The effect of prolonged cycling on pedal forces

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Introduction

Few biomechanical studies have probed the changes that occur as a result of whole body fatigue during steady-rate cycling. In running kinematic changes that result from fatigue have been investigated by Bates and Osternig (1977), Chapman (1981; 1982), Elliot et al. (1980;1981), and Siler and Martin (1991). In each study these authors found measurable changes in the patterns of motion that the athletes exhibited during separate running protocols leading to fatigue. Although velocity was measured in each of the studies there was no control or maintenance of constant over ground velocity. Therefore, as the athlete exercised the kinematics that changed were a result of not only fatigue but of over ground velocity decreases as well. Siler and Martin (1991) removed the confounding variable of decreased over ground speed by exercising the athletes on a treadmill at constant velocity. By maintaining the velocity of the run these investigators were able to quantify the kinematic changes in running that accompanied the fatigue process. For the present study the operational definition of fatigue was the voluntary cessation of exercise following a steady-rate period of cycling. The riders were encouraged to ride as long as possible maintaining the riding cadence within 5 rpm of the target of 90 rpm. It was the aim of this study to measure and describe the changes in biomechanical measures, specifically changes in joint kinematics, pedal force kinetics and joint moments, during this ride. The hypothesis we wished to test was that cyclists would modify the application of pedal force such that they become more effective. This modification would be manifested with altered effective force component during the propulsion phase of pedalling. It was thought that while cycling offered fewer possibilities for kinetic or kinematic variation, it was nonetheless possible for the rider to modify the effective force component. In doing so more output could be created without increasing the needs for force generation.

Methods

Competitive male cyclists (n=12) completed a steady-rate exercise ride to exhaustion at 30% and at 80% of their maximum power output (measured prior to test) at 90 RPM on a bicycle ergometer. Pedal force, pedal and crank angle data were collected from the right pedal of an instrumented bicycle for 3 pedal cycles at the end of initial and final minute of the steady-rate exercise test while simultaneous video recordings of the lower limbs were made. From these data crank torque, angular impulse, effective force, and index of effectiveness were calculated. The digitised kinematic data were combined with the force data and using inverse dynamics the joint moments of force at the hip, knee, and ankle joints were computed. Analysis compared the pedal forces and impulses and the joint moments between the first and final minutes of the prolonged ride.

Results and Discussion

The objective for including the 30% condition was to ensure that there was no contamination of data from the 80% ride that could be attributed to riding itself for a similar duration but at a very low level of intensity. Analysis of the kinematic and kinetic data showed no
difference in any selected variables for the 30% riding condition. Subsequent analysis was therefore focussed on the 80% condition. As the goal was to have the riders perform to a level beyond which they felt they could no longer ride, heart rate was used as a verification that they were performing close if not at their maximum. The data in Table 1 indicated that indeed their performance levels, as reflected by the heart rate in the final minute, were very high. On average, their heart rate was 94% of the maximum.

It was hypothesized that as the athlete fatigued the force applied to the pedal would become more effective in order to maintain the test cadence. It was argued that a more effectively applied force would reduce resultant force applied to the pedals and therefore muscle stress. However, the results (Figure 1) indicated that while there was a change in the effective force it was in the opposite direction as hypothesised. The peak negative effective component also changed by becoming significantly more negative. Further, while the net angular impulse, computed over the complete pedalling cycle, was not significantly different between the initial (26.9 Ns) and the final minute (28 Ns) there was a significant increase in the positive angular impulse from the initial to the final minute and a significant increase in the negative angular impulse from the initial to the final minute. It was not possible to identify which came first. However, it seemed likely that as the athlete fatigued and, one might argue, style became compromised, the recovery phase degraded more rapidly. The increased negative angular impulse would necessitate an increased positive angular impulse in order for the rider to maintain the overall power output. This would explain the need for increased peak positive effective force to overcome the more negative component. Thus it would seem that as the riders fatigued they became less effective during the recovery phase and needed to increase the force application during the propulsive phase to account for that.

It was suggested here that the kinematic changes were linked to the change in the pattern of force application utilised by the athlete to maintain the given level of performance. At maximum dorsiflexion, there was a anatomical barrier or limitation to motion of the ankle joint (Figure 2). This limitation to further movement could enhance the plantar flexor muscle groups of the lower limb. Instead of combined ankle support and ankle plantar flexion action, the muscles could focus solely on plantar flexion. In order to maintain a high plantar flexor moment, the ankle dorsiflexed to its maximum dorsiflexed position, at which point there was a mechanical barrier to motion, thus stabilizing the ankle joint and allowing the transmission of force from the larger muscle further up the leg through the lower limb and into the pedal. These data support earlier findings of both Black

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**Table 1. Mean metabolic characteristics of the group.**

<table>
<thead>
<tr>
<th></th>
<th>Max. P.O.</th>
<th>Max Vo2</th>
<th>Duration at 80%</th>
<th>% max. HR at end</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>412.5</td>
<td>66.7</td>
<td>13.04</td>
<td>94%</td>
</tr>
<tr>
<td>SD</td>
<td>54.9</td>
<td>6.7</td>
<td>5.17</td>
<td>5%</td>
</tr>
</tbody>
</table>

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**Figure 1. Mean effective force for the initial (solid line) and final (Broken line) minutes.**

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**Figure 2. Crank Angle (degrees) vs. Force (N).**
et al. (1993) and Amoroso et al. (1994), who reported that as the athlete fatigued the plantar flexors fatigue first, perhaps because they were a smaller muscle group.

Using the argument put forward by Winter (1981) a propulsive moment was computed as the sum of the three joint extensor moments. This propulsive moment was significantly larger in the final minute compared to the initial minute. These increases were in the first 180° of crank rotation and were the result of the increased need for propulsive force during this phase. These increases were possibly the result of the larger muscle groups of the upper leg taking a more active role in propulsion and the smaller plantar flexor groups of the lower leg taking a smaller role as a result of fatigue. The ankle plantar flexor moment was increased because of the limited range of motion in the ankle joint in the dorsiflexed position.

These data suggested that as the bicycle rider fatigued the retarding forces generated in the recovery phase resulted in increased force production during the propulsion phase. This suggested that increased endurance may be achieved if training focused on maintaining an effective recovery force profile. Sanderson and Cavanagh (1987) have shown that the pattern of force production during the recovery phase can be modified with appropriate feedback. Focussing on this segment of the pedalling cycle may well offer improvement in performance. While recovery forces are small they can nonetheless contribute in an important way as the exercise progresses. To ensure that the rider can perform to maximum improving the effectiveness during the recovery phase may be an important factor worthy of more detailed examination.

References

![Figure 2. Mean joint moment for the initial (solid line) and the final (broken line) minutes.](image-url)