Lovell et al., J Athl Enhancement 2013, 2:1
http://dx.doi.org/10.4172/2324-9080.1000104

Journal of Athletic Enhancement

Case Report

A SCITECHNOL JOURNAL

The Use of Performance Tests for the Physiological Monitoring of Training in Combat Sports: A Case Study of a World Ranked Mixed Martial Arts Fighter

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Abstract

Currently there is little data on the changes in physiological performance of combat athletes in response to changes in training during fight preparation. Therefore the aim of this study was to examine the use of the 30-s Wingate test as a means of monitoring an athlete's performance during their fight preparation. A world ranked mixed martial arts fighter volunteered to participate in the eight week study. Upper and lower body anaerobic performance was assessed at baseline and three and six weeks into the preparation phase with the final assessment two weeks after the tapering period. Upper and lower body maximal oxygen uptake (VO_2 max) was measured before and after the eight weeks of fight preparation. Increases in training load were matched by substantial decreases in upper and lower body anaerobic performance during first three and six weeks of the preparation phase. During the tapering period anaerobic performance substantially increased in both the upper and lower body. The upper and lower body VO_2 max (14% and 3% respectively) substantially increased after the eight week preparation phase with upper body peak power (10.5%) and maximum heart (4%) higher. Our data suggest that Wingate performance is able to track changes in training loads and can assist in the monitoring of performance of high-intensity combat athletes.

Keywords

Anaerobic performance; Mixed martial arts; Training; Tapering

Introduction

The sport of mixed martial arts (MMA) is a full contact sport that has had a rapid rise in popularity and participation in recent years [1]. Although initial attempts were made to ban MMA competitions by the medical community and politicians [2], changes in rules and increased fighter safety and an increased acceptance of this style of combat sport [3] has seen its popularity outstrip more conventional combat sports such as pro wrestling and boxing [4]. Participation in martial arts is seen as an important form of exercise providing individuals with physical well-being as well as a sense of psychological well-being [5].

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Received: October 22, 2012 **Accepted:** December 15, 2012 **Published:** December 18, 2012

MMA is a mixture of traditional martial arts and Western combat sports where opponents use combinations of standing striking techniques such as boxing and kick boxing and grappling and ground fighting techniques such as wrestling and Brazilian jiu-jitsu. A match consists of three rounds, each of which has five minutes of continuous full contact fighting followed by a one minute rest period. A fighter can win by knockout, referee stoppage, submission, or outscoring an opponent based upon the judges' decision [2].

To ensure success in the ring, the modern day MMA fighter needs to be able to combine different fighting techniques with a high level of physical fitness. Although little data exists on the physical fitness of MMA fighters, similar sports such as free style wrestling [6], boxing [7], Muay Thai boxing [8] and karate [9] show a high level of upper and lower body aerobic and anaerobic power is needed to be successful in their sport and reduce the incidence of injury [10]. To achieve the desired level of fitness many professional MMA fighters can train up to three times a day, seven days per week [11]. Furthermore fighters often increase their training intensity while trying to reduce body weight leading up to competition. Few data exist on the changes in a fighter's physical performance in the lead up to a competitive fight. While some sports have had considerable research into athlete preparation for optimal performance, combat sports in particular have been identified as having little or no research in the area of athlete peaking for an upcoming event or competition [12]. A badly designed and implemented training program in the lead up to an event can be detrimental to training-induced adaptations, and elicit a partial or complete loss of training-induced anatomical, physiological and performance adaptations [13].

The difficulty of regular performance tests in monitoring an athlete performance is that the test themselves can be exhausting, invasive and disruptive to an athlete's preparation. Therefore, the primary aim of this study was to examine the use of the Wingate Anaerobic Test (WAnT) as a means of monitoring an athlete's performance during the final preparation phase. The WAnT is a maximal intensity cycle ergometer test lasting 30 s and is often utilized as a method to evaluate anaerobic performance [14]. The secondary aim was to monitor an elite MMA fighter's anthropometric and physiological performance in response to changes in training load during the final preparation phase of training prior to a MMA fight.

Methods

Study design

All testing was conducted by qualified staff at a nationally recognized and certified university high performance centre. Baseline anthropometric, upper and lower body aerobic and anaerobic performance was measured prior to changes in the participant's regular training program, eight weeks before the MMA fight. Subsequently, every three weeks during the preparation phase and after two weeks after the tapering phase upper and lower body anaerobic performance was assessed by the Wingate anaerobic test (WAnT). The WAnTs were separated by 15 minutes passive rest. The second upper and lower body aerobic tests were conducted six and five days prior to the

doi:http://dx.doi.org/10.4172/2324-9080.1000104

fight with 24 hr between tests. Final anthropometric measurements were made three days prior to the fight. The participant maintained their normal dietary and fluid intake for the duration of the study. All tests were conducted at the same time of the day to reduce diurnal variation in performance variables [15].

Participant

A 25-year-old MMA athlete, who has been actively training and competing in MMA events for over 5 yrs and ranked among the top 2 in Australia, volunteered to participate in this case study over the 8 weeks leading up to his fight. The participant was fully informed about the risks and stresses associated with the research protocol, completed a Physical Activity Readiness Questionnaire (PAR-Q) and signed an informed consent form before the monitoring period started. The study was approved by the Ethics and Research Committee of the School of Health and Sport Sciences of the University of the Sunshine Coast. The study was approved by the University of the Sunshine Coast Ethics Committee in and performed in accordance with the ethical standards of Harriss and Atkinson [16].

Anaerobic tests

The upper body WAnT was conducted on a modified electro-magnetically braked cycle ergometer (EE; Excalibur Sport, Lode B.V., Netherlands). The EE was fixed to a table with the table fixed to the ground to prevent any movement in the EE during the WAnT. The participant sat in a chair (also fixed to the ground) and was advised to keep their feet flat on the ground and remain seated throughout the WAnT. The seat height and back rest were adjusted so that with the crank position on the opposite side to the body and the hand grasping the handles, the elbow joint was almost in full extension (165-175°) and the shoulders in line with the centre of the ergometers shaft. The lower body WAnT was conducted on an electronically braked cycle ergometer (Velotron, Racermate, Inc., Seattle, WA, USA). A fly wheel braking force corresponding to 5% and 7.5% of the participants body weight was used for the upper and lower body respectively [14,17].

Prior to the commencement of each WAnT the participant completed a 5-min warm-up which included three short sprint efforts followed by a 5 min recovery. Following the warm-up the participant stretched for approximately 3 min before the commencement of the test. The participant was instructed to cycle as fast as possible and given a 3-s countdown before the set resistance was applied. Verbal encouragement was given to the participant to maintain the highest possible cadence throughout the WAnT.

Aerobic tests

Lower body cardiovascular fitness (VO_2 max) was assessed during a graded exercise test on a treadmill (Woodway, Waukesha, USA). After an initial warm-up of three minutes at 6 kmh^{-1}, the test began at 8 kmh^{-1} and speed increased by 1 kmh^{-1} every 1 min until 16 kmh^{-1} with grade increasing thereafter until exhaustion. Upper body VO_2 max was assessed during a graded exercise test on a modified electro-magnetically braked cycle ergometer (EE) (Excalibur Sport, Lode B.V., Netherlands). Set-up of the arm crank was as per the upper body WAnT. After an initial warm-up of two minutes at 45 Watts, the test began at 60 Watts and increased one Watt every five seconds until volitional exhaustion or until fly wheel revolutions dropped below 60 rpm.

Cardiorespiratory-metabolic variables were measured using open circuit spirometry (Parvo-Medics TrueOne® 2400 Metabolic Measurement System, Sandy, UT). Heart rate (HR) was measured via a HR monitor (Polar S610 HR Monitor, Polar Electro Oy, Kempele, Finland) strapped against the participant's chest. During the progressive exercise test, each participant was encouraged to give a maximal effort. Maximal values for oxygen consumption were calculated from the average of the last minute of exercise before volitional fatigue. VO_2 max was confirmed when three or more of the following criteria were met: (1) a plateau in VO_2 despite an increase in running speed/grade or ergometer power; (2) a respiratory exchange ratio (RER) higher than 1.20; (3) a heart rate within 10 bpm of its predicted maximum; (4) a lactate concentration higher than 10 mmol l^{-1}.

Body composition

The participant's height was measured with a wall-mounted stadiometer (Holtain Ltd, Crymych, Wales). Body mass was measured with a beam balance scale (Avery Ltd, Fairmont, MN) with the participant wearing shorts only. Skinfold thickness was measured by a highly qualified observer on the right side of the body at appropriately marked sites and recorded to the nearest 0.2 mm with a Harpenden caliper (range: 0.00–50.00 mm; minimum graduation: 0.20 mm; accuracy: 99.00%). Skinfold thickness was measured at six sites (triceps, abdominal, subscapular, supraspinale, front thigh, medial calf) according to standardized anatomic locations and methods [18]. From the sum of skinfolds, body density was calculated using the formula for males aged 20–29 years of Durnin and Womersley [19] and percentage body fat estimated using the Yuhasz equation [20].

Mid-upper arm circumference was measured at the location of the triceps skinfold measurement with the participants arm hanging relaxed at his side. Mid-thigh circumference was determined as the distance halfway between the greater trochanter and lateral epicondyle while the participant was standing. Circumference measurements were to the nearest 0.1 cm with a non-stretchable tape. Upper arm muscle cross-sectional area (UAMA) was then calculated according to the equation: $[(MAC - \pi \times TSF)^2/4\pi] - 10$ where MAC is mid-arm circumference and TSF is triceps skinfold thickness [21]. Mid thigh muscle cross-sectional area (MTMA) was calculated according to the equation: $(4.68 \times MTC) - (2.09 \times FTSF) - 80.99$ where MTC is mid-thigh circumference and FTSF is front thigh skinfold thickness [22]. Total body muscle mass (TBMM) was calculated according to the equation: $H \text{ x } (0.00744 \text{ x } MAC^2 + 0.00088 \text{ x } MTC^2 + 0.00441 \times MCG^2) + 2.4 \times 1 - 0.048 \times age + 7.8$ where H is height, MCC is mid-calf circumference [23].

Statistical analysis

No statistical analysis could be performed during this study due to the nature of the case study (n=1). Therefore to determine if changes were substantial and meaningful, results were compared to technical error of measurement (TEM) values reported by our laboratory. The TEM value is used to determine the probability that any real change in an individual's performance is due to training and not artefact from performance and equipment variation and/or poor participant preparation [24].

Training

An overview of the number of days and hours per day of training are presented in table 1. Regular training was conducted 4-5 days per week with approximately 14-16 hours of training. The hours and intensity of training increased for the first three weeks of training in the preparation phase and increased further the following three weeks with training on 5-6 days per week. Two weeks prior to the MMA fight, training hours decreased to eight per week and training intensity increased. The last week of the preparation phase consisted of three hours training, with one session of high-intensity exercise.

Training consisted of technique/drills - kick boxing, wrestling, jujitsu and boxing technique and drills designed to improve fighting skills.

Sparring/wrestling: Fighting opponents in the ring with varying work to rest ratios. Regular training consisted of 10 x 5 min rounds with 2 min recovery. The number of rounds reduced but intensity via reduced recovery and simulated fight conditions increased over the preparation phase.

Circuit training: Consisted of 30-s a station with varying work to rest ratios with increasing intensity (less rest) during the preparation phase. Stations consisted of rope climb, sand bag carry, sledge hammer, kettle bells, 10-m sprints, bike ergometer, jump squats, arm ergometer, tyre flipping, medicine ball throws and rowing ergometer.

Weight training: Exercises included deadlift, squat, pull-ups, weighted push-ups, power cleans. Increased weight and intensity with decreasing repetitions during the preparation phase.

Hill sprints: Commenced during the preparation phase with 10-s hill climb and 20-s recovery.

Stretching: Static and dynamic stretching before and after every workout to maintain flexibility.

Results

All anthropometric measurements were conducted by the same qualified observer before and after the eight week preparation phase (Table 2). Substantial decreases in body weight and sum of six skinfolds were found after eight weeks. Changes in percent body fat and upper arm muscle CSA were also found although comparisons to TEM data were not possible (due to calculations and not direct measurements).

Apart from the first upper body VO_2 max test, all other VO_2 max tests met three of the four criteria for establishing VO_2 max. The upper and lower body VO_2 max had substantial increases after eight weeks of the preparation phase. The upper body also had substantial increases in HR_{max} and peak power during VO_2 max testing after the preparation phase of training (Table 3).

Upper and lower body anaerobic performance was assessed before and three and six weeks after the preparations phase with the last tests conducted after the final tapering period (Table 4). For the upper body peak and mean power substantially decreased during the first three and six weeks of the preparation phase and substantially increased after the tapering period. For the lower body peak and mean power substantially decreased during the first three and six weeks of the preparation phase but did not substantially increase above baseline data after the tapering period. Mean power did not substantially decrease during the preparation phase for the lower body but was substantially higher than baseline data after the tapering period.

Discussion

The aim of this case study was to monitor the physical

Table 1: Days and hours per week of regular training and for the preparation phase.

	Regular training	Weeks 8-6	Weeks 5-3	Week 2	Weeks 1
Days per week	4-5	4-5	5-6	4	3
Total hours per week	14-16	16-18	10-12	8	2.5
Technique/drills	4-6	4-6	2-4	2-4	1
Sparring/wrestling	3-4 (50%)	3-4 (70%)	2-3 (80-100%)	1-2 (100%)	0.5 (100%)
Circuit training	1-3 (50-70%)	2-3 (70-80%)	1-2 (90-100%)	1 (100%)	0.5 (slow jog)
Weight training	2 (70-90% of 1RM)	2 (85-95% of 1RM)	1 (90-95% of 1RM)	-	-
Hill sprints	-	0.5	0.5	0.5 (with 10 kg vest)	-
Stretching	1	1	1	1	0.5

Table 2: Anthropometric data before and after the eight weeks of training/monitoring period.

Variable	Test 1	Test 2	Change	% Change	TEM
Age (years)	25	25	-	-	N/A
Height (cm)	182	182	0	0	2.0
Body weight (kg)	90.2	87.4	-2.8	3.1	1.1
Body fat percentage (%)	8.5	8.2	-0.3	3.5	N/A
Sum of six skinfolds (mm)	56.3	53.9	-2.4	4.3	1.3
Upper arm muscle CSA (cm^2)	73.5	85.7	+12.2	16.6	N/A
Mid thigh muscle CSA (cm^2)	154.9	150.1	-4.8	3.0	N/A
Total body muscle mass (kg)	42.3	42.2	-0.1	0.2	N/A

CSA = Cross-sectional area; N/A = not applicable

doi:http://dx.doi.org/10.4172/2324-9080.1000104

Table 3: Aerobic data before and after the eight weeks of training/monitoring period.

Variable	Test 1	Test 2	Change	% Change	TEM
Upper Body					
VO_2 max $L{\cdot}min^{-1}$ $ml{\cdot}kg{\cdot}min^{-1}$	 3.59 40.35	 4.13 45.96	 +0.54 +5.61	 15.0 14.0	 0.16 1.60
HR_{max} ($beats{\cdot}min^{-1}$)	183	191	+8.0	4.4	3.4
Peak power (W)	181	200	+19.0	10.5	8.2
RER	1.22	1.26	+0.04	3.3	0.09
Lactate ($mmol\ l^{-1}$)	15.8	16.7	+0.9	5.5	1.1
Lower Body					
VO_2 max $L{\cdot}min^{-1}$ $ml{\cdot}kg{\cdot}min^{-1}$	 4.89 54.96	 5.11 56.75	 +0.22 +1.79	 4.5 3.3	 0.11 1.35
HR_{max} ($beats{\cdot}min^{-1}$)	193	194	+1.0	0.5	3.1
RER	1.24	1.27	+0.03	2.4	0.07
Lactate ($mmol\ l^{-1}$)	16.7	16.5	-0.02	0.1	0.09

VO_2 max = maximal oxygen consumption; HR_{max} = maximum heart rate; RER = respiratory exchange ratio; TEM = technical error of measurement

Table 4: Anaerobic data before and after the eight weeks of training/monitoring period.

Variable	Test 1	Test 2	Test 3	Test 4	Change	% Change	TEM
Upper body							
Peak power (W) ($W{\cdot}kg^{-1}$)	798 8.9	766 8.6	754 8.6	841 9.7	+43 +0.8	5.4 9.0	28 0.4
Mean power (W) ($W{\cdot}kg^{-1}$)	521 5.8	472 5.3	461 5.2	542 6.1	+21 +0.3	4.0 5.2	17 0.2
Minimum power (W)	334	273	265	335	+0.1	0.0	21
Fatigue index (%)	58.1	64.4	64.9	60.2	+2.1	3.6	N/A
Lower bodyt							
Peak power (W) ($W{\cdot}kg^{-1}$)	914 10.2	885 9.9	869 9.8	934 10.4	+20 +0.2	2.2 2.0	22 0.3
Mean power (W) ($W{\cdot}kg^{-1}$)	681 7.6	671 7.5	668 7.6	711 7.9	+30 +0.3	4.4 3.9	16 0.2
Minimum power (W)	507	467	385	509	+2.0	0.4	18
Fatigue index (%)	44.5	47.2	55.7	45.5	+1.0	2.2	N/A

TEM = technical error of measurement; % change = between test 1 and test 4

performance of an elite MMA fighter during the final eight weeks of fight preparation and to determine if the WAnT is a suitable method of monitoring changes in training during the preparation phase. The intensity of training increased above regular training levels during the first six weeks of the preparation phase with the last two weeks used as a tapering period. The increased training load was reflected in reduced Wingate performances during the first six weeks with improved Wingate performances after the taper period.

The results of the present study indicate that the WAnT can be used to monitor the changes in training intensity during an elite athlete's preparation for a MMA fight. Presently no single measure has been identified that can accurately assess how an athlete is responding to training [25]. While we do not propose that the WAnT can accurately access every athlete's response to training it does appear in this case study to track changes in training intensity. Indeed a recent review [25] found that the reason many physiological tests fail to monitor changes in training is the absence of a measure of individuality in each athlete's response to training and that future studies should be directed towards measurements that reflect individual responses. The establishment of laboratory based TEM's where the measurement error for Wingate values are known with the equipment to be used in the monitoring of the athlete ensures the smallest worthwhile changes in performance can be detected in an individual [24].

Our results show reductions in both upper and lower body anaerobic peak and mean power during the first six weeks of increased training intensity. The overload above normal training levels appears to affect both short term neuromuscular power (PP) as well as the glycolytic power (MP). Although the WAnT has not previously been used to monitor changes in training load, its strong correlation with muscular strength [26,27] and muscle contractile characteristics [28] make it a suitable method to assess the effect of training on neuromuscular function. During the two week tapering period the upper and lower body demonstrated increased anaerobic MP and PP compared to the previous test session (43-87 Watts) and compared to baseline data (20-43 Watts). This super-compensation effect is a typical response after a period of increased training or 'over reaching' and is designed to maximise performance leading into competition [29]. The upper and lower body WAnT values in the present study are similar to other high-intensity combat sports with anaerobic power one of the key performance indicators that

doi:http://dx.doi.org/10.4172/2324-9080.1000104

differentiate between successful and less successful athletes in sports such as wrestling [6,30].

Several recent studies have also used the WAnT as a method of monitoring changes in training load and assessing athletic performance [31-33]. Reductions in peak WAnT power were found after preseason training and in mid-season competition for competitive collegiate wrestlers compared to their baseline values. The authors suggested this may be the result of an increased training load during this period as seen in the current study. Similarly, peak WAnT power increased for the final competitive meet possibly due to a reduced training load [33]. No adverse effects from the use of the WAnT on the athletes' subsequent preparation and/or training have been reported from the above mentioned studies or were found in the present study. Although the WAnT requires maximal effort and is metabolically demanding, complete recovery from the WAnT has been reported within three hours after the initial test [34].

In addition to the WAnT's, upper and lower body VO_2 max tests were performed before the eight week preparation phase and prior to the fight. While there were small worthwhile changes in lower body VO_2 max substantial increases were found in upper body VO_2 max. The increase in upper body VO_2 max was accompanied by substantial increases in upper body PP, heart rate and lactate concentration. These increases in upper body performance may, in part be due to the substantial increases in upper arm CSA found after the preparation phase. Therefore, it appears that the increased training intensity of the preparation phase had a substantial effect on the upper body and to a lesser extent on the lower body. The lower body may have achieved its required upper limit of VO_2 max for MMA performance with the present study value of 56.75 ml·kg·min^{-1} higher or similar to other combat sports [7,30,35]. Less data is available on upper body aerobic performance in combat sports. The stimulus of increased training intensity substantially increased the upper body aerobic performance (14-15%) with our VO_2 max (45.96 ml·kg·min^{-1}) greater than other combats sports such as wrestling (40-41 ml·kg·min^{-1}) [30]. A high upper body VO_2 max is important for the MMA fighter due to the large amount of upper body work required in competitive MMA.

The preparation phase resulted in small but worthwhile changes in the sum of six skinfolds and subsequently percentage body fat. The participant began the eight week preparation phase with low body fat (8.5%) and required 4.2 kg of weight loss over the eight weeks to qualify for the weight limit. A very gradual weight loss over several weeks coupled with a high-intensity taper has been shown to substantially improve wrestling performance while peaking for a major competition [36]. In the present study, body weight was reduced without compromising total body muscle mass while upper arm muscle CSA was increased and aerobic and anaerobic performance increased.

While the use of the WAnT as a means of assessing the anaerobic performance of athletes is commonplace, this study is unique by using the upper and lower body WAnT to track changes in training load of an elite MMA fighter and how these changes subsequently affect anaerobic performance. The WAnT is a quick test to implement with minimal disruption to an athlete's training and preparation. However laboratories must establish TEM's to ensure the accuracy of results. Future studies should confirm these results by monitoring larger groups of elite athletes involved in high-intensity sport.

References

1. Ngai KM, Levy F, Hsu EB (2008) Injury trends in sanctioned mixed martial arts competition: a 5-year review from 2002 to 2007. Br J Sports Med 42: 686-689.
2. Buse GJ (2006) No holds barred sport fighting: a 10 year review of mixed martial arts competition. Br J Sports Med 40: 169-172.
3. Garcia RS, Malcolm D (2010) Decivilizing, civilizing or informalizing? The international development of Mixed Martial Arts. Int Rev Sociol Sport 45: 39-58.
4. http://sportsillustrated.cnn.com/2007/more/05/22/ultimate0528/index.html.
5. Woodward TW (2009) A review of the effects of martial arts practice on health. WMJ 108: 40-43.
6. 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.
7. Guidetti L, Musulin A, Baldari C (2002) Physiological factors in middleweight boxing performance. J Sports Med Phys Fitness 42: 309-314.
8. Crisafulli A, Vitelli S, Cappai I, Milia R, Tocco F, et al. (2009) Physiological responses and energy cost during a simulation of a Muay Thai boxing match. Appl Physiol Nutr Metab 34: 143-150.
9. Doria C, Veicsteinas A, Limonta E, Maggioni MA, Aschieri P, et al. (2009) Energetics of karate (kata and kumite techniques) in top-level athletes. Eur J Appl Physiol 107: 603-610.
10. Halloran L (2008) Wrestling injuries. Orthop Nurs 27: 189-192.
11. Amtmann JA (2004) Self-reported training methods of mixed martial artists at a regional reality fighting event. J Strength Cond Res 18: 194-196.
12. Pyne DB, Mujika I, Reilly T (2009) Peaking for optimal performance: Research limitations and future directions. J Sports Sci 27: 195-202.
13. Mujika I (2010) Intense training: the key to optimal performance before and during the taper. Scand J Med Sci Sports 2: 24-31.
14. Inbar O, Bar-Or O, Skinner JS (1996) The Wingate Anaerobic Test, Human Kinetics, Champaign, IL, 110 p.
15. Souissi N, Driss T, Chamari K, Vandewalle H, Davenne D, et al. (2010) Diurnal variation in Wingate test performances: influence of active warm-up. Chronobiol Int 27: 640-652.
16. Harriss DJ, Atkinson G (2009) International Journal of Sports Medicine - ethical standards in sport and exercise science research. Int J Sports Med 30: 701-702.
17. Dotan R, Bar-Or O (1983) Load optimization for the Wingate Anaerobic Test. Eur J Appl Physiol Occup Physiol 51: 409-417.
18. Roche AF, Lohman TG (1988) Anthropometric standardization reference manual, Human Kinetics Books, Champaign.
19. Durnin JV, Womersley J (1974) Body fat assessed from total body density and its estimation from skinfold thickness: measurements on 481 men and women aged from 16 to 72 years. Br J Nutr 32: 77-97.
20. Yuhasz MS (1977) Physical fitness manual, University of Western Ontario, London.
21. Heymsfield SB, McManus C, Smith J, Stevens V, Nixon DW (1982) Anthropometric measurement of muscle mass: revised equations for calculating bone-free arm muscle area. Am J Clin Nutr 36: 680-690.
22. Knapik JJ, Staab JS, Harman EA (1996) Validity of an anthropometric estimate of thigh muscle cross-sectional area. Med Sci Sports Exerc 28: 1523-1530.
23. Wang Z, Zhu S, Wang J, Pierson RN Jr, Heymsfield SB (2003) Whole-body skeletal muscle mass: development and validation of total-body potassium prediction models. Am J Clin Nutr 77: 76-82.
24. Gore CJ (2000) Physiological tests for elite athletes, Human Kinetics, Champaign.
25. Borresen J, Lambert MI (2009) The quantification of training load, the training response and the effect on performance. Sports Med 39: 779-795.

26. Arslan C (2005) Relationship between the 30-second wingate test and characteristics of isometric and explosive leg strength in young subjects. J Strength Cond Res 19: 658-666.

27. Pearson SN, Hume PA, Cronin JB, Slyfield D (2009) Strength and power determinants of grinding performance in America's Cup sailors. J Strength Cond Res 23: 1883-1889.

28. Morris MG, Dawes H, Howells K, Scott OM, Cramp M, et al. (2010) Muscle contractile characteristics: relationship to high-intensity exercise. Eur J Appl Physiol 10: 295-300.

29. Halson SL, Jeukendrup AE (2004) Does overtraining exist? An analysis of overreaching and overtraining research. Sports Med 34: 967-981.

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

31. Chtourou H, Chaouachi A, Driss T, Dogui M, Behm DG, et al. (2012) The effect of training at the same time of day and tapering period on the diurnal variation of short exercise performances. J Strength Cond Res 26: 697-708.

32. Coppin E, Heath EM, Bressel E, Wagner DR (2012) Wingate anaerobic test reference values for male power athletes. Int J Sports Physiol Perform 7: 232-236.

33. Ratamess NA, Hoffman JR, Kraemer WJ, Ross RE, Tranchina CP, et al (2012) Effects of a competitive wrestling season on body composition, endocrine markers, and anaerobic exercise performance in NCAA collegiate wrestlers. Eur J Appl Physiol.

34. Thompson K, Harrison K, Dietzig B, Cosgrove M, Hardman S, et al. (2005) The effect of 3 hours rest on performance and metabolism during a 30-s Wingate test. J Sports Sci 23: 138-139.

35. Franchini E, Nunes AV, Moraes JM, Del Vecchio FB (2007) Physical fitness and anthropometrical profile of the Brazilian male judo team. J Physiol Anthropol 26: 59-67.

36. Lambert C, Jones B (2010) Alternatives to rapid weight loss in US wrestling. Int J Sports Med 31: 523-528.

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