Influences of mountain bike suspension systems on energy supply and performance

ISHII Takumi, UMEMURA Yoshihisa, KITAGAWA Kaoru

Abstract

Purpose: The purpose of this study was to clarify the effects of three types of mountain bikes upon cyclists’ oxygen consumption and changes of blood lactate concentration, with consideration of the test course and bicycle mass. Methods: We tested the same mountain bike with three suspension conditions: without suspension systems (RIG), with a front suspension system (FS) and with front and rear suspension systems (FRS). Five male cyclists participated in the study. First, we investigated the effects of the suspension systems on a motor-driven treadmill through VO₂, heart rate and RPE measurements. Next, we conducted time trial tests in the field so that the essential function of suspension systems could be demonstrated. We measured VO₂, heart rate, blood lactate concentrations and performance time. Results: There were no significant differences among the suspension conditions in the treadmill tests. In the field cycling test, VO₂ was significantly greater with FRS than with FS. On the other hand, the highest blood lactate concentration was observed with FS. Conclusion: Our off-road tests suggested that the FRS mountain bike attenuated blood lactate accumulations and allowed the participants to exercise more aerobically than the FS bike. FRS might therefore be more suitable for 2-hour long cross-country mountain bike races. Key Words: OFF-ROAD, BICYCLING, CROSS-COUNTRY RACE, LACTATE, OXYGEN CONSUMPTION

Introduction

Studies on mountain bikes have been one of the most discussed subjects in bicycling in recent years (Baron 2001, Berry et al. 2000, De Lorenzo and Hull 1999a, De Lorenzo and Hull 1999b, Mastroianii et al. 2000, Rowe et al. 1998, Wang and Hull 1997, Wilber et al. 1997). Especially, mountain bike suspension systems are one of the most discussed subjects in off-road bicycling (Karchin and Hull 2002, MacRae et al. 2000, Nielens and Lejeune 2001, Seifert et al. 1997). Suspension systems provide many advantages in mountain bicycling, such as enhancing cycling velocity and braking capacity due to shock absorption (Burke 1996, MacRae et al. 2000, Seifert et al. 1997). In addition, a rear suspension system may assist in keeping the rear tire in contact with the ground, so that loss of velocity is minimized while pedaling over rough terrain (Burke 1996, Kayaba Industries Co. 1994). While the benefits are numerous, there are some drawbacks. The primary drawback is a suspension motion ‘coupled’ with the pedaling action (Burke 1996). Since the pedaling action is periodic, suspension bobs as the rider pedals. This bobbing is thought to be disadvantageous because energy is lost in overcoming the dissipative forces in suspension systems, and also because pedaling motion may be affected (Karchin 2002). Accordingly, much attention has been devoted by the off-road bicycle industry in developing designs that either minimize or eliminate the coupling between the pedaling actions of the rider and the motion of suspension.

In recent years, mountain bikes with both front and rear suspensions are becoming more popular than those with front suspension only. This is because well-engineered suspension systems have become substantially lighter and their mechanical operation has been refined considerably (Nielens and Lejeune 2001, Seifert et al. 1997). Despite significant advances in mountain bike suspension systems, little is known about the effects of these systems on rider performance (MacRae et al. 2000, Nielens and Lejeune 2001, Seifert et al. 1997).

Seifert et al. (1997) reported the effects of suspen-
sion systems on energy expenditure. They assessed the physical stress of mountain bicycling according to creatin kinase by sampling blood after trials. Creatin kinase assessment, however, is not sufficient to investigate the entire energy supply system of cyclists during off-road time trials. Blood lactate concentration and oxygen consumption should be measured for more detailed investigation.

MacRae et al. (2000) demonstrated the effects of front only and front and rear suspension systems on uphill cycling performance. They investigated oxygen consumption, blood lactate concentration and pedaling power during uphill cycling. They speculated that FRS might provide a greater advantage than FS during downhill riding, thereby resulting in faster race times. Since they conducted uphill tests only, however, there would not seem to be solid grounds for this speculation. Additionally, they determined blood lactate concentration not for assessment of physiological responses but for indexes of cyclists’ efforts.

Moreover, these previous researchers did not consider the differences in bicycle mass. Kyle suggested that at a given force output the addition of as little as 1 kg of mass to a road bicycle could decrease speed as a result of an increase in rolling resistance (1991). Howe (1995) estimated that reducing the weight of the bicycle by using lightweight parts could significantly improve performance. Thus, small differences in bicycle mass would be vitally important point when researchers compare the suspension systems in mountain bikes.

The purpose of this study is to investigate the effects of three types of suspension systems (rigid, front suspension, and both front and rear suspension) on cyclists’ oxygen consumption and blood lactate responses, with consideration of test course and bicycle mass.

METHODS

Subjects. Well trained male cyclists participated in this study (N=5; age, 21.8±3.3 yr; height, 171.4±4.0 cm; weight, 61.6±6.3 kg). All subjects had experienced mountain biking (4.6±1.9 yr) and cross-country racing and were ranked from the intermediate to elite level in Japan. The subjects were fully informed of the protocol, and consent was obtained prior to all testing. The Ethics Committee of the Chukyo University Graduate School approved this experiment.

Bicycle. A mountain bike was used with three sus-

![Rear suspension](image1)
![Front suspension](image2)

![Rigid fork](image3)
![Suspension fork](image4)

Fig. 1 Schematic illustration of the tested bicycle. The mainframe of mountain bike (‘Y’-style) was made of hollowed carbon-monocoque and the rear triangular part was made of alloy tube. The fork crown was used in all conditions and the front suspension was replaced with the rigid fork as needed. The rigid fork was made of ferrochrome molybdenum tube. The detail drawing shows the remote controller of the rear suspension unit that could be switched between active (unlocked) or inactive (locked).
pension conditions: without a suspension system (RIG), with a front suspension system (FS) and with front and rear suspension systems (FRS). The same bicycle (‘97 Y-33, TREK, USA) was used for all three conditions to minimize the influences of mass and geometrical changes (Fig. 1). The mountain bike used in this study had front and rear suspension systems (i.e. FRS) and a mass of 11.6 kg. The rear suspension unit (Strashock-pro, STRATOS, USA) of this bike could be switched between active or inactive (locked): thus, the mountain bike could be changed to one with only a front suspension system (FS) by locking the rear suspension. This rear suspension system had 111 mm of wheel travel. The front suspension fork (Gravier-DH, SHOWA, JAPAN) had 90 mm of travel. Both front and rear suspension systems consisted of an air spring and oil damper, and the spring rate was changed for each subject according to the manufacturer’s recommended value. This is the standard construction (i.e. telescopic style, air spring and oil damper) of suspension systems on mountain bikes for the cross-country race. The mountain bike without suspension systems (RIG) was made by exchanging the front suspension system for a rigid fork blade. This rigid fork blade was made exactly the same size as the suspension fork. The weight loss to the mountain bike from this exchange was 0.5 kg. All subjects were allowed to set their seat height, and a sufficient familiarization period was provided.

Test Protocol.

a) Treadmill test

To begin, the authors investigated mountain bicycling on a motor-driven treadmill to eliminate the influences of terrain in determining the effect of the suspension systems. The reason we carried out the study on a flat-surface was that suspension systems could lead to energy losses for two reasons, as reported (Nielens 2001, Wang and Hull 1994). First, the energy losses may be induced by the terrain. The suspensions reduce the energy variations induced by the terrain irregularities, leading to a greater comfort and a better performance during off-road courses. If this absorbed energy were not returned completely and usefully to the rider-bike system, the rider would expend more energy to make up for it. Second, the energy losses may be induced by the rider. Indeed, the rider’s movements as well as the forces generated on the pedals are responsible for an oscillatory displacement of the rider. The movement of the suspended part of the bicycle is usually referred to as “bobbing”. This could dissipate energy and increase the energy expended by the cyclist. Therefore, we tested the three types of bike on a treadmill. We asked the subjects to cycle in seated and standing postures with each type of bicycle, so the subjects completed six trials in total. For each test, the subjects exercised in random order through the combinations of suspension types and cycling postures. The duration of each test was three minutes, and the cycling was done with a grade of 0% and speed of 250 m/min, which was considered to be the average speed in the past national championships. Each trial was separated by enough time to give the subjects sufficient rest before the next trial. We measured oxygen consumption (VO₂, Oxycon Sigma, Mijnhardt, Netherlands), heart rate (DS-800, Fukuda Electronics, Japan) and rating of perceived exhaustion (RPE) (Borg 1973). Data were collected from the last 30 seconds of the test.

b) Field bicycling test

On the occasion of field bicycling test, we paid special attention to the following: the test course must include ascending and descending sections and make differences in bicycle characteristics (i.e. bicycle mass and geometrical changes) smaller. The test course was a 2,100 m shuttle course 2 m wide. Approach to the half way mark (1,050 m) was ascending with approximately 50 m elevation gains. The elevation gain was confirmed using a 1:25000 contour map issued by Geographical Survey Institute. The course was covered with dry granite sand and had some trenches (<20 cm) and many rocks (<10 cm). This test course, however, had no technically difficult sections. The subjects were instructed to complete the distance as fast as possible and completed three trials with the different suspension conditions in random order on the same day. Sufficient rest time of at least one hour was taken.
Influences of mountain bike suspension systems on energy supply and performance

![Graph showing oxygen consumption over time](image)

**Fig. 2** Typical oxygen consumption during the field bicycling tests. Open symbols indicate halfway mark.

<table>
<thead>
<tr>
<th>Variable</th>
<th>grade (%)</th>
<th>speed (m/min)</th>
<th>seated posture</th>
<th>standing posture</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>RIG</td>
<td>FS</td>
</tr>
<tr>
<td>$\text{VO}_2$ (ml/min/kg)</td>
<td>0</td>
<td>250</td>
<td>13.3 ± 1.2</td>
<td>14.1 ± 1.3</td>
</tr>
<tr>
<td>HR (bpm)</td>
<td>0</td>
<td>250</td>
<td>95.6 ± 11.3</td>
<td>96.2 ± 10.4</td>
</tr>
<tr>
<td>RPE</td>
<td>0</td>
<td>250</td>
<td>6.8 ± 0.8</td>
<td>6.8 ± 0.8</td>
</tr>
</tbody>
</table>

N = 5

RIG: MTB without suspension systems; FS: MTB with front suspension system; FRS: MTB with front and rear suspension systems.

* A significant difference (P < 0.05) between seated and standing postures in the same types of bike.

between trials. We measured $\text{VO}_2$, heart rate and performance time throughout the time trials. The values of $\text{VO}_2$ and heart rate were recorded on a portable data recorder (VM 4-064, Vine, Japan) from start to finish. Subjects wore a Hans Rudolph facemask with a bellows hose that was connected to the data recorder. The data recorder was fixed to a meshed breathable backpack worn by the subject. Examples of oxygen consumption and heart rate during the field bicycling test are shown in Fig. 2 and Fig. 3. Furthermore, we measured blood lactate concentration before the time trial, and immedi-
ately, 5 minutes and 30 minutes after the time trial using a portable blood lactate analyzer (1500 Sport, Yellow Spring Instruments, USA). The portable blood lactate analyzer was calibrated before each trial, and blood samples were collected from a finger tip and analyzed immediately. Performance time was determined by handheld stopwatch.

Statistical analysis. All data are expressed as mean±SD. SPSS 9.0 J for Windows was used for all statistical analyses. A two-way analysis of variance
was used to reveal the differences between the suspension systems and cycling postures when the treadmill was used. A one-way analysis of variance was used to reveal the differences among the suspension systems in the field bicycling test. When an analysis of variance showed significant differences, Tukey’s HSD tests were used to determine the differences between the two suspension systems. A significance level of $P < 0.05$ was used for all statistical tests.

Results

a) Treadmill test

Table 1 shows $\dot{V}O_2$, HR and RPE in the treadmill tests. There were no significant differences among the three suspension conditions. Significant differences were observed in all measured values between the cycling postures except HR with RIG.

b) Field bicycling test

Table 2 shows $\dot{V}O_2$, HR and performance time in the time trials. $\dot{V}O_2$ and HR data were averaged by performance time. $\dot{V}O_2$ was significantly greater with FRS than with FS. However, heart rate and performance time during the time trials were not significantly different.

Figure 4 is a time series graph of blood lactate concentration from rest to 30 minutes after the time trial. Blood lactate concentration increased to the peak when subjects completed the test trials. Concentrations with FS were significantly higher than with RIG immediately and 5 minutes after trial. However blood lactate concentrations decreased similarly up to 30 minutes in all the three conditions.

Discussion

We hypothesized that the FRS would provide considerable advantage over FS before we engaged in this study. The main reason is that, as we have mentioned before, suspension systems have become substantially lighter and the mechanical operation has been refined considerably. There is also practical evidence in that many riders have obtained good results in world championships and other competitions using FRS mountain bikes. This practical condition differs from previous researchers’ speculations. Thus, we carried out this study to clarify the effects of mountain bike suspension systems on the physiological response of cyclists in practice.

First, we investigated mountain bicycling on a treadmill to determine the rider-induced energy loss. As shown in Table 1, $\dot{V}O_2$ measurements during this test revealed no distinct differences among the suspension conditions. This result extends the findings of previous studies. Wang (1994) reported bobbing was minimal and that energy loss due to bobbing should also be minimal when cyclists ride a FRS bicycle on a flat surface. Moreover, Berry et al. (1993) found no significant increase in $\dot{V}O_2$ of subjects riding on a treadmill, on FRS. Nielsens (2001) also found no significant increase in $\dot{V}O_2$ of subjects riding on a mountain bike with electromagnetically braked cycle ergometer, on FRS as compared to RIG and FS. Consequently, these results suggested that energy dissipation by adding rear suspension system would not be caused by pedaling action but by terrain irregularity. Therefore, the mechanical construction of rear suspension systems might have become more sophisticated than in previous researchers’ generation.

Next, we conducted off-road tests since we considered that the essential function of suspension
systems could be observed in off-road conditions. There are some reasons that we investigated off-road cycling. One is that cross-country mountain bike races consist of uphill and downhill cycling. A conventional treadmill used in the laboratory, however, does not operate under uphill and downhill conditions alternatively. Another is that cornering, braking and shock-absorbing actions are necessary conditions for comprehensive assessment of a mountain bike suspension system on the physiological responses of cyclists. Moreover, terrain-induced energy loss might be observed when cyclists ride over rough surfaces.

Averaged oxygen consumption during the field bicycling test, as shown in Table 2, was significantly greater with FRS than with FS. Blood lactate concentration, on the other hand, was lower with FRS than with FS. Seifert et al. (1997) assumed that FRS would be associated with energy loss because some of the torque energy may be absorbed by the rear spring, and thus not be transmitted directly to the rear wheel of FRS. They could find, however, no evidence of energy loss according to the physiological responses of cyclists. We found a significant increase in \( \text{\textit{VO}}_2 \) of subjects riding on FRS as compared to FS, but we did not consider the negative factors. Since FRS showed lower blood lactate concentration compared to FS. Typically, mountain bike cross-country events are approximately 2-hour long. Due to the duration of this event, the aerobic system of energy production is the dominant energy system. An equally important performance component for the cross-country race event is anaerobic power (Baron 2001). The generation of relatively high power output of short duration plays a vital role for the off-road cyclist in a mass start event, during steep climbing, and when sprinting to pass slower riders or in sprints at the finish of a race. Therefore, attenuating blood lactate accumulation is more advantageous in competitive situations even though cyclists are required to expend more energy when riding with FRS. This is because all competitive cyclists do not pursue energetic economy, but want to obtain the best results in cross-country events.

Let us provide another explanation of why FRS showed greater \( \text{\textit{VO}}_2 \) and lower blood lactate accumulations. Cyclists are exposed to continuous shocks and vibrations during off-road bicycling. Vibration might have been a deterrent to cycling performance as reported (Samuelson 1989). When cyclists ride over rough terrain, they must work to support themselves with arm and leg movements (Burke 1996). In such moments the rider will stop pedaling instantaneously and stand up from the saddle to absorb high impact forces (Burke 1996). The high impact force invites isometric contraction to absorb shocks and handle and stabilize the bicycle (Seifert 1997). It has also been noted that intense or repeated muscular contraction due to off-road bicycling increases the amount of damage to the muscles. As Burke (1996) noted, however, rear suspension systems can absorb much destructive energy, allowing the rider to remain seated and relaxed, concentrating on maintaining the best line during hill-climbing and putting out a smooth flow of power. Hence, the authors consider that FRS may help cyclists achieve a steady state and attenuate blood lactate concentrations as a consequence. It might be correct to say that higher \( \text{\textit{VO}}_2 \) on FRS indicates not energy loss, but greater cycling performance.

Previous studies disregarded the fact that differences in bicycle mass may have affected the results. The FRS bicycle in a previous study (Seifert et al. 1997) was 2.2 kg heavier at maximum than the other bicycles. Kyle (1991) noted that during competitive road cycling the addition of as little as 1 kg to the mass of a bicycle on flat terrain could decrease bicycle speed due to increases in rolling resistance. Also supporting this hypothesis, Howe (1995) estimated that the reduction in bicycle mass could significantly improve uphill cycling performance. We paid special attention to bicycle mass and to assuring that differences were 0.5 kg at maximum. Hence, the discrepancy in the physiological response of the cyclists would not be due to differences in the bicycle mass.

In conclusion, when FRS was compared with FS in off-road cycling, the increase in blood lactate concentration was lower with FRS, in contrast to the high oxygen consumption. Given that cross-country
Events are approximately 2 hours long, the authors suggest that a lower blood lactate accumulation is a better condition for cross-country race events, even though the FRS mountain bike requires greater energy consumption than the FS bike. It must not be considered a diseconomy when cyclists can obtain a higher competitive performance. The time trial in our study was less than 10 minutes; it will be necessary to study longer times in order to further clarify the effect of these suspension systems.

Address for correspondence: Takumi Ishii, Laboratory for Exercise Physiology and Biomechanics, School of Health and Sport Sciences, Chukyo University, 101 Tokodachi, Kaizu-cho, Toyota, Aichi 470-0393, Japan; E-mail: tisii@cnc.chukyo-u.ac.jp

References
Burke ER (1996) : High-tech cycling. Human Kinetics, Champaign, 45–64
Kayaba Industries Co. (1994) : Motor-cycle Suspension. Sankaido, Tokyo, 1–76