

The Physics of Kicking a Soccer Ball

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Introduction

Soccer is the most popular sport in the world. Soccer players all work very hard to keep in shape, and to improve their kick. Most of them don't know that there is a scientifically correct way of going about doing this. I researched the physics of soccer and found some very interesting facts that all soccer players would do well to learn. The topics that I looked into are: What actually happens when you kick a soccer ball? Who kicks harder – shorter or taller people? Does a big follow through help your kick? How much force, in weight, would a professional soccer player experience on their foot in a kick? How do soccer players curl a soccer ball?

I chose this project because soccer is my passion and foremost hobby. I also chose it because I find it very interesting how simple physics can drastically improve my kick.

What actually happens when you kick a soccer ball?



When you kick a soccer ball, multiple things happen.

First of all, your leg is putting kinetic (or “movement”) energy into the ball. The formula for this is:

$$KE = \frac{1}{2}mv^2$$

Here the kinetic energy equals one half of the mass of your leg multiplied by the velocity of your leg, as it hits the ball, squared. Another thing that happens when you kick the ball is that the ball deforms. The side of the ball that your foot strikes becomes flat for just over 0.01 seconds.

The energy going in to the collision is the kinetic energy of your foot plus the stored energy in the deformed ball; the energy coming out is the kinetic energy of the ball plus some heat.



The more the ball deforms the more energy is lost to heat. The conservation of energy causes the ball to go faster than the velocity of your foot! The actual formula for the velocity of the ball is:

$$v_{ball} = V_{leg} \frac{M_{leg}}{M_{leg} + m_{ball}} (1 + e) \quad (*)$$

The “ e ” in this formula is called the *coefficient of restitution* and measures what speed a ball bounces up at compared to the speed it hits the ground on the way down. This ranges from 0 to 1, with zero being that the ball does not bounce up at all, and one being that the ball bounces to the same height every time. This can also be measured by taking the square root of the ratio of the height of the bounce to the original height. When I used my Barclays Premiere League soccer ball, I dropped it from a height of 6 feet. It bounced up to a height of 3 feet, so

$$e = \sqrt{\frac{3\text{ft}}{6\text{ft}}} = \sqrt{\frac{1}{2}} = 0.7.$$

The conservation of energy has some interesting applications. An experiment you can carry out is to place a tennis ball over a soccer ball and drop both at the same time. The soccer ball won’t bounce much, but the tennis ball will get the kinetic energy from both itself and the soccer ball and will explode upwards. This *slingshot effect* is even used by scientists to increase the speed of satellites by having them almost collide with a big planet – using the planet’s gravitational pull.

Who kicks harder – shorter or taller people?



It is commonly thought that the larger or taller a soccer player is, the harder they will kick. This is not necessarily true. In fact, it is usually the opposite. Using formula (*), I will explain why. The mass of a professional soccer ball is about $m = 0.4$ kg. The velocity of the ball equals the velocity of the leg multiplied by the fraction of the mass of the leg over the total mass of the leg and the ball, multiplied by $1 + e$. Suppose the mass of the leg for a small person (who has a mass of 60 kg) is 6 kg and the mass of the leg of a tall person (who has a mass of 100 kg) is 10 kg. If they both have a leg velocity of 20 meters per second, and e is 0.7, then the ball velocity for the tall person's kick is

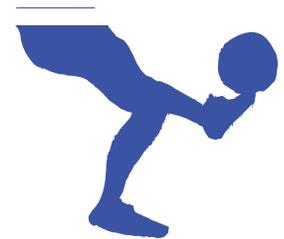
$$v_{ball} = 20 \frac{10}{10 + 0.4} (1 + 0.7) = 32.7 \frac{\text{m}}{\text{s}}$$

and the ball velocity for the short person's kick is

$$v_{ball} = 20 \frac{6}{6 + 0.4} (1 + 0.7) = 31.9 \frac{\text{m}}{\text{s}} .$$

The kicks would have almost the same ball velocity, even though the tall person is much heavier. In real life, the shorter person would likely have a higher leg velocity as putting about the same energy into moving a small leg compared to a big leg would result in a higher leg velocity for the shorter person. Now if the shorter person can get his leg velocity up to 28 m/s, then we would find that the short person's kick would give a ball speed of almost 45 m/s, a HUGE difference over the taller person's ball speed of 32.7 m/s. So it is more worthwhile to work on your leg speed rather than trying to bulk up!

How much force, in weight, would a professional soccer player experience on their foot in a kick?



Here is how we would go about answering this question. One of Newton's laws was that force equals mass multiplied by acceleration. We already know that the ball is about 0.4 kg. Now, we just need to find the acceleration of the ball, which is the change in velocity of the ball. The ball starts with no speed and ends up at about 30 m/s, in about 0.01 seconds. So

$$a = \frac{30 \text{ m/s} - 0 \text{ m/s}}{0.01 \text{ s}} = 3000 \frac{\text{m}}{\text{s}^2}.$$

The force acting on the ball is the mass of the ball, 0.4 kg, multiplied by the acceleration, 3000 meters per second squared, which is 1200 kilograms times meters per second squared. By another of Newton's laws, every force is balanced by an equal but opposite force, so the same amount of force would be acting on the player's leg as well as on the ball. If we want to convert this amount to a weight, we would look for what mass would have this as its weight. The weight of a mass m kilograms is $9.8m$, so we want $9.8m = 1200$. This means $m = 1200/9.8 = 122$ kg. So a professional soccer player would experience a force on his leg that would be like a weight of 122 kg.

Does a big follow-through help your kick?

The answer to this question is no! In fact, a big follow through takes away power from your kick.

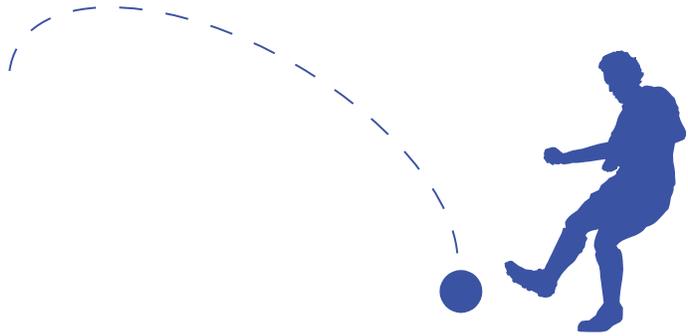
You are only in contact with the ball for a very short amount of time (approximately 0.01 seconds). All the

energy that is used in the follow through and other body motions during or after the kick, uses energy that could have been put into the ball with the



kick. The best possible kick would be a kick with little follow through, no other body movements – all of your energy focused on the ball.

How do soccer players curl a soccer ball?



Bend it like Beckham is the common term to describe curling a soccer ball. Many people can do this, but few actually know the physics behind it. To curl a ball, you simply kick it slightly off center, causing it to spin horizontally. When the ball travels, air moves over the ball. The air will move more quickly around one side, making less pressure on that side of the ball (*faster* speed of air means *lower* pressure). On the other side of the ball, the air moves more slowly, as the spin is going directly against the flow of the air, causing there to be more pressure on that side of the ball. The ball is pushed in the direction from high pressure to low pressure, making the ball curve; this is called the *Magnus effect*. Another interesting fact about curling a ball is that the ball will go straight for a small amount of time after you kick it, as there is less air resistance when the ball is traveling quickly. Only after the

ball slows down because of turbulent air flow will it start to curl when the Magnus effect occurs. The slower the ball goes, the more it curls.

Other spins can cause different effects on the ball. If you put backspin on a ball, the air will go faster over the ball with more pressure underneath. This will cause the ball to rise and travel farther.

Golf balls have dimples on the surface to increase the air resistance so that the effect of spinning is much larger (in particular, golf balls are hit with back spin and they travel farther because of it). Scientists have created a soccer ball that uses the same principles to create a dimpled soccer ball that will curl sooner after being kicked with spin.

Acknowledgements and References

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