

Biomechanics

Equilibrium: Biomechanical Implications

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Gymnastics skill combinations are predominately dynamic motion and usually not performed in equilibrium. Hay and Reid (1982) suggest that equilibrium is often absent in movement experiences because forces such as aerodynamic drag, gravity, and other external forces act on the athlete and generally create either linear or angular acceleration. Positive and negative accelerations disassociate from equilibrium because changes in state of motion are quite normal during gymnastics performance. The performing gymnast is often out of equilibrium because of continuous changes in linear and angular velocities and directions. Although there is both static and dynamic equilibrium in gymnastics routines, equilibrium most often exists when associated with static positions.

Hay and Reid (1982) point out that dynamic equilibrium is less common and is only present when the system is moving with constant linear and angular velocity. In gymnastics activities, for example, it is possible to see change in motion for both the individual human segment and the center of gravity. To suggest that dynamic motion is without control would be misleading. Kreighbaum and Barthels (1996) indicate movement of the body is usually dependent upon some degree of control or balance. Control is often associated with maintenance of a series of skills moving in and out of equilibrium in conjunction with effective skeletal alignment or human segment positioning. This is particularly true with gymnastics performance and can be observed in Figure 1. Table 1 provides a summary of the frame by frame variations in equilibrium. The purpose of this article, therefore, is to discuss equilibrium as it relates to a combination of gymnastics movements and positions.

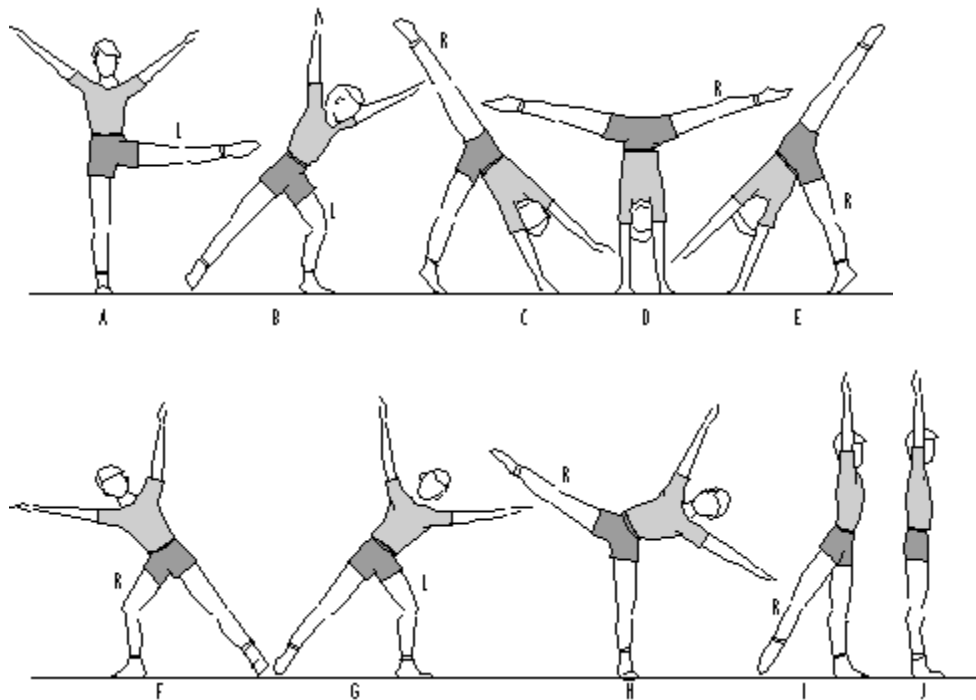


Table 1. Summary of Variations in Equilibrium.

Frames	Out of Equilibrium	Dynamic Equilibrium	Static Equilibrium
A			LOG within base
A-B	Positive Acceleration		
B-G	When positive ang accel &/or LOG outside base	When zero ang accel &/or LOG inside base	
H			LOG within base & zero ang & lin accel
H-1	Positive ang accel		

*Line of gravity (LOG)

Center of gravity (CG)

Base of support (base)

Angular acceleration (ang accel)

Linear acceleration (lin accel)

Analysis of Change and Control

Initiating the cartwheel

The combination shown in Figure 1 begins in frame A, illustrating abduction and lateral rotation of the left leg at the hip joint to a position horizontal to the contact surface, with the arms raised in bilateral symmetry. This requires that the center of gravity (CG) be shifted slightly to the right in order for the CG to be over the base of support. Static equilibrium can be present if this position is maintained. Control is present because the line of gravity is directed vertically from the CG to a point within the base of support. Certainly control is dependent upon stable ankle and subtalar joints in the support leg. Hay and Reid (1982) suggest that equilibrium is evident when both the sum of the external forces and the sum of moments are equal to zero. Static equilibrium is changed from frame A to B as the gymnast concentrically contracts the hip abductors of the right leg, resulting in an internal action force that translates to an external ground reaction force. Dynamic motion follows and is imbedded in a loss of equilibrium as the gymnast positively accelerates around the anteroposterior axis. Gravity now acts as an external torque from frame A to B as the CG moves to the left and the line of gravity temporarily relocates at a distance from the base of support.

Altering the base of support

The base of support changes from frame to frame throughout Figure 1. This is essential when the gymnast must create a change in angular velocity. There is a concurrent translation of the body segments about the axis of rotation at floor contact as the center of gravity translates linearly. Both linear and angular motion must go through change from frame to frame as the base of support is reestablished and the gymnast translates in and out of equilibrium. For example, the gymnast moves out of static equilibrium from frame A to B, continues changing in and out of dynamic equilibrium during the frame B through G sequence, moves to static equilibrium in frame H, translates out of static equilibrium with changes in dynamic equilibrium from frame H to I, and moves back to static equilibrium in frame J. Consequently, there is general maintenance of control from frame B to G as the gymnast moves in and out of equilibrium with a changing base of support.

The system's velocity and its line of gravity (LOG) are important considerations in determining the state of equilibrium. Static equilibrium exists when the line of gravity is within the base of support and there is zero velocity. This indicates the system is at rest. Dynamic equilibrium is present when the system is in motion, but there is no change in velocity or direction (Kreighbaum and Barthels, 1996). Static equilibrium does not exist when the CG and its corresponding line of gravity are outside the base of support; however, this is not the case with dynamic equilibrium. Dynamic equilibrium can exist as long as there is no fluctuation in the velocity of a moving body. Being out of equilibrium, however, is often necessary for the gymnast to effectively change a state of motion. Consequently, a gymnast often deals with the continuum existing in most skills and combinations between being in and out of equilibrium.

A changing base of support is needed during most gymnastics performance. The base of support provides opportunity to produce an external torque for controlling angular acceleration and an external force for controlling linear acceleration. For example, angular acceleration can be effectively increased as the left foot touches the surface between frames A and B. This certainly allows for greater control or stability within equilibrium and an ability to better manipulate direction and velocity. External torque must continue if the gymnast is to positively accelerate or maintain zero acceleration when rotational inertia remains large around the anteroposterior axis through the cartwheel sequence (Frames B-F). Control is preserved as the maintenance of equilibrium continues with re-establishment of the base of support. This is best accomplished as the LOG is repeatedly moved away from and into the base of support.

Control and skeletal alignment are dependent upon effective manipulation of human body segments around the CG in both static and dynamic motion. For example, slight left knee and hip flexion in Frame B allows decreased rotational inertia and maintenance of a straight line connecting the left arm and right leg. This assists in providing improved aesthetic alignment of human segments and an ability to translate the CG forward beyond the base of support. The short term lowering of the CG, associated with hip and knee joint flexion, permits positive angular acceleration of body segments around the CG. This permits the left hand and arm biomechanical unit to make earlier surface contact while the right leg maintains the required straight line from right leg through the trunk and left arm. Early left hand contact permits re-establishment of the base of support and renewed angular impulse in Frame C. To further continue positive acceleration of the right leg from frame B to C, the left knee is forcefully extended as the left hip joint continues into flexion. Left ankle plantar flexion fosters additional positive acceleration around the CG in the counterclockwise direction. Angular acceleration continues into Frame D. Dynamic equilibrium can be reached by frame D and continued through E when a desirable velocity is attained. Consequently, zero acceleration and resulting dynamic equilibrium allows the gymnast to effectively prepare for or anticipate change in the rate of motion in the subsequent sequence connecting the side scale.

Transition to the scale

Moving beyond the cartwheel with dynamic motion, into a side scale that establishes static equilibrium, requires the gymnast to begin negative angular and linear acceleration well before Frame H. This leads to moving out of dynamic equilibrium in the later stages of Frame E by maintaining a large rotational inertia, relative to the axis of rotation at the right foot. Further reduction in angular velocity will be possible in Frame F as the left foot establishes a wide base of support and applies a resistive torque to curtail the

counterclockwise movement. A large rotational inertia and a resistive torque both provide needed resistance required to continue moving the body out of equilibrium from Frame F to G. Angular velocity should be significantly lowered prior to Frame H. The net torque established around the CG and the net linear force applied through the CG must reach zero if the gymnast is to establish static equilibrium at frame H. A progressive reduction in angular velocity during this stage, therefore, is necessary if the side scale is to be successfully reached with control. A side scale can be successfully performed when the system is negatively accelerated over time to the point where static equilibrium results. The narrow base of support in frame H is best augmented with plantar flexion at the ankle joint and flexion of the toes at the phalangeal and metatarsophalangeal joints (left segment). This increased joint stabilization further influences the mechanism by which control can be established.

Effective use of flexibility

It is imperative to possess high levels of joint range of motion (ROM) or flexibility in the performance of many gymnastics skills; this is particularly true with the combination in Figure 1. ROM allows the gymnast to secure required symmetry between human body segments in gymnastics combinations and controlled positions. Frames C through E are exemplary of the important relationship existing between flexibility and artistic motion. Particular focus on hip flexibility during the cartwheel is shown in frame D with the side splits position. This position of hip joint abduction requires high levels of extensibility in the medial soft tissues of the hip joint. Frame H further demonstrates the crucial contribution made by ROM in performing gymnastics skills.

Multiple axes and change in equilibrium

The human system is capable of moving around multiple axes simultaneously. Figure 1 provides an example of multiple axes rotation, while in support, as the gymnast moves out of equilibrium in leaving the side scale position. Rotation and angular momentum are initiated around the anteroposterior axis as the right leg drops or adducts at the hip joint in Frame H, transfers to both the mediolateral and longitudinal axes toward Frame I, and continues rotation with flexion at the right hip joint as the gymnast moves to a position of static equilibrium in frame J. Rotational inertia changes relative to the three axes. Rotational inertia increases around the anteroposterior and mediolateral axes as the distribution of the gymnast's mass moves further away from these axes. There is a decrease in rotational inertia as both arms and the right leg move closer to the longitudinal axis. These segmental adjustments reduce resistance to rotating about the longitudinal axis and increase resistance about the anteroposterior and mediolateral axes. Consequently, the gymnast is able to remain under control to the standing position in frame J, while turning 90 degrees around each of the three axes. A controlled tempo is more likely about the anteroposterior and mediolateral axes when the arms and the right leg remain extended. This creates a large rotational inertia relative to the anteroposterior and mediolateral axes and promotes transfer of angular momentum around the longitudinal axis as conservation of angular momentum is established. Consequently, the system temporarily moves out of equilibrium in the initial dynamic motion in leaving the scale, but quickly reestablishes dynamic equilibrium in moving to frame I. Technical execution of frame I requires that the right leg move at a constant velocity with the line of gravity intersecting the left leg base of support. The final state of motion is static equilibrium in frame J.

Summary

Gymnastics skills and combinations are identified with both static and dynamic motion and can be performed in equilibrium as well as out of equilibrium. Typically, gymnastics skills affiliate with change in linear and angular velocity and/or change in direction, rather than always being in equilibrium. This characterizes an important association that is inherent with gymnastics skills and combinations and suggests that because they are out of equilibrium much of the time, repeated re-establishment of equilibrium is needed in maintaining control.

References

Arnheim, D.D., and Prentice, W.E. (1993). *Principles of Athletic Training* (8th ed.). St. Louis: Mosby Year Book.

Hay, J.G. and Reid, J.G. (1982). *The Anatomical and Mechanical Bases of Human Motion*. Englewood Cliffs: Prentice-Hall, Inc.

Kreighbaum, E., & Barthels, K.M. (1996). *Biomechanics: A Qualitative Approach for Studying Human Movement* (4th ed.). Boston: Allyn and Bacon.

This article appears in the February 1997 issue of *Technique*, Vol. 17, No. 2.