

Impact of Wheel Size on Energy Expenditure during Mountain Bike Trail Riding

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Abstract This study examined the energy expenditure during mountain bike trail rides on a 26-inch wheel (26er) compared to a 29-inch wheel (29er). Thirteen experienced bikers (four women, nine men, age=33.0±10.1 yrs), completed similar 6.7km trail rides on a 26er and 29er. GPS was used to measure distance and speed during each ride. Energy expenditure was determined by measuring oxygen consumption. Compared to the 26er, the 29er rides took less total time (24.2±3.2 vs. 25.5±3.5 minutes, $p=0.015$), hence faster speeds (4.7±0.6 vs. 4.4±0.6 m·s⁻¹, $p=0.022$), lower average heart rates (155.0±19.2 vs. 162.2±16.8 bpm, $p=0.047$), and lower total calories (263.3±34.3 vs. 290.7±36.9 kcals, $p=0.001$). Work rates represented by the rate of oxygen consumption (ml O₂·min⁻¹, $p=0.65$) were not different. At similar work rates, riders apparently gained a mechanical advantage on the 29ers allowing for 5% lower riding times and heart-rates, 6.8% faster speeds, and a 9.4% reduction in the total caloric expenditure for a standardized trail ride.

Keywords Caloric Cost, Cycling, Wheel Diameter, Cross-country Biking, Performance

1. Introduction

Mountain bikes with 26-inch diameter wheels (26er or 559mm ISO) were the industry standard for decades. More recently, mountain bikes with larger circumference and fatter wheels have gained popularity. One of the most common modifications is alterations in wheel diameter or size. Bikes with 29-inch diameter wheels (29er or 622mm ISO) are now very common. In countries where the metric system is the standard for weights and measures, the terms for mountain biking wheel diameter is still often reported in inches and is well understood. Therefore, the terms 26er and 29er to describe wheel diameter will be used throughout this report.

Anecdotally, experienced mountain bikers have claimed that the 29er “rolls over” obstacles more easily requiring

less energy to ride. In other words, the 29er may have a lower rolling resistance and, therefore, less energy is needed to maintain speed. Previous research, when examining road bikes, found that a larger wheel diameter had a lower rolling resistance than smaller wheel diameters [1, 2, 3]. Moreover, Steyn and Warnich [4] reported that the 29er had less rolling resistance compared to the 26er on soft surfaces such as sand, with little difference on hard surfaces such as rock or asphalt. Given that most mountain biking trails include a combination of terrain surfaces, the difference in rolling resistance may translate into a difference in total energy expenditure and speed of riding.

Another possible advantage to the 29er might be the conservation of angular momentum because of rotating mass. When wheels hold their momentum over a combination of terrain as opposed to changing momentum, mountain bikers will use less energy and obtain faster times. According to Newton’s laws of motion, a heavier rim would maintain a more constant speed, such as the 29-inch wheel. In other words, the 29er requires less energy to maintain momentum. Macdermid, Fink, and Stannard [5] found that 29-inch wheels showed a clear performance advantage during hill climbs, agreeing with the theory of angular momentum. In summary, the 29er may maintain angular momentum because the rotating mass reduces deceleration over the rough and rocky terrain. On the other hand, 26ers may decelerate to a greater extent over rough and rocky terrain causing the rider to expend energy to re-accelerate. Reduced rolling resistance on some trail surfaces and the maintained angular momentum of the 29er could offer an advantage in energy expenditure.

Currently, only one study has directly examined energy expenditure when riding a 29er versus a 26er. From unpublished results, Hurst [6] found no significant difference between elite riders’ energy expenditure for the 29-inch, 27.5-inch, and 26-inch wheels during a 3.48km (2.16 miles) mountain bike course. Hurst measured elite competitive cyclists at race pace and, therefore, the results may not be generalizable to recreational cyclists that are not highly trained. Hurst also reported that the 29er was

marginally faster with less effort suggesting that if the course distance were longer, there would be an energy saving benefit to the 29er. Therefore, increasing the length of the mountain bike ride may result in lower energy expenditure on a 29er versus 26er.

In addition to lower energy expenditure, studies indicate that a lower rolling resistance and maintaining angular momentum results in faster performance. Steiner, Muller, Maier, and Wehrin [7] found that, on average, Swiss National Team Mountain bikers were 7.5s faster on 29ers than 26ers, yet there were no differences in power output, cadence, time spent not pedaling, work, and heart rate. Furthermore, Macdermid, Fink, and Stannard [5] reported that nationally competitive mountain bikers were significantly faster on 29ers than 26ers (635.4 vs. 616.6 s, respectively). Again, faster times were reported even though there was no significant difference between power output and heart rates. In contrast, Hurst, Sinclair, Atkins, Rylands, and Metcalfe [8] found no significant difference in the time to complete the course between competitive male mountain bikers on a 29er versus a 26er. It is important to note that all three studies comparing performance time of a 29er to a 26er involved elite athletes under race conditions; therefore, it is difficult to generalize the results to recreational riders under submaximal conditions.

Therefore, the purpose of the present study was to determine if the larger 29-inch wheel size had an impact on the energy expenditure and speed during a standardized 6.7km mountain bike ride compared to 26-inch wheels for recreational rides under a self-selected submaximal pace for a 6.7km course. Energy expenditure and speed during two trail rides, one on a 26er and one on a 29er, were compared to determine the impact on energy expenditure due to wheel size.

2. Materials and Methods

2.1. Subjects

Following approval from the Southern Utah University ethics committee, experienced recreational mountain bikers were recruited to complete this study. Subjects were both male ($n=9$) and female ($n=4$) with an average age of 33.0 ± 10.19 yrs. All subjects completed an informed consent and were determined to be currently healthy, with no conditions that would limit their riding ability during the study. All subjects reported at least two years of mountain biking experience and were familiar with the trails used for this study.

2.2. Design and Methodology

A random crossover design was applied. Subjects were asked to complete two similar trail rides on two different bikes and two separate days. One ride was completed on a

26er, and one ride was completed on a 29er. The rides were performed in random order with at least 24 hours between rides. Rides were only scheduled when environmental conditions were dry (no precipitation), low wind (less than $20 \text{ km} \cdot \text{hr}^{-1}$), and between 10 and 30 degrees Celsius. Subjects provided their riding gear (helmet and shoes) but rode matched Rocky Mountain full-suspension mountain bikes (26er and 29er). The bikes were matched as closely as possible for total mass, tire pressure, shock pressure and rider position. A water bottle filled with sand was attached to the frame of the 29er to equalize the mass of both bikes.

Before and during each ride, temperature and relative humidity were recorded along with time of day. Height, weight, and age were recorded for each subject. Subjects were then fitted with a portable gas analyzer system (K4b2, Cosmed Inc., Italy) with an integrated global positioning system (GPS). Expired oxygen (VO_2) and carbon dioxide (VCO_2) were collected and measured on a breath-by-breath basis during each ride. The gas analyzer system consisted of a face mask covering both mouth and nose, with a sampling line connected to the small portable analyzer. The analyzer and related components weighed approximately 1.5kg and were carried by the rider in a small backpack during each ride. The gas analyzer system also included an integrated heart rate monitor (Polar Electro Inc, Lake Success NY) allowing for continuous measures of heart rate (HR). The gas analyzer, GPS unit, and other cycling components were calibrated before each ride.

An established, 6.7km outdoor mountain bike trail loop was selected for the rides. The trail was an established public access trail located within the Three Peaks National Recreation Area in southwestern Utah. Permission to use the trails for research purposes was granted by local federal officials before any testing. The single-track trail was familiar to all participants and ranked as a beginner to intermediate level trail by the local chapter of the International Mountain Biking Association. The trail had a combination of rock, sand, packed dirt and some technical features. There was a total increase in vertical elevation of about 75m over the course of each ride. Subjects completed the standardized 6.7km trail ride on each of the bikes at the same relative intensity for both rides. They were asked to ride at an intensity that they could replicate and that they would consider “moderately-hard” or at a Rating of Perceived Exertion (RPE) of about 13 to 14 on a scale of 6 (rest) to 20 (maximum intensity).

2.3. Statistical Analysis

Variables recorded during each ride were HR, VO_2 , VCO_2 , speed, temperature, and elevation. The rate of energy expenditure ($\text{kcal} \cdot \text{min}^{-1}$) and total energy expenditure (kcal) was determined based on respiratory exchange ratios and VO_2 during each ride. Paired t-tests were used to compare the two riding conditions with

significance for all comparisons set at $p < 0.05$. Cohen's d for paired samples were calculated and used to infer the effect of the wheel size [9, 10]. Analyses were performed with SPSS version 24.0 (IBM, Armonk, NY).

The 6.7km trail had three distinct trail segments with easily identifiable landmarks. One trail segment was primarily uphill, the second segment was variable with both up and downhill sections and the third segment was primarily downhill. Post hoc comparison of individual trail segments was also conducted to determine if the impact of tire diameter was more evident on uphill/climbing segments or downhill/descending segments.

3. Results

Thirteen participants ($n=13$; 4 women and 9 men) completed both trail rides. They were all experienced mountain bikers who were familiar with the trail and conditions for this study. Participant demographics are listed in Table 1. Environmental conditions, temperature, and relative humidity were found to be similar across all rides for both riding conditions ($p > 0.05$).

Table 1. Participant demographics (N=13; 4 Women and 9 Men)

	Mean \pm SD	Range
Age (yrs)	33.00 \pm 10.19	18 – 49
Height (cm)	175.95 \pm 6.61	165.10 – 185.00
Weight (kg)	75.21 \pm 10.47	54.00 – 88.60
Riding Experience (yrs)	6.24 \pm 0.94	2 – 10+

On average, participants were 1.2s faster on the 29er than on the 26er during the entire ride (Table 2). Moreover, the average speed for the 26er was less than the average speed for the 29er. In addition, heart rates, on average, were 6.4 bpm lower on the 29er compared to the

26er that corresponds with a 9% lower energy expenditure. On the other hand, work rates, represented by the rate of oxygen consumption ($\text{ml O}_2 \cdot \text{min}^{-1}$) and rate of caloric expenditure ($\text{Kcal} \cdot \text{min}^{-1}$) were not different. Post hoc comparison of three distinct trail segments indicated that differences between the 26ers and 29ers were most evident during uphill segments of the course. Segment 1 was primarily uphill and segment 3 primarily downhill. The course profile with distance and vertical elevation change for each trail segment is provided in Figure 1.

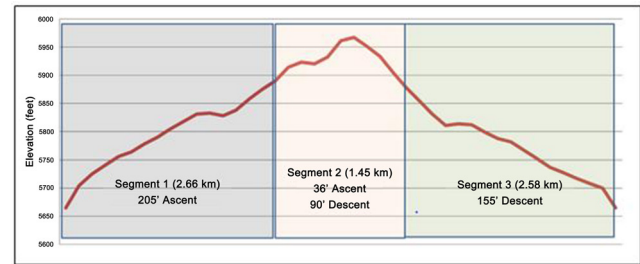


Figure 1. Profile of the 6.7km cross-country mountain bike course during the study, including the different sections

Average values for each segment are presented in Tables 3, 4, and 5. During uphill riding in segment 1, 29ers had approximately 7% faster times and speeds, with 10.4% lower caloric expenditure compared to 26ers (Table 3). Participants, on average, had a lower rate of oxygen consumption during the uphill segment while on the 29er compared to the 26er; yet, there was no significant difference between the heart rates or rate of caloric expenditure.

Segment 2 had 7.5% faster times and 9.4% lower caloric expenditure on the 29er (Table 4). There were no differences in any measured variables on downhill segment 3 (Table 5). Segment ride times and energy expenditure are presented in Figure 2 and Figure 3.

Table 2. Average values of analyzed parameters for both bike types during a 6.7km trail ride

	26er	29er	Difference (26er – 29er)		
			Mean	p	ES
Total Time (min)	25.29 \pm 3.50	23.97 \pm 3.19	1.20	0.015	0.28
Speed ($\text{m} \cdot \text{s}^{-1}$)	4.50 \pm 0.59	4.72 \pm 0.58	-0.22	0.022	-0.27
Avg. HR (bpm)	161.66 \pm 16.28	155.26 \pm 18.51	6.41	0.047	0.26
Abs. VO_2 ($\text{ml} \cdot \text{min}^{-1}$)	2246.89 \pm 406.02	2107.79 \pm 321.30	139.26	0.065	0.27
Rel. VO_2 ($\text{ml} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$)	30.35 \pm 6.43	28.50 \pm 5.70	1.85	0.058	0.22
Total Kcals	283.19 \pm 37.62	257.43 \pm 32.80	25.80	0.001	0.52
Avg. Kcals ($\text{kcal} \cdot \text{min}^{-1}$)	11.44 \pm 2.16	10.89 \pm 1.84	0.55	0.168	0.19
VE ($\text{l} \cdot \text{min}^{-1}$)	92.84 \pm 22.10	88.52 \pm 16.96	4.32	0.217	0.16

Values are presented as means \pm SD. Abbreviations: 26er, 26-inch-wheel bike; 29er, 29-inch-wheel bike; ES = effect size; HR, heart rate; VO_2 , oxygen consumption; Kcals, kilocalories; VE, minute ventilation.

Table 3. Average values of analyzed parameters for both bike types during segment 1 (2.66km; ascent: 62.4m)

	26er	29er	Difference (26er – 29er)		
			Mean	<i>p</i>	ES
Total Time (min)	11.84 ± 1.88	11.00 ± 1.42	0.83	0.010	0.36
Speed (m·s ⁻¹)	3.82 ± 0.59	4.08 ± 0.51	-0.26	0.013	-0.33
Avg. HR (bpm)	161.90 ± 16.40	155.20 ± 18.33	6.70	0.089	0.27
Abs. VO ₂ (ml·min ⁻¹)	2488.69 ± 428.86	2303.94 ± 311.73	184.75	0.033	0.35
Rel. VO ₂ (ml·kg ⁻¹ ·min ⁻¹)	33.60 ± 6.24	31.37 ± 5.54	2.23	0.043	0.27
Total Kcals	144.51 ± 18.68	129.43 ± 16.10	15.08	0.000	0.61
Avg. Kcals (kcal·min ⁻¹)	12.53 ± 2.30	11.95 ± 1.90	0.58	0.191	0.20
VE (l·min ⁻¹)	95.31 ± 21.90	89.55 ± 16.97	5.75	0.200	0.21

Values are presented as means ± SD. Abbreviations: 26er, 26-inch-wheel bike; 29er, 29-inch-wheel bike; ES = effect size; HR, heart rate; VO₂, oxygen consumption; Kcals, kilocalories; VE, minute ventilation.

Table 4. Average values of analyzed parameters for both bike types during segment 2 (1.45km; descent: 27.5m; ascent: 16.4m)

	26er	29er	Difference (26er – 29er)		
			Mean	<i>p</i>	ES
Total Time (min)	5.22 ± 0.75	4.83 ± 0.66	0.39	0.003	0.40
Speed (m·s ⁻¹)	4.82 ± 0.64	5.08 ± 0.64	-0.26	0.074	-0.29
Avg. HR (bpm)	167.54 ± 17.45	162.90 ± 19.20	4.64	0.135	0.18
Abs. VO ₂ (ml·min ⁻¹)	2241.01 ± 411.72	2159.05 ± 382.47	81.96	0.316	0.15
Rel. VO ₂ (ml·kg ⁻¹ ·min ⁻¹)	31.03 ± 7.29	29.47 ± 6.51	1.56	0.266	0.16
Total Kcals	58.98 ± 8.94	53.45 ± 7.06	5.53	0.003	0.49
Avg. Kcals (kcal·min ⁻¹)	11.49 ± 2.24	11.25 ± 2.08	0.24	0.589	0.08
VE (l·min ⁻¹)	101.58 ± 24.60	100.29 ± 20.43	1.29	0.749	0.04

Values are presented as means ± SD. Abbreviations: 26er, 26-inch-wheel bike; 29er, 29-inch-wheel bike; ES = effect size; HR, heart rate; VO₂, oxygen consumption; Kcals, kilocalories; VE, minute ventilation.

Table 5. Average values of analyzed parameters for both bike types during segment 3 (2.58km; descent: 47.4m)

	26er	29er	Difference (26er – 29er)		
			Mean	<i>p</i>	ES
Total Time (min)	8.26 ± 1.12	8.16 ± 1.27	0.09	.692	0.06
Speed (m·s ⁻¹)	5.29 ± 0.71	5.36 ± 0.73	-0.07	.595	-0.07
Avg. HR (bpm)	157.70 ± 16.92	151.55 ± 19.69	6.15	.069	0.24
Abs. VO ₂ (ml·min ⁻¹)	1952.84 ± 431.47	1847.05 ± 350.93	105.78	.116	0.19
Rel. VO ₂ (ml·kg ⁻¹ ·min ⁻¹)	26.57 ± 7.23	25.28 ± 6.43	1.29	.143	0.13
Total Kcals	78.87 ± 13.45	74.67 ± 12.13	4.21	.116	0.23
Avg. Kcals (kcal·min ⁻¹)	9.75 ± 2.24	9.32 ± 1.81	0.43	.191	0.15
VE (l·min ⁻¹)	83.98 ± 22.42	82.28 ± 19.72	1.71	.530	0.06

Values are presented as means ± SD. Abbreviations: 26er, 26-inch-wheel bike; 29er, 29-inch-wheel bike; ES = effect size; HR, heart rate; VO₂, oxygen consumption; Kcals, kilocalories; VE, minute ventilation.

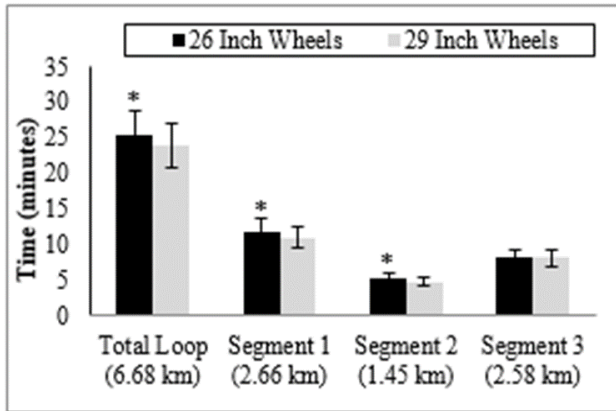


Figure 2. Average ride time for both bike types for the total loop and for each segment. *Significantly different ride times for given segment of the course ($p < 0.05$).

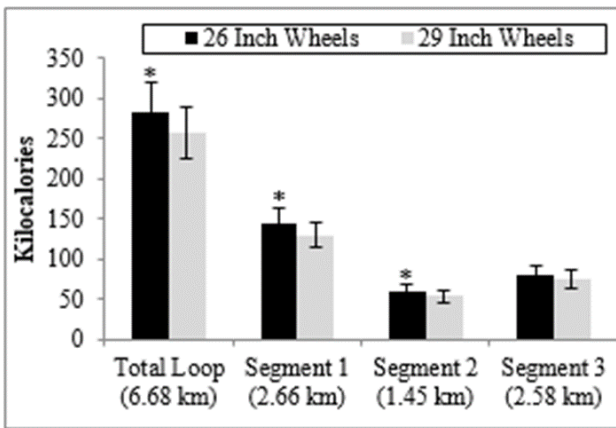


Figure 3. Average total energy expenditure for both bike types for the total loop and for each segment; *Significantly different total energy expenditure for a given segment of the course ($p < 0.05$).

4. Discussion

We hypothesized that the 29er would provide an advantage over the 26er in regards to energy expenditure and completion time of a 6.7km mountain bike ride. The main findings were: (a) energy expenditures were significantly lower with the 29er compared to the 26er for the total loop and two trail segments that included uphill riding; (b) average heart rate was significantly lower with the 29er than with 26er; and (c) overall, the 29er rides were faster than the 26er rides particularly during uphill riding.

Participants were asked to complete the laps at steady, yet similar, pace, and the validity of the rides depended on their self-selected work rates during the task. There were no significant differences between wheel sizes regarding rates of oxygen consumption during each ride indicating that participants did maintain similar work rates. Similar results were reported among competitive mountain biking athletes [7,11] indicating no differences between a 26er

and a 29er in work rates as measured by power output (254.5 ± 39.5 vs. 253.5 ± 43 W, respectively) and heart rate (170 ± 11 vs. 170 ± 10 bpm, respectively). In both previous studies cited [7,11], participants performed all trials as fast as possible; unlike the current study asking participants to complete each lap at a steady, yet similar, pace. Combining the results from the current study and previous research, mountain bikers were able to maintain similar work rates on 26ers and 29ers whether asked to ride maximally or sub-maximally.

The current study examined the energy expenditure of recreational athletes performing the trials at a steady, yet similar, pace as opposed to previous studies that examined elite athletes completing the trials as fast as possible. Therefore, the measures of intensity (e.g., heart rates and oxygen consumption) were lower in this study than previous studies on elite cross-country mountain bikers [11, 12, 13]. For instance, Wilber and colleagues [13] reported oxygen consumption during an elite mountain bike race at 48.4 to 56.4 $\text{ml} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$, which is noticeably higher than the current study (25.3 - 33.6 $\text{ml} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$). Moreover, heart rates were also higher in previous research of elite athletes (165 - 175 bpm) than our recreational athletes (155 - 161 bpm). The ranges measured in the current study for heart rate and relative oxygen consumption would indicate that the rides were valid representations of moderate to hard intensity mountain biking conditions.

The present study reported a lower energy expenditure with the 29er compared to the 26er, especially during uphill climbing. Reporting on unpublished data, Hurst [6] found no significant difference in energy expenditure during mountain biking on a 29er compared to a 26er among elite mountain bikers at race pace (data unavailable). Moreover, previous studies have reported that wheel size did not significantly influence power output during a cross-country mountain bike performance of elite riders at a maximal pace [7, 8, 11]. However, the present study examined energy expenditure of recreational athletes at a steady, submaximal pace. Therefore, there appear to be energy savings associated with riding a 29er among recreational athletes who are riding at a relatively steady pace rather than a maximal pace during race conditions.

In addition to a lower energy expenditure, rides with the 29er in the current study were faster, especially during uphill segments of the course. This result is in agreement with previous research indicating that Swiss national team mountain bikers were, on average, 7.5s faster on the 29er than the 26er on a 6.15km course performed as fast as possible [7]. Moreover, the 29er was 2s, on average, faster on the uphill segment of the course. Similarly, speeds were significantly faster for the 29er ($v_{\text{overall}} = 4.08$ $\text{m} \cdot \text{s}^{-1}$, $v_{\text{uphill}} = 3.47$ $\text{m} \cdot \text{s}^{-1}$) compared to the 26er ($v_{\text{overall}} = 4.00$ $\text{m} \cdot \text{s}^{-1}$, $v_{\text{uphill}} = 3.39$ $\text{m} \cdot \text{s}^{-1}$) [7]. Likewise, MacDermid, Fink, and Stannard [11] reported that nationally competitive

mountain bikers completed a 5.9km, at race pace, faster on a 29er compared to a 26er (616.6±49.2 vs. 635.4±41.5s, respectively). Although the 29er was, on average, 3s and 10s faster on the uphill segments of the course than the 26er, the difference was not statistically significant [11]. Only one study has reported no difference in trail riding speed comparing 26 and 29 inch wheels [8]. The course was only 3.48km and the authors stated that the 29er was marginally faster with less effort and, therefore, performance benefits of the 29er may be apparent on a longer course. Thus, based on this study and previous research, overall 29-inch wheels were consistently faster than 26-inch wheels. Despite the potential drawbacks of a bigger wheel, the 29er may have a performance advantage during uphill climbs.

Lower energy expenditure and faster mean ride times on the 29ers can be attributed to higher bicycle mass, lower rolling resistance or increased angular momentum. Kyle [14] noted that during competitive road cycling the addition of as little as 1 kg to the mass of the bicycle on flat terrain could decrease bicycle speed due to increase in rolling resistance. Also, Howe [15] estimated that the reduction in bicycle mass could significantly improve uphill cycling performance. Given that the bikes used for the current study were matched for mass, it is unlikely that this accounted for faster times. Differences in rolling resistance and angular momentum are more likely explanations for the differences in energy expenditure and ride times.

Rolling resistance, defined by the resistance to the steady motion of the wheel, is a significant factor in determining energy expenditure and mountain bike speed and performance. In fact, rolling resistance contributes significantly to the energy cost of mountain biking at slow speeds ($< 4.16\text{m}\cdot\text{s}^{-1}$), although this has been disputed [16, 17]. Grappe and colleagues [18] found a threefold increase in rolling resistance with reductions in speed of 50% from 14 to 7 $\text{m}\cdot\text{s}^{-1}$. Lower speed, therefore, would increase rolling resistance and, thus, the energy cost of mountain biking, even if the differences in rolling resistance are small [19]. In the current study, specifically, during the uphill segment, the 26er was 6% slower than the 29er. Consequently, there may have been greater rolling resistance on the 26er than the 29er, and therefore, the rider expended more energy [2, 18].

Furthermore, the major factors affecting rolling resistance are riding surface, tire pressure, and tire diameter [1,18,20]. Rolling resistance changes in response to irregular gradients and surface terrain changes. In fact, Berry, Koves, and Benedetto [21] demonstrated a significantly higher oxygen consumption ($7\text{-}20\text{ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$) riding on difficult surface terrain than riding on a treadmill belt. The increase in energy cost, as suggested by the authors, was caused by a higher rolling resistance on irregular terrain. Lower tire pressures would also result in greater rolling resistance [20]. However, in the current study both terrain and tire pressures were the

same for both the 26er and 29er. Thus, neither terrain nor tire pressure explains the difference in energy cost and speed between the 26er and 29er. On the other hand, the tire diameter, which is inversely proportional to rolling resistance, may influence energy expenditure. Kyle [3] reported lower rolling resistance for 27-inch tires compared to 24-inch tires on linoleum, concrete, and smooth asphalt. Moreover, MacDermid, Fink, and Stannard [5] attributed the 2.3% and 3.5% faster time to complete a riding lap on the 29er to a decrease in rolling resistance. This reduction in rolling resistance was attributed to less deformation and reduced energy loss of the 29er during the ride. Therefore, larger wheels have lower rolling resistance than smaller wheels [1,2,3,4], thereby rolling more easily over obstacles, which contributes to increased mountain biking efficiency. As demonstrated by the current study, mountain biking with 29-inch wheels had a lower energy expenditure.

A smaller change in angular momentum with the 29ers also likely contributed to the differences in energy expenditure and ride times. During mountain bike trail riding, wheels that can better hold their momentum over rough and rocky terrain are preferred. The larger 29er tires have a higher rotating mass, which means a higher moment of inertia, and therefore, a more significant resistance to angular deceleration.

Previous research comparing similarly sized tires (26ers) has evaluated the effect of tire mass, and tread surface depth on riding speed. Although there was no difference in the wheel diameter, MacDermid, Fink, and Stannard [5] reported that the heaviest tires consistently had the fastest riding and coasting speeds (X-King, 1050g) regardless of tread depth or “classification” (slick, mud, or all-purpose).

Therefore, a smaller change in angular momentum maintains angular velocity, and consequently, linear velocity. The heavier tire/rim, as found on the 29er, would maintain a more constant speed. Thus, the 29er had faster ride times during the uphill climb. Likewise, MacDermid, Fink, and Stannard [5] found that the participants using the X-King, the heaviest wheel, climbed just as fast as those riding with lighter tires during a climb test ($t = 197.3\pm 1.2\text{s}$ compared to the $t = 201.5\pm 1.1\text{s}$ respectively). Therefore, faster times reported in this study and previous studies, especially during uphill climbing, may reflect a smaller change in angular momentum due to a higher rotational weight of the 29-inch wheels.

Another factor contributing to the lower energy cost of the 29er rides is the smaller change in angular momentum due to the larger moment of inertia. Angular momentum is the resistance to change in the wheel’s angular velocity. Moreover, angular momentum is the product the wheel’s moment of inertia and angular velocity. The 29er would have a larger moment of inertia because of a higher rotational mass than the 26er. Therefore, with all else being equal, the 29er would have a greater angular

momentum. According to Newton's Laws, a higher external torque is necessary to change the angular velocity of a rotating wheel if the wheel has a higher moment of inertia such as the 29er. Moreover, the 26er, with its smaller moment of inertia, will experience a greater change in momentum than the 29er when the same external torque (e.g., irregular gradients and surface terrain changes) is acted on it. More energy, therefore, is expended to compensate for the greater changes in angular velocity experienced by the 26er. It appears, then, that the 29er had smaller changes in angular momentum, which was reflected in a lower total energy expenditure and faster speeds.

4.1. Practical Application

The results indicate that recreational mountain bikers will benefit from larger diameter wheels, especially when riding on a variety of surfaces with consistent uphill segments. The 29er was faster on the uphill sections with less energy expenditure; therefore, recreational mountain bikers interested in conserving energy or trying to choose a bike appropriate for conditions they most commonly encounter may benefit from these results. The present study has several limitations that may affect the generalizability of the result. First, further studies should be performed with a greater sample size to confirm these results. Second, it is difficult to precisely control for environmental conditions in the field thus potentially increasing the variability of measures. Third, subjects were given the opportunity to optimize bike set up (e.g., seat height, tire pressure) before the ride. While this setup guarantees a valid comparison of the overall performance of the two bike types, it is difficult to entirely separate the results into effects of the wheel size alone or other factors associated with the choice of bike type and set up (e.g., geometric differences, tire type, etc.). Furthermore, future research is needed to determine if these effects are transferable to longer rides (e.g., >30 min), more technical trails and technical uphill trail sections, as well as including comparisons with a 27.5-inch wheel.

5. Conclusions

The results of the present study show that faster times on the 29er were obtained with lower energy cost during a standardized 6.7km trail ride. At similar work rates, riding time and heart rates were about 5% lower on the 29er, while average speed was 6.8% faster. Moreover, the 29er required 9.4% lower total energy expenditure (kcal) compared to the 26er, with the greatest advantage manifested during the uphill portions of the ride.

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