Yeadon, M.R. 2000. Aerial movement. In Biomechanics in sport (ed. V.M. Zatsiorsky), pp. 273-283. Oxford: Blackwell Science. ISBN: 0-632-05392-5

Introduction

Most sports movements have an aerial phase. In sprinting the runner spends less than half of the time in contact with the ground (Hopper, 1973) while in the triple jump the aerial phases are much longer than the contact phases (Hay and Miller, 1985). Typically tennis players are off the ground when the ball is played (Elliott, 1989) and basketball players release the ball while airborne (Hay, 1993). The same is true for the release in the discus and shot events (Hay, 1993). In jumping activities it is the aerial phase that is evaluated to give a score for the performance. In the long jump and high jump events the horizontal and vertical displacements during the aerial phase are used as measures of performance while in trampolining and diving rotation and aesthetics are also included in the evaluation.

In an aerial phase of a sports movement the athlete is freely falling under gravity. In freefall the balance mechanisms of the inner ear do not operate normally since they too are in freefall (Graybiel, 1970). The otolith and semi-circular canals can no longer provide information on the orientation of the head relative to the vertical direction. They do, however, give information on linear and angular accelerations (Wendt, 1951) which can be used by athletes to help control aerial movements (Yeadon and Mikulcik, 1996).

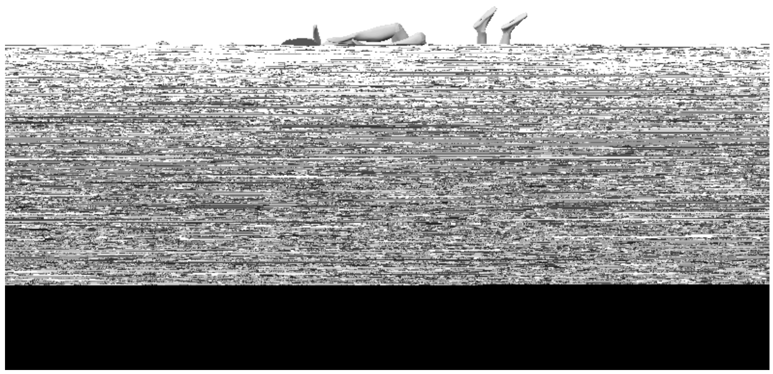

Figure 1. The flight phase of a high jump performance showing the parabolic path of the mass centre.

Rotation during flight

In running jumps, the takeoff phase typically produces rotation even where this is disadvantageous to the performance. In long jumping undesirable forward angular momentum is produced during the takeoff and a hitch-kick, involving arm and leg rotations, is often used to minimise the forward rotation in the aerial phase (Hay, 1975; Herzog, 1986). In high jumping, both twist and somersault rotations are produced during takeoff and these are used to advantage in clearing the bar (Dapena, 1980, 1995; Hopper, 1963). In gymnastics skills, the somersault is initiated during the takeoff phase, while twist may be initiated either during the takeoff or during the aerial phase (van Gheluwe, 1981). Although the movement of the mass centre is predetermined at takeoff (so long as air resistance can be neglected) the athlete has considerable control over rotational motion during the aerial phase.

At takeoff a gymnast has a certain quantity of angular momentum about the mass centre and this remains constant during the aerial phase since the only force

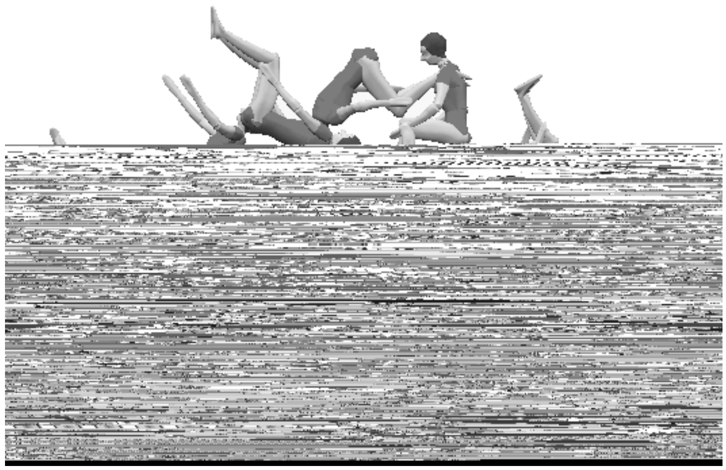

Figure 2. A double backward somersault from a floor exercise showing the increased speed of somersault rotation when the body is tucked.

Somersaulting

While a gymnast has considerable control over the rotation in the aerial phase the angular momentum for a specific skill is often quite tightly constrained by the

For body positions other than straight there is more freedom for the gymnast to adjust the somersault rate. In the tucked triple somersault dismount from high bar shown in Figure 4 there is sufficient angular momentum to allow the movement to be completed successfully. If there were slightly less angular momentum than this, the gymnast could compensate by adopting a tighter tucked position. There could, however, be considerably more angular momentum without this being detrimental to a good performance. With more angular momentum the gymnast could delay the movement into the tucked position and could extend earlier prior to landing. In fact the angular momentum of the straight double somersault shown in Figure 3 is 18% greater than the angular momentum of the tucked triple somersault shown in Figure 4. This indicates that a gymnast who can do a straight double somersault dismount from high bar should be able to generate ample angular momentum for a tucked triple somersault dismount. Some gymnasts have employed a split tuck technique in which the knees are pulled wide to reduce the moment of inertia about the somersault axis but this technique is a break in form and only marginally increases the somersault rotation (Kerwin et al., 1990).

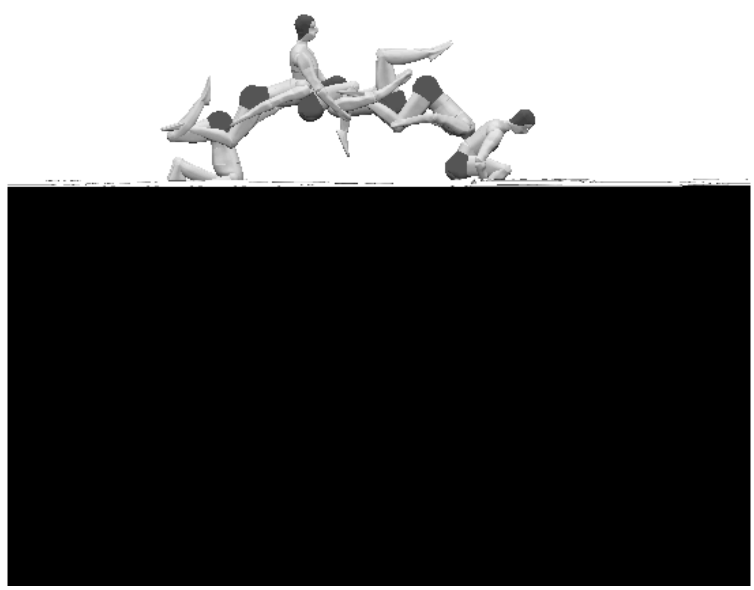

Figure 4. A triple somersault dismount from the high bar with the body tucked.

Figure 5. During a wobbling somersault the twist oscillates left then right.

The second type of motion is the ***twisting somersault*** in which the twist is always in the same direction (Figure 6). During this motio the wobble in the piked position becomes excessive and the twist is much harder to control (Yeadon, 1993b).

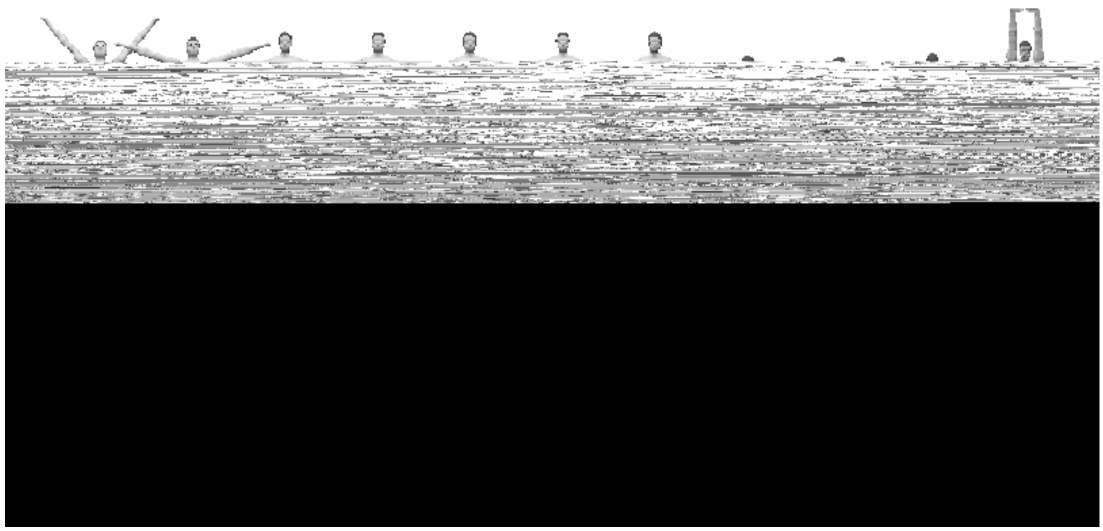

Figure 7. A computer simulation of a backward 1 ½ somersault dive with 1 ½ twists in which the twist is produced during the takeoff.

Aerial twist

The way in which a cat rights itself by producing a half twist in mid-air after being dropped in an inverted position has been studied for more than a century (Marey, 1894; McDonald, 1960). Some coaches have thought that this is the main mechanism that divers use to produce twist (Eaves, 1969; Rackham, 1960). The twist is produced by using a hula-hoop circling movement of the hips during the aerial phase. If the initial angular momentum is zero it must remain so during flight and so the angular momentum associated with the hip circling produces a twisting of the whole body in the opposite direction (Kane and Scher, 1969). A simulation of this movement is shown in Figure 8 in which the hips circle to the right producing a twist to the left. The body moves from a forward flexed position through a side arch over the right hip, into a back arch, through a side arch over the left hip and ends in a forward flexed position again, having completed a half twist. A skilled trampolinist can produce a full twist using two cycles of such a movement while airborne.

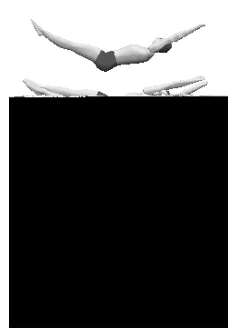

Figure 8. Computer simulation of an aerial half twist using the "hula" or "cat" technique.

It is evident that gymnasts, trampolinists and divers do not use this hula technique to produce multiple twists during the aerial phase of a somersault since the body typically remains straight during the twist. If somersault is present then any technique that tilts the body away from the somersault plane will result in twist in order to maintain constant angular momentum (Frolich, 1980). The most obvious way of producing tilt during freefall is to raise one arm laterally while lowering the other. In a plain jump there is no angular momentum and this arm movement will produce a tilting of the whole body in order to maintain zero angular momentum (upper sequence of Figure 9). If the same arm movements are made during a plain somersault, a similar amount of tilt (8^o) results and the body automatically twists in order to maintain constant angular momentum (Yeadon, 1990).

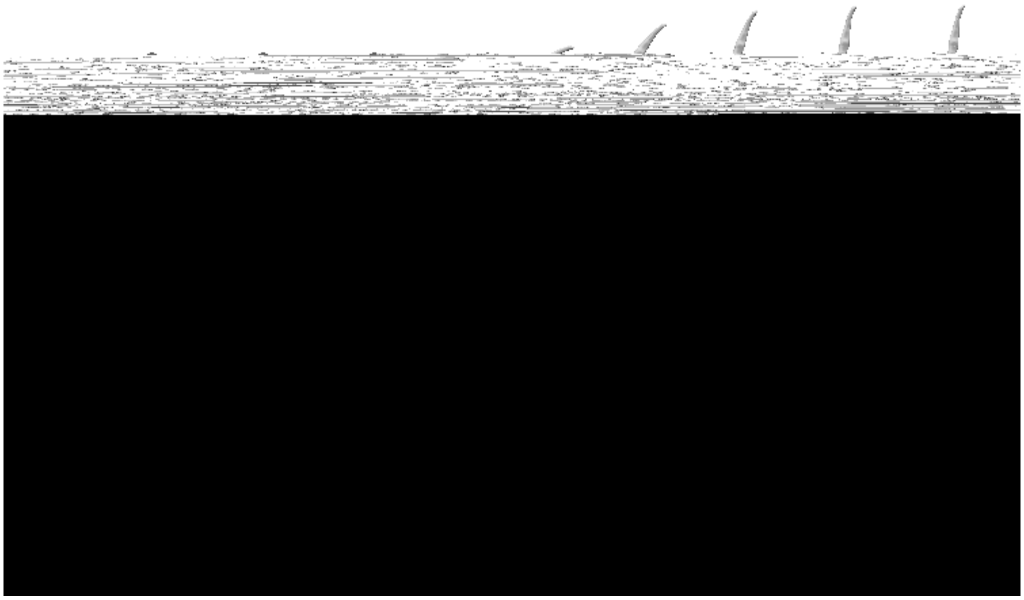

Figure 9. Aerial twist in a somersault resulting from tilt produced by asymmetrical arm movement.

Any movement in which left-right symmetry is not maintained is likely to produce some twist. In the simulation shown in Figure 10 the body makes a partial hula movement while extending from a piked to a straight position. In a plain jump this hula movement with wide arms produces tilt while the body is in a side arch configuration due to a reorientation of the principal axes of inertia (Yeadon and Atha, 1985). Once the body extends, however, the final tilt is only 3^o (upper technique produces considerable tilt (11^o) in a somersault and is a viable method of producing aerial twist.

It is fortuitous that the hula movement that produces a twist to the left in a jump also produces tilt which will result in a twist to the left in a forward somersault. During the takeoff for a forward somersault from the floor or trampoline or diving board the body flexes at the hips so that initially it is in a piked position which is suitable for this technique. For a backward somersault the body is initially arched and use of a partial hula movement while extending again produces tilt which results position and produces little change in the tilt angle since the reorientation of the body manifests itself mainly as a change in somersault rotation.

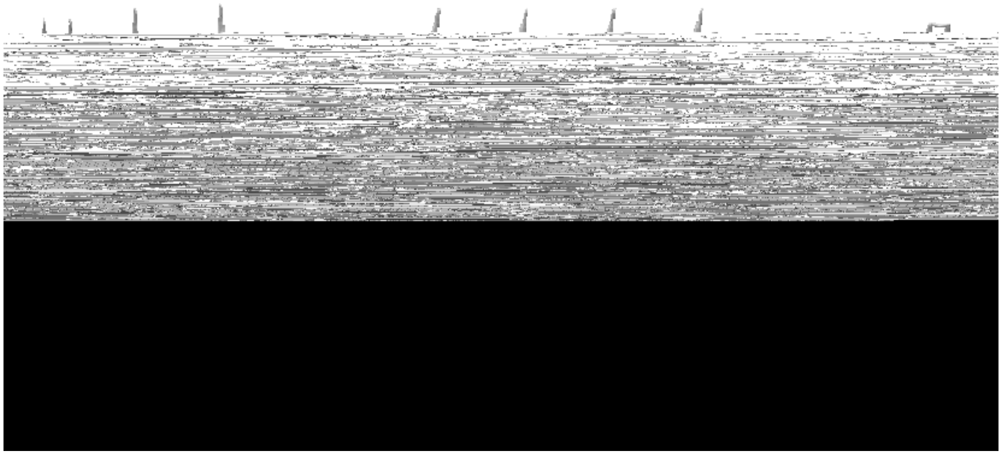

Figure 11. Simulation of a forward 1 ½ somersault dive with three twists using asymmetrical movements of the arms.

The asymmetrical hip technique shown in Figure 10 may be used to produce 1 ½ twists in a single or double somersault. In Yeadon (1997a) a progression based on computer simulations is described for learning a double somersault with 1 ½ twists in the second somersault (Figure 12). In the first somersault the body is flexed into a piked position and then moves through a side arch position with wide arms while extending. The arms are then adducted to accelerate the twist and as the 1 ½ twists are completed first the right arm and then the left arm is abducted to help remove the tilt. The body also moves through a side arch p

Stopping the twist

In the simulation shown in Figure 11 tilt was removed using a reversal of the initial asymmetrical arm movement that was used to produce the tilt. This technique may be used in dives with an even number of half twists. For an odd number of half twists a reversal of the initial arm movement would increase the tilt and speed up the twist. In such a case it is necessary to reverse the arm positions during the twist without affecting the tilt so that they are in a suitable position for removing the tilt prior to entry. In backward and reverse twisting dives there are typically 1 ½, 2 ½ or 3 ½ twists and this technique is often used. The lower sequence of Figure 13 is taken from a performance of a backward 1 ½ somersault dive with 1 ½ twists. The upper sequence shows the body configurations used in the dive. After takeoff the left arm is lowered and the right arm is held high producing tilt that results in a twist to the left. During the twist the arm positions are reversed while keeping the arms close to the body so as not to slow the twist. As the 1 ½ twists near completion the diver first pikes and then lowers his left arm while raising his right arm so as to remove the tilt. By first flexing at the hips the moment of inertia about the frontal axis is reduced so that more tilt can be removed by the asymmetrical arm movement.

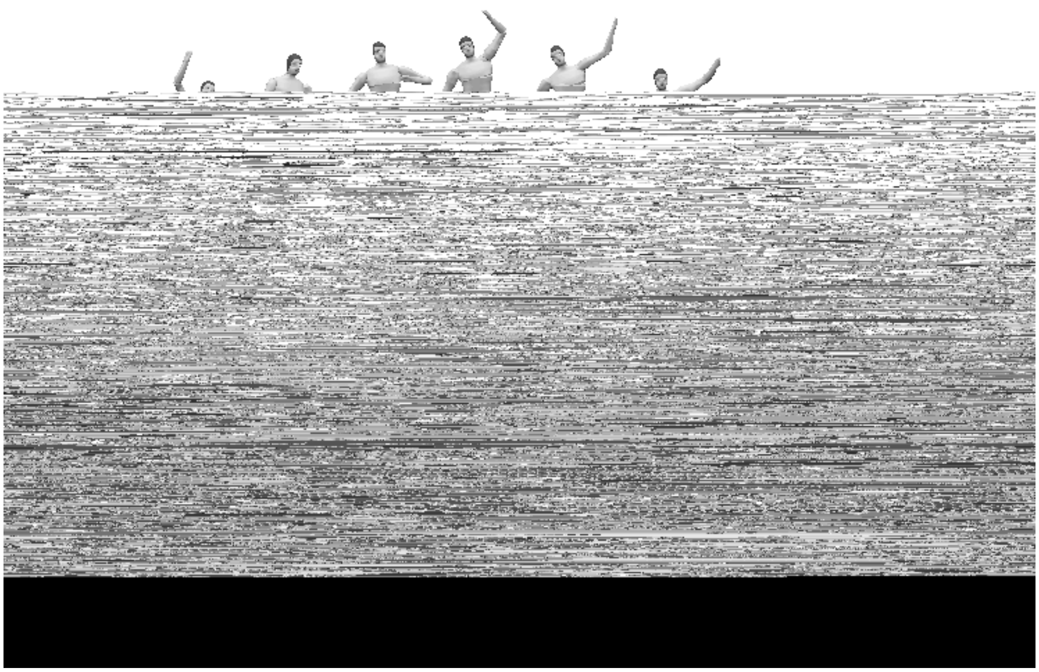

Figure 13. Stopping the twist by removing the tilt in a backward 1 ½ with 1 ½ twists using asymmetrical arms.

Contributions

The simulation model of Yeadon et al. (1990a) has been used to determine the contributions of the various twisting techniques to the production of tilt and hence twist in actual performances by using modifications of the body configurations used by the athlete. To determine the contribution of asymmetrical arm movement, for example, a modified simulation can be carried out i actual arm movement gives a measure of the contribution to the tilt angle from asymmetrical arm movement (Yeadon, 1993d). Other contributions can be determined in a similar manner.

Figure 14 depicts a performance of a double somersault from trampoline with a full twist in the second somersault. In such a movement where almost a complete somersault occurs prior to the initiation of twist it is to be expected that little contact twist is used and that aerial techniques are responsible for the production of twist. Prior to twisting the body is piked and since it is rotating backwards asymmetrical hip movement is unable to produce much tilt since the directions of hula twist and tilt twist are in conflict. As a consequence it might be expected that the twist is

Figure 15. Simulation of an unstable double backward somersault leading to a quarter twist.

In actual performances of straight double somersaults such asymmetrical arm

Figure 17. Simulation of a double backward somersault with one twist in the second somersault arising from slight arm asymmetry in the first somersault.

Summary

Most sports movements contain an aerial phase during which the body loses contact with the ground or apparatus. While the path of the mass centre during flight is determined by its location and velocity at takeoff, the amount and type of rotation of the body is largely under the control of the athlete. Somersault rotation is a consequence of the angular momentum generated during takeoff. Twist rotations may be initiated during takeoff or during the aerial phase by means of asymmetrical arm or hip movements. Asymmetrical arm movements may be used to stop the twist in a twisting somersault or to prevent the build-up of twist in a non-twisting somersault. The control of the twist in this way is possible using feedback via the inner ear balance mechanisms provided that the somersault rate is not too high.

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Figure 2. A double backward somersault from a floor exercise showing the increased speed of somersault rotation when the body is tucked.

Figure 3. A double somersault dismount from the high bar with a straight body.

Figure 4. A triple somersault dismount from the high bar with the body tucked.

Figure 5. During a wobbling somersault the twist oscillates left then right.

Figure 6. During a twisting somersault the twist continues in one direction.

Figure 7. A computer simulation of a backward 1 ½ somersault dive with 1 ½ twists in which the twist is produced during the takeoff.

Figure 8. Computer simulation of an aerial half twist using the "hula" or "cat" technique.

Figure 9. Aerial twist in a somersault resulting from tilt produced by asymmetrical arm movement.

Figure 10. Aerial twist in a somersault resulting from tilt produced by asymmetrical hip movement.

Figure 11. Simulation of a forward 1 ½ somersault dive with three twists using asymmetrical movements of the arms.

Figure 12. A double somersault with 1 ½ twists in the second somersault produced using asymmetrical hip movement.

Figure 13. Stopping the twist by removing the tilt in a backward 1 ½ with 1 ½ twists using asymmetrical arms.

Figure 14. Performance of a double backward somersault from trampoline with one twist in the second somersault.

Figure 15. Simulation of an unstable double backward somersault leading to a quarter twist.

Figure 16. A performance of a double straight somersault in which corrective arm asymmetry is apparent late in the movement.

Figure 17. Simulation of a double backward somersault with one twist in the second somersault arising from slight arm asymmetry in the first somersault.