Affect of the Posture and Rolling Resistance on the Required Effort to Ride a Recumbent

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Among recumbent riders, there are often discussions about the effects of factors such as rolling resistance of tires, lying down more, or sitting upright more, having the steering wheel low or high on speed. Sometimes opinions are formed by riders' own subjective observation, but more often, they are formed by what other people say. The most commonly made error is comparing apples with pears.
Reasoning like: "After changing the path my chain follows on my bike, changing my tires or posture I went faster or slower on my recumbent" is often heard in discussions. But then factors like fitness, type of road surface, direction and strength of wind, temperature etc. are then not taken into account.
Or a fitter cyclist A is compared to a less fit cyclist B. Of course not everybody is in the situation to make objective measurements or have enough knowledge about the effects that are a factor in the efficiency of movement.
Many recumbent rides still want to express their opinions because it is fun to talk about it.
The reality is often very complicated and is described by the quote "It depends on and is caused by".

Of course, we all want to ride on a comfortable recumbent, which at the same time efficiently converts the limited pedalling power into speed. We all know that by lying down more, for example, you catch less wind and thus have to deliver less pedalling power for the same speed. But the relation between those two factors is not known, or at least has not been published. If we want to be able to say objectively something about these effects, we have to measure them in a controlled environment. To test this, I had the idea of measuring resistance using a basic measuring recumbent. This recumbent should be adjustable so that we can measure the factors of posture (air resistance) and tires (rolling resistance).
In cooperation with the NVHPV, this bike (see picture 1) was created. In December 2002, a series of measurements were

executed using this measuring recumbent and a power measurement system entitled SRM. This systematically set up test environment is unique for as far as I know. The results, of course, only say something about what could be measured within the available budget and time. The effects of the biomechanics (how efficiently a body converts body energy in pedal energy), for example, are not measured. And energy-efficient recumbent riding is also related to comfort. But as many experienced recumbent riders know, comfort and speed don't exclude each other on a recumbent. Before reading any further, I want to warn you that the reading can be tedious, but it was hard to make it more readable. However, you will be rewarded with many interesting conclusions and more insight into these two resistance factors from which you can benefit.

The test environment:

- Measuring system: SRM
- Measuring speeds: 35km/h.
- Measuring location: The Velodrome at Sloten, Amsterdam, The Netherlands (covered velodrome with a 200 meter wooden track).
- Type of recumbent: Adjustable measuring recumbent.
- Design and production of measuring recumbent: Bram Moens of M5-recumbents.
- Adjustable or replaceable are:
    - Brackets (both horizontal and vertical).
    - Angle of reclination.
    - Steering wheel, narrow under seat or above seat.
    - Type of wheel 406, 451 and 559.
    - Type of tire: IRC 20(451) x 1 1/8 at 8bar
- The other types of tires tested were also at 8bar
- Test rider: Bram Moens of M5-recumbents
- Air temperature: About 10°C.
- Pedal revolutions: About 80 revolutions per minute if not indicated otherwise.
- Speed and power were measured on average every 10 laps or 2km.

If there were small deviations of the measuring speed of 35km/h, then the measured power was corrected with commonly accepted formulas.

- During the measurements, the average speed could be kept within a 0.2 km/h margin.
- Clothing: long cycling pants + thin thermo jacket.

- Weight of recumbent plus rider about 92 kg.
- Inaccuracy of SRM-meter < 2%.
- The results were easy to reproduce because the SRM meter only had to be mounted and calibrated once.

The measuring variables:
The resistance a rider experiences during cycling is determined by the factors air resistance, rolling resistance, chain- and bearing energy losses.
In this test, we have limited ourselves to the most important factors. The air resistance and the rolling resistance. Chain- and bearing energy losses are interesting as well, but they have to be measured another time. The air resistance is determined by the frontal surface of the body and bike. Equally important is the streamlining. I.e. how well the flowing air is guided alongside the body and bike. With a recline angle of 40°, the frontal surface of the body will be larger than with a recline angle of 20°.
For the tests, we have chosen for 3 reclining angles. From a fairly upright position (38°), to a commonly used middle position (29°), to an almost reclined position (21°).
The more the legs and feet protrude, seen from the front, the more the air resistance will increase. One of the factors in this protrusion is the difference in height between the bracket and the seat. In practice, this varies between 0 and 30 cm. We have chosen 3 positions: +5cm, +14 cm and +22cm.
Furthermore, we thought it would be interesting to measure the difference between under seat- and above seat steering wheel. We have chosen to test a narrow under seat steering wheel and a narrow above seat steering wheel. The rolling resistance is determined by the material, the build and the width of the tire, and in addition, by the wheel diameter and the tire pressure. You can imagine that a stiff tire (e.g. a lot of rubber) gives more resistance than a supple tire (e.g. a little rubber and many threads per cm^2). Also, we know that the same tire gives less resistance on a larger wheel than on a smaller one.
The results table below indicates the tires chosen for the test. What we want to know is which of the indicated parameters have more or less of an influence on the required effort.
For example, it would be less interesting to recline very much if this would have only limited effect on the air resistance.

A good measure for the required effort is the required power in Watts. This is measured using the NVHPV's SRM-meter. During the measurements, only one parameter was changed at each test run so that the influence of each parameter could be measured separately.

The table below indicates the relationship between the posture on a recumbent and type of tire and the amount of power in Watts (W) measured at 35km/h.

Reclineation °	Difference in height in cm. Between bracket and seat (hvs) (If not indicated otherwise, the tests are executed with the above seat steering wheel).		
	+ 5 cm	+14 cm	+ 22 cm
	Power and type of tire	Power	Power
21°	-184 Watt----Specialized Fatboy 26x1,25inch -199 Watt** -201 Watt----Schwalbe Stelvio Kevlar 25x559 -218 Watt---IRC 20(451)x1 1/8 inch (6bar) -222 Watt---Schwalbe Stelvio Kevlar 28x406 -234 Watt---Vredestein Monte Carlo Double Density 37x406	189** Watt	-188**Watt -190**Watt (under seat steer + wintercoat) -194** Watt (under seat steer) -197** Watt (under seat steer + 105 rev/min)
29°		210** Watt	201** Watt
38°		235** Watt	234** Watt
	** Measured with **2xIRC Road Lite (451x1 1/8inch)-tires (8bar)**		

Possible conclusions from this test:

- Rolling resistance.

This factor has been measured with a hvs of +5cm and an angle or reclination of 21°.

1. Influence of diameter of wheel

There is a difference in total resistance of 21W (10%) between the Schwalbe Stelvio in 559 (201W) and the 406- type (222W), contrary to the fact that the air resistance of the 559- type must be more. From measurements in the past, we know that the rolling resistance is inversely proportional to the increase in diameter of the wheel. I.e. a 20 inch wheel gives about 40% more rolling resistance than a 26 inch wheel.

The rolling resistance of this recumbent at a speed of about 35km/h is about 25% of the total resistance. This matches very well with the total difference in resistance of 40% of 25%, which equals 10%.

2. Influence of type of tire

The relatively large influence of the tire type is shown by the difference (17W) between the Specialized Fatboy (184W) and the Schwalbe Stelvio Kevlar (210W), both of the 559- type. The difference is 9%. The increased stiffness of the Stelvio profile tire can be felt by hand and thus gives more resistance to the changing of its shape than the supple (e.g. no Kevlar) and wider, slick fatboy. The result of the extreme stiff Vredestein double density tire speaks for itself.

3. Influence of tire pressure

Decreasing the tire pressure from 8 to 6 bar for the IRC-451(199W versus 218W) increased the resistance with 19W(10%). So keep your tires pressurized!!.

The share of rolling resistance in the total resistance only increases at lower speeds.

- Air resistance

1. Influence of difference in height between bracket and seat.

This influence is measured at a 21° reclining angle and with the reference tire IRC 451 Road Lite at 8 bar.

An increase in the difference in height (bracket/seat) of +5cm(199W) to +22cm(188W), decreased the resistance with 11W(6%). The relatively small influence on the total resistance by the difference in height between the bracket/seat at a given reclining angle was also demonstrated in earlier tests I had done (1996).

The total resistance hardly changes between +15 and +25 cm hvs.

Under the +15cm and above the +25cm the feet, leg and knees protrude more below or above the upper body. The amount of protrusion of course also depends on the reclining angle.

2. Influence reclining angle

This influence is measured using a hvs of +14cm and with the reference tire.

Decreasing the reclining angle from 38° (189W) to 21° (235W) resulted in a decrease of resistance of 46W (20%). Now we are talking!

This means more than 1% reduction in resistance per degree of decrease of reclining angle. The decrease in resistance of 25° to 20°, for example, will probably be bigger than from 40° to 35°. This is caused by the fact that the frontal surface of the upper body decreases more (sinus curve) and by a bigger length/width ratio of the upper body, which is favourable for streamlining. Slim cyclists should, in my opinion, then experience relatively less air resistance then wider cyclists. We'll have to measure that as well someday!!

3. Influence of type of steering wheel

This influence is measured at a reclining angle of 21°, a hvs of +22cm and with the reference tire.

A relatively small increase in resistance of 6W(3%) using the under seat steering wheel(194W) was achieved in place of using the above seat steering wheel (188W). The increase in frontal surface for the under seat steering wheel is probably partly compensated by a better streamlining. The approaching air going through the arms in front of the chest probably gives extra turbulence.

4. Influence of winter jacket (see picture 2).

This influence is measured using a reclining angle of 21°, a hvs of +22 cm and with the reference tire.

This was actually meant to be a joke, but the thick jacket and hat gave a resistance decrease!!! (194W versus 190W) of 4W (2%),

The thick jacket gives a larger frontal surface, but filling up the belly and rounder shape gives probably a better streamline (lower cw-value).

5. Influence of the amount of pedaling revolutions

Same configuration as in 3.

Only a small increase in resistance of 3W(1.5%) was measured when increasing the revolutions from about 80 (194W) to 105(197W). You would expect a larger difference.

Difference in resistance comparing a relatively slower and faster version of the bare recumbent.

Slow version

- Recline angle 38°.
- Difference in height bracket/seat +5cm.
- Under seat steer
- Tires Schwalbe Stelvio 406 and 28 mm wide

Fast version

- Recline angle 21°.
- Difference in height bracket/seat +22cm.
- Above seat steer
- Tires Specialized fatboy 26x1,25 inch.

When comparing these two differing versions with each other, the fast version will use about 102W (about 39%) less energy for the same speed of 35km/h when compared with the slow version. This 102W is equivalent to the resistance caused by the installation of about 7 AXA HR-dynamo's on a recumbent. This is a tire driven dynamo that is being used often on regular bikes. I tested the resistance of this dynamo a couple of years ago. Don't take the comparison with the dynamos too literally, but see it more as a metaphor.
Expressed differently, it is the difference between relaxed touring and having a hard time.
At a constant effort, the difference of about 39% will give an increase in speed of about 4km/h at a speed of 35km/h. By the way, at lower speeds the percentage difference in speed will be the same. A rule of thumb is that the cube root of the difference in power in % gives you the difference in speed in %.
For example, the cubed root of a 30% difference in power is equivalent to the cubed root of 1.3, or 1.1, which represents a 10% difference in speed.

The resistance increasing effects of chain tubes, (extra) chain rolls, gears, mudguards etc. has not been taken into account with these measurements. We will also measure this sometime in the future.

As we can see from the measurements, the benefit of the reclined position is nullified when we add resistance increasing parameters to our bikes such as sitting more upright, positioning our feet lower, and mounting stiff tires. The translated inverse of the M5 motto does then apply more and more: Less miles with more effort.

Since most (recumbent) cyclists only can output a power of 100-200W for a couple of hours, it is important to make use of this energy efficiency.

Speed is not important for all recumbent riders. But you can also ride slowly on a more efficient recumbent with less effort.
Cyclists riding traditional cycles will in addition to having this sort of bike, also have a road bike and/or an mountain bike. They will, for example, choose the more efficient road bike for longer tours than their traditional bike. If you would equip your road bike with 20 inch wheels, stiff tires with a lot of profile, chain tubes, a hub and touring handle bars, then it would be a lot tougher to keep up with your mates on their race-roadbikes.
Recumbent riders usually buy only one recumbent due to the high price. This bike should then be suitable for all situations where riders would want to use a bike (commuting, going to town, cycle vacationing, touring, in nice weather, in bad weather, in the hills etc.). For those who buy an all around recumbent and find the difference in speed between it and a road bike (for the same effort) disappointing, a solution could be to buy a second or third (used) recumbent and use each for a different situation.

Conclusion:
Many little bits add up (to huge reistance). It is an art to be able to distinquish the large factors from the small ones. I hope that this article can contribute to being able to make such distinctions. But everyone makes his or her own considerations when choosing a new recumbent or bike.

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