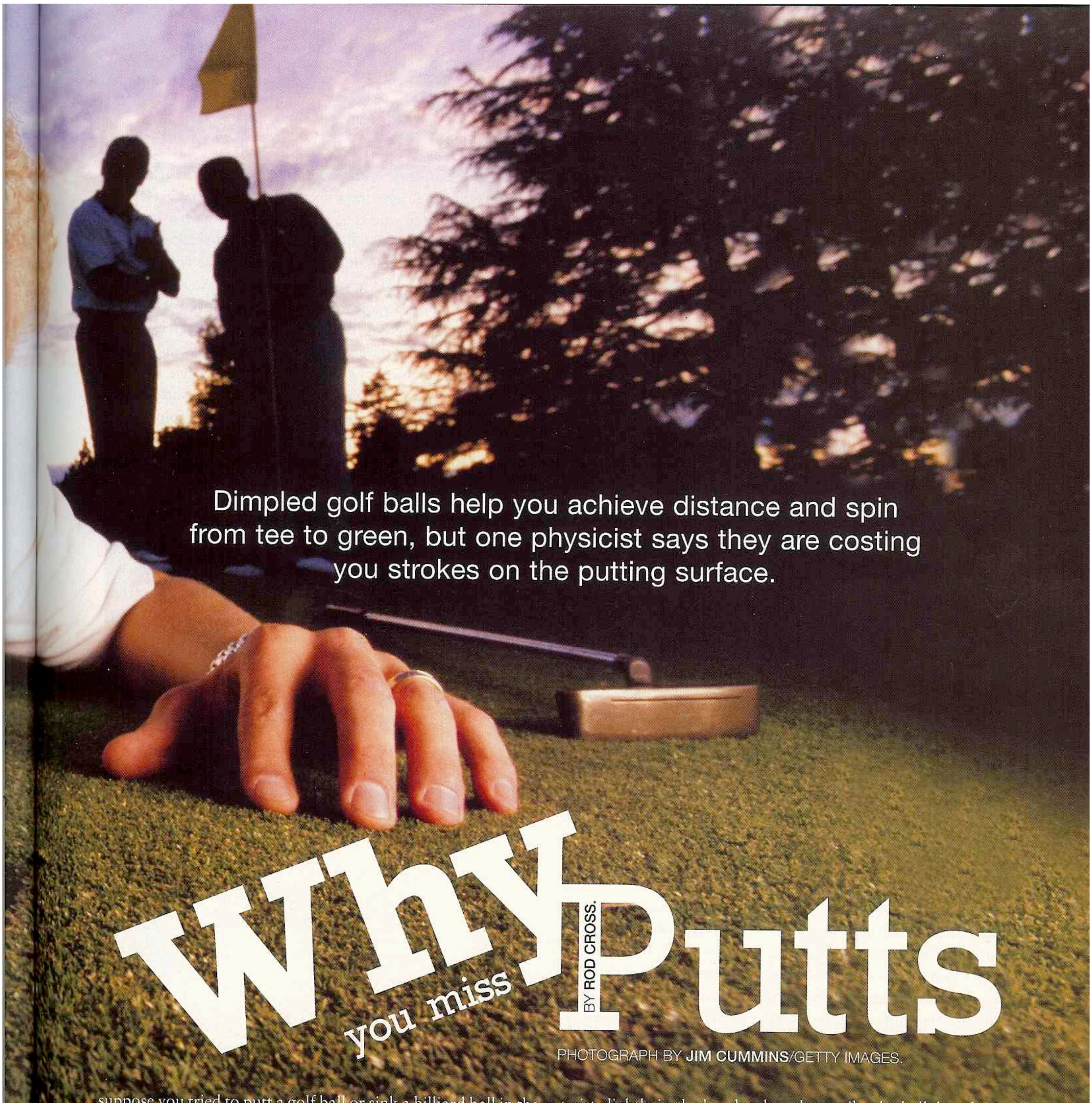
Editor's note: Rod Cross is an Associate Professor in the Physics Department at the University of Sydney, specialising in the physics of sport and sporting equipment. He has written two books on tennis plus various articles for tennis magazines and "Inside Cricket" magazine.

Many years ago it was discovered that dimpled golf balls travel further than perfectly smooth golf balls, and it has been that way ever since. Hit from the tee with backspin, a dimpled golf ball travels even further than it would in a vacuum despite the fact that the ball is slowed down by air resistance. The air also pushes upwards on a ball with backspin, keeping it aloft for a longer time than it would in a vacuum. The opposite effect is employed by tennis players who use topspin so that the air assists gravity by pushing the ball down onto the court. Without topspin, a typical Roger Federer forehand would strike the back fence.

However, there is a nasty side effect to the dimples that seems to have escaped the attention of golfers until recently – dimpled golf balls are more difficult to putt. Ideally, a golf ball used for putting should be perfectly smooth and round, for the same reason that billiard balls are perfectly smooth and round.

The reason is fairly obvious but to make it even more so,



Dimpled golf balls help you achieve distance and spin from tee to green, but one physicist says they are costing you strokes on the putting surface.

Why you miss Putts

BY ROD CROSS.

PHOTOGRAPH BY **JIM CUMMINS**/GETTY IMAGES.

suppose you tried to putt a golf ball or sink a billiard ball in the shape of a cube or the shape of a pear. Even if you could get the ball to roll, it would tumble and turn in a crazy manner. Only a perfect sphere will roll in a perfectly straight line, provided it rolls on a perfectly flat horizontal surface or rolls straight up or down a perfectly flat inclined surface.

A slightly imperfect sphere rolling on a perfectly flat horizontal surface will not roll along a perfectly straight line, nor will it bounce vertically if dropped vertically onto the surface. And it won't be launched at right-angles to the face of a putter. Only a perfect sphere can be launched at right-angles every time, but even then there is a complication. All putters twist slightly in the hands when they strike the ball, but that's a separate issue that has nothing to do with the dimples. It is due to the fact that the ball is not struck in line with the centre of the mass of the putter. The twisting effect is something that happens every time a player putts the ball and is something the player can get used to since the effect is reproducable. It's the dimples that cause the ball to come off the putterface at a different angle every putt.

A dimpled golf ball comes off the putter at an angle that depends on the number and size of the dimples and their exact alignment with respect to the putter. If dimples were smaller than one millimetre in diameter, they would not have much

'My guess is that only one player in a thousand or more would have ever cursed the dimples.'

effect on putting. But they typically span about 4mm and have a greater effect than previously realised.

Given that greens are not perfectly flat and not perfectly horizontal, and given that golfers are not perfect either, the effects of the dimples themselves are not immediately obvious. If a player misses a putt then he or she will normally assume there was something wrong at impact or that the green was uneven or they misjudged the slope. My guess is that only one player in a thousand or more would have ever cursed the dimples.

Professional golfers sink only about half of all six-foot putts, about a quarter of 10-foot putts and only about 10 per cent of 20-footers. I wondered if this might have something to do with the uneven surface of the ball as much as – if not more than – the green itself, in which case luck and skill might both play similar roles.

To investigate the effects of the dimples, I undertook a number of controlled experiments. First, I dropped a golf ball onto a flat horizontal surface from a height of 80 centimetres so that the ball speed on impact would be similar to that of a relatively firm putt. Instead of having the putter approach the ball, I had the ball approach the putter, which happened to be a flat, smooth slab of concrete. I then dropped a golf ball from a smaller height, this time onto a flat, polished granite surface. For the last experiment, I rolled a golf ball along a flat, 13mm-thick, 66cm-diameter horizontal glass plate with coloured paper underneath to mark a straight line. For each experiment I filmed the ball with a video camera to measure how true it bounced or rolled. I also filmed a billiard ball and a ball bearing for comparison. The filmed results can be seen in the golf section of my website (physics.usyd.edu.au/~cross).

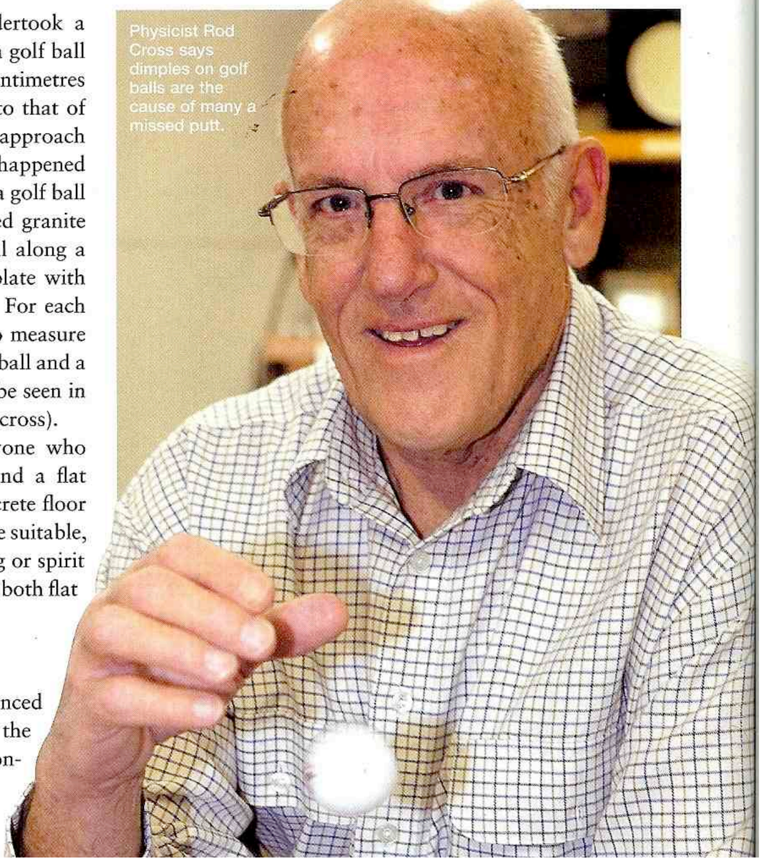
The experiments can easily be repeated by anyone who wants to try them. All you need is a golf ball and a flat horizontal surface. A marble floor or a smooth concrete floor in the carpark at a shopping centre would probably be suitable, but you would first need to test it with a ball bearing or spirit level and a straight edge to test whether the surface is both flat and horizontal.

The 80cm drop test

On the concrete slab, the golf ball sometimes bounced vertically but often didn't. The top surface of the concrete was much smoother than the ball, so non-vertical bounces can be attributed to the uneven surface of the ball rather than any imperfections in the surface itself. A non-vertical bounce would be expected if the surface was not exactly horizontal, if the ball was not dropped vertically, or if the incident ball was spinning, but (a) the surface was levelled with a spirit level, (b) the path of the ball was exactly parallel to a vertical plum-bob line and (c) the incident ball had zero spin. Most times the ball bounced within one degree of the vertical, but a one-degree error is quite large in this context.

For example, consider a 10-foot putt. The hole has a radius of 5.4cm and is 305cm away. On a perfectly level surface, the ball has to be aimed within one degree of the line joining the centre of the ball and the centre of the hole. To sink a 20-foot putt, the required angle drops to half a degree.

After a non-vertical bounce, the ball acquired a small amount of spin, consistent with the fact that a horizontal force acted on the bottom of the ball pushing it sideways. Such a force can arise if there are more 'hills' or protuberances on one side of the ball in contact with the surface than on the other side. Each hill can be envisaged as an object pointing out from the ball along a radius, and each hill will tend to push both downwards and sideways on the surface. Within the contact area there might be, say, 10 dimples on the left side and 10½ dimples on the right side, depending on the exact alignment of the ball – but that could be enough to change the bounce angle by about one degree.


Physicist Rod Cross says dimples on golf balls are the cause of many a missed putt.

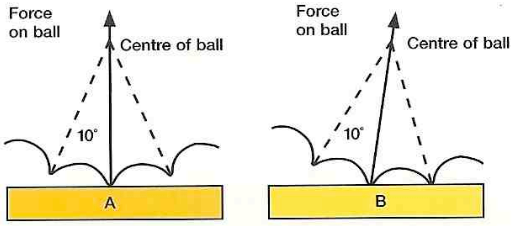
Position of ball bearing at start of drop and after two bounces off a horizontal granite slab.

Position of golf ball at start of drop and after two bounces off a horizontal granite slab. The ball 'walked' its way to the left edge of the slab in this series of bounces.

Low-speed bounces

Non-vertical bounces were even more pronounced in the low-speed bounce tests. A ball bearing dropped from a height of 30cm onto the granite slab bounced vertically every time. It bounced up and down about 30 times on the same spot before it came to a stop. It was pretty to watch. The golf ball sometimes bounced vertically but it also bounced up to five degrees away from the vertical. It bounced to about the same height as the ball bearing, but it took only about 10 bounces to get from the middle of the slab to the edge 20cm away. It sometimes bounced vertically on the same spot three or four times in a row, but it always found a dimple that projected it away from the vertical. It was not a pretty sight.

At low-bounce or low-putting speeds, the ball does not compress as much, in which case there might be only three or four dimples contacting the surface. Within the contact

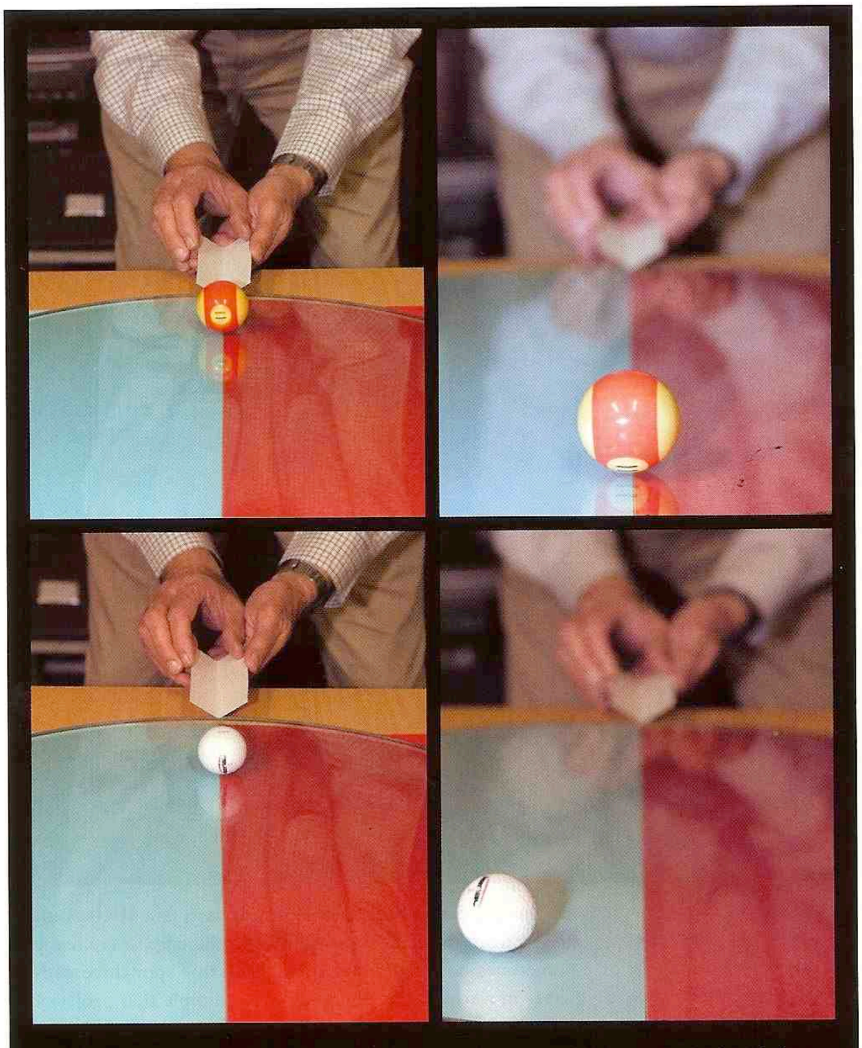


Nine dimples from equator to north pole, each 10 degrees apart. The ball can bounce up to five degrees away from the perpendicular.

area there might be, say, 1½ dimples on the left side of the contact area and two dimples on the right, depending on the exact alignment of the ball. As a result, there would then be a relatively large imbalance in the forces on each side of the ball, giving a relatively large deflection away from the vertical.

The situation is shown in the diagram (*left*), where I have assumed that the ball makes contact with the surface at only one or two points. The force on the ball acts towards the centre of the ball when one takes into account friction between it and the surface. However, the contact point is not necessarily directly under the centre of the ball. Since there are usually about nine dimples from the equator to the north pole, each dimple is separated by about 10 degrees from the next. The ball can therefore bounce up to five degrees away from the vertical in a low-speed bounce. In the diagram, rotation of the ball from position A by five degrees will alter the number of contact points from one to two, the force on the ball being exactly vertical in both cases. In position B, the ball is rotated about four degrees away from position A and the force on the ball is about four degrees away from the vertical.

What this means in practice is that a ball struck at low speed with a putter will usually bounce at right-angles to the putter or within one or two degrees of a right angle, but it will sometimes bounce up to five degrees away from a right-angle. If that happens, then a ball struck two feet from the hole will head for the edge of the cup if the putter is aimed at the centre of the hole. It would be enough to a give a golfer the yips. But that assumes that a golf ball rolls along a straight line on a horizontal surface. It doesn't. Dimples can therefore give golfers a double dose of the yips.



The position of two different balls after rolling down a slight incline and then across a horizontal glass plate. Round balls roll in a straight line, dimpled balls don't.

Does a golf ball roll in a straight line?

Given the bad bounce problem, it is not surprising that golf balls don't roll along a straight line even on a perfectly flat, horizontal surface. Instead, the ball gets deflected slightly to

PHOTOGRAPHY: KEVIN LING

the left or right on a random basis as it encounters each new dimple. The accumulation of random deflections can lead to a large deflection to the left or right, but it can also lead by chance to a path that is essentially straight.

The rolling path was investigated by rolling balls at low speed on the thick glass plate. I found that:

1. A pool ball rolls along a straight line every time.
2. A ball bearing rolls along a straight line every time.
3. A golf ball sometimes rolls straight and sometimes it doesn't. Along a 60cm path I found that a golf ball could veer up to five centimetres off the straight-line path, left or right, so it can veer about five degrees either side of a straight path.

The effect of the sideways push produced by each dimple is reduced when a golf ball rolls on surfaces with greater friction since the surface then reacts by pushing back on the ball. On glass there is very little surface friction to prevent the sideways motion. By rolling the golf ball on felt I found that the sideways deflection was much reduced but it was still evident to a small extent. The ball also slowed down faster since the felt behaved as a relatively slow green. Nevertheless, the rolling experiment indicates there could still be a significant effect of the dimples, particularly on a fast green.

There is another potential problem in getting the ball to roll along a straight line. If one side of the ball is slightly heavier than the other, the ball will curve towards the heavy side. You can prove this for yourself by adding a small weight (such as gum or Blu-tack) to one side of the ball. The ball will then roll like a coin on its edge or a lawn bowl.

Solutions to the dimpled ball

Given that dimples are good for long drives and bad for putting, from my perspective there is a need for a solution to the putting problem. One possibility would be to make golf balls more spherical by changing the dimple pattern. It might be possible to produce a smoother ball with good aerodynamic properties and improved putting properties by fiddling with the depth, shape and spacing of the dimples. However, it is likely that any attempt to make the ball smoother will result in shorter drives.

After I discovered this year that golf balls don't bounce or roll like perfect spheres, I found that another Aussie, based in Colorado, had already discovered this for himself a few years ago. Slazenger markets his patented Bald Eagle golf ball, which has six bald spots without any dimples. I have not seen or tested them, and they are not yet available in Australia, but it sounds like a good solution to the imperfect bounce problem. However, they won't solve the crooked rolling problem.

A much simpler and a more logical solution would be to allow players to use different balls in the same way as they are allowed to use different clubs for different shots. Given that players are allowed to mark and pick up the ball once it's on the green, it would be a simple matter when they change their club to a putter to change the ball to a smooth sphere. The point of changing the club is to make it easier for the player to hit the ball into the hole. In that case, why not change the ball as well? It makes no sense at all to use a dimpled ball for putting, unless the purpose of the rules of the game is to make it as difficult as possible for players to sink a putt and to provide a lucrative source of income for yip psychologists. In that case, it would make more sense to make the hole smaller since it would then be a test of skill rather than luck.

In the meantime, it might help to know that if you miss the occasional easy putt it may not be your fault – you can blame the ball. That way you can confidently strike your next putt in exactly the same manner and avoid getting the yips over something that was not your fault in the first place. But if you miss five easy putts in a row, then it's unlikely to be the ball's fault. ◘

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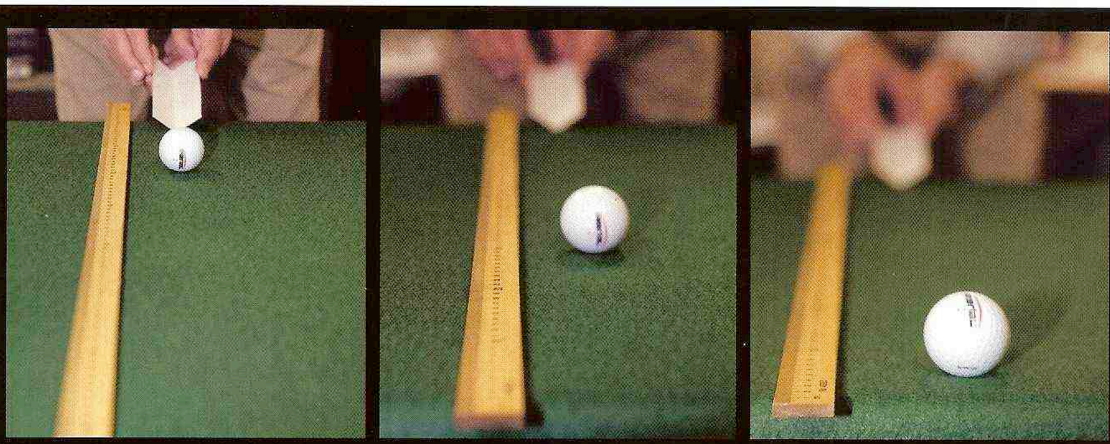

On a flat surface that best resembles a green – like felt – the golf ball still wanders off-course.