Wheelie Physics

Wheelies are a good example of the use of both torque and angular momentum to control a motorcycle.

When a motorcycle is moving along a level surface, gravity exerts a force on the *center of mass* of the motorcycle, perpendicular to the wheelbase of the motorcycle, that is balanced by normal forces exerted by the ground on the motorcycle at the front and rear wheels. The first and second conditions of equilibrium are met. $\Sigma F = 0, \Sigma \Gamma = 0$

To loft the front wheel into the air, the rider must do something to upset this equilibrium, i.e. they must unbalance the torques about the rear wheel.

Whatever torque is applied about the rear axle must be greater than the downward torque that gravity exerts about the rear axle by acting on the bike and the rider at their respective centers of mass. When the bike has both wheels on the ground, this torque is balanced by an upward normal force that acts on the front wheel (the normal force on the rear wheel exerts no torque about the rear wheel). If the engine is able to transmit, through the drive train, more torque to the rear wheel than the gravitational torques, the front end will rise.

Let's assume that your motorcycle is a Ducati S2R100, with a wheelbase of 1.44 meters, a mass of 195 kg and that your mass is 70 kg. How much torque to the rear wheel will be required to pop a wheelie?

We begin by computing the torques that the force of gravity exerts on the bike and the rider. Let's assume that the rider is sitting well aft of the center of mass of the bike (very helpful in wheelie production), and that the bike's c.m. is also a little aft of the center of the wheelbase.

$$\Sigma\Gamma = \left(M_{bike}\, g\right)\left(\frac{r}{3}\right) sin\,\theta + m_{rider}\, g\,\frac{r}{6}\, sin\,\theta$$

$$\left(195kg\right)\left(9.8m/s^2\right)\left(\frac{1.44m}{3}\right)\left(1\right) + \left(70kg\right)\left(9.8m/s^2\right)\left(\frac{1.44m}{6}\right)\left(1\right) = 1082 N \cdot m$$

In the simplest sense, the rider needs only to dial up something north of 1082 N · m of torque about the rear wheel with the engine to counter these gravitational torques and cause the bike to wheelie.

A 2006 Ducati S2R1000 produces a maximum of around 70 ft-lbs (95 N · m) of torque at the crankshaft (at around 6000 rpm). To convert this to torque about the rear axle we have to take into account the effect of the drive train: transmission, chain and sprockets – all of which serve as torque multipliers. To do this we multiply the primary drive (crankshaft to clutch) by the drive gear ratio (transmission gears) by the final gear ratio (front and rear sprockets). The values for this motorcycle, in 1st gear, are:

$$\left(1.84\right)\left(2.45\right)\left(2.73\right) = 12.3.$$

This means that the engine torque is multiplied by a factor of 12.3. In this case the engine generates about 1169 N · m of torque at the rear wheel. So it is possible to *more* than counter the torques produced by gravity with a torque from the engine.

Notice that the torques produced by gravity about the rear axle become smaller as the front wheel rises into the air. In the picture above, the angle θ that the force makes with the moment of the motorcycle is less than 90 degrees (it is less by the same amount for the force of gravity on the rider. This means, of course that the torque becomes less as the bike rises since the *sin(*θ*)* decreases as the angle θ decreases.

If the rider dials up a constant amount of torque as the front of the motorcycle rises, it results in an increase in the angular acceleration of the motorcycle about the rear axle as the counter torques diminish. It's easier to loop a motorcycle (especially a powerful one) than you might think. To ride a wheelie for any distance the rider must develop a sense of how to modulate the throttle to balance all of the involved torques at the desired attitude of the motorcycle.

The things that make some bikes easier to wheelie than others are torque (more at lower rpm is better), seating position (as far back as possible), wheelbase (shorter is better), weight distribution (aft is better) and final drive gearing (small front sprocket, big rear).