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The physics of twisting somersaults

Fred Yeadon

Perhaps the most spectacular moment of the 1996 Olympic Games in Atlanta was the half twist performed in the air by Lilia Podkapayeva of Ukraine at the end of a double forward somersault from the floor. In order to score full marks out of ten, a competitive gymnastics routine must include a sufficient number of complex skills. Judges check how many of the required technical elements are completed, and deduct points for missing elements, imperfect body shapes and unsteady landings. So how is it possible for a gymnast to land correctly on every occasion?

To answer this question it is useful to compare the motion of an aerial gymnast with that of a falling cat. A cat falls out of a tree and unerringly nas upwards rather than downwards. Similarly the gymnast can maintain visual contact with the ground during a double somersault by introducing a twist into the second somersault. Such a manoeuvre ensures that the landing area is in view continuousl

forwards and the legs moving backwards. Since the head and the legs are in line, no clockwise or anticlockwise momentum is associated with this “plain” somersault.

The right side of figure 2 shows the same views after the gymnast has completed one somersault and has used suitable limb movements to tilt his body out of the vertical somersault plane. From the overhead view, we see that the movements of the head and feet are not in line so that the gymnast has some momentum in the clockwise direction. Since the total angular momentum must remain zero from this view, the gymnast must also be twisting to his left to counter the clockwise momentum. In other words, a gymnast can introduce twist into a somersault by producing tilt during the flight phase. Moreover the gymnast will continue to twist until he or she removes the tilt and returns to the vertical somersault plane.

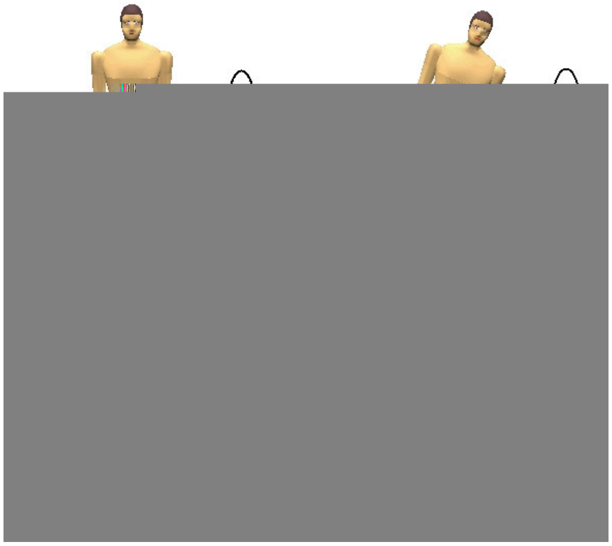

Figure 2. Angular momentum in action

The images show a forward somersault viewed from in front and above (

Producing tilt using asymmetrical arm movement

Once the apparatus has been released, the gymnast makes appropriate limb movements that cause the body to tilt and therefore to twist as well. The most obvious way a gymnast can produce tilt is by moving the arms asymmetrically. The upper sequence in figure 3 shows what happens when a gymnast with no angular momentum raises his left arm sideways while lowering his right arm. This anticlockwise arm movement has an associated angular momentum, and so the whole body rotates in the opposite direction (i.e. tilts clockwise) to keep the gymnast's total angular momentum equal to zero.

The lower sequence in figure 3 shows what happens when the gymnast makes exactly the same arm movement during a somersault. Again the arm movement produces tilt but now the gymnast will also acquire a twist velocity in order to maintain constant angular momentum. Asymmetrical arm movement can also be used to remove tthe

In springboard diving, divers often use asymmetrical arm movements to produce the twist after they have taken off from the board, and they continue to hold one arm over the head during the twist. Competitors doing a forward-somersault dive incorporate 1, 2, 3, or 4 twists so that the water is kept in view just prior to entry. Backward-somersaulting dives use ½, 1½, 2½, or 3½ twists for the same reason.

In forward-somersaulting dives, the arm movement may simply be reversed near the end of the dive to remove the tilt and ensure that the diver enters the water vertically. In backward-somth resalre asymmetrically during a forward somersault. This is done by flexing the hips sideways while straightening from the forward-flexed position. The upper sequence in figure 4 shows the result of this hip movement when the gymnast has no angular momentum. The flexion to the side can be seen cTd (c)Tj 5.28 0 Td (a)Tj 5.76 0 Td ( )Tj 3 0 Td (t)Tj 2.64 0 Tde this results in twist because somersault is present. However, in this case the tilt angle does not disappear when the body is straightened. This is primarily because the body has twisted through about a quarter turn when the body extends from the flexed position. As a consequence any reorientation of the twist axis changes the somersault angle rather than the tilt angle.

Another reason why the tilt is greater when somersaulting is that a freely-rotating rigid body that is twisting and somersaulting will “nutate”. In other words, the tilt angle will oscillate. The nutation arises because the principal moment of inertia about the axis through the front of the body ($\boldsymbol{a_2}$ in figure 1) is larger than the principal moment of inertia about the lateral axis through the hips ($\boldsymbol{a_1}$ in figure 1). This difference in the moments of inertia is more pronounced when the arms are wide and the body is flexed sideways, as in the fourth graphic of figure 4.

As a consequence of this asymmetry in the moments of inertia, the tilt angle oscillates together with the somersault and twist rates in order to maintain constant angular momentum. The nutating tilt angle reaches a maximum after a quarter twist, so it is advantageous for the gymnast to straighten at this time. Once the gymnast has straightened his or her body and pulled the arms in close, the two large principal moments of inertia will be nearly equal and the nutation in the subsequent motion will be small. In other words the tilt angle will remain large and the twist will be fast.

Analysis of twisting techniques

The movements shown in figures 3 and 4 were s arpr ee t1) h [illegible] simulation model is implemented in the form of a computer program that solves the equations of constant angular momentum for the rates of change of the three orientation angles shown in figure 1. The program then integrates these rates of change to give the somersault, tilt and twist angles as functions of time.

The model may also be used to assess how such aerial twisting techniques contribute to a real gymnast’s performance of twisting somersaults. For example, figure 5 shows how the simulation model was used to determine the effect of asymmetrical arm movement on the twist in a double somersault dismount from the rings. The gymnast’s movement is first recorded using two video cameras, and the three-dimensional coordinates of the joints edh s sv nt2h93.96 0 Td (2.(.es76 0 Td (v)Tj 5.28 0 T

The movement is then modified so that the movement of the left arm is changed to mirror the actual movement of the right arm (see the lower sequence in figure 5).

In other words, the upper sequence in figure 5 uses the actual asymmetrical arm positions adopted by the gymnast, while the lower sequence uses symmetrical arm positions throughout. In this modified simulation, the gymnast only twists through a quarter revolution to the right rather than through a whole revolution to the left. This result shows that asymmetrical arm movements are responsible for producing the twist. The same kind of procedure can be used to determine how asymmetrical hip movements contribute to twisting performances.

Since 1980 the author has investigated twisting techniques used in competitive gymnastics, trampolining, diving and freestyle aerial skiing. In general, elite competitors use asymmetrical arm and hip movements to initiate the twist when they are airborne, rather than starting the twist during takeoff. The advantage of aerial twisting is that the takeoff and the landing are simpler. Moreover, the competitor can use the same takeoff technique regardless of whether he or she is performing twisting or non-twisting somersaults. There is also less chance that the competitor will still be twisting on landing when aerial twisting techniques are used.

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figure 6). The gymnast produces the tilt by flexing over the right hip (shown in the second graphic) and later removes it by flexing the over the left hip. Once this wide-arm half twist has been mast process have been incorporated into a video of simulation and coaching progressions produced as part of a collaborative effort between Loughborough University and British Gymnastics to inform gymnastics coaching.

A look to the future

Advances in sporting performances arise from an improved understanding of technique and training. Such understanding comes from sports science research as well as from advances within the sport. Thirty years ago, for example, the most complex trampoline routines were mainly composed of double somersaults with twists, and perhaps included one half-twisting triple somersault. Since then routines have steadily increased in difficulty with the record for the most triple somersaults in a ten skill routine standing at five -- held jointly by Igor Galimbatovski of the Soviet Union (1986 World Championships) and by Daniel Neil of Great Brɵ

For clips of the simulations see www.lboro.ac.uk/departments/ps/biomech/aerial.html

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