Communicating the Biomechanics of Selected Gymnastics Skills Through Newton's Three Laws of Motion

An Honors Thesis (ID 499)

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Ball State University
Muncie, Indiana
February 24, 1984
Graduation Date: February 24, 1984
I. Introduction

As a young girl growing up, I had many gymnastic coaches. Each of the coaches had different philosophies and styles of teaching. The styles and philosophies which have remained with me most prevalently have been those of my high school coaches, Daniel and Pamela Poe. Their methods have impressed and influenced me so much that it is they whom I wish to emulate in my own teaching career.

One aspect of their teachings which I value is their simplified explanations of the mechanics of gymnastics stunts. Mr. and Mrs. Poe were able to communicate biomechanical principles in the teaching of gymnastic skills at the intellectual level of their gymnasts. They made things sound so easy by using simple terms to describe them. I may never know if their ability to do so rests on their knowledge of the actual mechanics of the skills, or if the clues they gave me were the same ones their instructors gave them. Regardless, the explanations were usually correct. Too often coaches do not understand the mechanics of the skills and incorrectly teach them to their students and athletes. For this reason, it is important for coaches and teachers to learn the basic biomechanical principles which apply to gymnastics skills.

Many of the coaching hints Mr. and Mrs. Poe gave me may be explained through Newton's three laws of motion. These three principles may be simplified for all to understand, just as the Poes did for me. This paper attempts to do just that: explain the mechanics of a few selected skills through Newton's three laws of motion. The selected skills are as follow:

a. Cast wrap on the uneven parallel bars
b. Handspring full twist on the vault
c. A tumbling pass
d. Tuck, pike, and layout somersaults
e. Back hip circle on uneven parallel bars
f. Jump full twist on floor
g. Full twist dismount on uneven parallel bars
Definition of Terms

A. **Turn**: "A skill revolving around the longitudinal axis while maintaining contact with the apparatus."

B. **Twist**: "An airborne skill revolving around the longitudinal axis..."\(^{2}\)

C. **Longitudinal axis**: The axis which runs from the top of the head through the feet dividing the body into two equal and symmetrical parts.

D. **Transverse axis**: It is perpendicular to the longitudinal axis cutting the body into upper and lower halves.

E. **Moment of inertia**: the resistance of a body to rotate.

F. **Radius**: the separation distance from rotation to axis.

G. **Angular momentum**: the speed at which a body rotates.

H. **Torque**: the effort exerted on or by the radius of a body to rotate that body.

I. **Newton's first law**: "A rigid rotating body will tend to continue to rotate with constant angular momentum unless acted upon by an unbalanced external torque."\(^{3}\)

J. **Newton's second law**: "The torque applied to an object is proportional to the change in angular momentum."\(^{4}\)

K. **Newton's third law**: "For each torque exerted by one body on a second, there is an equal and opposite, and simultaneous reaction torque exerted by the second on the first."\(^{5}\)
II. Review of Literature

It is important for both gymnasts and coaches to understand the mechanics of gymnastics stunts. Many noted authors have also aspired to this philosophy. The reasons they give for this include the fact that a biomechanical approach secures a firm foundation for teaching the skills involved in gymnastics, and any sport. From this may emerge a successful and productive coaching style which benefits both the gymnast and the coach.

Also, it is this analytical ability of the coach which will enable the gymnast to correct her/his technique. This is the role of the coach, to observe the techniques of the gymnasts and correct them mechanically.

Many times the difference between success and failure lies in the modification of a technique which may be determined only by someone who understands mechanics of movement. The gymnast may only improve her/his skill when s/he learns one technique will improve the movement over another technique.

Usually, the coach is the one who does the assessment of the skill since s/he is more trained in such, and as it is difficult to see oneself.

The mechanics of gymnastic skill is often confusing to the gymnasts or to a coach who is ignorant of mechanical principles. Communicating the abstract physical laws to the athlete is often difficult and considered truly an art if by doing so the athlete's body responds appropriately.

Still, it is important. If a gymnast simply relies on a book description of a skill without also understanding the mechanics, s/he may not end up performing the skill intended. Either the book or the coach will need to include the mechanics for the gymnast. If the mechanics are left out in the initial leaning, progress will be slower. Some gymnasts often try
to copy champion level gymnasts' styles to perfect skills, seeing the champions having success with them. This, again, eliminates the use of mechanics in perfecting skills. In doing this the gymnast rarely takes into account her/his size, shape, or physical limitations. Nor does s/he realize that the champion was probably coached through the use of the mechanical principles that the amateur is leaving out. Size, shape, and physical limitations all have mechanical implications when attempting any skill. These implications will lead to success or failure of movement. It is individual to each gymnast. An understanding of the mechanics may prevent this error.¹³

Finally, understanding the mechanics of a skill will give the gymnast self-confidence. This confidence emerges from the fact that s/he knows her/his techniques are correct.¹⁴

None of the authors are advocating an in depth study of the mechanics of all gymnastics skills. Rather they are suggesting that many of the skills employ the same principle.¹⁵ Instruction in these principles may allow for greater transfer of understanding when a new skill is being learned. The authors also mention that the principles should only be taught to gymnasts who are intending to advance in gymnastics, not to the beginner.¹⁶ This type of instruction may be too confusing for the beginner, and the beginning skills may usually be easily learned without the gymnasts understanding them. The beginners' teachers, though, should know the mechanics. So, although actually communicating these laws to the gymnast may be hard, it is necessary.

In the literature I researched comments were made on the skills analyzed in this paper.

Cast Wrap and Back Hip Circle on the Uneven Parallel Bars

These two skills are reviewed together due to their similarities.

G.S. Aaron (2) notes that the displacement of the head, arms, and trunk in a rotating skill slows angular velocity since they have such large moments.
of inertia. For this reason, while performing hip circles correct body position is necessary. Don Tonry (3) also notes that to complete this type of revolving skill the gymnast must extend the limbs away from the axis of rotation. This method also concludes rotation in hip circles.

Handspring Full Twist on Vault, Full Twist on Floor, Full Twist Dismount on Uneven Parallel Bars

Due to the similarities in these skills they are grouped together here. Myke Gluck (1) notes that while the body in a layout position may drop an arm to initiate the twisting motion. When the twisting is supported, i.e. either hands or feet are fixed points, the twisting initiates at the end of the body which is not affixed to a stable object and winds itself either up or down to the other end and the apparatus. On the same subject, Tonry contends that rotation is acquired by the reaction of the each to push-off and arm thrusts in the jump full twist. Gerald S. George (5) concurs on these points, and adds that the twist is uniform with all body parts moving collectively in the intended direction of the twist (except the feet), body parts move through this angle with the same amount of time and through the same angle.

Tumbling Pass

This paper's discussion on a tumbling pass includes the importance of correct feet placement and continuity of movement. William T. Boone (4) agrees continuity of movement is important because to stop after each skill is to lose angular momentum. When this occurs each subsequent skill must start from the beginning to overcome the body's moment of inertia. Tonry adds the importance of correct feet placement. According to Tonry when feet are placed at an angle which conceals rotation and linear motion the angle is zero. They must be placed at a lesser angle to continue movement.

Tuck, Pike and Layout Somersaults

Many authors have discussed the biomechanics of all three types of
somersaults. Aaron and Gluck concur that as the radius of the body shortens, i.e. pike or tuck, resistance is decreased and rotation speeds up. This is the basis of the discussion on somersaults in this paper.
III. Methods

To research this topic I went to the physical education section of the Bracken Library at Ball State University in Muncie, Indiana. Here I found books written on the biomechanics of gymnastics, kinesiology books, and books concerned with tumbling and trampoling skills. I did not choose to research books with a general view of gymnastics and basic skills for one of the reasons stated in the review of literature: they often leave out the mechanics of the skills and attend only to a basic description of the skills.

After an examination of the available literature, I identified the gymnastic skills to be studied and applied the basic mechanical principles of motion to each of the selected skills. The application of the mechanical principles were then verified by two gymnastics experts, Daniel and Pamela Poe.
IV. Results

Cast Wrap

Newton's first law of motion can easily be illustrated in a discussion of a cast wrap on the uneven parallel bars. In performing this trick the gymnast begins in a front support on the high bar with zero momentum. The gymnast starts the motion by casting away from the high bar by extending the body away from it with straight arms and legs, body slightly arched. The high bar becomes the external axis of rotation. Gravity pulls the gymnast down toward the ground. The momentum from the swing would carry the gymnast back up along the opposite arc if a force did not act. The force is the low bar.

As the low bar is met, the gymnast wraps her/his legs around it and changes the hand grasp from the high to the low bar. Now s/he rotates about the low bar. The gymnast will continue to rotate around this external axis unless, as Newton's law predicts, another force acts upon it. The force of gravity acts to slow or stop the body's rotation.

Gravity pulls any mass towards the center of earth. In pulling the gymnast toward the ground it will halt any upward rotation. To counter the force of gravity, the gymnast should put an end to the rotation her/himself. This may be accomplished by one of two methods. The first method involves tightening the grip of the hands on the low bar. This increases the friction between the gymnast and the bar, thus producing a force which will slow rotation. The second method involves, as my coaches call it, "opening," or extending the body. As the gymnast wraps the bar the body position is a pike position. Opening means to straighten the body to an
extended position. In doing so the gymnast slows rotation and works against gravity by opening the body in a different direction from where gravity is trying to pull it. To do this, when the gymnast's legs reach a horizontal position in the wrap s/he extends and tightens the muscles surrounding the hips so that s/he is no longer flexible in this area. This opening and tightening of the grip slows and stops the gymnast's angular momentum before gravity has a chance to. Therefore, the gymnast stays on the bar at the completion of the trick.

Somersaults

When executing aerial or somersaulting skills which are intended to terminate on the ground (or on the beam), rotation is cancelled by extension of the limbs and placement of the feet. Extending the limbs aids in halting rotation by producing more resistance and thus increasing the moment of inertia. Correctly placing the feet will cancel rotation upon landing the skill. This occurs when the gymnast opens at the appropriate moment. For instance in a front somersault, if the gymnast opens too early her/his feet will be in front of the body causing backward rotation to occur. This causes the gymnast to fall backward. If s/he opens too late, her/his feet will be behind the body causing forward rotation, thus landing on her/his face. Opening at the correct time will allow the gymnast to place the feet directly under the center of gravity and prevent and further movement. In this case, it is the combined forces of opening (extension of the limbs) and gravity (pulling the body towards the ground) along with correct feet placement which cause a termination of the rotation about the transverse axis.

Tumbling Pass
It is not always desirable to stop after each skill. Unless it is a dismount, one trick follows another in a series during a routine. When this is the case, the gymnast will want to place the feet in a position which will facilitate further movement. An illustration of this may be seen in a description of a tumbling pass. For example, a gymnast's pass may consist of a round-off, back somersault, back handspring. Upon landing the round-off the gymnast will pull her/his feet in front of the body, keeping off balance in a backward manner. This coupled with the powerful legs and arm thrusts will lift the body into a back somersault. The gymnast will open from the back somersault slightly late so that the feet land in front of the body again keeping the momentum going backwards. The momentum is used finally for the back handspring.

Gravity and extension of the limbs throughout the above tumbling pass are both working against linear and angular momentum. However, placing the feet so that the center of gravity is outside the supporting base, the gymnast is enabled to keep moving. My coaches always told me to "work through a skill," that is to keep the routine moving. This helps in continuity of movement in a routine, but also satisfies another principle. A gymnast's linear inertia is greatest at rest. For this reason, if s/he stops after each skill, the force needed after each skill will be greater than if the motion was continuous making the next movement more difficult. However, if the gymnast keeps moving, it will be easier to perform skill after skill until the end of the routine. Thus, external forces Newton referred to in his first law may work to the advantage of the gymnast or to the disadvantage depending upon the intent and ability to manipulate these forces.

Handspring Full Twist
"Reach for a penny in your pocket." Mr. Poe said this to his gymnasts while spotting them for a handspring full twist on the vault. As they pushed off with their hands, they dropped one of their hands to the opposite hip. Upon doing so, their bodies twisted 360 degrees around the longitudinal axis before their feet met the ground. This phenomenon can be easily explained through Newton's second law of motion. To review it says the rate of rotation can be altered by shortening the radius of the rotating body. Likewise, extending the radius decreases angular momentum also. In shortening the radius, a gymnast decreases the moment of inertia, thus lessening the resistance to rotate, allowing rotation to occur.

On the other hand, lengthening the radius will increase the resistance to rotate which will either slow or halt the movement. In performing a handspring full twist on the vault, Mr. Poe did not really want his gymnasts to look for pennies. Rather, he was asking them to shorten their radii by pulling in one of their arms close to their body. Upon landing the vault, the correct position is with the arms again extended over the head, thus increasing the radius and slowing rotation.

Somersaults

Shortening the radius to speed up rotation is a principle applied in somersaulting moves also. The first somersault a gymnast is likely to learn is one executed in a tucked position. All somersaults start off as layouts with the body and its limbs straight and extended to gain height. Tucking the legs from this initial position shortens the radius and speeds up rotation. This is just what a beginner wants because it is the easiest and fastest type of somersault. A pike somersault comes next in the progression. Here too the radius is shortened from the initially extended position, but not as much as the tuck is. Piking does increase the.
speed of rotation, yet is relatively slower than the tucked somersault. Obviously the layout somersault is the most difficult of the somersaults to perform since the body remains in and extended position, thus having a long radius and large moment of inertia. Yet, after the initial upward thrust of the arms and lift of the body, the arms are brought back in close to the body. This is done in an attempt to shorten the radius without losing the layout position. Also, in the layout somersault, there is a tendency for the beginner to arch the back. Doing this displaces the center of gravity and lengthens the radius making the whole trick harder. For this reason it is important to keep the body straight and tight throughout the execution of the skill.

Back Hip Circle

A back hip circle is correctly executed with straight arms, straight legs, extended spine and with the head in a neutral position. Many beginners bend at the hips and the knees while performing the stunt. Mr. and Mrs. Poe argued that this made the trick harder. This is incorrect. By bending at these joints the trick is actually made easier. What the gymnasts are doing, unbeknownst to them, is shortening the radius of their bodies to speed up the rotation of the trick. Doing this makes the trick easier, although form-wise incorrect. The weight of the calves is minimal when one considers how much the moment of inertia is decreased by flexing these joints. In defense of the Poes, when a beginner does have form breaks such as bent knees and hips, others are often present too. For example, they may bend their knees behind them which does pull them backward. It is best to learn the trick and perform it correctly each time, than to just do it the fastest and easiest way.

In these examples we have seen that the shortening of the radius
may produce the desired effect or an undesirable one depending upon the skill. The coach and the gymnast need to know the difference.

Jump Full Twist

The third law of motion as espoused by Newton may be illustrated through an examination of the jump full twist on floor. As the gymnast pushes clockwise (for example) and down to initiate the jump and the twist, the ground pushes counterclockwise and up. The gymnast receives the forces of lift and rotation from this action-reaction. All of the body parts move collectively in the intended twist direction (except the feet). The twist is uniform with all body parts twisting in the same direction, in the same amount of time, and through the same angle. This produces consistent, nonaccelerating force. Upon landing, the opposite actions as used in initiating the twist will be exerted by both the gymnast and the ground simultaneously to cancel rotation.

Full Twist Dismount off Uneven Parallel Bars

Supported twisting (twisting initiated from fixed points, usually the apparatus) is slightly different from free twisting (twisting initiated from the gymnast's body). In this type the apparatus develops the twisting. A swing full twist dismount on the uneven parallel bars is a good example of this. In this stunt the hands are the fixed points, and are affixed to the high bar. As the body swing out to the desired height, and the legs begin to twist clockwise (for example), the twisting action flows up the body to the hands. By holding onto the bar and keeping the body tight throughout the trick the twist meets with resistance. This provides the action-reaction force required to complete the twist. Rotation is cancelled upon the feet meeting the ground in landing.
V. Conclusions

One may now see how Newton's three laws of motion and rotation may be simplified for a person not trained in the mechanics of gymnastics to understand. Still, a basic understanding of gymnastics moves is required, so this is not appropriate for a beginner, or one who is not interested in pursuing this sport. However, it is vital for serious gymnasts who plan to advance in their skills. Knowledge of these three laws explain the mechanics of many skills to the gymnast and may help her/him in performing the skills described in this paper, and other similar actions.

The three laws of rotation apply to each and every one of the skills described. However, if I had described each skill in terms of each law it may have become rather confusing. I tried, instead, to pick out common mistakes of gymnasts and to correct them through the use of these laws. Coaches will not want to explain each skill they teach through each of these laws. Instead, they should correct, or teach, the skills through the law which will best suit it.

In addition, these principles, although major ones, are not the only mechanical principles applicable in gymnastics skills. These are just the few I chose to write on. The other principles are just as worthy to teach to athletes, and should be. The key is to keep the explanations simple, but true. Make sure what is being said is mechanically sound. Teaching gymnastics skills through their mechanics will insure that they are correct and help the athletes to progress at a fast and safe rate. Also, helping them to understand the mechanics of their movements will make them more confident in performing them. It may also make them more willing to try new stunts if
they understand where they are coming from, and what they relate to.

For these reasons, and others stated in this paper, it is important for both gymnasts, who are serious about the sport, and all coaches to have an understanding of the biomechanics of gymnastics skills.
FOOTNOTES


4. Ibid.

5. Ibid.


12. Ibid.

13. Ibid.

14. Ibid.


BIBLIOGRAPHY


