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Physiological and metabolic characteristics of elite tug of war athletes

G Warrington, C Ryan, F Murray, P Duffy, J P Kirwan

Abstract

Objective—To determine the aerobic power ($V_{O_2 \text{MAX}}$), 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.

Keywords: tug of war; body composition; $V_{O_2 \text{MAX}}$; strength; power; flexibility
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 off 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 suprailliac) using Harpenden calipers (British Indicators Ltd, St Albans, Hertfordshire, UK). Body fat and lean body mass were estimated as described by Jackson and Pollock.1

**AEROBIC POWER**

Maximal oxygen uptake (V\textsubscript{O\textsubscript{2}} MAX) was determined using a constant speed, incremental grade, treadmill protocol test as previously described.3 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 90° 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.4

**FLEXIBILITY**

Before flexibility assessment, each subject performed a standardised 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 differential 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

<table>
<thead>
<tr>
<th></th>
<th>Tug of war</th>
<th>Rugby forwards</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (years)</td>
<td>34.4 (1.9)*</td>
<td>26.8 (0.6)</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>181.8 (1.2)*</td>
<td>188.2 (1.6)</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>83.6 (3.0)*</td>
<td>104.4 (1.8)</td>
</tr>
<tr>
<td>Body mass index (kg/m²)</td>
<td>25.2 (0.7)*</td>
<td>29.5 (0.6)</td>
</tr>
<tr>
<td>Body fat (%)</td>
<td>16.7 (0.9)</td>
<td>16.3 (1.1)</td>
</tr>
<tr>
<td>Fat mass (kg)</td>
<td>14.2 (1.1)*</td>
<td>18.2 (1.2)</td>
</tr>
<tr>
<td>Lean body mass (kg)</td>
<td>69.4 (2.1)*</td>
<td>86.2 (1.2)</td>
</tr>
</tbody>
</table>

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

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

<table>
<thead>
<tr>
<th></th>
<th>Tug of war</th>
<th>Rugby forwards</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sit and reach (cm)</td>
<td>25.4 (2.0)</td>
<td>25.7 (1.8)</td>
</tr>
<tr>
<td>Forward flexion (cm)</td>
<td>8.0 (2.1)</td>
<td>9.4 (1.6)</td>
</tr>
<tr>
<td>Back flexion (cm)</td>
<td>28.6 (1.4)*</td>
<td>34.2 (1.5)</td>
</tr>
<tr>
<td>Dominant hand grip strength (N)</td>
<td>622 (20.9)</td>
<td>607 (13.2)</td>
</tr>
<tr>
<td>Non-dominant hand grip strength (N)</td>
<td>591.4 (20.7)</td>
<td>568.2 (12.5)</td>
</tr>
<tr>
<td>Composite strength/kg BW</td>
<td>28.8 (1.2)</td>
<td>32.4 (4.8)</td>
</tr>
<tr>
<td>Composite strength/kg LBM</td>
<td>46.4 (1.5)*</td>
<td>35 (1.5)</td>
</tr>
<tr>
<td>Back strength (N)</td>
<td>2004.8 (104.4)</td>
<td>1930.8 (73.8)</td>
</tr>
<tr>
<td>Bench press 3-RM (kg)</td>
<td>46.9 (3.3)</td>
<td>N/A</td>
</tr>
<tr>
<td>Squat 3-RM (kg)</td>
<td>162.7 (6.2)</td>
<td>N/A</td>
</tr>
<tr>
<td>Vertical jump (W)†</td>
<td>465.9 (151.6)*</td>
<td>6198.2 (105)</td>
</tr>
</tbody>
</table>

Values are presented as mean (SEM).
†Converted to watts using the regression equation of Sayers et al.
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

<table>
<thead>
<tr>
<th></th>
<th>Tug of war</th>
<th>Expected laboratory values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Glucose (mmol/l)</td>
<td>5.3 (0.1)</td>
<td>3.5–6</td>
</tr>
<tr>
<td>Cholesterol (mmol/l)</td>
<td>5.3 (0.3)</td>
<td>3.6–6.5</td>
</tr>
<tr>
<td>Triglycerides (mmol/l)</td>
<td>1.0 (0.2)</td>
<td>0.8–1.8</td>
</tr>
<tr>
<td>Creatinine (µmol/l)</td>
<td>110 (2.8)</td>
<td>60–115</td>
</tr>
<tr>
<td>Total protein (g/l)</td>
<td>71.3 (1.0)</td>
<td>64–83</td>
</tr>
<tr>
<td>Alkaline transaminase (U/L)</td>
<td>17.5 (1.8)</td>
<td>&lt;40</td>
</tr>
<tr>
<td>Calcium (mmol/l)</td>
<td>2.0 (0.03)</td>
<td>2.1–2.6</td>
</tr>
<tr>
<td>Creatine kinase (U/L)</td>
<td>209.3 (40)*</td>
<td>24–195</td>
</tr>
<tr>
<td>Aspartate amionotransferase (U/L)</td>
<td>29.5 (21.2)</td>
<td>7–40</td>
</tr>
<tr>
<td>Lactate dehydrogenase (U/L)</td>
<td>288.8 (10.4)</td>
<td>230–460</td>
</tr>
<tr>
<td>Iron (µmol/l)</td>
<td>19.0 (1.2)</td>
<td>9–29</td>
</tr>
<tr>
<td>Urea (mmol/l)</td>
<td>4.8 (0.3)</td>
<td>2.5–6.4</td>
</tr>
<tr>
<td>Uric acid (µmol/l)</td>
<td>282.1 (11.4)</td>
<td>210–420</td>
</tr>
<tr>
<td>Sodium (mmol/l)</td>
<td>139.3 (0.7)</td>
<td>135–145</td>
</tr>
<tr>
<td>Potassium (mmol/l)</td>
<td>4.1 (0.1)</td>
<td>3.5–5</td>
</tr>
<tr>
<td>Chloride (mmol/l)</td>
<td>105.8 (0.6)</td>
<td>100–106</td>
</tr>
</tbody>
</table>

Values are presented as mean (SEM).
*Outside the normal range.
Elite tug of war athletes

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

<table>
<thead>
<tr>
<th></th>
<th>Tug of war</th>
<th>Rugby forwards</th>
<th>Expected laboratory values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Packed cell volume (%)</td>
<td>43.3 (0.5)*</td>
<td>46.4 (0.4)</td>
<td>40–54</td>
</tr>
<tr>
<td>Haemoglobin (g/l)</td>
<td>150 (2)*</td>
<td>154 (1)</td>
<td>14–16</td>
</tr>
<tr>
<td>Red blood cells ×10^12/l</td>
<td>5.0 (0.1)</td>
<td>5.0 (0.1)</td>
<td>4.6–6.5</td>
</tr>
<tr>
<td>White blood cells ×10^9/l</td>
<td>6.7 (0.3)</td>
<td>6.6 (0.3)</td>
<td>4–8</td>
</tr>
<tr>
<td>Red blood cell volume (%)</td>
<td>86.4 (0.8)*</td>
<td>82.2 (1.7)</td>
<td>82–89</td>
</tr>
<tr>
<td>Platelets ×10^12/l</td>
<td>232.2 (11.1)</td>
<td>246.3 (10.6)</td>
<td>150–400</td>
</tr>
</tbody>
</table>

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.

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 VO₂MAX, was higher in the tug of war group than age and sex matched norms for the general population but below values reported for elite endurance athletes. 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 VO₂MAX, 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, VO₂MAX was higher in the tug of war group. As body weight was different between the two groups, the normalisation of VO₂MAX 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. 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) and greater than those reported for Olympic class sailors. The data are similar to those observed elsewhere for elite rowers, rugby players, and taekwon do athletes. 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. The 1-RM bench press and squat are widely used tests for the evaluation of upper and lower body dynamic strength. 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. 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. 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, but nevertheless higher than those reported for taekwondo athletes. 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 scrumming. The data for rugby forwards in the present study are similar to values reported elsewhere for rugby and soccer.

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 difference between the tug of war and rugby groups in flexibility of the hamstring 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. 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 scrumming, 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. 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. These exercise-induced increases in creatine kinase may remain for up to 10 days after an exercise bout. 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 difference in haematological measures between the two groups may be due to greater haemolysis, haemodilution, or differences in body composition. 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, differences 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. Regression analysis showed a direct correlation between lean body mass and all three haematological measures between the two groups may be due to greater haemolysis, haemodilution, or differences in body composition. 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, differences 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. Regression analysis showed a direct correlation between lean body mass and all three haematological measures, confirming previous observations for these variables in Olympic squads. Although androgen levels were not measured in this study, there is a direct relation between testosterone and muscle mass. 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 effectiveness 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 staff of the NCTC for facilitating the work. We are especially grateful to the athletes who contributed their time and effort and to the late Tommy Gilmore and the Tug of War Association of Ireland for their cooperation in this study.

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