Biomechanics

An insight into the Biomechanics of Twisting

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Introduction

An understanding of how a gymnast twists in the air is still not complete, even in the mind of physicists and mathematicians; however, the past decade has seen much progress in identifying which of these mechanisms are most effective or contributory to successful twisting.

A major problem has been that, although the human body must obey the laws of physics, it does not act as a rigid system and therefore is not easily analyzed. In fact, a recent survey (Frohlich, 1979) of the 59 physicists who responded to a questionnaire, more than 56% believed that a somersaulting diver could not initiate a twist having left the board; something practitioners have known to be readily possible for some time.

Ten years earlier a paper was published (Leigh & Bengerter 1967) which attempted, with the use of cinematography, to demonstrate that coaches were poorly prepared in basic theory because all in the study believed (probably correctly) their divers and trampolinists to have initiated their twists in the air, contrary to what the authors believed the film to show.

The reasons for past difficulties are not hard to understand. All "knew" that according to the principle of conservation of angular momentum, rotation could not be initiated in the absence of an applied torque. Also until the late 1960s not many aerial performances in the sense of multiple somersaults with delayed multiple twists had been seen; the common appearance of which finally did challenge theoreticians to explain. Finally it may well be, and the issue is far from resolved, that as many as three or four twisting mechanisms are active during one performance and that these mechanisms may interact throughout a complicated twisting and somersaulting performance.

Twisting Mechanisms

For purpose of simplification, validated twisting mechanism may be identified in the following manner:

A. Torque twists
B. Non torque twists

i. Zero angular momentum mechanisms

a) Cat twist or two axis theorem

b) Hula hoop or conical twist

ii. Non zero angular momentum mechanisms

a) Tilt twist

Understanding angular momentum

The principle of the conservation of angular momentum is most simply stated as:

Angular momentum = moment of inertia x angular velocity or, AM = Iw

For meaningful discussion the forgoing relationship must be understood completely:

1. Angular momentum can be viewed as the quantity of rotation a body has about some given axis as a result of its speed of rotation and the distribution of mass about the axis.

2. Moment of inertia (I) is a measure of how the mass of body is distributed about the axis of rotation. The further the mass is away from the object, the larger the "I" and vice versa. In fact "I" increases as the square of the distance of the mass and therefore small increase in distance can result in relatively large increases in "I."

3. Angular velocity (w) is simply the stated speed of rotation about the axis of rotation.

4. Since AM must be conserved (unless an external force or torque is applied) the product of "I" and "w" must stay constant. However the human body can change position in the air which has the effect of changing "I" and thus "w." If a gymnast tucks up in the air, "I" will decrease and then so that "AM" will be conserved, "w" will increase accordingly and vice versa.

5. No discussion of rotation is meaningful unless axis of rotation is specified.

Angular momentum can be created only by the application of an eccentric force, that is, a force that at some distance from the axis of rotation. Such a force is known as a torque and is most effective the further that it is applied from the axis.

Twisting Mechanisms

Torque Twists

Clearly the most effective twisting mechanism is to apply a large torque relative to the longitudinal axis during take off. The gymnast will then have a considerable twisting "AM" in the air and then if the arms have been held wide (large "I"), "w" can be increased quite significantly simply by pulling the arms in (small "i").

For most twisting gymnastics skills the application of torque during take off is the major twisting mechanism.

Non Torque Twists

Two conditions can occur, the gymnast can begin with total body "AM" equal to zero about all axes or the gymnastics can begin with some quantity of "AM" about one of the non twisting axes (i.e. somersaulting or cartwheeling).

Zero "AM" Twisting Mechanism

a) Cat twist or two axis theorem: It is possible to perform a limited twist by varying the relative movements of inertia of the upper and lower body, in essences, successively twisting one part of the body with small "I" against one with large "I" which will therefore twist less in the opposite direction.

Figure 1.

b) Hula Hoop or Conical Twist Theory The simplest explanation is that if a body part is used to introduce an extraneous component of "AM," the total body must turn in the opposite direction to maintain the total "AM" at zero. The hand or arms could be rotated overhead. But more effective because of its mass is to use the trunk in a hula hoop fashion. The total body will respond by twisting in the opposite direction about the longitudinal axis.

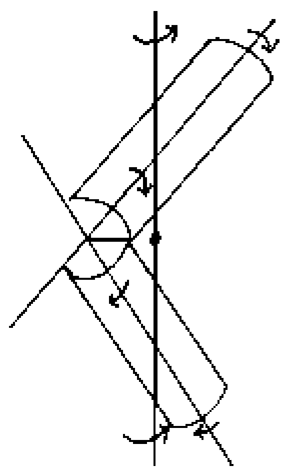

Figure 2.

It is important to recognize that these mechanisms under conditions of zero total body "AM" provide only for a reorientation of the body in space while certain body parts are moved and that the twisting action ceases immediately that the body actions are stopped.

Non Zero "AM" twisting Mechanism

a) Tilt twist

If a gymnast has considerable angular momentum about the transverse (somersaulting) axis it has now been established that the most effective mechanism for initiating a non torque sustained twist is what is commonly referred to as the tilt twist. This took many years to discover because it had been neglected that "AM" is a vector quantity, that is, it has a magnitude component and a directional component. For "AM" to be conserved both components must be considered. The direction of the angular momentum vector during a somersault is along the axis of rotation (left for forward somies and vice versa).

The tilt mechanism requires the gymnast to shorten one side of the body relative to the other (by throwing the are, one up, one down, or by side flexion or both). This has the effect of tilting the somersaulting axis away form the "AM" vector the direction of which (in order to be conserved) requires the body to undertake a compensating sustained twist about the longitudinal axis as long as the tilt exists.

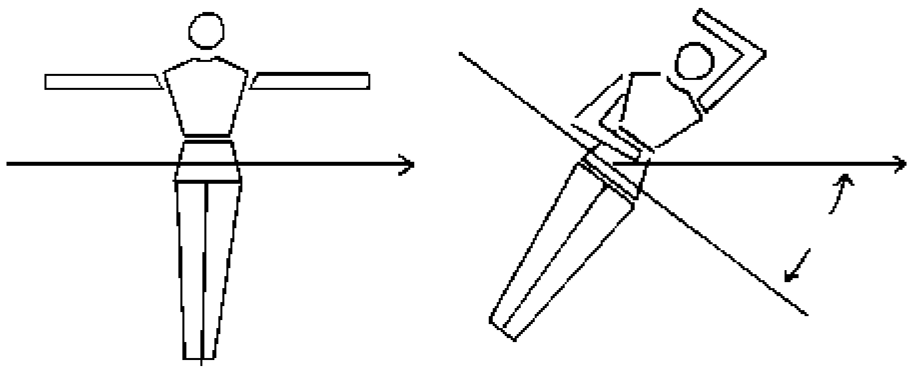

Figure 3.

Though this is not a mathematical paper the simplified mathematics of what occurs can be very enlightening.
Amt = AMssine (1)
Itwtt = Iswssine
wt = ws (Is/Is) sine (2)
where t = twist s = somersault J = angle of tilt

Equation (1) gives the relationship of how much twisting "AM" is induced by a given degree of tilt, but equation (2) is especially useful once it is understood. If we assume that we wish to maximize the speed of the twist (wt) then the equation tells us the following.

1. wt will be larger, the larger the ws (the speed of the initial somersault).

2. wt will be the largest if the somersaults are performed in the layout position since the value of Is/Is is maximized if the numerator is maximized and the denominator minimized (a layout position in each case).

3. wt will be greatest the greater the amount of tilts or the greater the amount one side is shortened relative to the other since the value of sine increases from 0 to 1.0 as the angle o approaches 90 degrees. In other words if the body tilts sideways (J = 90 degrees; sine = 1.) completely then the total somersault is converted to twist.

The message should be clear. One of the most effective uses of the tilt mechanism is in multiple layout somersaults with late twists (i.e., double layout with full out) which gives a large value of ws maximizes the value of Is/Is and perhaps the sine because of the arch to hollow body position change.

It has been demonstrated that in backward somersaults the feasible tilt of 10 degrees will result in a twisting speed of three twists for each somersault forwards the feasible tilt is 20 degrees, which can result in 5 1/2 twists per somersault.

Conclusion

It is likely that in most twisting gymnastics skills there is an interaction of the various twisting mechanisms. Although the "cat twist" and the "hula hoop" mechanisms were explained in reference to zero angular momentum twists it is clear that they may also be active in non zero angular momentum twists. In these cases the "cat twist" likely assists in initiating twist and the "hula hoop" mechanism assists in and may be sufficient for sustaining it although it is not clear if these actions can be maintained consciously throughout a complex performance.

In all cases, other things being equal, a torque twist is the most effective twisting method provided it does not aesthetically detract from the performance or result in modification of other performance parameters (i.e., height or somersaulting "AM"). Ion delayed non zero "AM" twists the tilt twist mechanism is the most effectively and the only one that can create a sustained twist. It is the only in-air mechanism that is certainly under conscious control during the initiation and maintenance of complicated twisting skills.

References

Bartree, H. and Dowell, I. (1982) "A cinematographical analysis of twisting about the longitudinal axis when performers are free of support." *Journal of Human Movement Studies* 8:41-54.

Fink, H. (1985) "A critical review of biomechanical research in the sport of gymnastics." University of British Columbia, unpublished paper.

Fink, H. (1986) "The principle of the conservation of angular momentum and its application to gymnastics." *Coaching Review*, March 1986.

Frolich, C. (1979) "Do springboard divers violate angular momentum conservation?" *American Journal of Physics*. 47(7)"583-592.

Frohlich, C. (1980) "The physics of somersaulting and twisting." *Scientific American*, March 1980.

Leigh, L and Bangerter, B. (1967) "A cinematographic analysis comparing techniques and mechanics of selected forward and backward twisting somersaults in competitive and rebound tumbling." Paper to AAHPER March 13, 1967.

Liu, Z. and Nelson, R. (1985) "Analysis of twisting somersault dives using computer diagnostics." *Biomechanics* IX-B.

Van Gheluwe, B. (1981) "A biomechanical simulation model for airborne twist in backward somersaults." *Journal of Human Movement Studies* 7:1-22.

Van Gheluwe, B. and Duquet, W. (1977) "A cinematographic evaluation of two twisting theories in the backward somersault." *Journal of Human Movement Studies* 3:5-20.

Yeadon, M. and Atha, J. (1985) "The production of a sustained aerial twist during a somersault without the use of asymmetrical are action." *Biomechanics* IX-B (edited by Winter et al) 195-400.

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