Rotating Bodies and Angular Momentum
Torque and Momentum

Narrator: (Judy Ekins)
There are many sports that involve rotation: twisting and turning. Spinning on the spot… or turning in mid-air… twisting in one direction… or turning in two. In this video we are going to investigate the nature of rotations and how they start and finish. We'll be concentrating mainly on rotations in sport. As you watch these sportspeople ask yourself these questions about the rotational motion you see. How is the spin or rotation started, and how is it kept going? How is the rate of rotation changing? And why throw this end?

Highland Games PA Commentator:
And over it goes but…

Narrator:
In this mathematical sideshow why does one of these tins roll faster than another?

Judy:
(TO WATCHING CROWD) Ready, steady, go! (CHILDREN CHEER) The liquid one won.

Narrator:
To answer these questions we have come here to a village fete in Cambridgeshire, which also features performances from the New Image Majorettes. Each of the members of this group has a baton that they spin and throw as part of their routines. But to see what's happening, let's slow down the action. When the baton is in the air the rotational motion combines with motion under gravity. The centre of mass of the baton is moving under gravity and the baton rotates about it. But this makes understanding the motion more complicated. So let's start with a case where the centre of mass hardly moves, twirling the baton. Despite the trickiness of the manoeuvres, the design of the baton actually helps. I asked Jacquy Neale, New Image trainer, to explain.

Jacquy Neale:
It's all to do with the wrist movement and also it's weighted at one end - one end is heavier than the other. So you're throwing it, you've got it down and then you throw the heavier end up first so that it spins round.

Narrator:
Rather than a baton, the troop leader uses a sixty inch mace. Yet, exactly the same principles apply. Jacquy exerts an upward force with one hand and then the other in the opposite direction to the weight, causing the mace to rotate. The net total force on the mace is zero, and so the centre of the mass of the mace doesn't move. The two forces are not in the same straight line and so there's a resulting turning action, which we call a torque. The torque about the axis of rotation is the vector product of the displacement from the axis and the force. It's this that initiates the rotation about the centre of mass. Torques are always associated with turning motions. And they are common in all sorts of sports. Look for the torque which initiates the following rotations. In each case there are at least two forces acting. One of them is the weight and the other is the push. Here the competitor pushes at one end. The gymnast pushes off the beam, and the diver from the board. So it's torque that initiates the motion but it doesn't explain why the baton keeps spinning once it has left the hands.

Judy:
Well, I've asked Dave Cobner, of the University of Wales Institute in Cardiff, to talk to us about these things and to explain to us what's happening.

Dave Cobner:
Thanks a lot, Judy. As we look at the mace example to start with, we might get a clue as to how the torque and the angle of momentum is actually related. You talked about off-centre forces or torques that create angular momentum. Once the angle of momentum has been created it's then going to be conserved within the system until another torque is applied to speed up or slow down the action.

Judy:
So torque creates angular momentum?

Dave Cobner:
That's correct, and once it's been created, it is then conserved within a closed system until another torque acts to either increase or decrease the momentum that's in the system. But interestingly, Judy, the design of the mace is such that the centre of mass is not actually at geometric centre. Therefore when the majorette holds the mace in the centre, in the middle, it's always a torque acting because the centre of mass is off-centre.

Narrator:
So once the body acquires angular momentum it will continue to rotate at the same rate unless there's another torque applied to speed it up or slow it down.

Majorette Leader:
(OVER PA SYSTEM)
Majorettes, forward, march.
(APPLAUSE AND CROWD CHEERS)