The impact of tyre diameter and surface conditions on the rolling resistance of mountain bikes

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Cycling has been a mode of transportation since the first bicycle was invented in 1790. It became an organised sport in 1868. Four important components of a bicycle affect its performance when racing: frame mass, brakes, suspension and wheels.

As the bicycle's design developed, the wheels evolved to the modern 26-inch wheels that most mountain bikes use today. A larger wheel, with a diameter of 29 inches, was developed for mountain bikes in the mid-1990s. This wheel diameter was deemed unsuccessful, until it was reintroduced in 2001. This raised a debate about the difference in speed and performance between 26-inch and 29-inch wheels (Herlihy, 2004). A study was conducted to determine how the rolling resistance of 26-inch wheels compares to that of 29-inch wheels in terms of a bicycle's performance. The five parameters that influence rolling resistance include surface, tyre inflation, cyclist mass, wheel diameter and suspension type.

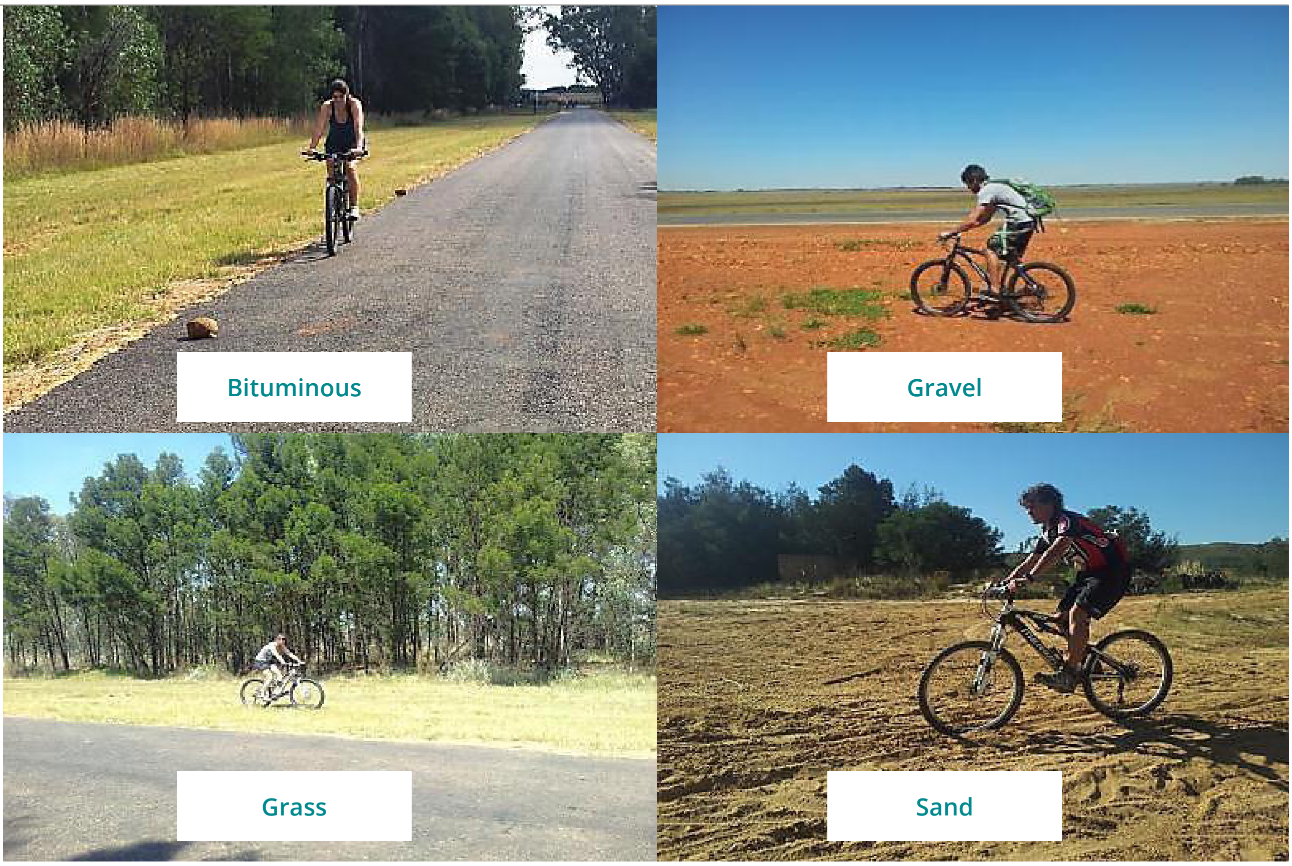
Rolling resistance between the wheel and the road surface is a major factor in the performance of any vehicle. Rolling resistance is the reaction force acting on the bicycle due to the interaction between the tyre of the mountain bike and the surface of the terrain on which it is travelling.

The interaction between the tyre and the terrain surface causes a loss of energy. By investigating the physics of this interaction, a better understanding of the performance efficiency of different wheel diameters will develop. The terrain surface has a major impact on the rolling speed of a wheel and the overall performance of the vehicle (Jackson, Willis, Arnold and Palmer, 2011). Grappe, Candau, Barbier, Hoffman, Belli and Rouillon (1999) found increased rolling resistance for bicycles with added mass and decreased rolling resistance for conditions of increased tyre inflation pressures. The key to reducing rolling resistance is to minimise the tyre casing deformation and, in so doing, minimise the loss of energy as a result of the interaction between the tyre and terrain.

Tyre inflation pressure affects the contact surface between the tyre and the ground. When the tyre is underinflated, the rolling resistance increases (Grappe et al., 1999). When the tyre is overinflated, it has poor grip due to the minimal contact surface, which will result in slippage. The slippage will render the brakes ineffective, especially during wet conditions. When comparing the difference between the deformation of the 26-inch and 29-inch wheels with the same tyre inflation pressure, it is evident that the larger wheel diameter suffers less deformation. This means that the 29-inch wheel should perform better than the 26-inch wheel.
The main cause of the loss of energy is the deformation of the tyre (depending on tyre properties), the deformation of the terrain surface (depending on terrain material properties) and the movement below the surface.

The following components directly affect the rolling resistance of a mountain bike (Schwalbe, 2011):

- The cyclist's mass affects the rolling resistance of the bicycle tyre. The cyclist's technique also contributes to the rolling resistance of the tyres in terms of



The four surface types used in the experiment

how mass is distributed while riding. The bicycle's suspension will determine whether or not the vertical load on the tyre will fluctuate. The change in the combined rolling resistance of both tyres depends on the cyclist's technique.

- The tyre consists of four major components that influence the performance of the entire bicycle: width, tread pattern, tread count and tyre inflation pressure. The quality of any of the components of the wheel affects the performance and durability of the wheel.
- Suspension ensures that less vertical mass fluctuation is transferred to the tyres, decreasing tyre deformation. Mountain bike suspensions can be divided into three types: rigid, hard tail and full suspension. Rigid bicycles have no suspension and are not very common in mountain biking. A hard tail only has suspension at the front fork, and coil or air-compressed shocks absorb the impact. A full suspension bike has suspension on the front fork and rear stays.
- The terrain surface influences rolling resistance. Four surfaces were used to determine the effect of rolling resistance on the performance of 26-inch and 29-inch wheels. These are bituminous, gravel, grass and sand.

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The difference between the rolling resistance of the two wheel diameters was tested. The experiment was conducted on four different terrain surfaces. The difference in the effect of the masses of three different cyclists on rolling resistance was tested. The masses of the three cyclists were adjusted by weights to represent masses of 70 kg, 80 kg and 90 kg respectively. The cyclists accelerated to 15 km/h to incorporate some air resistance in the measurements and calculations. Four mountain bikes were used in the experiment: a 26-inch hard tail (HT26), a 26-inch full suspension (FS26), a 29-inch hard tail (HT29) and a 29-inch full suspension (FS29) (Figure 1).

The experiment was conducted using the same four terrain surfaces, the same two wheel diameters, different tyre inflation pressures and the different masses of the same three cyclists. The difference between the effect of different tyre inflation pressures on rolling resistance was tested, as was the difference between the effect of two different suspensions on rolling resistance. The difference between the effect of the two wheel diameters with an obstruction on the terrain surface on rolling resistance was also tested. The test was conducted on the gravel surface with the same two wheel diameters at two different tyre inflation pressures with the different masses of the same three cyclists. The difference between the rolling resistances measured when rolling over an obstruction, as well as the rolling resistances of the corresponding terrain surfaces and wheel diameters previously measured, was calculated. These differences are the preservation of the momentum of each wheel diameter in terms of rolling resistance force.

The data was separately analysed for each of the different parameters, based on the average rolling resistance coefficients calculated for each of the various parameters.

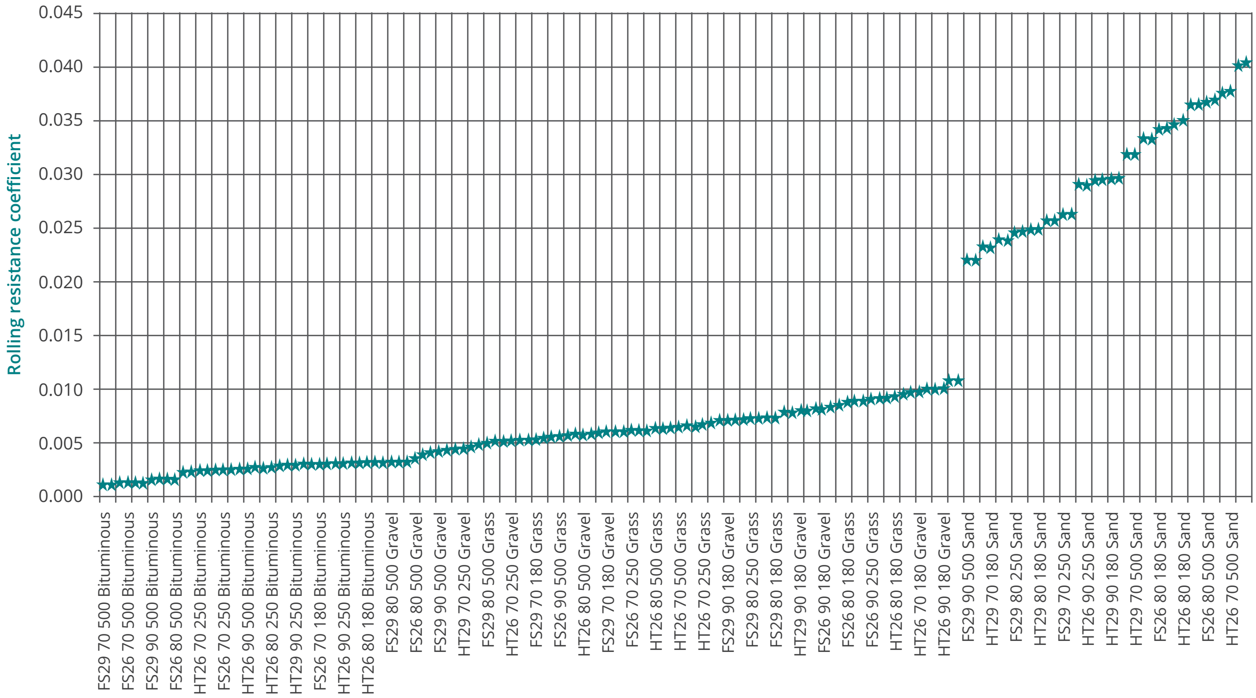

Figure 1: Rolling resistance coefficients measured for all four types of bicycle, cyclist masses, wheel diameters, tyre inflation pressures and surfaces.

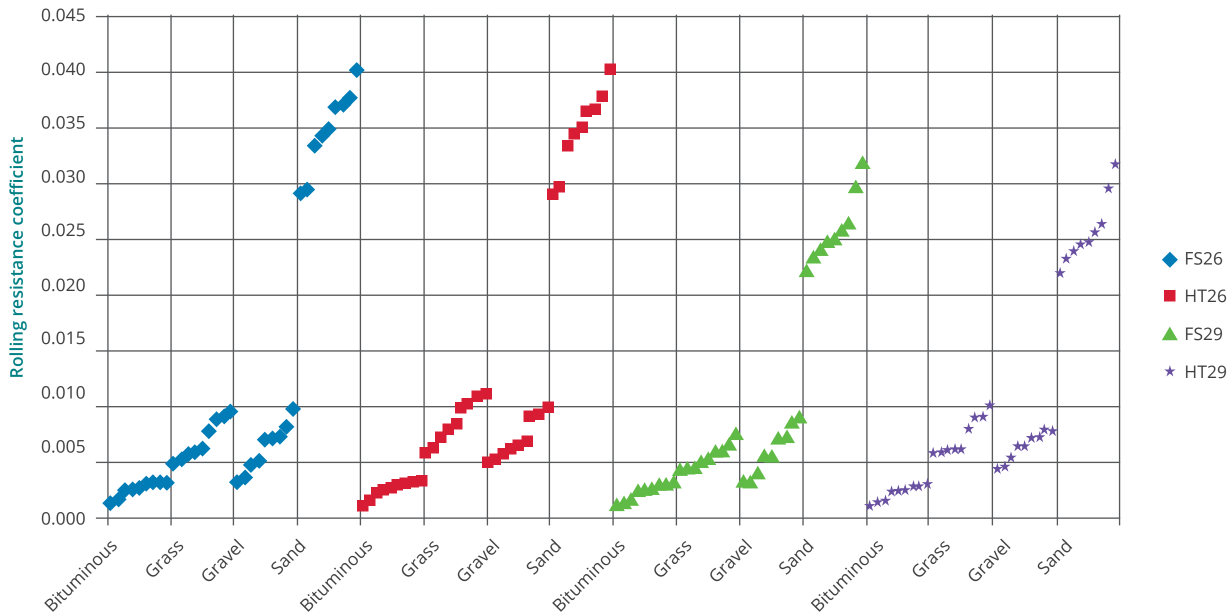

Figure 2: Measured rolling resistance for four mountain bikes indicating the effects of wheel diameter and suspension type.

A summary of the average, standard deviation and coefficient of variation of the rolling resistance coefficients calculated for the five main parameters investigated in this research study are provided in Table 1.

The average rolling resistance of the 26-inch diameter wheel was higher than that of the 29-inch diameter wheel. The data indicates that the 26-inch wheel diameter (both suspension types) has a higher rolling resistance for the sand, grass and gravel surfaces. For the bituminous surface, the differences were negligible. The data thus indicates that the 29-inch wheel diameter should be beneficial when riding on off-road surfaces, but on paved surfaces, the benefit will be negligible.

> The terrain surface showed the largest effect on rolling resistance.

An analysis of the data in Table 1 and Figure 1 indicates that the bituminous surface had the lowest average rolling resistance coefficients, followed by the grass and gravel surfaces with similar values, and the sand surface with the highest average rolling resistance coefficient, a factor of between 4.5 and 15 times higher than the other three surfaces.

The data in Table 1 and Figure 2 indicates that higher tyre inflation pressure causes lower rolling resistance. This agrees with published data (Grappe et al., 1999). The data in Table 1 is based on three repeats of each measurement.

The average rolling resistance coefficient was not affected to the same degree by cyclist mass as it was by the tyre inflation pressure and surface type. Although a general increasing rolling resistance coefficient trend is visible as the cyclist's mass increases, it does not constitute a major increase. Therefore, cyclist mass appears to have a secondary effect on rolling resistance.

Data from Figure 2 indicates that, in terms of rolling resistance and the four surfaces evaluated, there is no measurable advantage in using full suspension, as opposed to hard tail suspension.

When evaluating the average rolling resistance ranges for all five parameters, the terrain surface showed the largest effect on rolling resistance, followed by wheel diameter and tyre inflation pressure. Both the cyclist mass and the suspension type showed only secondary effects on rolling resistance. This may be partly attributed to the relatively small difference in the cyclists' masses in the experiment.

→ *Table 1: Average and standard deviation of rolling resistance coefficients calculated for the five main parameters*

	Average rolling resistance coefficient	Standard deviation rolling resistance coefficient	Coefficient of variation [%]
Surface			
Bituminous	0.002	0.001	29%
Grass	0.007	0.002	23%
Gravel	0.006	0.002	33%
Sand	0.030	0.006	18%
Tyre inflation pressure			
180 kPa	0.012	0.011	91%
250 kPa	0.012	0.011	94%
500 kPa	0.011	0.012	114%
Cyclist mass			
70 kg	0.011	0.012	107%
80 kg	0.012	0.011	98%
90 kg	0.012	0.011	93%
Wheel diameter			
26-inch	0.013	0.013	100%
29-inch	0.010	0.009	93%
Suspension type			
Hard tail	0.011	0.012	103%
Full suspension	0.012	0.011	95%

→ *Table 2: Percentage shorter distance travelled after the obstacle was introduced*

Tyre inflation pressure	500 kPa			250 kPa		
Cyclist mass	**70 kg**	**80 kg**	**90 kg**	**70 kg**	**80 kg**	**90 kg**
HT26	10%	12%	16%	19%	23%	28%
FS26	6%	8%	14%	14%	16%	20%
HT29	5%	5%	6%	7%	11%	16%
FS29	2%	3%	5%	6%	8%	10%

The last test evaluated the effect of an obstacle (a rock 100 mm in height) that the mountain bike had to negotiate during a typical coast-down test on the distance before the mountain bike came to a standstill. The objective was to determine to what extent a typical obstacle will affect the cyclist's momentum. The shorter distance that each of the mountain bikes travelled after traversing the obstacle is shown as a percentage in Table 2. Higher values indicate that the mountain bike came to a standstill a shorter distance after the obstacle (greater loss of momentum) than for lower values, with a 100% value indicating that the mountain bike stopped at the obstacle. The obstacle test was only conducted on the bituminous surface.

An analysis of the data in Table 2 indicates that the best combination for maintaining momentum after traversing over an obstacle is high tyre inflation pressure, low cyclist mass and the full suspension 29-inch wheel diameter option. The 29-inch wheel diameter has an advantage over the 26-inch wheel diameter, with even the low tyre inflation pressure hard tail 29-inch mountain bike being on par with the high tyre inflation pressure full suspension 26-inch mountain bike.

Conclusion

The 26-inch wheel diameter (both suspension types) has a higher rolling resistance than the 29-inch wheel diameter for the sand, grass and gravel surfaces, with the bituminous surface showing negligible differences.

The sand surface has a rolling resistance coefficient factor of between 4.5 and 15 times higher than the gravel, grass and bituminous surfaces. Terrain surface was shown to have the largest effect on the rolling resistance coefficients of the evaluated parameters, followed by cyclist mass and wheel diameter, and finally tyre inflation pressure.

No measurable advantage could be identified for using a full suspension as opposed to a hard tail suspension in terms of rolling resistance on the four surfaces evaluated. The best combination for maintaining momentum after traversing an obstacle is the high tyre inflation pressure, low cyclist mass and full suspension 29-inch wheel diameter option. ❶

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