MECHANICS OF THE JUMP APPROACH

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Importance of the Jump Approach

When projected into flight, the center of mass of any object (including the human body) follows a predetermined, predictable, unalterable parabolic curve. Thus, establishment of the proper flight path is totally dependant upon proper force application during ground contact. Since all takeoff forces, including eccentric forces, are applied while still in contact with the ground, any resultant rotations are produced during ground contact as well. These rotations continue into flight and assist or interfere with efficient landings and clearances. In light of these facts, it is obvious that proper force application at takeoff is the only way to produce good performances in the jumping events.

Although good takeoffs produce good jumps, there are prerequisites to the execution of correct takeoff mechanics. Consider an athlete executing an approach run in a jumping event. A person running at relatively low speed can demonstrate greater accuracy in aligning the body into positions favorable for efficient takeoffs, because prior mechanical errors can be easily corrected. However, when dealing with the high velocities we see in competitive jumping, the correction of errors occurring during the run is limited due to time constraints, and is often impossible without great compromises. Also, at these higher velocities, reflexes play a much greater part in the pattern of movement, again minimizing the chances to correct earlier errors in body positioning. The execution of any part of an athletic endeavor is largely dependant upon the proper execution of prior parts. In cyclic tasks such as running, the correct execution of one cycle is prerequisite to the correct execution of the next cycle.

It is then obvious that in competitive situations, an error during the approach run will cause the takeoff, and thus the jump, to be compromised to some extent. The resultant jump is simply a modification of running mechanics, for better or worse. Considering that good execution of the run is prerequisite to proper takeoff and flight mechanics, it is logical that much time and effort be devoted to teaching this technical component, developing it into a contributing, rather than a negating factor.

Overview of the Locomotive Process

In humans, the goal of the locomotive process is to displace the body while maintaining stability. Human locomotion is produced by the creation of force and its application to the ground so that the ground reaction forces produce displacement without permanent sacrifice of stability.

Establishing the Base of Support

Consider one goal of locomotion, that being displacement. Horizontal momentum gained earlier in the locomotion process would be an aid in continuance of movement in that direction, so the conservation of that momentum is desirable. Mechanics that cause the foot to be moving backwards with respect to the forward moving center of mass at contact would reduce braking forces and help us to conserve this momentum. The further back touchdown occurs with respect to the body's center of mass, the more attainable this goal would be.

At the same time another goal of locomotion is maintenance of dynamic stability. The further back the contacts occur with respect to the center of mass, the more likely the body is to topple over. Touchdowns must be sufficiently advanced to insure stability.

It follows that these two strategies are clearly at odds with each other. There exists therefore a tradeoff between the attainment of the goals of stability and conservation of horizontal momentum. The ideal touchdown point maximizes the benefits gained in light of both goals. For any given point in the acceleration process, the point of touchdown is predetermined if this tradeoff is to be optimized.

Postural Integrity

When force is applied to any elastic body which is not properly aligned and stabilized, the force intended to cause movement will instead cause distortion within the body. Improper alignment may also cause forces to act eccentrically, causing excessive rotation rather than maximum displacement.

Postural integrity is essential for this reason. During running, forces must be applied to and from a stable base to produce efficient movement. Postural concerns in running and jumping involve proper alignment of the head, spine and pelvis along with stabilization by appropriate musculature to establish this base. At the same time, this aligned unit must be kept in place and moved predictably as a unit so that forces may be applied appropriately. Erratic movements make force application difficult.

The head, throughout the process of acceleration and sprinting, must be kept in its natural alignment with the cervical spine, so that associated musculature is not overused and vestibular function is not disturbed. The spine must be stabilized in its correct alignment as to best accept the loading it receives from the forces produced by the legs and gravity. The pelvis should be stabilized with a slight upward tilt, in order to best facilitate force production and proper leg movements. A neutral alignment of the pelvis effects slight compromise, while a downwardly rotated pelvis and its associated lordosis offers great force production compromises and impairs proper function of the legs. Training implications for muscle groups responsible for pelvic alignment are profound.

Optimal Velocity

Jump takeoffs, as stated earlier, are a modification of the mechanics of running being performed prior to preparation and takeoff. Extremely high levels of coordination are necessary to perform these modifications efficiently at high velocities, The optimal final velocity of the approach is then somewhat less than maximal velocity. We shall call this value the maximal desired velocity. For a certain event, the maximal desired velocity for an approach is dependant on (1) the athlete's maximal velocity, (2) the athlete's coordination levels, and (3) the freedom of movement the athlete demonstrates at high velocities. Training these qualities can improve optimal final approach velocity for an individual athlete.

Development of Momentum and Velocity

The development of horizontal momentum is of the utmost importance in the jump approach. Momentum is developed by impulse generation. Impulse is defined as the product of force applied and the time over which the force is applied. This means that increasing force production and/or lengthening the time spent in force application will increase impulse.

Consider the process of maximal velocity sprinting. At high velocities, due to the cyclic nature of running, the duration of each ground contact is short, and the distance the center of mass traveled while the foot is in contact with the ground is very small. A greater percentage of the total distance traveled is due to the flight phase. Since these low ground contact times correlate directly to high velocity, minimizing contact time at maximum velocity is a worthwhile goal. In any sprint or jumping event, development of high horizontal velocity creates greater potential for optimal performances.

Unfortunately, these short ground contact times give us little opportunity to generate impulse and greatly change velocities and momentum values. The distances used in approach running are necessarily short due to energy system and coordination limitations, offering further limitation to momentum development. Impulse generation requires large force applications and long ground contact times, conditions that are clearly at odds with the high velocities that are desirable at takeoff.

At the initiation of the acceleration process, the cyclic process is slower and the body is moving at lower velocities, meaning longer ground contact times are appropriate. These velocities allow force to be applied for a longer period of time. More recovery opportunity exists as well, making it possible to more easily adjust the location of the base of support. It follows that the majority of the acceleration process should be accomplished at the initiation of the approach run, and that certain momentum values are prerequisite to proper execution of mechanics at high velocities. It is then necessary to devise some type of mechanism to develop momentum early in the approach.

The long ground contact times during the initiation of acceleration supply the opportunity for long periods of force application. To facilitate these long periods, the center of mass should travel a long path while the body is in motion and force is being applied to the ground. Since the optimal point of touchdown with respect to the center of mass is predetermined by the tradeoffs mentioned earlier, the only opportunity for lengthening contact times is to use a strategy that allows the foot to stay in contact with the ground until the center of mass is well past, allowing toe-off to occur far behind.

The only way to accomplish these rearward toe-offs during initial acceleration while maintaining postural integrity is to establish a forward body lean. This forward lean is the tool chosen by sprinters and jumpers to develop momentum early in the acceleration process. Generally the more hurried the acceleration process, the greater the initial lean, until a point is reached where the low initial body angle allows insufficient flight time for the correct execution of recovery mechanics.

Displacement

Since displacement gains without additional energy expenditures clearly indicate efficiency, it is desirable to optimize the flight path associated with each stride to achieve maximal effective stride length. The most obvious method of increasing stride length, advancing the location of foot touchdown, subjects us to the tradeoffs mentioned earlier, and would cause corresponding decreases in the length of succeeding strides.

An appropriate strategy for maximizing the flight phase without compromising successive strides is to idealize the undulation path of the body's center of mass. The body's center of mass, during the running action, follows a sinusoidal curve. The peaks of this curve occur during the flight phase, while the low points occur during the support phase. Through proper joint extension and stabilization techniques, we can adjust this path as a unit, keeping the center of mass an optimal distance above the surface, maximizing the distance of the flight phase while still optimizing the yield from the tradeoffs involved in selecting touchdown location.

The Acceleration Process

These mechanical alterations (body lean, long contact times, rearward toe-offs, and maximizing displacement) give us our mechanism for efficient acceleration and momentum development in the approach run. As the acceleration process continues, velocities increase, and changes must occur. Until maximal desired velocity is reached, ground contact times must decrease so that the base of support can be rapidly readjusted and dynamic stability can be preserved. Toe-offs must advance until they are occurring only slightly behind the center of mass at maximal desired velocity. Touchdowns must constantly occur somewhat in front of the center of mass to insure stability. (In the pole vault, the mass of the pole must be considered as part of the postural unit). Failure to accelerate in accordance to these principles must result in inefficient force applications and postural alignments.

As toe-offs advance, initial body lean must decrease until maximal desired velocity is reached, when erect postures result. The body angle, from the onset of acceleration until the desired maximum velocity is reached, must progressively become larger. Sufficient advancement of the foot at touchdown and proper joint extension, changing the body's alignment as a unit, is the proper vehicle for this process. Attempts at volitional lifting of the upper body without adjustment in the location of the base of support result in a pelvis misaligned with respect to the spine.

Distribution

The time and/or distance required to perform and complete these mechanical changes varies from event to event. Part of the process of distribution involves allowing this process an ideal length of time for a particular race or event. Proper distribution insures that momentum prerequisites are met, insuring top performance and preventing injury. Rushing the process too much results in compromised momentum values, while spending too much time in the process eventually causes the base of support to fall behind, requiring a corresponding frequency increase to maintain stability. This increase is facilitated by corrupted posture and faulty recovery mechanics.

Coaches should exercise caution in using rhythmic cues while teaching distribution and acceleration. Rhythmic cues can be interpreted within many mechanical modes, some of which are at odds with proper momentum development.

Elastic Energy

Muscles can create much greater forces when contractions are preceded by a pre-stretch of the muscle and its tendons. The rebounding effect that occurs creates elastically produced energy. The fact that this energy creates no metabolic fatigue, yet produces greater forces than purely concentric contractions means that the development of elastic energy is a highly desirable goal in a variety of athletic endeavors.

The processes of acceleration and sprinting occur much more efficiently when elastic energy is developed. The processes associated with elastic energy gains during running are spinal engine function, hip oscillation, undulation of the center of mass, and establishment of proper amplitude of motion.

The spinal engine theory resulted primarily from observance of the vital function of the spine in producing locomotion in lower vertebrates. It seems logical that some of the gait producing function of the spine and its associated musculature would have survived the process of evolution, and that in man the spine does perform some locomotive function. While traditional models of locomotion assume the vertebral column simply rests upon the moving pelvis, the spinal engine theory hypothesizes that the spinal musculature actually participates in the generation of gait. The action of the pelvis and legs are an amplification of this movement.

During the process of running, the pelvis viewed from above rotates clockwise somewhat with each stride taken by the left leg, and rotates counterclockwise with each stride taken by the right leg. We shall call this repeated movement in the transverse plane hip oscillation. This oscillation produces stretches in the local musculature and connective tissue, creating great elastic energy gains. Hip oscillation also results in increased stride length without metabolic energy cost.

As stated earlier, during running the center of mass follows an undulating path. The low points of this curve occur during support. These periods of amortization offer opportunities for stretch shortening cycles to be developed in the pelvic stabilizing and leg extensor muscles, again producing elastic energy. Care must be taken so that the amortization process is not excessive and that foot contacts occur in the correct location, so that the undulatory path of the center of mass may be located for maximal displacement and elastic energy producing benefits.

Finally, large amplitude of motion in the hip joint, as evidenced by a long angular path of the femur, sets up elastic energy gains. Sufficient amplitude must be developed since stretches occur only near the limits of motion. Proper elastic operation of the hip joint will be discussed shortly.

Postural Integrity and Elastic Energy Generation

The process of postural integrity previously discussed is complex. The pelvis must be stabilized in an ideal alignment so that forces applied produce displacement without excessive distortion and rotation. However, the pelvis must be stabilized in a way such that the development of elastic energy is not impaired by restricting movement. Proper posture during the acceleration process should not be associated with total rigidity. This idea of stability while allowing elastic movement is consistent with the spinal engine theory.

The degree of elastic energy generation during the locomotive process is dependant upon dynamic stability and posture. Excessive instability and/or postural misalignment cause postural muscles to overwork to compensate for this instability and to maintain balance. This restricts their ability to function in elastic fashion.

Ramifications of Elastic Movements

The large involvement of elastic energy generating reflexes in athletic movement, along with the high velocities involved mean the execution of one part of the task is dependant upon execution of prior parts. Many errors of technical execution are simply reflexive actions set up by previous errors, so backtracking to earlier movements is often a very effective troubleshooting tool. Also, because of the reflexes involved, the value of technical learning exercises and drills which occur at velocities insufficient to evoke these reflexes must be questioned.

Summation of Forces

The musculature of different joints differ in their ability to produce force, and differ in the rate of development of force as well. The production of large forces by the body is dependant upon the ideal timing of the stabilizations and extensions of each individual joint involved in the motion. The force generating characteristics of the musculature of each joint determine the most appropriate point for that joint to contribute to the entire motion. Generally proximal muscles with great force producing ability and slower rates of force development contribute early, while distal muscles with less force generating capability and faster rates of force development contribute later. We will refer to a particular timing of stabilizations and extensions of joints as a firing order.

Consider a single force application (push-off) during a certain point in the acceleration process. The force created and applied to the ground can be thought of as a summation of the forces generated by the extension of the hip, knee, and ankle joints. The hip extends initially while the knee and ankle stabilize, Later, as the hip continues to extend, musculature of the knee shifts from stabilizer to force generator, extending the knee and applying force through a stabilized ankle. Finally, as the hip and knee have nearly completed their extensions, the ankle contributes.

Effective push-off forces during acceleration and sprinting are the result of appropriate firing orders. It follows that this ideal firing order of extension requires a certain unique amount of time, thus a certain ground contact time is prerequisite for this ideal process. Different firing orders are ideal at different points in the acceleration process, because of the varying amounts of ground contact time available.

During the onset of acceleration, firing orders which take longer yet involve more musculature and produce more force are more appropriate. This is consistent with the idea of early impulse generation and momentum development, Such firing orders effectively act as a low gear, a mechanical mode for efficiently accelerating the body from rest, which again points to the importance of using these firing orders early in the approach.

Summation of Forces and Stability

Given a certain velocity, the degree of dynamic stability of the body determines the time available to apply force to the ground. If touchdown occurs too far back with respect to the body's center of mass, dynamic stability will be sacrificed and insufficient time will be available. The next stride must come quickly as the body topples forward. This means the extension will be rushed or incomplete, joints must fire simultaneously or fail to contribute, and an inefficient summation results.

If the foot contact is too far advanced with respect to the center of mass, braking forces will be encountered and too much contact time will be available. Two strategies are often employed to conserve horizontal momentum in this situation. One involves overworking the initial force generators (the hip extensors). The body must be pulled over its base of support. A certain degree of acceleration by the hip extension movement must occur prior to the extension of other joints for an efficient summation to take place. By the time the hip extends, other joints can no longer contribute because the time required would place toe-off too far back, resulting in excessive instability. This means the remaining extension will be rushed or incomplete, joints must fire simultaneously or fail to contribute, and an inefficient summation results.

The other strategy involves collapsing the knee and/or ankle joint, allowing the body to continue forward. This eliminates the existence of a stable base through which force can applied to the ground, and an inefficient summation results.

Facilitation of Steering

Steering refers to the adjustments in stride length made in order to takeoff from a desired location, whether it be from a takeoff board, a certain spot on the runway or apron, etc. Although it is desirable to develop accuracy in the approach through rehearsal, it should be realized that steering is a useful, desirable tool for making certain necessary adjustments, and even to prevent injury in some instances. Steering ability exists to varying degrees in different individuals, but is a trainable ability.

The steering process is primarily dependant upon visual sensory input, It follows that visual location of the target should occur as early as permitted by body alignment, at the onset of the run if possible. This visual contact should be maintained as long as possible. Usually visual contact must eventually become peripheral, and later aborted or readjusted in order to keep the head in proper postural alignment. This should not present a problem. By establishing visual contact early and maintaining it as long as possible, the jumper has developed a sense of his velocity and the rate at which the target seems to be approaching, so that this process need only be cognitively continued (target tracking) to execute an accurate takeoff.

Because sensory input throughout the run is essential to the jumper establishing a sense of his relative location and rate of approach, it is necessary that desired mechanical changes included in the run are performed gradually. Any abrupt changes in mechanical execution cause abrupt changes in sensory information fed to the steering mechanism, disrupt target tracking, and inaccurate approaches result. This implies that changes in body angle and the location of the base of support with respect to the center of mass found in sound acceleration patterns must be progressive and gradual.

Often abrupt changes in body angle and the location of the base of support with respect to the center of mass are performed late in the approach. These are usually last second attempts to correct these factors and get into efficient jumping postures, but because of their lateness usually result in inaccurate takeoffs and short fouls.

Often, as changes (especially postural changes) are made in the takeoff mechanism over time, the steering mechanism must be retrained for accuracy. Perceived distances from the target can be greatly changed by differing postural alignments, even if they are improved alignments.

Finally, the steering mechanism works to put the jumper in position to accurately execute an anticipated takeoff mechanism. Steering to inappropriate locations may occur when a mechanically improper takeoff is expected. These expectations usually arise due to past experience, incorrect prior positioning of the body, or both. An example would be a high jumper who senses inadequate development of centrifugal force during the approach, steering to a point too close to the bar as a compensating strategy. Improving the takeoff mechanism often solves the problem of training an athlete to takeoff from a correct location.

Elastic Energy Conservation and Steering

As stated previously, the existence of an undulating path of the center of mass and hip oscillation serve as a great elastic energy producing mechanism. It is logical that we would want to continue to enjoy the benefits of this elastic energy gain throughout the takeoff. Thus, undulation and oscillation must continue to exist in some form throughout final part of the run and the takeoff process.

Often in jumpers, the production of elastic energy through undulation and hip oscillation is disrupted during the later stages of the approach, as a result of bracing in anticipation of takeoff forces. In addition to the loss of elastic energy available for takeoff, this disruption causes decreased stride length, disrupts location of the base of support with respect to the center of mass, and causes disturbances in target tracking. Inaccurate approaches result. Since stride lengths are decreased as elastic energy is diminished and target tracking occurs, the approach usually falls short of the target.

Amplitude of Motion and the Action of the Hip Joint

The hip extension movement is the prime locomotor in acceleration and sprinting. During acceleration, other joints are involved to greater degrees than at maximal velocities. At the onset of acceleration, due to the low center of mass caused by forward lean, most of the hip extension movement occurs during support. As acceleration progresses and the body angle increases, the center of mass rises and more of the hip extension movement occurs prior to touchdown.

During the approach run, the femur in elite horizontal jumpers, moves through a range of motion of approximately 100 degrees. At the onset of acceleration, the femur moves from a position of flexion parallel to the long axis of the body, to a position of extension forming an angle of about 80 degrees to the trunk. This progresses to a range of motion during maximum velocities that exhibits 10 degrees of hyperextension to a position of flexion parallel to the surface. The occurrence of hyperextension only at maximal velocities suggests that hyperextension is a result of angular momentum of the thigh.

Sufficient amplitude of motion in the hip assures that as extension occurs, the foot will be moving backwards with respect to the body’s center of mass at contact to minimize braking forces, but still contacting somewhat in front of the center of mass to insure dynamic stability. Proper femoral path of movement is also prerequisite to correct penultimate mechanics. In addition, great amplitude produces elastic energy gains. In light of these benefits of large amplitude in the hip joint, ramifications for mobility training are profound.

It is of value to consider the femur as an elastic pendulum (the femoral pendulum model). Some properly timed, voluntary hip flexion is combined with the elastic energy generated by the hip flexors to raise the femur. On the other hand, well timed voluntary contractions of the hip extensors, along with elastic energy generated by their pre-stretch produces the hip extension movement. Thus, voluntary contractions enhance the elastic contractions if they are properly timed.

Causes of Incorrect Path of the Femur

If at any time the voluntary contractions are improperly timed, or too much voluntary involvement by any muscle group exists, the elastic energy generation of the entire system is diminished and efficiency is reduced. The possibility of injury due to co-contraction is increased as well. When the hip flexors are over-involved, typically the femur reaches its normal upward location, but does not reach the desired range of extension, reducing stride length and elastic energy benefits. This is why a sitting type posture often results when knee lift is overemphasized.

On the other hand, when excessive extension of the hip, knee, or ankle joint occurs, the hip extends too far, extended beyond desirable ranges. This makes recovery difficult. Although correct amplitude may exist, that angle is misaligned, with the excessive extension lowering the femur's upper limit of motion.

When this trailing of the femur results, it is generally because extension of the leg is taking too long and toe-off is occurring too far back. It must then be determined which joint is overextending and causing the delay in recovery. One possibility is that the neural message to stop extending the hip is being sent too late, allowing the hip to overextend before recovering it. Overextension of the knee may be the cause. This is seldom the case in early stages of acceleration, but at maximum velocity the knee does not have enough time to fully extend without disrupting recovery of the femur. Finally, the ankle may be overextending, approaching extreme degrees of plantar flexion.

A final consideration is timing the sending of the neural signals. It must be remembered that messages starting or stopping the flexion or extension of any joint must be sent before the action is desired to occur, because it takes time for the message to travel from the brain to the musculature initiating the action. This fact must be considered when devising cue systems.

Another consideration when adjusting the range of motion of the femur to its proper position is the position of the pelvis. A pelvic girdle with a slight upward tilt is favorable for effective force application and gaining the proper range of motion of the femur. A pelvis with a downward tilt however skews the appearance of the femoral path. Although the femur may appear to be trailing because of its appearance with respect to the trunk or the surface, it may indeed be moving correctly with respect to the misaligned pelvis.

<u>Recovery Mechanics</u>

The primary mechanical concern of the recovery phase is to reduce the effective radius of the recovery leg. This is accomplished by flexion at the knee joint. The degree of flexion present is a function of velocity. Shorter segments are able to generate greater angular velocity, therefore a tightly flexed knee with a high heel recovery path are desirable at maximum velocities. During the acceleration process, since velocities are submaximal, commensurately lesser degrees of knee flexion should be seen during recovery. At maximal velocities, maximal knee flexion should be seen as the femur reaches a position perpendicular to the ground, since it is at this point that the other leg is commensurately at maximum extension.

The knee flexion seen in recovery is primarily the natural result of well timed flexion of the hip. When the direction of the femur is changed, the prior angular momentum of the lower leg results in knee flexion. Volitional knee flexion plays a very small part.

Efficient recovery assures that the next foot contact will occur in the correct location to insure stability and proper contact time. Efficient recoveries also insure that the thigh will have sufficient time to reach its proper upward range of motion, maintaining freedom of movement and elasticity in the musculature of the hip joint. However, it should be noted that poor recoveries are generally symptoms of incorrect firing orders.

Recovery and Dynamic Stability

As shown earlier, improper firing orders may exist in the form of overuse or overextension in one or more joints. Improper firing orders cause inefficient recovery mechanics. Overextension in the hip, knee, or ankle joint will delay toe-off and compromise stability. The recovery mechanics are corrupted and hurried in an effort to restore stability.

Since toe-off has been delayed, these corrupted recovery mechanics generally take the form of delayed flexion of the knee during recovery, resulting in lower heel recovery path. In extreme cases, there may not be enough time available to allow the knee to reach its ideal degree of flexion before preparing for the next ground contact. In either case, the compromised recovery generally results in a hip that does not flex sufficiently. Injury due to co-contractions may result, since the hip extensors may still be in contraction while the hip flexors start to contract (or vice versa). This causes severe compromise of elastic energy gains and impairs free movement in the hip joint.

Frequency Generation

As stated earlier, efficient movements in the hip and spinal area during running are primarily a result of elastic energy formed by stretch reflexes and well timed voluntary contractions of proper duration and magnitude. Since improper voluntary contributions can over-stabilize and prevent the development of stretches, obviously there exists a limit on the magnitude and duration of even well timed voluntary contractions, beyond which elasticity suffers. Therefore, there exists a maximum frequency for each stride in the acceleration process for any given individual. To attempt to achieve a frequency greater than that maximum frequency is possible, but at the expense of inefficiency due to the corresponding loss of elastic energy.

The development of frequency must be gradual and progressive, with the resultant frequency of each stride not exceeding that maximal frequency. The resonance of the oscillating system must be maintained, and excessive volitional energy being fed into the system creates artificial frequency.

The first requisite for creating artificial frequency is a base from which to apply force. The strategy generally chosen to accomplish this goal is excessive stabilization of the torso and pelvic regions, which (1) disrupts elastic energy production in that region, (2) causes a lowering of the center of mass, (3) causes a decrease in stride length because oscillation and freedom of movement have been compromised and (4) causes alterations in the location of' touchdown with respect to the center of mass. In light of these considerations, the wisdom of a strategy that employs a frequency increase in the final few strides of the approach (in excess of the normal associated increase in frequency) should be questioned.

Kinetics of the Knee Joint

At the onset of acceleration, during support at the initiation of the hip extension movement, the knee joint is stabilized by its associated musculature so that force generated by hip extension may be efficiently transmitted to the ground. However, as the hip continues to extend, the knee's function shifts from stabilizer to force generator. The knee extends, contributing to force application through a stabilized ankle joint. As stated earlier, knee flexion occurs during the recovery process. When the flexion of the hip is stopped and extension occurs, the angular momentum possessed by the leg causes some knee extension to occur prior to ground contact. The knee is then stabilized by the quadriceps in preparation for the next ground contact.

As velocities increase, changes occur. The knees function during support shifts from stabilizer and force producer to stabilizer. At maximal velocities, the knee does not display full extension at toe-off. Excessive extension by the knee joint would delay recovery excessively. This decreased contribution by the knee joint at high velocities results in a very efficient kinesiological arrangement. The musculature of the knee joint is primarily slow twitch in nature, and is called upon to stabilize, while the fast twitch rich gluteals act as locomotors.

As stated earlier, the degree of knee flexion during recovery increases as velocity increases. As greater angular velocities develop during recovery, more knee extension results when the flexion of the hip is reversed. As the hip starts to extend, the quadriceps stabilizes the knee at a certain degree of extension. This stabilization prior to and during the support phase provides the opportunity for elastic energy generation by stretch shortening cycles set up in the musculature. This energy is produced without excessive degrees of extension.

The degree of knee extension that occurs prior to ground contact differs greatly among individuals. Those who show large degrees of knee flexion at touchdown are more able to use the hip extensors as producers of large forces. Those who exhibit great degrees of knee extension at touchdown keep the center of mass at a higher point throughout the process of sprinting, locating the undulating path of the center of mass higher and maximizing displacement and the flight phase.

Position and Kinetics of the Ankle Joint

Ankle position during acceleration and maximum velocity sprinting is important in two realms, joint stability and force production. A dorsiflexed position of the ankle is superior in both aspects.

Anatomically, the dorsiflexed ankle is more stable due to the skeletal construction of the joint, contraction of the plantar flexors, and the pre-stretched gastrocnemius and soleus. This stability makes the ankle joint resistant to collapse upon ground contact, making short ground contact times at high velocities achievable. Elite sprinters and jumpers show ankle angles during the approach which seldom vary greatly from 90 degrees.

The pre-stretch on the gastrocnemius and soleus offer opportunity for necessarily quick elastic force generation through tendon reflexes upon ground contact, without introducing great degrees of plantar flexion upon push-off which would delay toe-off and hamper recovery efforts. Also, since the gastrocnemius originates above the knee, keeping it on stretch by dorsiflexing the ankle allows it to assist in any voluntary knee flexion during recovery, allowing the hamstrings to remain relaxed.

Stability of the ankle is of the utmost importance in acceleration, sprinting, and jumping. A stable ankle provides a solid base through which the hip and knee joints may apply force to the ground, During acceleration, touchdown occurs on the ball of the foot, and excessive collapse in the ankle joint means force will be absorbed rather than transmitted to the ground. As velocities increase, the ankle is stabilized in a very slightly plantar flexed position, to facilitate this force application by the ball of the foot through the stable ankle. In either case, the ankle remains stable and the ball of the foot acts as a fulcrum and point of force application as the tibia pivots forward, rather than allowing the ankle to collapse and the tibia to pivot forward at the heel. During the final stages of support, a quick force contribution occurs by way of the tendon reflex. The fact that many quadruped mammals use the ankle in a similar fashion, can give us insight into the correct function of the ankle joint during locomotion.

Conversely, a plantar flexed ankle position results in joint instability and creates longer contact times, delaying toe-off and disrupting the location of the base of support with respect to the center of mass, Because of this instability, some collapse of the ankle joint upon contact is inevitable, and a compensatory plantar flexion occurs as a substitute force producer. Another compensating strategy involves the ankle joint stabilizing upon contact by firing early, out of sequence.

It is important that any contribution by the ankle be quick, elastic, and reflexive in nature. Excessive contribution by plantar flexion at toe-off results in delayed recovery, because the plantar flexors are primarily composed of slow twitch muscle fiber. An unstable ankle joint also delays hip and knee extension because establishment of a firm base of support occurs too late, resulting in poor pushoffs and takeoffs.

Because of time restrictions and reflexes that occur at high speeds, it is not possible to recruit ankle stabilizers at selected points. Proper ankle positioning must be constantly maintained.

Action of the Arms

During acceleration and sprinting, the function of the arms is to counter force applications by the legs, thus aiding in the maintenance of stability and posture, While small oscillations of the shoulder axis do occur in opposition to the oscillation of the hip axis, most of this countering is accomplished by the arms themselves, as they work in opposition to the legs.

The action of the arms at the shoulder joint should be elastic in nature. Stretch reflexes are set up which, along with well timed voluntary contractions, produce the movement at the shoulder joint in each direction. Very slight outward flare of the elbows helps to set up elasticity in the shoulder joint. Too much voluntary muscular involvement results in a decrease in elastic energy generation and decreased efficiency. Attempts at frequency increase often produce this involvement.

There should be a commensurance between the length of the firing order and the length of the arm as an effective lever. Longer ground contact times should be associated with more obtuse angles of the elbow. This means elbow angles should progressively decrease in size as acceleration progresses.

There should also be a commensurance between the length of the arm as an effective lever and the rate of force generation of the joints involved in locomotion. As the hip initiates its extension, the angle of the opposite elbow should be somewhat large, since the acceleration produced during this particular pushoff is not yet maximized. As the knee and ankle contribute, the body has accelerated somewhat, thus the elbow angle should be decreased somewhat. This means that for any stride, as the arm moves forward, the elbow angle should be decreasing in correspondence to the acceleration occurring during that pushoff and the size of the primary joint contributing.

The wrists should be stabilized in a normal extended alignment to create minimal muscular involvement, and to allow the effective length or the arm to be accurately controlled by elbow flexion and extension. A loosely cupped position of the hand creates minimal muscular involvement and the most elastic situations in the arms and shoulders.

<u>Importance of the Start</u>

As previously stated, in elastic situations and at high velocities it becomes very difficult to correct previous errors in body positioning. Thus, it follows logically that many of these mechanical variables should be established correctly at the start, since chances for later corrections are slight. Because of the large number of elements that must be correctly established at the start, it also follows that as little extraneous movement as possible be involved in the start. This implies that standing or rocking starts give better control of these variables, and that walking or jogging starts may cause difficulty in adjusting vital mechanical parameters.

In any start, any preliminary movements and/or the position reached immediately prior to pushoff should establish (1) positioning of the front-side femur near its ideal upward range with respect to the torso, (2) positioning of the backside arm high enough and extended enough to correctly counter the force of pushoff, (3) positioning of the front-side arm in correct opposition to the other arm, (4) dorsiflexion of both ankles, (5) proper location of the center of mass with respect to the base of support (front foot) so that an ideal degree of initial lean can be established when pushoff occurs, (6) adequate height of the center of mass so that the initial flight phase will be long enough to permit recovery and a correct successive foot strike, (7) some pre-stretch on the hip flexors of the rear leg so that as the rear leg comes forward, adequate range of motion can be established, and (8) proper postural alignment of the pelvis, torso, and head.

The pushoff should establish, (1) a correct summation of force generation by the front leg (well timed hip, knee, and ankle extension in correct quantities), (2) correct degree of initial body lean (3) sufficient dynamic stability, (4) correct postural alignment of the pelvis, torso, and head, (5) repositioning of the arms to counter the next pushoff, (6) slight force application by the rear leg, (7) partially elastic lifting of the rear femur to its correct upper position, (8) establishment of correct amplitude of motion in both femurs, and (9) sufficient flight time to execute recovery correctly.

With the exception of the obvious limitations that arise from arm length and positioning, the block start should not deviate from any of the aforementioned parameters.

Individual Differences

It should be noted that many elite performers deviate from one or more of the guidelines, principles, and suggested optimal methods stated above, Some of these differences result in somewhat compromised efficiency, yet are not harmful enough to prohibit performance at high levels by talented individuals.

Other deviations from the above stated principles are compensating maneuvers. Some elite performers employ seemingly stylistic maneuvers which are actually corrections of prior errors. When one or more of the above principles are violated, some strategy must be adopted to compensate, and often this compensation is sufficient to allow high levels of performance. An example would be a high jumper who starts incorrectly; allowing toe-off's to occur too far behind the center of mass and instability to result. A high, bounding skip in the middle of the run may be a strategy employed to buy time to correct the location of the base of support with respect to the center of mass.

Closing

The purpose of this manuscript has been to examine the kinetics and kinematics of certain mechanical parameters of the jump approach, explain the behavior of these parameters, and examine any special considerations for jumpers that would affect these parameters, It is the hope of the author that this manuscript will suggest new avenues for research and new parameters for examination in biomechanic reports.

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