The effect of velocity-specific strength training on peak torque and anaerobic rowing power

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Abstract

This study investigated the effect of low- and high-velocity resistance training on isokinetic peak torque and anaerobic power output. Eighteen male varsity oarsmen were blocked on peak knee extension torque at 3.14 rad s⁻¹ and assigned to a high-velocity resistance training group (HVR), a low-velocity resistance training group (LVR) or a control group. Subjects trained four times a week for 5 weeks. Each training session included three circuits of 12 stations using variable-resistance hydraulic equipment. The HVR training significantly improved peak torque (P<0.05) in knee extension and flexion at 2.61, 3.14, 3.66 and 4.19 rad s⁻¹. The LVR training produced significant improvements (P<0.05) in peak torque for knee extension and flexion at 0.52, 1.05, 1.57 and 2.61 rad s⁻¹. High positive correlations were found between peak torque and anaerobic power outputs for all groups. However, no significant changes occurred in 15 s power output, average 90 s power output or peak blood lactate in either training group. These results indicate that velocity-specific strength training does not necessarily improve anaerobic power output in a different exercise mode despite the high positive correlation between isokinetic strength and anaerobic power output.

Keywords: isokinetic, hydraulic resistance training, power output.

Introduction

Angular velocity is controlled and remains constant during isokinetic exercise which allows for maximal accommodating resistance through the full range of limb movement (Nobbs and Rhodes, 1986). Research has shown that isokinetically induced improvements in peak torque are dependent on training velocity (Cacioppo et al., 1981; Coyle et al., 1981; Kanazawa and Miyashita, 1983a). Training with variable-resistance hydraulic equipment has also shown velocity-specific strength improvements and increases in average 30 s anaerobic power output (Petersen et al., 1984, 1987).

Recently, Smith (1987) demonstrated significant positive correlations between isokinetic strength measures of knee and hip extensors and flexors at high and low angular velocities with peak 5 s and mean 30 s power output during a maximal anaerobic cycle ergometer test. The author inferred from these data that high-velocity strength training may enhance...
anaerobic power output as the two are highly correlated and maximal anaerobic power is elicited at a high velocity.

Research has described rowers as athletes with a well developed cardiovascular system (aerobic power) and a high degree of strength (Larsson and Forsberg, 1980; Hagerman and Staron, 1983; Clarkson et al., 1984). Secher (1983) has estimated that the contribution of the anaerobic energy system to rowing ranges between 14 and 23% during simulated race conditions but little research has evaluated anaerobic performance in rowers. The contribution of anaerobic power output is greatest during the start and drive to the finish during a rowing race.

The purpose of this research was to determine the effect of high- and low-velocity hydraulic resistance training on anaerobic power output, peak blood lactate and peak torque of knee extensors and flexors. The relationship between isokinetic strength measures and anaerobic power of oarsmen was also investigated.

Methods

Eighteen male varsity oarsmen signed informed consent forms agreeing to participate in a 5-week resistance training programme. Three groups were equated on peak torque in right knee extension at 3.14 rad s\(^{-1}\) and were assigned to the following groups: high-velocity resistance training group (HVR) which trained at approximately 3.14 rad s\(^{-1}\); low-velocity resistance training group (LVR) which trained at approximately 1.05 rad s\(^{-1}\); and, a control group. No significant difference for knee extension at 3.14 rad s\(^{-1}\) was observed between the groups (Table 1). All rowing performance tests were conducted on a mechanically braked rowing ergometer (Gjessing Ergorow, Bergen, Norway). Subjects were asked to refrain from any physical activity 1 day prior to testing.

<table>
<thead>
<tr>
<th>Group</th>
<th>Age (years)</th>
<th>Height (cm)</th>
<th>Weight (kg)</th>
<th>Peak torque (N m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>HVR (n=6)</td>
<td>21</td>
<td>182.9</td>
<td>77.8</td>
<td>153</td>
</tr>
<tr>
<td></td>
<td>(1)</td>
<td>(3.1)</td>
<td>(3.6)</td>
<td>(9.2)</td>
</tr>
<tr>
<td>LVR (n=6)</td>
<td>23</td>
<td>181.3</td>
<td>79.9</td>
<td>158</td>
</tr>
<tr>
<td></td>
<td>(1)</td>
<td>(3.8)</td>
<td>(3.4)</td>
<td>(9.4)</td>
</tr>
<tr>
<td>Control</td>
<td>22</td>
<td>183.0</td>
<td>83.4</td>
<td>151</td>
</tr>
<tr>
<td>(n=6)</td>
<td>(2)</td>
<td>(3.9)</td>
<td>(4.2)</td>
<td>(11.7)</td>
</tr>
</tbody>
</table>

The first testing session consisted of a laboratory orientation and completion of a 90 s maximal anaerobic rowing test which required the subjects to complete as many flywheel revolutions as possible against a resistance equivalent to 29.42 N. Flywheel revolutions were recorded every 15 s with an electronic timing device for determination of power output. The test was initiated from a standing start (no movement) to simulate an actual racing start. Thus, peak 15 s power output (PO) was calculated from the highest 15 s work period which occurred during the second timed interval, and average 90 s PO was determined from the total revolutions achieved during 90 s. Power output was determined as the product of
flywheel revolutions, resistance (kp) and distance the ergometer flywheel rotates (1 m) per
min and converted to watts.
Venous blood samples were collected from an antecubital vein 5 min after completing the
90 s power test. These samples were used to determine peak lactate concentration, as
maximal venous lactate levels have previously been shown to occur at approximately 5 min
post-exercise (Belcastro and Bonen, 1975; Dodd et al., 1984). Lactate concentration was
determined in 0.5 ml of blood deproteinized in 2 ml of 4% perchloric acid and analysed
spectrophotometrically (Sigma Chemical Company, 1981).
On the following day isokinetic strength testing was conducted to determine peak torque
for the right knee extension and flexion on a Cybex II isokinetic dynamometer (Lumex Inc.,
Ronkonkoma, New York, USA). Peak torque was determined as the highest point achieved
on the torque vs angle curve using the right leg. This was recorded on a Cybex II dual channel
recorder set at 5.0 mm s\(^{-1}\) (damping setting of 2). Calibration of the dynamometer was
checked before each testing session using procedures outlined by the manufacturers. Subjects
were seated and the upper body was immobilized with chest, waist and thigh straps in an
attempt to isolate the knee extensors and flexors. The input axis of the dynamometer was
visually aligned with the rotational axis of the knee, and the lever arm was secured to the tibia
proximal to the ankle. Subjects were instructed to exert a maximal effort through the full
range of motion for both extension and flexion of the knee joint. The test began with the knee
in the flexed position. Peak torque was determined from the highest of four continuous
repetitions at 2.61, 3.14, 3.66 and 4.19 rad s\(^{-1}\). The number of repetitions was decreased to
three at 0.52, 1.05, 1.57 and 2.09 rad s\(^{-1}\) to reduce fatigue as a result of testing a number of
angular velocities. Adequate rest (approximately 1–2 min) was given between each set of
exercises. Subjects were verbally encouraged to give a maximal effort throughout all testing
sessions.

Training programme

Strength training was conducted on a variable-resistance hydraulic equipment (Hydra-
Fitness Industries, Sherwood Park, Alberta, Canada) four times a week for 5 weeks. Twelve
stations were used to exercise upper and lower body muscle groups involved in rowing. These
stations included the following Hydra-Fitness apparatus: two stations of unilaterally seated
knee extension and flexion; two stations of bilateral seated hip and knee extension; unilateral
reclined hip abduction and adduction; unilateral supine hip flexion and extension; unilateral
seated elbow flexion and extension; seated bilateral elbow extension and flexion, horizontal
shoulder adduction and abduction; supine bilateral elbow extension and flexion, horizontal
shoulder abduction and adduction; supine unilateral horizontal shoulder abduction and
adduction; bilateral reclined hip and knee extension, elbow flexion and horizontal shoulder
abduction; standing bilateral elbow flexion and extension, shoulder abduction and
adduction. Training was conducted in a circuit fashion consisting of two intervals of 20 s
exercise/20 s rest with 60 s between stations (Petersen et al., 1984, 1987). A 4 min rest period
was allowed between circuits. Subjects alternated between upper and lower body stations.
The hydraulic cylinders do not provide a true isokinetic loading system; however, average
angular velocity may be calculated from the range of motion and the number of repetitions
performed in a fixed time period. Each session was monitored by a supervisor who adjusted
the cylinders to maintain consistent angular velocities of approximately 3.14 rad s\(^{-1}\)
for the HVR group and 1.05 rad s\(^{-1}\) for the LVR group. The number of contractions
performed during each exercise period was dependent on the range of motion of the subject and the exercise station. Thus, the HVR training group ranged between 18 and 22 repetitions of maximal effort in 20 s and LVR completed six to eight repetitions of maximal effort in 20 s. The subjects progressively increased from two to three complete circuits after 2 weeks of training with no further increase in the number of circuits. Also, the resistance setting on the hydraulic cylinder was increased when a subject consistently exceeded the number of prescribed repetitions during an exercise set. Repetitions and resistance settings were recorded each session.

Statistical analysis

The three experimental groups were compared over the training programme with a $3 \times 2$ analysis of variance (ANOVA) with repeated measures. Multiple comparisons of significant $F$ ratios were conducted with a Duncan post-hoc analysis. A one-way ANOVA was used to determine if any significant differences for knee extension peak torque at 3.14 rad s$^{-1}$ existed between the groups prior to training. Pearson product-moment correlation coefficients were utilized to determine the relationship between absolute peak torque (at 1.05 and 3.14 rads s$^{-1}$) and absolute anaerobic power output (peak 15 and average 90 s PO) before and after training. These variables were uncorrected for body weight, lean body mass or leg muscle mass. Alpha was preset at $P < 0.05$.

Results

High-velocity resistance training significantly increased knee extension peak torque at 2.61, 3.14, 3.66 and 4.19 rad s$^{-1}$ (Fig. 1a). Knee flexion was significantly improved at 0.52, 2.61, 3.14, 3.66 and 4.19 rad s$^{-1}$ (Fig. 1b).

Low-velocity resistance training significantly enhanced knee extension peak torque at 0.52, 1.05, 1.57 and 2.61 rad s$^{-1}$ (Fig. 2a). Knee flexion significantly improved at 0.52, 1.05, 1.57 and 2.61 rad s$^{-1}$ (Fig. 2b).

The control group exhibited no significant changes in peak torque with the exception of a significant decrease in knee extension and flexion at 0.52 rad s$^{-1}$.

Positive correlations were observed between slow (1.05 rads s$^{-1}$) and fast (3.14 rads s$^{-1}$) peak torques for knee extension and flexion with both peak 15 s and average 90 s PO on the 90 s anaerobic rowing test before and after training (Table 2).

There was no significant change in peak 15 s or average 90 s power output during the anaerobic rowing test with either resistance training programme. Also, there was no significant change in blood lactate concentration obtained 5 min after the anaerobic rowing test. However, a significant decrease in average 90 s PO was observed with the control group (Table 3).

Discussion

The present study demonstrated that training with variable-resistance hydraulic equipment at either low or high velocity resulted in significant peak torque adaptations which were specific at or near the training velocity. This finding is contrary to research that reported that
high-velocity training induces strength gains at both slow and fast angular velocities (Coyle et al., 1981; Dudley and Djamil, 1985). However, a significant improvement in knee flexion (14 N m) at 0.52 rad s\(^{-1}\) was observed with high-velocity resistance training in the present study. This result may have been due to a readjustment in a neural tension-limiting mechanism with training which may exist within the muscle or tendon (Perrine and
Fig. 2. Isokinetic peak torque for (a) right knee extension and (b) right knee flexion at various angular velocities before (pre) and after (post) low-velocity resistance training.

*Significant at $P<0.05$

Edgerton, 1978). Other research supports the contention that improvements in torque at high and low angular velocities generally correspond to the velocity of training (Caiozzo et al., 1981; Kamehisa and Miyashita, 1983a,b; Petersen et al., 1984). The majority of the improvements in this study occurred at or near the angular velocity of training.
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Table 2. Pearson correlation coefficients between absolute isokinetic peak torque and absolute anaerobic power output (PO) before and after training

<table>
<thead>
<tr>
<th>Group</th>
<th>Angular velocity (rad s⁻¹)</th>
<th>Condition</th>
<th>Peak 15 s PO (W)</th>
<th>Average 90 s PO(W)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Before</td>
<td>After</td>
<td>Before</td>
<td>After</td>
</tr>
<tr>
<td>HVR</td>
<td>1.05</td>
<td>Extension</td>
<td>0.70</td>
<td>0.70</td>
</tr>
<tr>
<td></td>
<td>3.14</td>
<td>Extension</td>
<td>0.84*</td>
<td>0.79*</td>
</tr>
<tr>
<td></td>
<td>1.05</td>
<td>Flexion</td>
<td>0.86*</td>
<td>0.91*</td>
</tr>
<tr>
<td></td>
<td>3.14</td>
<td>Flexion</td>
<td>0.71*</td>
<td>0.86*</td>
</tr>
<tr>
<td>LVR</td>
<td>1.05</td>
<td>Extension</td>
<td>0.80*</td>
<td>0.77*</td>
</tr>
<tr>
<td></td>
<td>3.14</td>
<td>Extension</td>
<td>0.42</td>
<td>0.82*</td>
</tr>
<tr>
<td></td>
<td>1.05</td>
<td>Flexion</td>
<td>0.63</td>
<td>0.81*</td>
</tr>
<tr>
<td></td>
<td>3.14</td>
<td>Flexion</td>
<td>0.72*</td>
<td>0.85*</td>
</tr>
<tr>
<td>Control</td>
<td>1.05</td>
<td>Extension</td>
<td>0.71*</td>
<td>0.71*</td>
</tr>
<tr>
<td></td>
<td>3.14</td>
<td>Extension</td>
<td>0.96*</td>
<td>0.88*</td>
</tr>
<tr>
<td></td>
<td>1.05</td>
<td>Flexion</td>
<td>0.89*</td>
<td>0.89*</td>
</tr>
<tr>
<td></td>
<td>3.14</td>
<td>Flexion</td>
<td>0.91*</td>
<td>0.91*</td>
</tr>
</tbody>
</table>

*Significant correlations at $P < 0.05$.

Table 3. Peak 15 s PO, average 90 s PO and peak blood lactate during a 90 s maximal rowing power test before and after training (± s.e.).

<table>
<thead>
<tr>
<th>Group</th>
<th>Peak 15 s PO (W) Before</th>
<th>After</th>
<th>Average 90 s PO (W) Before</th>
<th>After</th>
<th>Peak lactate (mmol 1⁻¹) Before</th>
<th>After</th>
</tr>
</thead>
<tbody>
<tr>
<td>HVR</td>
<td>433 (14)</td>
<td>441 (18)</td>
<td>385 (13)</td>
<td>388 (14)</td>
<td>11.2 (0.5)</td>
<td>12.5 (0.3)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>11.1 (0.5)</td>
<td>12.4 (0.9)</td>
</tr>
<tr>
<td>LVR</td>
<td>444 (17)</td>
<td>442 (18)</td>
<td>389 (15)</td>
<td>397 (14)</td>
<td>13.0 (0.9)</td>
<td>12.5 (0.8)</td>
</tr>
<tr>
<td>Control</td>
<td>448 (12)</td>
<td>447 (12)</td>
<td>410 (13)</td>
<td>392* (14)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Significantly different at $P < 0.05$

The duration of performance tests designed to stress the capacity of the anaerobic lactate system have ranged between 30 and 120 s (Fox et al., 1969; Katch and Weltman, et al., 1979; Vandewalle et al., 1987). The 90 s anaerobic rowing test utilized in this study was designed to assess both the power (peak 15 s PO) and capacity of the anaerobic lactate energy system (average 90 s PO). The second 15 s work period yielded the highest power output, as the test was started from a stationary position. The high post-exercise blood lactate levels provide support for the primary contribution of the anaerobic lactate energy system to the generation of power output during the test.

No significant change in peak 15 s or average 90 s power output or 5 min blood lactate post-exercise occurred with either resistance training programme. This lack of improvement
in anaerobic power output with velocity-specific resistance training was observed in spite of significant peak torque gains in knee extension and flexion. This finding was surprising because the strength training programme was specifically designed to enhance the application of force of the muscle groups involved in rowing. Since power is dependent on both force and velocity, the observed improvements in torque with resistance training should, theoretically, contribute to an increase in power. Improvements in isokinetic knee extension power with velocity-specific training have been previously shown (Kanehisa and Miyashita, 1983a). Furthermore, strength-trained athletes have been shown to attain high anaerobic power outputs (Bar-Or, 1987). The lack of improvement in anaerobic power output following velocity-specific strength training with the athletic population used in this study contradicts the suggestion of Smith (1987) that such training may enhance anaerobic power. However, the movement pattern in rowing is more complex than those movements involved in training and requires a high degree of skill. Therefore, it may be that the training effect is specific to power development in the training mode only and is difficult to transfer to more complex movement patterns. It could also be that the anaerobic rowing test was not sensitive enough to reflect the improvement in peak torque.

Research has shown that high-intensity sprint training can evoke changes in the rate of anaerobic energy production and power output (Thorstensson et al., 1975; Sharp et al., 1986; Troup et al., 1986). Reasons suggested for the improvement in anaerobic performance were an improved anaerobic energy production, enhanced muscle buffering capacity (Sharp et al., 1986; Bell and Wenger, 1988), and muscle fibre hypertrophy (Thorstensson et al., 1975). Mechanisms responsible for increases in strength include neural changes (Moritani and DeVries, 1979; Hakkinen and Komi, 1983) whilst increases in the anaerobic system with strength training have also been observed (Thorstensson et al., 1976; MacDougall et al., 1977; Costill et al., 1979). However, other research cited either no change or decreases in selected biochemical markers of the anaerobic system with strength training (Houston et al., 1983; Tesch, 1987; Tesch et al., 1987). The majority of strength increases with short-term resistance training programmes are probably due to neural factors (Moritani and DeVries, 1979; Hakkinen and Komi, 1983). Thus, it may be that the strength training programme used in this study was not sufficient in duration to evoke a change in anaerobic energy production or muscle size which may contribute to an increase in anaerobic power development. Further research is necessary to determine if resistance training over a more prolonged period could improve anaerobic power output.

Many sporting events require high-velocity limb movements and therefore should benefit from high-velocity training. Recently, Smith (1987) observed a high positive correlation between isokinetic peak torque (hip and knee flexion and extension) and anaerobic power output during a 30 s cycle ergometer test with male physical education students. The inference from these data was that training at relatively high velocity may enhance anaerobic power output as both are elicited at high velocities. Some support for this was reported by Petersen et al. (1984) who found significant improvements in average 30 s anaerobic power output on the cycle ergometer with high-velocity resistance training.

The present data demonstrate moderate to high positive correlations between absolute peak torque (knee extension and flexion) and anaerobic power output in both experimental groups and the control group. The correlations were determined at angular velocities which approximated the velocity of training and were somewhat lower than those observed by Smith (1987). Some increases in correlation were observed after completion of the resistance training programme, especially in the LVR group, suggesting some improvement in the
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relationship between anaerobic power output and peak torque. However, the slight improvement in correlation occurred despite no increase in anaerobic power output. Also, the control group exhibited correlations which were generally higher than both training groups. Thus, a positive correlation was observed between anaerobic power output and peak torque in the present study, but this relationship does not imply causality. However, a causal correlation may exist between the two variables due to peripheral factors (muscle mass, contractile enzyme activity, etc).

In summary, the present data demonstrated velocity-specific gains in peak torque with both low- and high-velocity resistance training. Furthermore, moderate to high correlations were found between isokinetic torque and anaerobic power output. However, no significant increases occurred in anaerobic power output during rowing despite isokinetic torque improvements. In spite of the apparent predictive relationship between isokinetic peak torque and anaerobic power output, caution is advised when interpreting this correlation as cause and effect. Further research is recommended to determine whether strength training can influence anaerobic power output.

Acknowledgement

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References


