Neuromuscular characteristics and fatigue in endurance and sprint athletes during a new anaerobic power test

Leena Paavolainen¹, Keijo Häkkinen², Ari Nummela¹, Heikki Rusko¹

¹ Research Institute for Olympic Sports, Rautpohjankatu 6, SF 40700 Jyvaskylä, Finland
² Department of Biology of Physical Activity, University of Jyväskylä, Finland

Accepted: 7 April 1994

Abstract. The purpose of this study was to investigate neuromuscular and energy performance characteristics of anaerobic power and capacity and the development of fatigue. Ten endurance and ten sprint athletes performed a new maximal anaerobic running power test (MARP), which consisted of n x 20-s runs on a treadmill with 100-s recovery between the runs. Blood lactate concentration [la−]b was measured after each run to determine submaximal and maximal indices of anaerobic power (P₃mmol-1⁻¹, P₅mmol-1⁻¹, P₁₀mmol-1⁻¹, and P₉max) which was expressed as the oxygen demand of the runs according to the American College of Sports Medicine equation: the oxygen uptake (ml·kg⁻¹·min⁻¹) = 0.2·velocity (m·min⁻¹) + 0.9·slope of treadmill (frac)·velocity (m·min⁻¹) + 3.5. The height of rise of the centre of gravity of the counter movement jumps before (CMJrest) and during (CMJ) the MARP test, as well as the time of force production (tF) and electromyographic (EMG) activity of the leg muscles of CMJ performed after each run were used to describe the neuromuscular performance characteristics. The maximal oxygen uptake (VO₂max), anaerobic and aerobic thresholds were determined in the VO₂max test, which consisted of n x 3-min runs on the treadmill. In the MARP-test P₉max did not differ significantly between the endurance [116 (SD 6) ml·kg⁻¹·min⁻¹] and sprint [120 (SD 4) ml·kg⁻¹·min⁻¹] groups, even though CMJrest and peak [la−]b were significantly higher and VO₂max was significantly lower in the sprint group than in the endurance group and CMJrest height correlated with P₉max (r=0.50, P<0.05). The endurance athletes had significantly higher mean values of P₃mmol-1⁻¹ and P₅mmol-1⁻¹ [89 (SD 7) vs 76 (SD 8) ml·kg⁻¹·min⁻¹, P<0.001 and 101 (SD 5) vs 90 (SD 8) ml·kg⁻¹·min⁻¹, P<0.01]. Significant positive correlations were observed between the P₃mmol-1⁻¹ and VO₂max anaerobic and aerobic thresholds. In the sprint group CMJ and the averaged integrated iEMG decreased and tF increased significantly during the MARP test, while no significant changes occurred in the endurance group. The present findings would suggest that P₉max reflected in the main the lactacid power and capacity and to a smaller extent alactacid power and capacity. The duration of the MARP test and the large number of CMJ may have induced considerable energy and neuromuscular fatigue in the sprint athletes preventing them from producing their highest lactacid P₉max at the end of the MARP test. Due to lower submaximal [la−]b, (anaerobic sprinting economy) the endurance athletes were able to reach almost the same P₉max as the sprint athletes.

Key words: Anaerobic power – Blood lactate – Electromyography – Maximal oxygen uptake – Force production

Introduction

It has been found that endurance athletes typically have a high oxidative capacity in their muscles (Gollnick et al. 1972; Tesch et al. 1983), a high potential to recover from exercise (Sjödin 1976) and in general a very good maximal oxygen uptake (VO₂max; Bergh et al. 1978; Rusko et al. 1978). In contrast, it has been found that sprint athletes have high glycolytic potential (Gollnick et al. 1974; Tesch 1980), are more susceptible to fatigue (Thorstensson and Karlsson 1976) and have very high anaerobic capacity and power (Kindermann and Keul 1977). Aerobic (Thₐer) – anaerobic threshold (Thₐer) and VO₂max tests have commonly been used to describe aerobic capacity (Kindermann et al. 1979), but the maximal anaerobic power and capacity of athletes is difficult to measure in laboratory conditions (Vandewalle et al. 1987). The vertical jump test (Bosco et al. 1983), staircase test (Margaria et al. 1966), treadmill running test (Schnabel and Kindermann 1983) and cycle ergometer test (Ayalon et al. 1974) have been used but, according to Vandewalle et al. (1987), none of these tests has enabled accurate measurement of all
the different determinants of maximal anaerobic performance. Rusko et al. (1993) have recently introduced a new laboratory test method to measure both the energy and neuromuscular components of submaximal and maximal anaerobic running power.

The purpose of the present study was to investigate the neuromuscular and energy performance characteristics of endurance and sprint athletes, who are well known to differ in their force, speed and endurance characteristics, using the new anaerobic running power test method developed by Rusko et al. (1993). A further aim was to examine in more detail the development of fatigue in endurance and sprint athletes during the anaerobic power test.

**Methods**

**Subjects.** The endurance athletes were ten male cross-country skiers and the sprint athletes ten male sprint runners. All the athletes were competing at national level. Some of the results obtained from the sprint group have been published earlier elsewhere (Rusko et al. 1993).

The physical characteristics of the subjects are presented in Table 1. The percentage of body fat was estimated from the thickness of four skinfolds (triceps, biceps, subscapula and supraillium; Durnin and Rahaman 1967).

**Measurements**

**Procedure.** After the anthropometric measurements, the subjects performed the maximal staircase running test (Margaria et al. 1966). The mean value of the three best times was taken for the calculation of the vertical component of running velocity (v). Thereafter, the subjects performed two tests on a treadmill on the same day: a maximal anaerobic running power (MARP) test (Rusko et al. 1993) and 3 h later a maximal aerobic power test. The MARP test consisted of n-20-s runs on a treadmill with 100-s recovery between runs. The first run was performed at 14.3 km·h⁻¹ on a 5° gradient. The speed of the treadmill was increased by 1.26 km·h⁻¹ for each consecutive run until exhaustion. Exhaustion in the MARP test was determined as the time when the subject could not longer run at the speed of the treadmill. Maximal anaerobic power (Pmax) of running was calculated from the power of the last completed 20-s run and from the exhaustion time of the following faster run (Rusko et al. 1993). The Thae was determined as a point just below that level of energy metabolism (Vo2) at which the blood lactate concentration increased distinctly from its initial level of around 2 mmol·l⁻¹ and the beginning of the nonlinear increase in V̇O₂ and VO₂. The Thae was determined as a point just below that level of energy metabolism (Vo2) at which the blood lactate concentration increased distinctly from its initial level of around 2 mmol·l⁻¹ and the beginning of the nonlinear increase in V̇O₂ and VO₂ with the horizontal. Fingertip blood samples (volume 50 μl) for determination of lactate concentration were taken at rest, 40 s after each run and 2.5, 5, and 15 min after exhaustion. Blood lactate concentrations were analysed by the Roche (model 640) lactate analyser. The blood lactate-power curve was used to calculate submaximal power at 3 mmol·l⁻¹ (P3), 5 mmol·l⁻¹ (P5) and 10 mmol·l⁻¹ (P10) blood lactate concentrations.

Voluntary maximal vertical counter movement jumps (CMJ) were performed on a force-platform (Komi and Bosco 1978), which was beside the treadmill, before the MARP test and 15, 25 and 35 s after each run. Series of three separate CMJ were also performed 1, 2.5, 5, and 15 min after exhaustion. Electromyographic (EMG) activities from the rectus femoris (RF), vastus lateralis (VL) and gastrocnemius (GA) muscles of the right leg were recorded telemetrically (Biomes 2000, Gloner). The sampling frequency was 1000 Hz. Bipolar (interelectrode distance 20 mm) surface EMG recording (miniature skin electrodes) was employed and the electrodes were placed longitudinally over the motor point area (Iliaikinen and Komi 1983). The EMG and force signals were stored during each single CMJ on video tape (Racal store) for later computerized analysis. The height of rise of the centre of gravity and the time of the force production (tF) (including both concentric and the previous eccentric phase) were determined in each case from the force-time curve (Komi and Bosco 1978) as the mean of the two best trials. The EMG data was integrated (iEMG) together with the force data using a Codas computer system (Dataq Instruments, Inc.) and expressed for 1 s. The EMG were later averaged for further analyses. The summing of the iEMG for GA, RF and VL muscles was taken up to the final results because the changes of the iEMG activity for each muscle separately were very similar to that change, when the iEMG of GA, RF and VL muscles were summed. The EMG analysis in the sprinters could be recorded only from nine subjects, because the EMG recording from the muscles was not successful for one of them.

The subjects performed the V̇O₂max test on the treadmill 3 h after the MARP test. The initial speed and gradient were 6.3 km·h⁻¹ and 1° and the speed was increased 1.8 km·h⁻¹ every 3 min until exhaustion. Fingertip blood samples for determination of lactate concentration and heart rate were taken every 3 min. Ventilation (V̇E), V̇O₂ and carbon dioxide production (VCO₂) were measured automatically by an Oxycon IV gas analyser (Mijnhardt) for every 30-s period. The Thae and Thae were determined according to blood lactate concentration, V̇O₂ and VCO₂. The Thae was determined as a point just below that level of energy metabolism (V̇O₂) at which the blood lactate concentration increased distinctly from its initial level of around 2 mmol·l⁻¹ and the beginning of the nonlinear increase in V̇O₂ and VCO₂ compared with V̇O₂. The Thae was determined as the beginning of accelerated lactate accumulation at around 4 mmol·l⁻¹ and was just below that point where the linearity in the V̇E:V̇O₂ and VCO₂:V̇O₂ curves disappeared markedly for the second time. V̇O₂max was taken as the highest 30-s V̇O₂ value (Rusko et al. 1980; Annona and Rusko 1984).

**Statistical methods.** Means, standard deviations and coefficients of correlation were calculated by standard methods. Differences between and within the endurance and sprint groups were tested for significance by Student's t-test (unpaired and paired).

**Results**

The Pmax did not differ significantly between the endurance and the sprint groups, but the endurance athletes

---

**Table 1. The physical characteristics of the endurance and the sprint groups**

<table>
<thead>
<tr>
<th>Variable</th>
<th>Endurance group (n = 10)</th>
<th>Sprint group (n = 10)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>mean</td>
<td>SD</td>
</tr>
<tr>
<td>Age (years)</td>
<td>21</td>
<td>2</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>179.1</td>
<td>1.3</td>
</tr>
<tr>
<td>Body mass (kg)</td>
<td>70.2</td>
<td>6.5</td>
</tr>
<tr>
<td>Fat (%)</td>
<td>8.3</td>
<td>1.3</td>
</tr>
<tr>
<td>Training background (years)</td>
<td>6.6</td>
<td>1.4</td>
</tr>
</tbody>
</table>

\[ \text{VO}_2 = 0.2 \cdot v \cdot (\text{g} \cdot \text{m}^{-1} \cdot \text{min}^{-1}) + 0.9 \cdot g \cdot (\text{fract}) \cdot v \cdot (\text{m} \cdot \text{min}^{-1}) + 3.5 \]

where VO₂ is oxygen uptake, v is the speed of the treadmill and g is the slope of the treadmill expressed as the tangent of the angle with the horizontal.