Comparison of Physiological Responses and Performance Between Mountain Bicycles With Differing Suspension Systems

Jeffrey E. Herrick, Judith A. Flohr, Davis L. Wenos, and Michael J. Saunders

Purpose: This study compared the metabolic and performance effects of riding front-only suspension (FS) and front-and-rear suspension (FRS) mountain bicycles on an off-road course that simulated competitive cross-country race conditions (>105 min in duration, with ~70% of time spent riding uphill). Methods: Seven competitive mountain bikers (73.8 ± 7.6 kg; 61.0 ± 4.3 mL·kg⁻¹·min⁻¹) completed two randomized FS and FRS trials. Bikes were similar, excluding rear wheel suspension on the FRS, which increased bike weight by ~2 kg. Each trial consisted of four laps of rugged 8 km trail with 154 m of elevation gain per lap. The first three laps were performed at ~70% of VO₂max; VO₂, HR, and RPE were collected during the first and third laps. The final lap was performed as a maximal time-trial effort. Results: During the first and third laps, VO₂, HR, and RPE were similar between FS and FRS. However, FS was significantly faster than FRS during the ascending segment of the course (17.6 ± 2.9 vs 18.9 ± 3.4 min, P = .035), despite similar VO₂ (P = .651). Although not statistically significant, FRS tended to be faster than FS during the descending portion of the course (8.1 ± 2.0 vs 9.1 ± 2.1, P = .067) at similar VO₂. Performance during the final time-trial lap was significantly faster for FS than FRS (24.9 ± 3.9 min, 27.5 ± 4.9 min, P = .008). Conclusion: FS was faster than FRS over a course that simulated competitive cross-country race conditions. The faster times were likely the result of improved cycling economy during ascending, which were at least partially influenced by the lighter weight of the FS.

Keywords: mountain bicycle, bicycle suspension designs, cycling physiology
Mountain bike (MTB) suspension systems are an important technological advancement for cross-country racing. All current elite-level MTB racers utilize front-suspension (FS) or front-and-rear suspension (FRS) bicycle designs for competition, compared with rigid frame designs favored by road cyclists. However, the choice between FS and FRS bike designs continues to be debated among athletes and in popular cycling media, and there are surprisingly few peer-reviewed studies comparing physiological and performance responses between these designs.

There are a variety of theoretical advantages to utilizing FRS bicycles for MTB racers. FRS designs reportedly enhance rider comfort, and decrease blood markers of muscle trauma compared with rigid frame and FS bicycles. FRS systems have also been theorized to enhance cycling velocity and braking capacity over rough terrain, which could positively influence rider efficiency and performance. However, there are also potential drawbacks to utilizing FRS bicycles. Rear suspension systems increase total bicycle mass, which may elevate the metabolic costs of cycling, particularly when riding uphill. In addition, suspension systems may dissipate rider-generated power via small compressions ("bobbing") that further impair rider economy. Therefore, well-designed FRS bicycles for cross-country racing should effectively displace terrain-induced energy without dissipating rider-generated energy; in order to minimize the energy expenditure required to cycle over a variety of terrain. However, as reviewed by Nielens and Lejeune (2004), relatively few peer-reviewed studies have compared the metabolic costs of riding FS and FRS bicycles, and generalizations are limited by considerable variations in the methodological approaches utilized in these studies. Perhaps most importantly, very few of these studies have been performed in field-settings that adequately represent the demands of cross-country MTB racing.

We are aware of only four peer-reviewed studies that have directly compared rider performance between FS and FRS bicycles in off-road conditions. The findings from these investigations are inconclusive, with one study reporting improved performance with FS, one reporting faster times with FRS, and the remaining studies reporting no differences between bicycle designs. The durations of these trials ranged from <10 min to approximately 60 min. However, Union Cycliste Internationale (UCI) regulations suggest optimal MTB competition times of 105–120 and 120–135 min for professional women and men, respectively. In addition, cross-country racers reportedly spend 70% of typical race time riding uphill, which could theoretically make higher bicycle weight a greater disadvantage than illustrated by some previous investigations. Thus, earlier studies comparing FS and FRS bicycles have not utilized exercise conditions that are fully representative of competitive MTB competition, and it remains unclear whether there are functionally relevant differences in physiological and performance responses to FS and FRS bicycles under these conditions.

The primary focus of the present study was to test the physiological and performance effects of both FS and FRS bicycles under two experimental conditions within an ecologically valid field based setting. First, we aimed to compare the overall, ascending, and descending times between the two bicycle designs under matched submaximal intensities. Second, and most importantly, we aimed to measure all out performance (time) during a single maximal final lap.
Methods

Subjects

Eight subjects volunteered to participate in the study. One subject failed to complete the experimental trials, and all statistical analyses were performed on the seven subjects (23.1 ± 6.3 y; 73.8 ± 7.6 kg; VO2peak 61.5 ± 4.3 mL·kg⁻¹·min⁻¹) who completed all testing. All participants were categorized as amateur “expert category” or category 1 MTB racers according to USA Cycling criteria (3.9 ± 2.9 y of racing experience). For study inclusion, they were required to be performing at least 3 d/wk of cycle training at the onset of the study. All subjects were considered low risk for cardiovascular complications, and provided written consent before study participation. All procedures and testing were approved by James Madison University’s Institutional Review Board.

Testing Procedures

Preliminary Testing. Height, weight and peak aerobic capacity (VO2peak) were assessed before any field-based trials. Subjects performed a graded exercise test on an electrically braked cycle ergometer to determine VO2peak, as described previously. Oxygen uptake was measured throughout the test using a Sensormedics Vmax 229 (Yorba Linda, CA) metabolic cart. Submaximal VO2, heart rate (HR), and rating of perceived exertion (RPE) were recorded for each stage, and utilized to select appropriate ride intensities for the initial portion of the field trials.

Experimental Trials. Following preliminary testing, subjects performed a familiarization trial consisting of three laps of the MTB course (described below; Figure 1); with a duration of ∼25–30 min per lap. Subjects were instructed to use the trials to become familiar with the course route and experimental bicycles. Using target HR and RPE data from preliminary testing (~70% VO2peak) as a starting point, subjects were instructed to select a moderately-hard pace that would be sustainable for a 2 h MTB race. Submaximal lap intensity was selected to represent a pace similar to reported competition intensities albeit slightly lower to ensure consistent effort and optimize completion. Time splits were noted at strategic points on the course to aid pacing strategies for the experimental trials. Targeted lap times to be utilized for the subsequent experimental trials were modified (if necessary) based on subjective feedback following the familiarization trial, to insure that all riders could complete a fourth lap of the course following three laps at the targeted intensity. No physiological data were recorded during the familiarization trials.

Within 10 d of the familiarization trial, subjects completed the first of two experimental trials. Subjects were instructed to perform ‘normal’ training during the time periods between all trials, but to avoid heavy training for 48 h before each experimental trial. The experimental conditions (FS or FRS bicycle, described below) were randomly assigned for each subject, and 5–10 d separated each trial. Each of the experimental trials consisted of four laps of the off-road course. The first three laps of each trial were conducted at a submaximal effort determined from the familiarization trials (~70% VO2peak). During each submaximal lap, riders viewed time-splits at three strategic time-points, and feedback was provided from
the investigators with the goal of maintaining consistent overall lap times between the two experimental trials. For example, if a rider completed their second lap (of their first trial) 30s slower than their first lap, they were provided feedback during the second trial to produce a consistent outcome during their second trial. Using the same instructional protocols, we have previously observed coefficients of variation (CV) between repeated trials of 3.5–4.0% in lap times (with subjects utilizing the same MTB course, and the same bicycle for both trials).

Following the three submaximal laps of the course, subjects performed a fourth lap of the course, with instructions to give an all-out effort, and complete the course in the fastest possible time. No time splits or feedback was provided to subjects during the performance lap.

**Course Description**

Riders performed a total of four 8 km laps, which included \( \sim 154 \) m of vertical elevation gain per lap (32 km, 616 m total). The course profile (Figure 1) is similar to reported Olympic level race circuits, and consisted of a long, sustained climb (totaling approximately 70% of total riding time) followed by a fast descent. The start/finish area was a gravel road section of approximately 200 m. The remainder of the course consisted of off-road single- and double-track trails. The trails in the study were segments of routes utilized in annual races of the Virginia State Mountain Bike Series and National Series U.S. Cup events. Thus, they were deemed a representative example of trails utilized by national level cross-country competitions. All trails were monitored before each ride for fallen debris and weather-induced trail modifications. Treatment rides were not conducted on rainy days or following heavy overnight rains. Trail conditions were relatively dry on the course throughout all treatment rides. The course was marked with flags to

![Course elevation profile](image)

*Figure 1* — Course elevation profile.
ensure all riders traversed the same trail. Temperature, humidity, and trail conditions were monitored before each trial to insure no systematic differences were present between trials.

**Physiological Data**

Subjects wore a portable metabolic gas analyzer unit (K4 b2, Cosmed Inc., Italy) with integrated global positioning system during the first and third laps (submaximal). Physiological and GPS data was not collected during the all-out performance (maximal) fourth lap. The analyzer was encased in an empty hydration backpack (Camelback, Inc.) with plastic shock absorbing material. Expired oxygen was collected via a Hans Rudolph mask on a breath-by-breath basis. The gas analyzer and GPS unit were calibrated before each trial. Values for VO2 and HR were obtained from the analyzer for the first and third laps (submaximal) of each trail, and averaged for each lap (overall), as well as the ascending segment and descending segments. The unit was removed following the first lap, and reapplied before the third lap (and removed again before the performance lap). All applications/removals of the unit were performed quickly (<45 s), and “transition” times were matched between trials. RPE was recorded at the completion of each of the four laps, using a Borg 6–20 scale. Subjects were asked to subjectively provide their representative RPE value for the entire lap (rather than provide an instantaneous value, as the recording period occurred at the end of the descent). Coefficients of variation for VO2, HR and RPE (obtained during field testing using identical equipment and similar, subject-monitored pacing during hiking) were reported to be 4.8–12.7% in a comparable study by the investigators.14

All laps were timed on a digital stopwatch (Accusplit, Inc.) and recorded to the tenth of a second. Subjects were provided 6 mL/kg/body mass of water at the completion of each lap.

**Experimental Bicycles**

Brand-new FS and FSR bicycles (2005 models), size medium, were utilized for study. The FS bicycle utilized an aluminum F-Series frame, and the FRS bicycle used an aluminum Prophet frame (both from Cannondale Inc., Bedford, PA). Both bicycles were equipped with matched parts specifications, including wheels/tires, components/brakes, gearing (44/32/22 chain ring, 9-speed [12-34] cassette) and saddles. Both bicycles utilized a 140 mm travel front-suspension fork (Lefty Max), and the FRS bike included a single-pivot rear suspension design, incorporating a rear shock with 140 mm of travel (Progressive 5th Element Cv/T). Bicycle set-up procedures were standardized for all trials. Only seat height and air pressure in the rear shock were varied between subjects (70% of rider weight added to shock in main air chamber). Compression and rebound damping for the forks and rear shock were set at midlevel for all trials. Tire pressure was uniformly set at 40 psi before each ride. Each bicycle was cleaned and adjusted before each ride by the same mechanic. Subjects utilized their own pedal/shoe systems for each ride. The
FS bicycle weighed 12.2 kg while the FRS bicycle weighed 14.4 kg. Before each ride, subjects were reinstructed on the operating mechanisms on each bicycle with a 10 min warm-up/refamiliarization ride.

Statistical Analyses

Statistical testing was conducted using SPSS version 18 (IBM, Chicago, IL), using an alpha level of $P < .05$ (two-tailed) for all hypothesis tests. To compare environmental conditions between trials, dependent $t$ tests were conducted between trials for temperature and relative humidity. A repeated measures analysis of variance (RM-ANOVA) was performed for VO$_2$, HR, RPE, and averaged time per lap, for the ascending and descending segments of the course; with condition, lap number, and course segment (ascending and descending) as within-subject factors. From these analyses we observed no interaction for lap number and as a result for simplification of interpretation, excluded the influence of lap number from further analyses. Subsequently, lap 1 physiological data for each of the variables described above (VO$_2$, HR, RPE, time; averaged per lap) with condition (FS and FRS) and course segment (ascending and descending) as within-subject factors. Post hoc tests were conducted, where appropriate, to assess differences between conditions (within course segment). Between-trial comparisons of overall performance times were conducted using a dependent $t$ test. We assessed potential relationships between treatment differences in submaximal performance times (for ascending/descending segments) and treatment differences in performance lap times using Pearson product-moment correlations.

Results

Subjects and Environmental Conditions

Descriptive data for the subjects are shown in Table 1, and VO$_2$max values were similar to those reported in prior studies of amateur MTB racers. Environmental conditions were similar between trials, and temperature (FS 54 ± 11; FRS 53 ± 10°C) and relative humidity (FS 69 ± 9; FRS 53 ± 10%) were not significantly different ($P > .05$) between FS and FRS.

Table 1  Subject Demographics

<table>
<thead>
<tr>
<th>Variable</th>
<th>Mean ± SD</th>
</tr>
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<tbody>
<tr>
<td>Age (y)</td>
<td>23.1 ± 6.3</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>73.8 ± 7.6</td>
</tr>
<tr>
<td>VO$_2$ peak (L·min$^{-1}$)</td>
<td>4.3 ± 0.3</td>
</tr>
<tr>
<td>VO$_2$ peak (mL·kg$^{-1}$·min$^{-1}$)</td>
<td>61.5 ± 4.3</td>
</tr>
<tr>
<td>Years racing</td>
<td>3.9 ± 2.9</td>
</tr>
</tbody>
</table>
Lap Number

Lap number was analyzed to determine if responses to the bike designs were influenced by the duration of the protocol. When analyzing overall lap times, there was no significant \((P = .905)\) main effect observed for lap number between the first (27.4 ± 4.5 min) and third (28.1 ± 4.6 min) laps of the trial (independent of treatment). The VO\(_2\) (2.91 ± 0.45; 2.61 ± 0.43 L/min, \(P = .082\)) was not significantly different between the first and third laps, respectively. Heart rate did not significantly change between laps (148 ± 10; 155 ± 8 bpm, \(P = .254\)) while RPE (13.5 ± 2.0; 16.2 ± 0.7, \(P < .001\)) increased significantly during the same time interval. No lap number × condition” \((P = .905)\) or lap number × course terrain \((P = .536)\) interactions were observed for any of the dependent measures. Therefore, to simplify interpretation of analyses regarding comparisons between bicycle designs, lap number was removed from all subsequent analyses (and subsequent analyses of RM-ANOVAs are based on physiological data from Lap 1).

Physiological Responses During Submaximal Cycling

A comparison of physiological responses between treatment bicycles is provided in Tables 2 and 3. Significant main-effects \((P < .001)\) for course segment were present for VO\(_2\), HR, and time, with higher values for each of these variables during ascending vs descending. No significant main-effects for condition were observed for any of the physiological values averaged per lap. There was no significant condition × course segment interaction effect for VO\(_2\) or HR \((P = .874, P = .286)\). However, significant condition × course segment interaction effects were reported in segment times \((P = .05)\). No significant condition differences were observed for VO\(_2\) \((P = .874)\) or HR \((P = .286)\) within any course segment. However, FS was significantly faster than FRS during the ascending segment of the course \((P < .05)\). Although not statistically significant, there was a tendency \((P = .067)\) for FRS to be faster than FS during the descending portion of the course.

Performance Assessment

Performance lap time was significantly faster \((P < .01)\) during FS (24.9 ± 3.9 min) compared with FRS (27.5 ± 4.9 min). As shown in Figure 2, all seven subjects rode faster with the FS bicycle. Ascending/descending times were not recorded during the performance lap. However, correlations between treatment differences in performance lap times (ie, FSR\(_{time} – FS_{time}\)) and treatment differences in ascending/descending times during the submaximal laps showed a trend \((r = .668, P = .08)\) suggesting faster submaximal ascending times with the FS were related to faster performance lap times. Differences in descending times during the submaximal laps were not related to differences in performance times between treatments \((r = –.008, P = .86)\). Performance lap RPE for all subjects was 20 in both treatment conditions.
### Table 2  Physiological responses during submaximal off-road cycling

<table>
<thead>
<tr>
<th>Variable</th>
<th>Overall</th>
<th></th>
<th>Ascending</th>
<th></th>
<th>Descending</th>
<th></th>
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<tr>
<td></td>
<td>FS</td>
<td>FRS</td>
<td>FS</td>
<td>FRS</td>
<td>FS</td>
<td>FRS</td>
</tr>
<tr>
<td><strong>VO₂ (L·min⁻¹)</strong></td>
<td>2.93 (±.17)</td>
<td>2.86 (±.17)</td>
<td>3.23 (±.18)</td>
<td>3.11 (±.18)</td>
<td>2.40 (±.17)</td>
<td>2.33 (±.28)</td>
</tr>
<tr>
<td>Percent VO₂peak</td>
<td>64.7 (±14.9)</td>
<td>65.3 (±9.7)</td>
<td>69.4 (±15.7)</td>
<td>71.8 (±10.9)</td>
<td>53.7 (±13.8)</td>
<td>51.9 (±8.3)</td>
</tr>
<tr>
<td>Heart rate (beats·min⁻¹)</td>
<td>167 (±11)</td>
<td>168 (±8)</td>
<td>172 (±10)</td>
<td>171 (±6)</td>
<td>158 (±13)</td>
<td>162 (±15)</td>
</tr>
<tr>
<td>Percent HR₉₀</td>
<td>84.1 (±5)</td>
<td>84.9 (±4.8)</td>
<td>86.5 (±4.5)</td>
<td>86 (±3.9)</td>
<td>79.6 (±6.1)</td>
<td>81.7 (±8.1)</td>
</tr>
<tr>
<td>RPE (6–20)</td>
<td>13.8 (2.0)</td>
<td>12.5 (1.5)</td>
<td>—</td>
<td>—</td>
<td>—</td>
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</table>

*Note.* The data reported are means (±SD). Differences between bike designs: *P* ≤ .05; **P* = .067.

### Table 3  Submaximal and maximal performance lap times

<table>
<thead>
<tr>
<th>Variable</th>
<th>Overall</th>
<th></th>
<th>Ascending</th>
<th></th>
<th>Descending</th>
<th></th>
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</thead>
<tbody>
<tr>
<td></td>
<td>FS</td>
<td>FRS</td>
<td>FS</td>
<td>FRS</td>
<td>FS</td>
<td>FRS</td>
</tr>
<tr>
<td><strong>Submaximal lap</strong></td>
<td>26.7 (±4.5)</td>
<td>27.1 (±5.1)</td>
<td>17.6 (±2.9)*</td>
<td>18.9 (±3.4)</td>
<td>9.1 (±2.1)</td>
<td>8.1 (±2.0)**</td>
</tr>
<tr>
<td><strong>Performance lap time</strong></td>
<td>24.9 (±3.9)*</td>
<td>27.5 (±4.9)</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>95% CI</td>
<td>21.23–28.47</td>
<td>23.92–31.16</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
</tbody>
</table>

*Note.* The data reported are means (±SD), and 95% confidence intervals (CI). Differences between bike designs: *P* ≤ .05; **P* = .067.
Discussion

The primary finding from the present study was that a front suspension only (FS) mountain bike (MTB) was significantly faster than a front and rear suspension (FRS) MTB during a performance trial that simulated cross-country racing conditions. These findings are consistent with those from Seifert et al., who also reported faster times with FS during an off-road trial. However, other field-based studies have reported faster FRS times, or no differences between bicycle suspension designs. In addition to assessing performance, the present study compared physiological responses between treatment bicycles. These data were obtained during "submaximal" riding (laps 1 and 3), during which time subjects were encouraged to provide equal effort (and matched lap-times) between trials. Although the first three laps were not performed maximally, the time to complete these laps was similar (FRS), or only slightly slower (FS), than final performance lap times. Thus, these data are representative of physiological responses during the early stages of races performed at relatively even paces throughout. As shown in Table 2, there were no significant condition or condition \times course terrain effects on VO_{2} or HR during the submaximal phase of the trials. This indicates that subjects successfully matched the metabolic demands (during submaximal laps) between trials, even during the ascending and descending segments of the course. Despite the matched metabolic costs, a significant condition \times course segment interaction was observed in segment times (Table 3). Although total lap times were equal between trials, FS was significantly faster on the ascending segment of the course (17.6 \pm 2.9 vs 18.9 \pm 3.4 min, \textit{P} < .05). There was also a trend toward faster descent times with FRS than the FS (8.1 \pm 2.0 vs 9.1 \pm 2.1 min, \textit{P} = .067 N.S.). These observations are consistent with some putative influences of FRS bicycle designs. For example, FRS bicycles are reportedly more comfortable than FS, and enhanced shock absorption may reduce trail-induced vibrations, which have been associated with decreased cycling performance. Theoretically, these characteristics may allow riders to travel faster

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**Figure 2** — Comparison of performance lap times between bike designs. Dashed lines represent data for each individual. Solid line illustrates group mean (*Significantly different from FRS; \textit{P} < .05).
Physiological Comparison of Mountain Bicycle

This was partially illustrated in the present study, as subjects tended to ride faster downhill with the FRS ($P = .067$), despite similar levels of oxygen uptake ($P = .765$). Although systematic data was not collected regarding the handling characteristics of the bicycles, subjects commonly reported they could be “less tentative/more aggressive” with the FRS on the downhill segment.

Despite the aforementioned potential advantages of FRS, adding rear suspension increases total bicycle mass, which may elevate the metabolic costs of cycling.$^{17}$ In addition, rear suspension systems may dissipate rider-generated power via small compressions (“bobbing”)$^{18}$ related to displacement of the cyclist’s body, or interactions between front chain ring and the rear suspension while pedaling.$^8$ Previous studies have reported mixed findings regarding the effects of rear-suspension systems on cycling economy.$^{2,7,8,10}$ However, as reviewed by Nielens and Lejeune, findings are difficult to generalize due to variations in the methodological approaches. Our findings indicate that metabolic economy was poorer with FRS during the ascending segment of the course, as oxygen cost was not significantly different between the two designs despite faster ascent times of the FS. A nonsignificant trend ($r = .0668, P = .008$) suggested that ascending times during the submaximal laps were associated with overall performance lap times. This trend may indicate that gains in ascending efficiency play a substantial role in the speed with which riders navigate rugged mountainous terrain as employed in this study. Although metabolic data were not obtained during the performance lap, we speculate that cumulative effects of the higher metabolic cost of climbing with the FRS bike (due to increased weight and/or “bobbing”), was a primary factor in the slower ascending and performance lap times.

Inconsistencies in the literature regarding the effects of bicycle suspension on performance are probably related to differences in test protocols and the specific bicycle designs tested. Previous field-based performance trials ranged in duration from $<10$ min$^5,10$ to approximately 60 min$^2,4$ on field and laboratory based conditions described as flat and bumpy,$^2$ simulated bumpy tracks,$^3$ off-road with no technical difficulty.$^10$ The present protocol resulted in total ride times of approximately 108 (FS) to 111 min (FRS), providing a higher degree of external validity.$^{11}$ However, no lap number × condition or lap number × course terrain interactions were observed for any of the dependent measures, suggesting that suspension-related effects between trials were consistent over time. Thus, differences in performance results between prior studies were probably not due to variations in test duration alone. However, the present study also included considerably more time spent ascending ($\sim 70\%$ of total time, $\sim 70–77$ min per trial) than previous studies; similar to typical climbing times in competitive cross-country races.$^{10,11}$ Because cycling economy was apparently improved with FS during climbing (ie, faster speed at the same metabolic cost), these bicycle designs may be preferable when racing on courses with considerable climbing.

It is not possible from the present study design to determine if the mechanisms associated with impaired climbing economy during the submaximal laps with FRS were related to “bobbing” of the rear shock, bike weights, athlete generated power, or other factors. Bobbing related to displacement of the rider’s body can be altered by suspension tuning, or adapted pedaling technique,$^{18}$ or possibly by increased athlete energy expenditure and power output, and is highly variable between
cyclists. In addition, bobbing related to front chain-ring/rear suspension interactions may be exaggerated during high-power conditions and further decrease speed, which is consistent with our observation of impaired FRS economy during climbing. However, energy losses via this mechanism potentially vary between specific FRS designs, due to factors such as differing pivot-point locations; and manufacturers have devoted considerable attention to minimizing these losses in modern designs. Because power data was not obtained during the trials, we cannot determine if alterations in power output occurred between trials, which could have provided additional insight regarding the mechanism responsible for the apparent differences in climbing economy. Due to the paucity of field-based studies on this topic, we purposely examined bicycle designs that were distinctly different in suspension characteristics (and weight). For example, the rear shock on the FRS bike had a relatively large amount of rear “travel” (140 mm), in order to maximize the putative benefits of this design on rocky and/or downhill segments. As a result, the FRS bicycle was 2.2 kg heavier than FS. Reductions in bicycle mass as small as 1 kg have been reported to influence climbing performance in road cyclists; thus, it is likely that increased bike weight was at least partially (and possibly entirely) responsible for the observed differences in climbing economy. This factor may reconcile differing performance results reported in other studies examining off-road MTB performance. Seifert et al reported faster times with FS vs FRS bicycles with a weight difference of 1.5 kg. Studies which showed no performance differences between bicycle designs had much smaller differences in bicycle weight (~0.3–0.5 kg). Furthermore, Nishii and colleagues reported faster times with a FRS bicycle that weighed 0.4 kg more than FS, using a 30-min off-road course without any sustained periods of climbing. Technological advancements continue to reduce bicycle weights, and top-line racing bicycles currently exhibit much smaller weight differences than the FS and FRS bikes utilized with this study; although it is worth noting that price-matched FS/FRS bicycles may still exhibit relatively large weight differences. Theoretically, smaller weight variations between bicycles would reduce differences in climbing economy between FS and FRS, which would presumably alter the reported effects on performance times, as suggested by other investigations. However, physiological/performance differences between FS and FRS with such small variations in weight have not yet been investigated using course conditions similar those described in this study.

**Practical Applications**

The results presented in this study provide direction for both cycling coaches and athletes in choosing the best (fastest) bicycle for MTB competitions. We have presented evidence that suggests MTB racers who compete in events that require extended climbing (≥70% total race time) may gain a performance advantage by choosing a front-only suspension bicycle over a front and rear wheel suspension bicycle. Further, from our study it appears that the gains in ascending efficiency of the FS MTB appear to outweigh the potential losses in downhill or descending performance to a FRS MTB, and this difference may produce shorter race durations for a FS over a FRS. We also suggest that athletes competing in off-road “hill climb” events where most if not all of the course is uphill riding, the FS is the best choice for the fastest overall time. Given the wide range of rear suspension designs
available it is difficult for us to suggest our results are indicative of all FRS bikes. Indeed, our experimental bicycle was one suspension design (traditional rear swing arm with a single pivot) of many available rear suspension systems coupled with 140 mm of rear wheel travel. As such, we suggest that future research investigates the physiological and performance response to other suspension designs (in addition to a single pivot design employed in this study) along with a wider range of rear wheel travel (80–120mm).

Conclusion

In summary, we observed that a FS bicycle design was faster than FRS over a course that simulated cross-country race conditions (>105 min duration, off-road single- and double-track trails, ~70% of time spent climbing). These performance benefits were likely related to improved cycling economy with FS during climbing segments of the course. However, these findings should not be generalized to bike designs or courses that vary considerably from those utilized in this study. Further investigation is required to determine how specific differences in bicycle weight and course characteristics influence the effects of bicycle suspension designs on metabolism and performance. In addition, further clarification is required to determine the primary mechanisms associated with reduced ascending efficiency for front and rear suspension mountain bicycles on rugged narrow mountainous trails. Specifically, the relationship between energy expenditure, power output, and differing suspension designs.

Acknowledgments

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References