Physiological and metabolic characteristics of elite tug of war athletes

G Warrington, C Ryan, F Murray, P Du y, J P Kirwan

Abstract

***Objective*—To determine the aerobic power ($\dot{V}O_{2MAX}$), body composition, strength, muscular power, flexibility, and biochemical profile of an elite international squad of tug of war athletes.**

***Methods*—Sixteen male competitors (mean (SEM) age 34 (2) years) were evaluated in a laboratory. For comparative purposes, data were analysed relative to normative data for our centre and to a group of 20 rugby forwards from the Irish international squad.**

***Results*—The tug of war participants were lighter (83.6 (3.0) *v* 104.4 (1.8) kg, p<0.0001) and had less lean body mass (69.4 (2.1) *v* 86.2 (1.2) kg) than the rugby players and had lower than normal body fat (16.7 (0.9)%); all values are mean (SEM). Aerobic power measured during a treadmill test was 55.8 (1.6) ml/kg/min for the tug of war participants compared with 51.1 (1.4) ml/kg/min for the rugby forwards (p<0.03). A composite measure of strength derived from (sum of dominant and non-dominant grip strength and back strength)/lean body mass yielded a strength/mass ratio that was 32% greater (p<0.0001) for the tug of war group than the rugby group. Dynamic leg power was lower for the tug of war group than the rugby forwards (4659.8 (151.6) *v* 6198.2 (105) W respectively; p<0.0001). Leg flexibility was 25.4 (2.0) cm for the tug of war group. Back flexibility was 28.6 (1.4) cm which was lower (p<0.02) than the rugby forwards 34.2 (1.5) cm. Whereas blood chemistry and haematology were normal, packed cell volume, haemoglobin concentration, and erythrocyte volume were lower in the tug of war group than in the rugby players (p<0.05). All three haematological measures correlated with muscle mass (packed cell volume, r^2 = 0.37, p<0.0001; haemoglobin concentration, r^2 = 0.13, p<0.05; erythrocyte volume, r^2 = 0.21, p<0.01).**

***Conclusions*—The data indicate that international level tug of war participants have excellent strength and above average endurance relative to body size, but have relatively low explosive leg power and back flexibility. The data provide reference standards for the sport and may be useful for monitoring and evaluating current and future participants.**

(*Br J Sports Med* 2001;**35**:396–401)

Keywords: tug of war; body composition; $\dot{V}O_{2MAX}$; strength; power; flexibility

National Coaching and Training Centre, University of Limerick, Limerick, Ireland
G Warrington
C Ryan
F Murray
P Du y
J P Kirwan

Correspondence to:
Dr Kirwan, Case Western Reserve University School of Medicine at MetroHealth Medical Center, Departments of Reproductive Biology and Nutrition, Bell Greve Bldg, Rm G-232E, 2500 MetroHealth Drive, Cleveland, OH 44109-1998, USA
jpk10@po.cwru.eu

Accepted 20 August 2001

The sport of tug of war has a long tradition, dating back to approximately 2000 BC. The term originates from the German "togga werra" which denotes "a contest in tugging or pulling". In some countries, tug of war was included in ceremonial rituals—for example, in Korea a tug of war competition was organised in advance of harvest time. In later times, tug of war became a competition of physical strength and it was included in the Olympic Games until 1920 (http://www.stowa.pwp.blueyonder.co.uk). More recently, the sport has become organised on a worldwide basis. The Tug of War International Federation (TWIF) was formed in 1960 and has 25 member nations. Regional and World Championships are staged on a yearly basis.

Tug of war involves two teams of eight, pulling against one another on a rope of not less than 33.5 m. The object is to pull the opposing team towards a centre line for a distance of 4 m. Two types of competition are used: knockout and points. Teams are categorised by weight, varying from lightweight (not exceeding 560 kg) to catchweight (not exceeding 720 kg). Typically, matches are decided over a best of three pulls. The duration of each pull varies, with a mean time of two minutes 30 seconds, but pulls lasting as long as 45–46 minutes have been recorded (Ireland *v* England, World Championships, Malmo, Sweden, 1988). Rest periods of up to six minutes are permitted between pulls.

Despite its long history, there is a paucity of information on the physiological and anthropometric characteristics of tug of war athletes. The basic requirements for success in the sport include strength, endurance, team coordination, and concentration. During competition and training, muscle contraction is primarily of the sustained isometric type as the participants resist the pull from the opposing team, or in training, attempt to pull considerable weight using a derrick or immovable object. The physical stress is substantial and not without health risk. There are several reports of medical complications such as hernias,[1] retinal haemorrhage,[2] and fractures.[3 4] Furthermore, as competitions are based on weight categories, the individual athlete must "make weight", and the use of di erent weight reduction strategies leading to acute dehydration is not uncommon. These practices may place the athletes at increased risk of electrolyte imbalance, possible cardiac irregularities, and impaired exercise performance.[5] Given the relatively unusual nature of the physical demands of the sport, it is important to gain a greater understanding of the physiological and anthropometric characteristics of its participants. The purpose of this study was to determine the aerobic power, body composition, strength, muscular power, flexibility, and biochemical profile of an elite national squad of tug of war athletes who had reached the highest levels of international success in the sport.

Methods

SUBJECTS

Sixteen male members of the Irish tug of war squad participated in the study. For comparative purposes we used normative data collected on national level athletes from all sports and a group of rugby forwards from the international squad who had been tested at our centre. Rugby forwards were selected for comparison because, like tug of war athletes, they perform activities that require some isometric strength, such as scrummaging and mauling, which are static or semistatic in nature. Both groups of athletes were tested during the transition from the o season to preseason conditioning phase of their respective training programmes. Signed informed consent was obtained from each subject in accordance with the guidelines for the protection of human subjects at the National Coaching and Training Centre.

BODY COMPOSITION

Standing height was measured without shoes, to the nearest 1.0 cm, using a stadiometer (model 220; Seca, Hamburg, Germany). Body weight was measured to the nearest 0.1 kg using an electronic digital scale (model 770; Seca), with the subjects wearing only training shorts. Skinfold thickness was measured to the nearest 0.1 mm at seven sites (chest, thigh, biceps, triceps, subscapular, abdominal, and suprailiac) using Harpenden calipers (British Indicators Ltd, St Albans, Hertfordshire, UK). Body fat and lean body mass were estimated as described by Jackson and Pollock.[6]

AEROBIC POWER

Maximal oxygen uptake ($\dot{V}O_2MAX$) was determined using a constant speed, incremental grade, treadmill protocol test as previously described.[7] Oxygen and carbon dioxide concentrations were analysed by a fully automated online system (OCM-2; Ametek, Pittsburgh, Pennsylvania, USA). Heart rate was monitored and recorded at five second intervals using a Polar Sport Tester (Polar, Kempele, Finland).

STRENGTH AND POWER

Isometric hand grip strength was measured using a hand grip dynamometer (GRIP-D TKK 5101; Takei, Tokyo, Japan) individually adjusted to hand size. Subjects performed three trials, with a minimum of 30 seconds rest between each trial. The highest score recorded over the trials was taken as a measure of maximal isometric grip strength. Subjects performed the test with both the dominant and non-dominant hand.

Isometric back strength was measured using a back and leg dynamometer (TKK 1858; Takei). Each subject stood on the dynamometer foot stand and gripped the handle in both hands, pulling upwards as strongly as possible with the knees straight and the back at a 30° angle. Subjects completed three trials, the highest score being recorded as the measurement of maximal back strength.

Upper body and lower body strength were determined using a three repetition maximum (3-RM) bench press and 90° squat respectively. A 3-RM test was used in preference to a 1-RM for safety reasons. After a standardised warm up consisting of 10 repetitions at a weight about 60% of estimated 3-RM, each subject attempted successive lifts of increasing weight. Each test was terminated when the subject failed to complete three repetitions. A minimum of three minutes recovery was given between each trial.

Leg power was determined by vertical jump using a jump meter (Jump MD, TKK 5106; Takei). The subject stood in the centre of the test mat. The display unit was attached around the subject's waist with the cable wound tight in a vertical position. The subject performed a counter movement jump, as high as possible, with free arm movement and landed with two feet on the mat. Three measurements were taken, with the result of the highest score being recorded. The data were converted from centimetres to Watts using the regression equations published by Sayers *et al*.[8]

FLEXIBILITY

Before flexibility assessment, each subject performed a standarised warm up consisting of five minutes running on a treadmill at 10 km/h, followed by a series of supervised stretching exercises. Flexibility was assessed using sit and reach, forward flexion, and back extension tests. The sit and reach and forward flexion tests were performed as a measure of lower back and hamstring flexibility. Subjects performed the test with the legs fully extended and knees relaxed. They were required to extend their arms forward as far as possible and hold at the furthest point for two seconds. A Sit and Reach Bench (Bodycare Products, Southam, Warwickshire, UK) and a Forward Flexmeter (TKK 1859; Takei) were used to perform the tests.

Subjects performed a back flexion test as a measure of the flexibility of the back extensor muscles. They lay in a prone position with hands clasped behind the back and feet about 45 cm apart, and arched the trunk up as far as possible from the mat ensuring the feet remained on the mat. Measurements were taken as the vertical distance from the chin to the ground, using a Backward Flexmeter (TKK 1860; Takei).

BLOOD ANALYSES

A blood sample was taken from an antecubital vein after a 12 hour overnight fast for determination of haematological and biochemical variables. All samples were obtained with the subjects lying on an examination table. A complete blood count with di erential was performed immediately on a 3 ml portion of whole blood (K-100, Sysmex, Kobe, Japan). A second sample was centrifuged at 4°C, and the plasma was stored at −80°C for subsequent biochemical

Table 1 Characteristics of 16 tug of war athletes and 20 rugby forwards

	Tug of war	*Rugby forwards*
Age (years)	34.4 (1.9)*	26.8 (0.6)
Height (cm)	181.8 (1.2)*	188.2 (1.6)
Weight (kg)	83.6 (3.0)*	104.4 (1.8)
Body mass index (kg/m^2)	25.2 (0.7)*	29.5 (0.6)
Body fat (%)	16.7 (0.9)	16.3 (1.1)
Fat mass (kg)	14.2 (1.1)*	18.2 (1.2)
Lean body mass (kg)	69.4 (2.1)*	86.2 (1.2)

Values are presented as mean (SEM).
*Significant di erence between groups, p<0.05 (unpaired *t* test).

analyses. All biochemical determinations were performed on an automated blood chemistry analyser (IL Monarch, Spokane, Washington, USA) using IL Test reagents.

STATISTICAL ANALYSIS

All values are expressed as mean (SEM). Di erences between independent variables were examined using unpaired *t* tests. The relation between lean body mass and packed cell volume was determined using univariate regression analysis. The data were analysed using the Statview II statistical package (Abacus Concepts, Berkeley, California, USA). An α level less than 0.05 was considered statistically significant.

Results

Table 1 presents the data for various physical and anthropometric characteristics of the tug of war participants and 20 rugby forwards. The mean age of the tug of war group was 34.4 (1.9) years (range 18–44). The tug of war group was not as tall as the rugby forwards, in addition they were lighter and had a lower body mass index (p<0.0001). The percentage body fat was comparable for both groups of athletes and well below the norms for sedentary individuals in this age range. Lean body mass and fat mass, estimated from skinfold measurements, were lower for the tug of war athletes than for the rugby forwards.

The mean absolute $\dot{V}O_2MAX$ for the tug of war group was 4.6 (0.1) litres/min, which is higher than expected sedentary untrained values (about 3.43 litres/min). The $\dot{V}O_2MAX$ of the rugby forwards was significantly higher than that of the tug of war athletes (5.3 (0.1) litres/min, p<0.0001). However, when adjusted for body weight, the tug of war group had a higher relative $\dot{V}O_2MAX$ than the rugby forwards (55.8 (1.6) *v* 51.1 (1.4) ml/kg/min, p<0.03). Resting heart rate was 64.3 (1.6) beats/min, which is slightly below the average of 65–67 beats/min for sedentary men of the same age group. Maximum heart rate (190.8 (2.5) beats/min) was within the expected range of 186–203 beats/min. There was no di erence between maximum heart rate for the two groups.

The tug of war group recorded a value of 25.4 (2.0) cm on the sit and reach test, which was similar to that of the rugby group (table 2). The mean values for forward flexion (8 (2) cm) and back flexion (28.6 (1.4) cm) for the tug of war group were below the expected ranges that we use as standards for athletes: (10–25 cm) and (35–50 cm) respectively. There was no difference between groups for forward flexion, but the rugby group did have greater back flexion (p<0.01). As expected, grip strength was relatively high for the tug of war group, and grip strength for the dominant hand was greater (p<0.01) than that for the non-dominant hand. The combined grip strength was obtained by summing the values for the dominant and non-dominant hands. No di erences were noted between groups for dominant versus non-dominant or combined grip strength. The mean back strength for the tug of war group (2004.8 (104.4) N) was within the expected range of 1471–2452 N for athletes. Back strength was not di erent between the two groups of athletes, but, when it was adjusted for body mass and lean body mass, the tug of war group was stronger. A composite measure of strength to mass was derived from the sum of dominant and non-dominant grip strength and back strength, which was then adjusted for either body weight or lean body weight. Using this measure, the tug of war group was stronger (p<0.0001) than the rugby forwards. Two other strength measures included a 3-RM bench press and squat. The amount of weight lifted by the tug of war group was relatively low for both of these tests compared with normative data. Estimated leg power for the tug of war group was 4659.8 (151.6) W, which was lower than that of the rugby forwards (6198.2 (105) W, p<0.0001).

Table 3 gives data on blood chemistry. Concentrations of blood glucose, triglyceride, and

Table 2 Flexibility, strength, and power measurements on 16 tug of war athletes and 20 rugby forwards

	Tug of war	*Rugby forwards*	*Normative values*
Sit and reach (cm)	25.4 (2.0)	25.7 (1.8)	15–30
Forward flexion (cm)	8.0 (2.1)	9.4 (1.6)	10–25
Back flexion (cm)	28.6 (1.4)*	34.2 (1.5)	35–50
Dominant hand grip strength (N)	622 (20.9)	607.1 (13.2)	540–687
Non-dominant hand grip strength (N)	591.4 (20.7)	568.2 (12.5)	540–687
Composite strength/kg BW	38.5 (1.1)*	28.8 (1.2)	30.4–45.5
Composite strength/kg LBM	46.4 (1.5)*	35 (1.5)	34.7–52
Back strength (N)	2004.8 (104.4)	1930.8 (73.8)	1471–2452
Bench press 3-RM (kg)	64.8 (3.3)	N/A	70–110
Squat 3-RM (kg)	162.7 (6.2)	N/A	160–230
Vertical jump (W)†	4659.8 (151.6)*	6198.21 (105)	4957–5995

Values are presented as mean (SEM).
*Significant di erence between the groups, p<0.05 (unpaired *t* test).
†Converted to watts using the regression equation of Sayers *et al*.[8]
N/A, Not available; BW, body weight; LBM, lean body mass; 3-RM, three repetition maximum.

Table 3 Blood chemistry profiles for 16 tug of war athletes

	Tug of war	*Expected laboratory values*
Glucose (mmol/l)	5.3 (0.1)	3.5–6
Cholesterol (mmol/l)	5.3 (0.3)	3.6–6.5
Triglycerides (mmol/l)	1.0 (0.2)	0.8–1.8
Creatinine (μmol/l)	110 (2.8)	60–115
Total protein (g/l)	81.3 (0.9)	64–83
Alanine transaminase (U/l)	17.5 (1.8)	<40
Calcium (mmol/l)	2.0 (0.03)	2.1–2.6
Creatine kinase (U/l)	209.3 (40)*	24–195
Aspartate aminotransferase (U/l)	29.5 (2.1)	7–40
Lactate dehydrogenase (U/l)	288.8 (10.4)	230–460
Iron (μmol/l)	19.0 (1.2)	9–29
Urea (mmol/l)	5.8 (0.3)	2.5–6.4
Uric acid (μmol/l)	282.1 (11.4)	210–420
Sodium (mmol/l)	139.3 (0.7)	135–145
Potassium (mmol/l)	4.1 (0.1)	3.5–5
Chloride (μmol/l)	105.8 (0.6)	100–106

Values are presented as mean (SEM).
*Outside the normal range.

Table 4 Blood haematology measures for 16 tug of war athletes and 20 rugby union forwards

	Tug of war	*Rugby forwards*	*Expected laboratory values*
Packed cell volume (%)	43.3 (0.5)*	46.4 (0.4)	40–54
Haemoglobin (g/l)	150 (2)*	154 (1)	14–16
Red blood cells (• 10^{12}/l)	5.0 (0.1)	5.0 (0.1)	4.6–6.5
White blood cells (• 10^{9}/l)	6.7 (0.3)	6.6 (0.3)	4–8
Red blood cell volume (fl)	86.4 (0.8)*	92.2 (1.7)	82–89
Platelets (• 10^{9}/l)	232.2 (11.1)	246.3 (10.6)	150–400

Values are presented as mean (SEM).
*Significant difference between the groups, $p<0.05$ (unpaired *t* test).

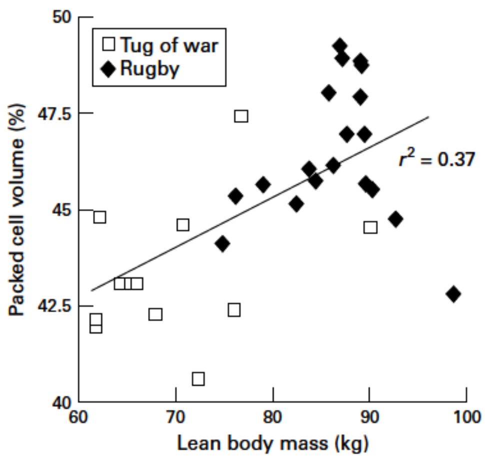

Figure 1 Correlation between lean body mass and packed cell volume. Data are shown for 16 tug of war athletes and 20 rugby union forwards. Lean body mass was estimated from skinfold measurements.

cholesterol were all within the normal range. Plasma creatine kinase levels were high and outside the normal range of the assay. The values for the group ranged from 91 to 607 U/l, and four of the subjects had values above the expected. Both urea and uric acid were within normal concentrations. Electrolyte levels were also normal.

Blood haematology data were within the normal range (table 4). Both packed cell volume ($p<0.001$) and haemoglobin concentration ($p<0.03$) were lower in the tug of war group than in the rugby forwards. Erythrocyte volume for the tug of war athletes was normal but was also lower ($p<0.02$) than the rugby group. Regression analysis showed a direct correlation between lean body mass and packed cell volume ($r^2 = 0.37$, $p<0.0001$; fig 1), haemoglobin concentration ($r^2 = 0.13$, $p<0.05$), and erythrocyte volume ($r^2 = 0.21$, $p<0.01$) for the combined group of athletes.

Discussion

The results of this study describe the physiological, anthropometric, biochemical, and haematological characteristics of elite tug of war athletes. For comparative purposes, the data were analysed relative to data collected on a group of international rugby union forwards.

Aerobic power, as measured by $\dot{V}O_2MAX$, was higher in the tug of war group than age and sex matched norms for the general population[9] but below values reported for elite endurance athletes.[10] Although the physical demands of tug of war are such that a high aerobic power is not a primary prerequisite for success, the training methods used by these athletes include development of general cardiovascular endurance. A relatively high level of aerobic fitness may be indirectly beneficial to these athletes because it may help them counteract general fatigue during training and competition. It is interesting that $\dot{V}O_2MAX$, expressed in absolute terms (litres/min), was lower for the tug of war group than for the rugby forwards. However, when corrected for body weight, $\dot{V}O_2MAX$ was higher in the tug of war group. As body weight was different between the two groups, the normalisation of $\dot{V}O_2MAX$ for body weight allows direct comparison of aerobic power.

Strength is a vital attribute of tug of war, with high levels of grip, back, and leg strength being essential to resist the large forces generated by the opposing team. Muscular contraction is mainly isometric, alternating slow concentric and eccentric contraction against a heavy resistance. Isometric strength is also essential for rugby forwards to effectively perform activities such as scrummaging and mauling, which are static or semistatic in nature.[11] The importance of isometric strength is reflected in the high levels of grip and back strength recorded by both groups, for which there was no significant difference between groups. The values for combined grip strength are well above the average for age matched normative data in untrained subjects (952–1020 N)[12] and greater than those reported for Olympic class sailors.[13] The data are similar to those observed elsewhere for elite rowers,[14] rugby players,[15] and taekwon do athletes.[16] In contrast, a comparison of isometric strength tests based on a composite measure of grip and back strength showed that the tug of war group had a significantly higher strength to body mass ratio when adjusted for either body weight or lean body mass. This is despite the fact that the rugby forwards had a similar percentage body fat and significantly higher lean body mass. This is consistent with other weight category sports such as rowing, where lightweight oarsmen have been found to have a significantly higher strength to body weight ratio despite their heavyweight counterparts having higher absolute strength values.[17] The 1-RM bench press and squat are widely used tests for the evaluation of upper and lower body dynamic strength.[18 19] However, it is uncommon for tug of war athletes to perform a 1-RM in training. Therefore the 3-RM test was used in preference to a 1-RM because of safety considerations and can be compared using the strength continuum developed by Fleck and Kraemer.[19] Although no comparison could be made with the rugby group in the present study, bench press values for the tug of war subjects were lower than those previously reported for rugby forwards.[15] The low values expressed for the bench press may be a reflection of the non-specific nature of the test for tug of war, where the main emphasis is on a pulling action using the latissimus dorsi, biceps, brachialis, and rhomboids. In contrast, the pectoralis major, deltoids and triceps predominate in the pushing motion of the bench press. Despite the lack of specificity, the two strength tests are commonly used as indicators of upper and lower body strength and were selected for the purpose of comparison with normative data and other sports. It should also be noted that tug of war is a weight category sport and it may be more appropriate to express strength values relative to body weight. Generally, one would expect that a well trained athlete in a strength based sport would be able to bench press at least their own body weight, and squat twice their body weight.

Because of the emphasis on isometric and slow dynamic muscular contraction associated with the pulling action in tug of war, it is not surprising that dynamic leg power was significantly lower in the tug of war group than in the rugby forwards. The values of the former were found to be unexceptional for young fit adults,[20] but nevertheless higher than those reported for tae kwon do athletes.[16] In contrast with tug of war, explosive leg power has been shown to be essential in the game of rugby and in particular for forwards in activities such as lineout and scrummaging.[11] The data for rugby forwards in the present study are similar to values reported elsewhere for rugby[15] and soccer.[21]

The results of the selected flexibility tests show that only a moderate level of flexibility appears necessary for high level performance in tug of war. The findings of this study showed no significant di erence between the tug of war and rugby groups in flexibility of the hamstrings and lower back as determined by the sit and reach and forward flexion tests. Although the mean sit and reach values for the group were within the expected range, they were lower than the average previously reported for age matched untrained subjects.[22] Although the sit and reach test is a widely recognised measure of gross hamstring flexibility, the movement, by its nature, also incorporates the lower back and may be influenced by factors such as limb length and trunk size. Nevertheless, the selection of the sit and reach test can be justified in that tug of war requires a similar movement pattern. In contrast with the tug of war group, back extension was found to be significantly higher in the rugby forwards and is reflective of specific activities in rugby such as scrummaging, where a high level of flexibility would be advantageous.

All of the tug of war participants had a normal healthy blood chemistry profile. Levels of blood glucose, triglycerides, cholesterol, and liver enzymes were within the normal range. However, plasma creatine kinase levels were elevated for the group as a whole. All of the subjects had a normal resting and exercise electrocardiogram and there was no reason to believe that the increased creatine kinase was of cardiac origin. An increase in plasma creatine kinase may indicate exercise induced skeletal muscle damage, which has been shown to result in disruption of the myofibril at the level of the sarcomere, Z band streaming, and necrotic fibres.[23–25] The process is generally initiated by unusual or extreme exercise that includes eccentric muscle contractions. We have previously shown elevated creatine kinase levels after a single bout of isometric exercise and exercise involving eccentric muscle contractions.[26–28] These exercise induced increases in creatine kinase may remain for up to 10 days after an exercise bout.[29] Tug of war includes not only high intensity isometric and concentric contractions, but also substantial eccentric loads on the active muscle groups. As the tug of war group was in training at the time of testing, they were asked to refrain from intense training for the two days preceding the tests. Given that creatine kinase levels may remain elevated for prolonged periods after exercise, it is most likely that tug of war training, with its associated stress on the muscles, caused some exercise induced muscle damage and the resultant elevated blood creatine kinase levels.

The tug of war group had a normal blood haematology profile although packed cell volume, haemoglobin concentrations, and erythrocyte volume were lower than for the rugby group. The di erence in haematological measures between the two groups may be due to greater haemolysis, haemodilution, or di erences in body composition.[30 31] It is unlikely that the intramuscular pressures consequent on sustained isometric contraction do actually rupture erythrocytes or cause intravascular haemolysis. It is also unlikely that the typical endurance training load of a tug of war athlete could lead to haemodilution. However, di erences in body size and composition between the two groups of athletes may provide an interesting explanation for the lower haematological measures in the tug of war group. Previous studies in athletes have shown that packed cell volume and haemoglobin concentrations are independently related to lean body mass.[32] Regression analysis showed a direct correlation between lean body mass and all three haematological measures, confirming previous observations for these variables in Olympic squads.[32] Although androgen levels were not measured in this study, there is a direct relation between testosterone and muscle mass.[33] It is also known that testosterone can increase packed cell volume and haemoglobin concentration.[34] Thus it is possible that the higher erythrocyte volume, packed cell volume, and haemoglobin concentration in the rugby group may have been due to increased androgen activity associated with a greater muscle mass in this group.

In conclusion, these data indicate that international level tug of war athletes have above average strength and aerobic power relative to body size, but have relatively low explosive leg power and back flexibility. These data provide reference standards for the sport and may be useful for monitoring and evaluating current and future participants. The data also have implications for coaches and point to the need for greater consideration of the demands of the sport, with a view to maximising specificity and the e ectiveness of training programmes. From a physiological perspective, the data confirm the relation between packed cell volume/haemoglobin and lean body mass in athletes. These data may be helpful in understanding the physiological and metabolic adaptations to exercise training in elite athletes.

We are grateful to Michael Fitzgerald for excellent technical support, Donal O'Gorman for assistance with data collection, and the support sta of the NCTC for facilitating the work. We are especially grateful to the athletes who contributed their time and e ort and to the late Tommy Gilmore and the Tug of War Association of Ireland for their cooperation in this study.

1 Iiai T, Ohmori K, Ohtaki M, *et al*. Adult bochdalek hernia after playing at a tug of war. *Kyobu Geka* 1997;**50**:968–70.
2 Moran M. Extensive retinal hemmorhage after a game of tug-of-war. *Ceskoslovenska-oftalmolgie* 1984;**40**:375–80.
3 Pedersen SS, Holst E. Tug-O-War: a dangerous sport. *Tandlaegebladet* 1981;**85**:187–90.
4 Ferguson A, Kierkegaard E. Trauma resulting from tug-of-war. *Ugeskrift for Laeger* 1981;**143**:2354.
5 Fogelholm M. E ects of bodyweight reduction on sports performance. *Sports Med* 1994;**18**:249–67.
6 Jackson AS, Pollock ML. Generalized equations for predicting body density in men. *Br J Nutr* 1978;**40**:497–504.
7 O'Gorman D, Hunter A, McDonnacha C, *et al*. Validity of field tests for evaluating endurance capacity in competitive and international-level sports participants. *J Strength Cond Res* 2000;**14**:62–7.
8 Sayers SP, Harackiewicz DV, Harmen EA, *et al*. Cross-validation of three jump power equations. *Med Sci Sports Exerc* 1999;**31**:572–7.
9 UK Sports Council and Health Education Authority. A report on activity patterns and fitness levels. In: *Allied Dunbar national fitness survey*. London: Sports Council and Health Education Authority, 1992.
10 Butts NK. Profiles of elite athletes: physical and physiological characteristics. In: Butts NK, Gushiken TT, Zarins B, eds. *The elite athlete*. New York: Spectrum Publications Inc, 1985:183–207.
11 Hazeldine R, McNab T. *Fit for rugby*. London: Kingswood Press, 1991.
12 Nieman DC. *Exercise testing and prescription*. 4th ed. Mountain View: Mayfield, 1999.
13 Plyley MJ, Davis GM, Shepard RJ. Body profile of olympic-class sailors. *Physician and Sports Medicine* 1985;**13**:152–67.
14 Secher N. Physiology of rowing. *J Sports Sci* 1983;**1**:23–53.
15 Nicholas CW. Anthropometric and physiological characteristics of rugby union football players. *Sports Med* 1997;**23**:375–96.
16 Heller J, Peric T, Dlouha R, *et al*. Physiological profiles of male and female taekwon-do (ITF) black belts. *J Sports Sci* 1998;**16**:243–9.
17 Hagerman FC. Applied physiology of rowing. *Sports Med* 1984;**1**:303–26.
18 Hoeger W, Barette S, Hale D, *et al*. Relationship between repetitions and selected percentages of one repetition maximum. *Journal of Applied Sports Science Research* 1987;**1**:11–13.
19 Fleck SJ, Kraemer WJ. *Designing resistance training programs*. 2nd ed. Champaign, IL: Human Kinetics, 1997.
20 Getchell B. *Physical fitness: a way of life*. New York: John Wiley and Sons, 1979.
21 Tumilty D. Physiological characteristics of elite soccer players. *Sports Med* 1993;**16**:80–96.
22 Raven PB, Gettman LR, Pollock ML, *et al*. A physiological evaluation of professional soccer players. *Br J Sports Med* 1976;**10**:209–16.
23 Frieden JM, Sjostrom M, Ekblom B. Myofibrillar damage following intense eccentric exercise in man. *Int J Sports Med* 1983;**4**:170–6.
24 Jones DA, Newham DJ, Round JM, *et al*. Experimental human muscle damage: morphological changes in relation to other indicies of damage. *J Physiol (Lond)* 1986;**375**:435–48.
25 Newham DJ, McPhail G, Mills KR, *et al*. Ultrastructural changes after concentric and eccentric contractions of human muscle. *J Neurol Sci* 1983;**61**:109–22.
26 Kirwan JP, Clarkson PM, Graves JE, *et al*. Levels of serum creatine kinase and myoglobin in women after two isometric exercise conditions. *Eur J Appl Physiol* 1986;**55**:330–3.
27 Kirwan JP, Hickner RC, Yarasheski KE, *et al*. Eccentric exercise induces transient insulin resistance in healthy individuals. *J Appl Physiol* 1992;**72**:2197–202.
28 del Aguila LF, Krishnan RK, Ulbrecht JS, *et al*. Muscle damage impairs insulin stimulation of IRS-1, PI3-kinase, and Akt-kinase in human skeletal muscle. *Am J Physiol* 2000;**279**:E206–12.
29 Manfredi TG, Fielding RA, O'Reilly KP, *et al*. Serum creatine kinase activity and exercise-induced muscle damage in older men. *Med Sci Sports Exerc* 1991;**23**:1028–34.
30 Green HJ, Sutton JR, Coates G, *et al*. Response of red cell and plasma volume to prolonged training in humans. *J Appl Physiol* 1991;**70**:1810–15.
31 Magnussen B, Hallberg L, Rosslander L, *et al*. Iron metabolism and "sports anemia". II. A hematological comparison of elite runners and control subjects. *Acta Med Scand* 1984;**216**:157–64.
32 Telford RD, Cunningham RB. Sex, sport, and body-size dependency of hematology in highly trained athletes. *Med Sci Sports Exerc* 1991;**23**:788–94.
33 Baumgartner RN, Waters DL, Gallagher D, *et al*. Predictors of skeletal muscle mass in elderly men and women. *Mech Ageing Dev* 1999;**107**:123–36.
34 Palacios A, Campfield LA, McClure RD, *et al*. E ect of testosterone enanthate on hematopoiesis in normal men. *Fertil Steril* 1983;**40**:100–4.

Take home message
This is the first study to evaluate the physiological and metabolic characteristics of tug of war. By providing an insight into the physical capabilities that produce success, the findings will have implications for current training practices. In adding to the current limited body of knowledge, the primary value will be to assist athletes and coaches in developing their understanding of the sport and implementing e ective training programmes, which replicate the demands of the sport and ultimately a ect performance.

Please note that the editorial o ce of *British Journal of Sports Medicine* has moved. Please send all future communications to: Dr Paul McCrory, *British Journal of Sports Medicine*, Centre for Sports Medicine Research & Education School of Physiotherapy Level 1, 200 Berkeley Street, Parkville, Victoria 3052, Australia. Tel: +61 3 8344 4118; Fax: +61 3 8344 3771; Email: bjsm@bmjgroup.com

Physiological and metabolic characteristics of elite tug of war athletes

G Warrington, C Ryan, F Murray, et al.

Br J Sports Med 2001 35: 396-401
doi: 10.1136/bjsm.35.6.396