectoralis or neck and core muscles. Similarly, it may also be advantageous to assess other speed components for wrestlers, such as reaction time, which seems to be related to wrestling performance (Horswill 1992; Kraemer et al. 2001).

Similar to a previous study (Horswill et al. 1989), the present results demonstrate that absolute and relative anaerobic power (i.e., Wingate peak power) and anaerobic capacity (i.e., Wingate mean power attained during the 30 s) are critical success factors for wrestling performance. Similar to the aforementioned strength and muscle power output differences, the higher anaerobic power and capacity values observed in elite wrestlers give them a clear advantage during the most frequent wrestling actions. As previously described, these advantages may be attributed to the higher lean body mass available to generate force, as well as differences in the neural activation patterns between amateur and elite wrestlers. The relative peak power (11.8–12.3 W kg^{-1}) and mean power (7.9–8.2 W kg^{-1}) normalized to fat-free mass detected in the three elite groups (LW_E, MW_E, and HW_E) were very similar to those reported in the only previous research to our knowledge used similar protocols and data analysis with wrestlers (peak power 11.2 W kg^{-1}; mean power 7.9 W kg^{-1}) (Hübner-Woźniak et al. 2004). This may be due to the similar competitive level of wrestlers in this research (i.e., members of the Polish national team) compared to the current study.

No significant differences were observed in crank-arm Wingate fatigue index values between elite and amateur wrestlers or between the three elite groups. These findings are similar to those described previously by Horswill et al. (1989) who found no differences in the fatigue index between elite and non-elite wrestlers during an arm and leg Wingate test. Nevertheless, the large standard deviations detected in the fatigue index for the six groups indicated the great individual differences that exist in the power declines during short and powerful efforts similar to wrestling bouts. As a practical point of view, the knowledge of the individual power declines that occur during a match can help wrestlers and coaches to individualize the technique and tactics required to win (Horswill 1992; Sharratt et al. 1986). A wrestler with a low fatigue index may take a defensive stand at the start of the match, tire out his opponent early on, and make his moves to score points later in the match. In contrast, if an athlete knows that he can produce relatively high power output early in a match but may fatigue very quickly, he may choose to attack early. Collectively, the logistic regression analyses revealed that years of training experience, fat-free mass and crank-arm Wingate power were the most important factors for wrestlers to achieve the elite level.

The peak blood lactate values attained following the crank-arm Wingate test is another variable that indicates the relationship between anaerobic metabolism and success in wrestling. Significantly higher peak blood lactate values were detected between elite and amateur wrestlers, whereas no differences were observed when the three elite groups were compared. These higher blood lactate levels may be related to elite athletes already possessing a high level of intracellular carnosine, succinate dehydrogenase, and lactate dehydrogenase activity, as well as greater total buffering capacity (Costill et al. 1976; Parkhouse et al. 2001). Some researchers have reported slightly higher blood lactate values following official bouts (12–20 mmol l^{-1}) compared to those described in the current study for elite wrestlers following the crank-arm Wingate test (9.5–11.2 mmol l^{-1}) (Karnincic et al. 2009; Kraemer et al. 2001; Nilsson et al. 2002). These differences in blood lactate levels between studies may be due to the lower muscle mass involved in the crank-arm ergometry test compared to an official wrestling bout. These data may suggest that the 30 s crank-arm Wingate test may not adequately simulate the metabolism involved in wrestling, but it still may be a reasonable index of wrestling performance.

In conclusion, elite wrestlers had similar values in body height, BMI, percent of body fat, and percentage of 1RM that maximizes power output, sprint running speed as well as muscle extensibility compared to the amateur wrestlers. On the other hand, elite wrestlers were older, had more, training background, fat-free mass, absolute and relative maximum muscle strength and power, vertical jump height and power, and crank-arm Wingate peak and mean power compared to amateur wrestlers. Although this study did not take into account other important physiological factors related to success in the sport, the higher absolute and relative levels of maximum strength, muscle power, and anaerobic power and capacity will give elite wrestlers a clear advantage in sustaining frequent and forceful muscle contractions that are required during wrestling combat techniques. Heavier wrestlers were older, taller, had a higher BMI, fat-free mass, vertical jump power, absolute maximum muscle strength and power and absolute peak, and mean crank-arm Wingate power compared to lighter weight classes. However, heavier wrestlers had similar values in training background, vertical jump height, normalized maximum strength and power to body mass, sprint running, and muscle extensibility compared to lighter wrestlers. The knowledge of the physical profiles of successful wrestlers at different weight classes can be of great interest for coaches and sport scientist to optimize talent selection for wrestling.

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Conflict of interest The authors declare that they have no conflict of interest relevant to the content of this manuscript.

References

Brozek JF, Grande JT, Anderson JT, Keys A (1963) Densitometric analysis of body composition: revision of some quantitative assumptions. Ann N Y Acad Sci 110:113–140

Cisar CJ, Johnson GO, Fry AC, Housh TJ, Hughes RA, Ryan AJ, Thorland WG (1987) Preseason body composition, build and strength as predictors of high school wrestling success. J Appl Sports Sci Res 1:66–70

Clark RR, Oppliger RA, Sullivan JC (2002) Cross-validation of the NCAA method to predict body fat for minimum weight in collegiate wrestlers. Clin J Sport Med 12:285–290

Costill DL, Fink WJ, Pollock ML (1976) Muscle fiber composition and enzyme activities of elite distance runners. Med Sci Sports 8:96–100

Gardner AS, Stephens S, Martin DT, Lawton E, Lee H, Jenkins D (2004) Accuracy of SRM and power tap power monitoring systems for bicycling. Med Sci Sports Exerc 36:1252–1258

Gorostiaga EM, Granados C, Ibáñez J, Izquierdo M (2005) Differences in physical fitness and throwing velocity among elite and amateur male handball players. Int J Sports Med 26:225–232

Granados C, Izquierdo M, Ibañez J, Bonnabau H, Gorostiaga EM (2007) Differences in physical fitness and throwing velocity among elite and amateur female handball players. Int J Sports Med 28:860–867

Horswill CA (1992) Applied physiology of amateur wrestling. Sports Med 14:114–143

Horswill CA, Scott JR, Galea P (1989) Comparison of maximum aerobic power, maximum anaerobic power, and skinfold thickness of elite and nonelite junior wrestlers. Int J Sports Med 10:165–168

Horswill CA, Miller JE, Scott JR, Smith CM, Welk G, Van Handel P (1992) Anaerobic and aerobic power in arms and legs of elite senior wrestlers. Int J Sports Med 13:558–561

Hübner-Woźniak E, Kosmol A, Lutoslawska G, Bem EZ (2004) Anaerobic performance of arms and legs in male and female free style wrestlers. J Sci Med Sport 7:473–480

Izquierdo M, Häkkinen K, Gonzalez-Badillo JJ, Ibáñez J, Gorostiaga EM (2002) Effects of long-term training specificity on maximal strength and power of the upper and lower extremities in athletes from different sports. Eur J Appl Physiol 87:264–271

Izquierdo M, Ibáñez J, Häkkinen K, Kraemer WJ, Ruesta M, Gorostiaga EM (2004) Maximal strength and power, muscle mass, endurance and serum hormones in weightlifters and road cyclists. J Sports Sci 22:465–478

Izquierdo-Gabarren M, Expósito RG, de Villarreal ES, Izquierdo M (2010) Physiological factors to predict on traditional rowing performance. Eur J Appl Physiol 108:83–92

Karnincic H, Tocilj Z, Uljevic O, Erceg M (2009) Lactate profile during greco-roman wrestling match. J Sports Sci Med 8(CSSI 3):17–19

Kraemer WJ, Fry AC, Rubin MR, Triplett-McBride T, Gordon SE, Koziris LP, Lynch JM, Volek JS, Meuffels DE, Newton RU, Fleck SJ (2001) Physiological and performance responses to tournament wrestling. Med Sci Sports Exerc 33:1367–1378

Lohman TG (1981) Skinfolds and body density and their relation to body fatness: a review. Hum Biol 53:181–225

López-Miñarro PA, Rodríguez-García PL (2010) Hamstring muscle extensibility influences the criterion-related validity of sit-and-reach and toe-touch tests. J Strength Cond Res 24:1013–1018

Mirzaei B, Curby DG, Rahmani-Nia F, Moghadasi M (2009) Physiological profile of elite Iranian junior freestyle wrestlers. J Strength Cond Res 23:2339–2344

Neville V, Pain MT, Kantor J, Folland JP (2010) Influence of crank length and crank-axle height on standing arm-crank (grinding) power. Med Sci Sports Exerc 42:381–387

Nilsson J, Csergö S, Gullstrand L, Tveit P, Refsnes PE (2002) Work-time profile, blood lactate concentration and rating of perceived exertion in the 1998 Greco-Roman Wrestling World Championship. J Sports Sci 20:939–945

Oppliger RA, Utter AC, Scott JR, Dick RW, Klossner D (2006) NCAA rule change improves weight loss among national championship wrestlers. Med Sci Sports Exerc 38:963–970

Parkhouse WD, McKenzie P, Hochachka PW, Ovalla WK (2001) The relationship between carnosine levels, buffering capacity, fiber type and anaerobic capacity in elite athletes. In: Knuttgen H, Vogel J, Poortmans J (eds) Biochemistry of exercise. The international series on sport sciences. Human Kinetics, Champaign, pp 590–594

Sánchez-Medina L, Perez CE, González-Badillo JJ (2010) Importance of the propulsive phase in strength assessment. Int J Sports Med 31:123–129

Sharratt MT, Taylor AW, Song TM (1986) A physiological profile of elite Canadian freestyle wrestlers. Can J Appl Sport Sci 11:100–105

Song TM, Garvie GT (1980) Anthropometric, flexibility, strength, and physiological measures of Canadian wrestlers and comparison of Canadian and Japanese Olympic wrestlers. Can J Appl Sport Sci 5:1–8

Stine G, Ratliff R, Shierman G, Grana WA (1979) Physical profile of the wrestlers at the 1977 NCAA Championships. Physician Sportsmed 7:98–105

Utter AC, Hager ME (2008) Evaluation of ultrasound in assessing body composition of high school wrestlers. Med Sci Sports Exerc 40:943–949

Utter AC, Lambeth PG (2010) Evaluation of multifrequency bioelectrical impedance analysis in assessing body composition of wrestlers. Med Sci Sports Exerc 42:361–367

Utter AC, O'Bryant HS, Haff GG, Trone GA (2002) Physiological profile of an elite freestyle wrestler preparing for competition: a case study. J Strength Cond Res 16:308–315

Yankanich J, Kenney WL, Fleck SJ, Kraemer WJ (1998) Precompetition weight loss and changes in vascular fluid volume in NCAA Division 1 College Wrestlers. J Strength Cond Res 12:138–145

Yoon J (2002) Physiological profiles of elite senior wrestlers. Sports Med 32:225–233