Biomechanics

Biomechanical Analysis of the Lower Extremity During a Back Salto

William L. Cornelius, Ph.D.
Associate Professor of Education
University of North Texas, Denton, Texas

There are a number of biomechanical considerations in the lower extremity during gymnastics performance. The gymnastics coach can provide a significant contribution to effective performance by being aware of how these considerations can enhance skills and combinations. This could apply to improving gymnastics technique or in reducing a predisposition to injury. The biomechanical structural units such as, the iliosacral, hip, knee, ankle, subtalar, and metatarsophalangeal joints play a primary role in how effectively the gymnast performs These structural units must possess both stability and mobility if the gymnast is to move explosively, artistically, and with control. The purpose of this discussion is to examine the anatomical and mechanical aspects of the lower extremity during the performance of a handstand snap-down to a back salto, pike position (Figure 1).

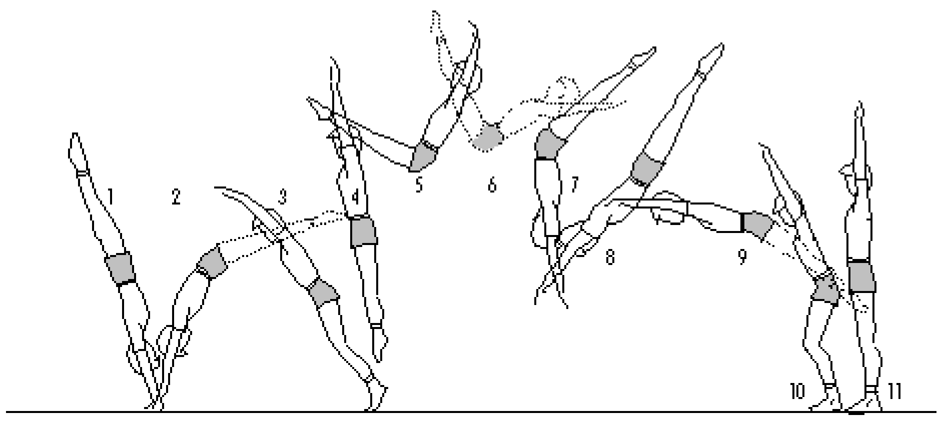

Figure 1

Purpose and Movement Classification

The handstand snap-down to a back salto, in pike position, can be performed in floor exercise and on the balance beam. The overall purpose of this combination is to project the gymnast for maximum vertical height while completing one revolution. This particular movement can be classified in the general movement pattern of jumping. The entire movement pattern is performed in the sagittal plane and around the mediolateral axis. A back salto is a discrete skill because it has a definite beginning and an end and is adapted to the constraints of the event or apparatus. The gymnast performs a particular back salto technique by incorporating a pike position in Figure I (frames 5-6). The open pike position is the style of performance and is considered to be an individual adaptation of the technique (Kreighbaum and Barthels, 1996).

Discrete Phases and Mechanical Purposes

A skill can be effectively observed and analyzed when separated into principal phases The major phases of a skill can be referred to as preparation, execution, and recovery (Kreighbaum and Barthels, 1996). Each phase should contribute to the subsequent phase; therefore, all phases are important to the overall performance. Each principal phase requires different consideration, but lends to completion of the overall purpose (Luttgens, Deutsch, and Hamilton, 1992).

The preparation phase acts as a way to initiate angular momentum and to effectively position the gymnast for take-off into the back salto (frames 1-3). This can vary depending on the mechanical purpose. The mechanical purpose in this case is to create the greatest possible ground reaction force at the completion of the preparation phase. A second major component of the total performance is the execution phase (frames 4-10). This is essentially the movement that projects the gymnast vertically and provides a 360 degree rotation. Consequently, the mechanical purpose of the execution phase is to move the gymnast in the optimum prescribed back salto pattern. The remaining phase consists of the recovery (frames 10-11). The mechanical purpose of the recovery phase is to negatively accelerate the gymnast to a controlled position in frame 11.

Anatomical and Mechanical Analysis

Preparation Phase

The preparation phase is depicted in Figure 1, frames 1-3. Frame 1 illustrates a quick stretch of the soft tissue crossing the anterior aspect of the pelvis and sacroiliac joint. This results in positioning the pelvis for producing the increased force magnitude needed in subsequent hip flexion (frame 1 to 2). The abdominal muscles help stabilize the sacroiliac joint during this maneuver (Table l) by counteracting anterior tilt of the pelvis as the hip flexors pull on their origin of attachment at the ilium, all lumbar vertebra, and twelfth thoracic. Consequently, a stable pelvis acts as the firm base upon which the hip flexors move the legs explosively at the hip joint.

Table 1. Lower Extremity During the Preparation Phase of the Back Salto

Frames	Joints	Actions	Contractions	Muscles
1-2	sacroiliac	stabilized	isometric	abdominal group
1-2	hip	flexion	concentric	hip flexor group
1-2	all others	stabilized	isometric	knee extensors, ankleplantar flexors, inverters and everters, metatarsophalangeal flexors
2-3	sacroiliac	stabilized	isometric	abdominal group, both erector spinae and quadratus lumborum
2-3	hip	stabilized	eccentric	hip extensors
2-3	knee	flexion	concentric	hamstring group and gastrocnemius
2-3	knee	flexion	eccentric	quadriceps group
2-3	ankle	dorsiflexion	concentric	dorsiflexion group
2-3	subtalar	stabilized	isometric	inversion and eversion groups

2-3	metatarso-phalangeal	flexion	eccentric	metatarsophalangeal flexors

Slight pelvic posterior tilt precedes stabilization of the sacroiliac joint. This plays an important role in facilitating hip joint flexion in frame 2. Reduced rotational inertia accompanies the hip flexion. This occurs by decreasing the distance between the segmental center of gravity of the legs and the axis of rotation (center of the hip joint). The resulting effect of reduced rotational inertia is to decrease the moment arm (resistance arm), permitting the motive force produced by the hip flexors to be more effective in increasing angular acceleration of the legs toward the takeoff point in frame 3. Table 1 provides the relationship between lower extremity joints, actions, and the type of contraction for particular muscle groups recruited during the preparation phase from frame 1 to 3. A force couple made up of the abdominal and hip extensor muscle groups counteract the ability of the hip flexor and back extensor muscle groups from moving the pelvis into anterior tilt during the explosive hip flexion maneuver in frame 2. A subsequent control mechanism, provided by eccentric contraction of the gluteal and hamstring muscle groups, limits the degree to which hip flexion occurs up to floor contact in frame 3. Angular momentum continues without additional segmentation at the hip joint. This reciprocal muscle relationship provides the control needed for the optimum position necessary in an explosive action at takeoff Additional hip flexion would place the pelvis beyond the base of support in frame 3, create a lower angle of projection in frame 4, and result in decreased vertical displacement of the total center of gravity.

The knee, ankle, subtalar, and metatarsophalangeal joints remain stabilized throughout the preparation phase until immediately prior to floor contact. Ankle dorsiflexion is necessary at this point in order for the toes to clear the floor and facilitate the optimum position for a quick plantar flexion maneuver in frame 3. Dorsiflexion places the plantar flexor muscle group on a quick stretch resulting in increased force during plantar flexion. Slight knee joint flexion is essential immediately prior to floor contact, through concentric contraction of the hamstring muscle group and gastrocnemius, but subsequent contraction of the quadriceps muscle group negatively accelerates knee joint flexion.

Static and dynamic stability is of major concern in reducing the chance of injury to the subtalar and ankle joint (Arnheim and Prentice, 1993). Both ligament integrity and muscle strength are primary components in stabilizing these joints. Lateral and medial muscle groups assist in reinforcing joint stability and help prevent unwanted inversion or eversion during floor contact. Joint stability helps assure the best possible facilitation of the critical takeoff maneuver in frame 3. Normal range of motion and muscular strength in the subtalar and ankle joint movers and stabilizers prevent a predisposition to injury and are necessary for effective plantar flexion in vertical displacement from frame 3 to 4.

Table 2. Lower Extremity During the Execution Phase of the Back Salto

Frames	**Joints**	**Actions**	**Contractions**	**Muscles**
3-4	sacroiliac	stabilized	isometric	abdominals and hip extensor group
3-4	hip	extension	concentric	hip extensor group
3-4	knee	extension	concentric	knee extensor group
3-4	ankle	plantarflexion	concentric	plantarflexor group

3-4	metatarso-phalangeal	flexion	concentric	metatarsophalangeal flexors
4	sacroiliac	posterior tilt	concentric	abdominal group
5-6	sacroiliac	stabilized	isometric	abdominal group
4-6	hip	flexion	concentric	hip flexor group
4-9	all except hip	stabilized	isometric	agonist and antagonist cooperation
6	sacroiliac	anterior tilt to normal alignment	concentric	back extensor group
6-8	hip	extension	concentric	hip extensor group
7-8	sacroiliac	anterior tilt	eccentric	hip flexor group
8	sacroiliac	stabilized	isometric	abdominal group and both errector spinae and quadratus lumborum
8-9	hip	flexion	concentric	hip flexor group
9-10	hip	flexion	concentric	hip flexor group
9-10	knee	flexion	concentric	hamstring group and gastrocnemius
9-10	ankle	dorsiflexion	concentric	dorsiflexor group
9-10	subtalar	stabilized	isometric	inversion and eversion group
9-10	metatarso-phalangeal	extension	concentric	metatarsophalangeal extensors
10	hip	flexion	eccentric	hip extensor group
10	knee	flexion	eccentric	knee extensor group
10	ankle	dorsiflexion	eccentric	plantar flexor group
10	subtalar	stabilized	isometric	inversion and eversion group
10	metatarso-phalangeal	flexion	eccentric	metatarsophalangeal extensors

Execution Phase

The execution phase is illustrated from frames 3-10 (Figure 1). Table 2 indicates lower extremity joint actions, the type of muscle contractions, and the muscle groups involved in the execution phase. The action taken from frame 3 to 4 is critical to the vertical translation achieved during execution. Consequently, all lower joints are involved in assisting with carrying out this maneuver. The entire lower extremity is stabilized on a vertical line (mechanical line) in frame 4. Joint stabilization is continued through frame 9 with agonist and antagonist cooperation. The sacroiliac joint is stabilized in order that the pelvis is able to act as a firm base upon which subsequent hip flexion may occur. Concentric contraction of the abdominal and hip extensor muscle groups move the pelvis to the mechanical line before assisting with stabilization. The hip and knee joints are extended, while the ankle joints are plantar flexed, and the metatarsophalangeal joints are flexed (frames 3-4). This sequence provides the action force into the take off surface in order to receive the needed equal and opposite external reaction force and to align the body in frame 4 for subsequent rotation around the mediolateral axis.

When sufficient angular momentum is created at take-off from frame 3 to 4, a pike position can result in an effective means of conserving angular momentum from frames 4 to 6 when the hip flexor muscle group concentrically contracts to create flexion at the hip joint. This leg flexion maneuver is preceded by posterior pelvic tilt in frame 4 and accompanied by stabilization in frames 5 to 6. Strong abdominal muscles are essential in the posterior pelvic tilt maneuver in order to position the hip joint (acetabulum) in a favorable position for accommodating the femoral head. Posterior pelvic tilt is necessary because of the extent of the 90 degree hip flexion action in frame 5; otherwise, the head of the femur would be obstructed by the upper margin of the acetabulum.

Hip extension occurs from frame 6 to 8 with concentric contraction of the hip extensor muscle group (Table 2). Slight anterior pelvic tilt precedes this maneuver to begin to reposition and stabilize the pelvic girdle (frame 6) for subsequent hip extension. Repositioning the pelvis serves to accommodate the femoral head during hip extension and assists in stabilizing the point at which the hip extensor muscle group originates. The hip flexor muscle group serves to decelerate hip joint extension by controlling the pelvis to a normal position of alignment through eccentric contraction (frames 7-8) Isometric contraction of the abdominal and back extensors then stabilizes the pelvis in frame 8.

Conservation of angular momentum occurs from frame 8 to 10 with a slight decrease in rotational inertia. This is facilitated with concentric contraction of the hip flexors and a stabilized pelvis (Table 2). Lower extremity biomechanical structural units distal to the hip joint, such as the knee, ankle, subtalar, and metatarsophalangeal joints are all stabilized from frames 4 through 9. There is a change in status leading into frame 10, however, in order to absorb the impact force of contacting the landing surface. Slight hip flexion, knee joint flexion, ankle joint dorsiflexion, and metatarsophalangeal extension begin immediately prior to floor contact. These maneuvers are essential to a safe, controlled landing. Full knee joint extension is undesirable in frame 10. This very stable knee joint position is expedited by the lock-home mechanism that accompanies a secure position between the femoral condyles and the fossa of the tibial plateau (Arnheim and Prentice, 1993). Slight outward rotation of the femur and tibia accompany the lock-home mechanism. The knee joint is quite vulnerable to hyperextension, valgus, and varus stresses when fully extended. Effective absorption of the landing impact force is possible only as the knee flexes. Ankle joint dorsiflexion positions the feet for contact. Eccentric contraction of the hip and knee extensor muscle groups assist in negatively accelerating the gymnast in frame 10. Eccentric contraction of these antigravity muscles of the lower extremity reduces angular momentum and accompanies the plantar fascia and four arches of the feet in further absorbing impact forces.

Maintaining the line of gravity within the base of support allows the gymnast to claim static equilibrium in frame 10.

Recovery Phase

The recovery phase is represented in frames 10 and 11 (Figure 1). Control is maintained with static equilibrium being secured in frame 11. A stable pelvis, held over the base of support, is an important consideration in this phase. Concentric contraction of the hip and knee extensors move the body to the controlled, standing position. Plantar flexor and metatarsophalangeal flexor muscle groups add significantly to control in this phase. Concentric contraction provides the internal motive force necessary to keep the line of gravity within the base of support.

Implications

Understanding relationships between joints, actions, type of muscle contractions, and the muscle groups involved in manipulating body segments, is essential for skill analysis and for designing conditioning activities specific to the task. Gymnastic coaches would be well advised to become students of Biomechanics, basing their advice on anatomical and mechanical principles of human motion.

Figure 1 was prepared by Steve Whitlock based on drawings by James Stephenson in the Men's Program *1984-1988 Junior Olympic Age Group Compulsories.*

References

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