Anaerobic Power, Creatine Kinase Activity, Lactate Concentration, and Acid-Base Equilibrium Changes Following Bouts of Exhaustive Strength Exercises

ADAM ZAJAC, ZBIGNIEW WAŚKIEWICZ, AND WIESŁAW PILIS

Academy of Physical Education, Katowice, Poland.

ABSTRACT

The study was conducted on 10 male bodybuilders and pow-
erlifters who performed highly exhaustive strength exercises for both the upper and lower limbs. They included 10 pro-
gressive sets of squats for the lower limbs and 10 progressive sets of the bench press for the upper limbs. Anaerobic power was evaluated by the 30-second Wingate test 3 times: after a 2-day rest period, and 10 minutes and 24 hours after the cessation of exhaustive strength exercises. Blood samples were drawn at rest, 5 minutes, and 24 hours after the strength exercise for the evaluation of creatine kinase (CK) activity, lactate (LA) concentration, and changes in acid-base equilibrium. Relative external work ($W_t$) evaluated immediately after the cessation of strength exercises decreased significantly for both the lower and upper limbs, whereas relative maximal power ($P_{max}$) did not change significantly throughout the protocol. The return of $P_{max}$ and $W_t$ to initial levels within 24 hours occurred in the upper and lower limbs for $P_{max}$ and only in the upper limbs for $W_t$. Postexercise LA concentration was nearly 3 times as high for the lower limbs in comparison to upper limbs, and it remained slightly elevated 24 hours after the cessation of exercise in comparison to resting values. CK activity increased significantly 10 minutes after the intense strength exercises and rose to significantly higher levels 24 hours after the cessation of exercise. The level of serum CK may not be related to the amount of muscle mass utilized in strength exercises. Acid-base equilibrium variable changes were significantly different immediately after the end of the exercise session and returned to resting values 24 hours after the exhaustive exercise protocol. The 2 analyzed anaerobic power indices ($P_{max}$ and $W_t$) were significantly different for the upper and lower limbs under initial circumstances, 5 minutes, and 24 hours after exhaustive exercise, whereas blood variables (LA, CK, pH, and base excess) differed significantly only immediately after the strength protocol.

Key Words: creatine kinase activity, acid-base equilibrium, lactate concentration, anaerobic power, strength training

dices following strength exercises may be beneficial in the estimation of the training load and the rate of recuperation.

Evaluation of anaerobic power through the use of the Wingate test seems justified because of its high reliability and validity (4). Also, the Wingate test allows for the distinction between the upper and lower limbs, which is very important for the evaluation of physiological responses to strength exercises (5). All of the above-mentioned physiological and mechanical variables allow monitoring of the state of the athlete's body and influence the effectiveness of the training process.

The main purpose of this study was to evaluate the changes in anaerobic power in the upper and lower limbs and to analyze changes in CK activity, LA concentration, and acid-base equilibrium following intensive strength exercise.

**Methods**

Ten male, well-trained powerlifters and bodybuilders participated in the study. The average age of the subjects was 22.6 ± 2.1 years, with a mean body mass of 89.6 ± 9.2 kg and height of 181.2 ± 10.2 cm. Six of the 10 participants were powerlifters, and 5 of them ranked nationally, whereas the remaining 4 were bodybuilders and members of the national team. Consent for participation was obtained from all subjects after they were informed of the purpose and nature of the study. All of the athletes performed the 30-second Wingate test for the lower and upper limbs 3 times using the MONARK 839 ergocycle. The first test followed a 2-day rest period; the second test was 10 minutes after an exhaustive strength training session, and the third was 24 hours after a session. The upper- and lower-limbs’ strength protocol as well as anaerobic power evaluations were separated by a 3-day rest period. The Wingate tests were carried out for the lower and upper limbs separately. The resistance for the Wingate test was set 0.075 kp·kg⁻¹ of body weight for the lower limbs and at 0.040 kp·kg⁻¹ of body weight for the upper limbs. Variables such as relative maximal power (P_max), relative total external work (Wt), and fatigue index (FI) were measured (3–5). The strength exercise protocol included 10 sets of squats for the lower limbs and 10 sets of the bench press for the upper limbs, with the starting load set at 50% of the personal best (one repetition maximum [1RM] weight). The load was increased by 5% up to the seventh set and decreased by the same amount for the last 3 sets. In each of the first 3 sets, 15 repetitions were performed, 12 repetitions in the following 4 sets, and the final 3 sets were carried to concentric failure.

At rest, blood samples were drawn from the antecubital vein for the evaluation of CK activity, whereas blood samples from the finger tip (blood from capillary) were used for the evaluation of LA concentration and acid-base equilibrium variables. Blood samples were also drawn 4–5 minutes and 24 hours after the cessation of training for the evaluation of postexercise CK, LA, pH, and BE levels. CK activity and LA concentration measurements were carried out enzymatically using commercial kits (Boehringer Diagnostica, Mannheim, Germany). Blood HCO₃⁻ and BE levels were measured using the 168 pH Blood-Gas Analyzer (Ciba-Corning, East Walpole, MA). For the evaluation of the differences and their significance (p ≤ 0.05), analyses of the Student's t-test for dependent samples were used. The relationship between the upper and lower limbs in the area of Wingate-test mechanical parameters were determined using Pearson's correlation coefficients.

**Results**

The results of the 2-way analysis of variance (ANOVA) with repeated measures indicated significant differences between upper- and lower-limb values for both P_max and Wt in relation to time. Tukey post-hoc tests showed that directly after the exhaustive strength exercises maximal relative power decreased significantly for both the upper and lower limbs. Relative P_max decreased insignificantly in the case of the upper and lower limbs. Twenty-four hours after the cessation of strength exercises, the level of relative P_max remained slightly below control values for the lower limbs, whereas in the case of upper limbs it returned to the initial level, yet both differences were statistically insignificant. The character of changes of total external relative work induced during the Wingate test, which was obtained in pre- and postexercise conditions, was different for the upper and lower limbs. Immediately after the squats, total external work dropped significantly and remained under the control value 24 hours after the cessation of exercise, and the difference was statistically significant. The exhaustive 10 sets of the bench press caused a significant decrease in total external work directly after the session, but 24 hours later this value exceeded the initial level, yet it was statistically insignificant.

The analysis of the pattern of changes in relation to LA, CK, and acid-base equilibrium with the use of an ANOVA indicated significant differences throughout the group variable (upper to lower limb) and repeated measures (rest and 5 minutes and 24 hours after cessation).

Plasma CK activity increased significantly immediately after the strength exercise protocol only for the lower limbs, yet it rose to significantly greater values 24 hours after the cessation of exercise for both limbs. The average LA concentration after the lower-limb training session was almost 3 times higher than the value obtained for the upper limbs, and both differ-
Table 1. The mean ± SD, the significance of 2-way analysis of variance (ANOVA) with repeated measures, and Tukey post-hoc tests in all measured variables.†

<table>
<thead>
<tr>
<th>Variables</th>
<th>Initial</th>
<th>5 minutes after Wingate</th>
<th>24 hours after Wingate</th>
<th>Group</th>
<th>Time</th>
<th>Group × Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>Blood lactate concentration (mmol·L⁻¹)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Upper</td>
<td>1.963*</td>
<td>5.991***</td>
<td>2.211</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lower</td>
<td>2.111*</td>
<td>15.287**</td>
<td>2.388</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Creatine kinase activity (U·L⁻¹)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Upper</td>
<td>350.107</td>
<td>468.043</td>
<td>584.109****</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
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</tr>
<tr>
<td>Lower</td>
<td>335.043*</td>
<td>567.012</td>
<td>675.014****</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Relative maximal anaerobic power (w·kg⁻¹)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Upper</td>
<td>6.917***</td>
<td>10.810***</td>
<td>11.200***</td>
<td>&lt;0.001</td>
<td>&lt;0.05</td>
<td>NS</td>
</tr>
<tr>
<td>Lower</td>
<td>11.422***</td>
<td>1.044</td>
<td>0.801</td>
<td></td>
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<td></td>
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<tr>
<td>Total relative external work (J·kg⁻¹)</td>
<td></td>
<td></td>
<td></td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>&lt;0.05</td>
</tr>
<tr>
<td>Upper</td>
<td>171.040****,**</td>
<td>153.108***</td>
<td>174.138****</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lower</td>
<td>267.041****,**</td>
<td>245.037***</td>
<td>250.014</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Blood pH</td>
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<td></td>
<td></td>
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<td></td>
<td></td>
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<tr>
<td>Upper</td>
<td>7.356*</td>
<td>7.221******</td>
<td>7.334</td>
<td>&lt;0.05</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
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<tr>
<td>Lower</td>
<td>7.364*</td>
<td>7.104******</td>
<td>7.334</td>
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<td>Base excess (mM)</td>
<td></td>
<td></td>
<td></td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
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<tr>
<td>Upper</td>
<td>−4.294*</td>
<td>−14.076******</td>
<td>−5.104</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
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<tr>
<td>Lower</td>
<td>−4.851*</td>
<td>−20.277******</td>
<td>−4.882</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
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<tr>
<td>HCO₃ ion concentration</td>
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<td></td>
<td></td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Upper</td>
<td>20.952*</td>
<td>14.878******</td>
<td>21.000</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Lower</td>
<td>21.648*</td>
<td>10.682******</td>
<td>20.884</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
</tr>
</tbody>
</table>

†NS = not significant.
*I vs. II, p < 0.001.
**II vs. III, p < 0.05.
***Statistically significant differences between groups (upper-lower) at p < 0.001.
****I vs. II, p < 0.001.
*****I vs. II, p < 0.05.
******II vs. III, p < 0.001.
ences were statistically significant from the rest period. The LA levels returned to resting values 24 hours after the cessation of both upper- and lower-limb exercise protocols. All 3 acid-base equilibrium variables decreased significantly immediately after the exercise protocol, yet returned to resting levels within the 24-hour restitution period. Tukey test post-hoc results indicated significant differences between these variables. It is worth noticing that upper- and lower-limb differences were statistically significant for all acid-base equilibrium variables under the postexercise conditions. The mean and SD, the significance of a 2-way ANOVA with repeated measures, and the Tukey post-hoc tests in all measured variables are presented in Table 1 and Figure 1.

Discussion

The level of maximal anaerobic power usually obtained in the fourth to sixth second during the ergocycle test is significantly related to muscle creatine phosphate (CP) capacity and the rate of adenosine triphosphate (ATP) resynthesis through the phosphagen system (11). The replenishment of CP takes little time, and even 10 sets of exhaustive strength exercises allow peak anaerobic power to reach close to 95% of the initial level within 4–5 minutes of restitution. The decline in peak power is greater for the lower limbs and the compensation process slower probably because of the greater muscle mass involved during the squats and the ergocycle test. The squats also involve greater negative acceleration and a component of eccentric work, thus inducing greater external work that may lead to increased muscular fatigue (7, 15, 19). Total external work induced during the Wingate test is significantly dependent on the glycolytic capacity of the athlete (11). This phenomena is clearly exemplified by a much higher postexercise LA concentration and by the values of external work obtained 24 hours after the exercise. The significantly lower values of total external work immediately after the exhaustive exercise sessions, in the case of both the upper and lower limbs, were probably caused by depletion of muscle CP and glycogen (15). LA concentrations and acid-base equilibrium variables changed significantly immediately after the exercise protocol. It is worth noticing that the level of all these variables were statistically different for the upper and lower limbs; however, they all returned to resting values within 24 hours. The tendency of the above changes are most likely influenced by muscular tension and muscle mass, which is significantly greater in lower limbs.

Several research projects have reported prolonged elevation of plasma CK following intensive anaerobic exercise (13, 18). It was hypothesized that the level of postexercise plasma CK is related to muscle tension, type of contraction, and most of all muscle mass involved in exercise (10). Despite a significantly greater muscle mass involved in the squats and lower limb ergocycle testing, the level of CK immediately after and 24 hours following the exercise was similar to that of the upper limbs. Some research projects have indicated that postexercise serum CK elevation is not necessarily related to the muscle mass involved or the type of contraction (8, 12). The analysis of individual values of resting and postexercise plasma CK shows great variations. The 2 least-trained athletes with a personal squat record of 150 kg had resting CK values below 300 U·L$^{-1}$, with postexercise values (24 hours) slightly above 600 U·L$^{-1}$. When considering the 2 national champions whose squat personal records equaled 230 and 250 kg, the resting and postexercise values of CK were nearly twice as high. This phenomena may be related to the greater strength potential and higher muscular tension of the high caliber athletes (1). High-caliber strength athletes are usually blessed with a high proportion of fast twitch fibers (11), and research has indicated that CK efflux is significantly related to mean strength level and fast twitch fiber area (9, 14). Results suggest that mechanical factors (e.g., muscle stiffness, joint compliance, and viscosity) associated with high resistance may be responsible for CK efflux following strength exercise (8, 10). Since some authors observed a biphasic change in
serum CK following strength exercises, it is suggested that postexercise CK efflux may reflect different histopathological reactions including muscle damage, repair, and regeneration (20).

**Practical Implications**

The results of this research project showed that posttraining restitution of relative maximal power is restored to a high extent within minutes of exercise cessation and completely within 24 hours. Total relative external work, which is highly correlated with anaerobic capacity, requires a much longer time of restitution, especially in the case of lower-limb exercise where a significantly greater muscle mass is involved. This justifies frequent sessions of explosive strength training dependent on maximal anaerobic power. Post-exercise LA concentration and acid-base equilibrium variables are good indicators for the intensity of anaerobic exercises; however, these variables give little information about the physiological state of the athletes muscles after a 24-hour restitution period. CK activity, which rises continuously after exercise cessation up to the 24-hour restitution period, may be a good indicator of the rate of muscular recuperation of the muscle and its work capacity potential.

**References**