Evaluation of a horse’s movement by a trainer or veterinarian is a subjective process and the information gained is qualitative in nature. Gait analysis applies measurement techniques to quantify the characteristics of locomotion. Kinematic analysis describes the movements of the limbs and body in terms of timing, distance and angular variables. Kinetic analysis describes the internal and external forces, such as the force between the hoof and the ground, and the torques around the joints.

Gait Analysis

During each stride, every limb has a stance phase when it is in contact with the ground and a swing phase when it moves forward in preparation for the next stance phase. When trainers assess quality of a horse’s movement, they tend to focus on the swing phase, since this is when the expressiveness of the horse’s movement is apparent. In the etiology of lameness, however, the swing phase is relatively unimportant because the forces associated with this phase of the stride are small. It is during the stance phase that large forces are applied to the musculoskeletal system, so evaluation of the stance phase is usually more informative in relation to performance-limiting factors or lameness.

Loading of the limbs during the stance phase occurs in two stages. Immediately after the hoof contacts the ground it is rapidly decelerated giving rise to a shock wave that travels proximally through the bones and joints during the impact phase. During the remainder of the stance phase, the limb is loaded more gradually as it accepts the body weight then pushes off against the ground. In general, the hard tissues (bones and joints) are more vulnerable to injury during the impact phase, whereas the soft tissues are more likely to be injured during the loading phase. An understanding of the characteristics of the impact and loading phases leads to a better appreciation of the factors that predispose to the development of lameness in athletic horses and offers an objective method of assessing strategies for prevention and treatment.

Impact Phase

Energy enters the locomotor system when the foot strikes the ground. Repetitive limb loading during locomotion generates intermittent waves of deceleration that are attenuated by the body’s natural shock absorbers as they travel proximally in the limbs. The impact shock wave is characterized by having a high amplitude with a rapid vibration frequency. Consequently, the amplitude of the impact wave decreases as it travels proximally in the limb. Ineffective attenuation of impact shock causes microtrauma to bone and articular cartilage and plays a primary causative role in acute and chronic skeletal and articular injuries.

The hoof acts as the initial shock absorber for the skeletal system by absorbing impact shock in the laminae and digital cushion. Our studies of cadaver limbs (Lanovaz et al., 1998) indicate that the soft tissues inside the hoof, such as the laminae and digital cushion, are primarily responsible for attenuating the frequency of the impact vibrations, whereas the bones and joints are more important for attenuating the amplitude. As the shock wave travels up the limb, it is further dissipated by subchondral bone, articular cartilage and other periarticular tissues. Subchondral bone is a fairly efficient shock absorber, but excessive impacts lead to sclerosis and microfractures. Articular cartilage is an even more effective shock absorber than an equivalent amount of bone, but because it is present in such a thin layer in the joints it makes a relatively small contribution to overall shock attenuation.

Factors that exacerbate the damaging effects of impact shock include faster speed, a harder work surface and perhaps certain types of shoes. In racehorses that accumulate a large mileage at high speed, impact shock is likely to be an important etiological factor in breakdown injuries, e.g. long bone fractures. Catastrophic fractures of the long bones are often preceded by fatigue fractures (Stover et al., 1992), which have been identified as a consequence of impact loading (Radin et al., 1973). In short bones and sesamoid bones, sclerosis often occurs prior to fracture in well-defined patterns that are related to the stress lines (Pool, 1992). Sclerosis of subchondral bone is also a consequence of impact loading (Radin et al., 1973).
Sport horses train at slower speeds than racehorses, leading to lower impact shock and, consequently, the effects may accumulate for many years before becoming clinically apparent. Articular cartilage is fatigue prone, and there may be a threshold of impulse intensity above which cartilage damage is progressive and irreparable. Changes in cartilage in response to repetitive impact loading include metabolic and biochemical alterations that are consistent with cartilage degeneration and the development of osteoarthritis, which further reduces the ability of the joint to attenuate impact shock, resulting in damage to the more proximal and distal joints. The role of exercise in initiating and perpetuating damage to articular cartilage in degenerative joint disease is well-established. For example, sheep housed on concrete floors are more prone to develop osteoarthritis than those housed on dirt due to the effects of repeated impulsive loading over a prolonged period. In sport horses, osteoarthritis is the primary reason for premature retirement. The damage is initiated long before it becomes clinically apparent and an awareness of the predisposing factors can be applied to ameliorate impact shock and so prolong the horse’s athletic career. In this case a prime consideration is the nature of the work surface used for daily training – a cushy, resilient type of footing is less damaging than a harder surface.

Even at relatively slow speeds of around 4 m/s the hoof experiences impact accelerations in the order of 80 to 100 g (Benoit et al., 1993). The amplitude and vibration frequency of the shock wave vary with gait, speed, fatigue, ground surface and shoeing. Both the amplitude and vibration frequency increase with speed. The onset of muscular fatigue is associated with a significant increase in amplitude of impact shock (Pratt et al., 1976), which may play a role in impact-related injuries. Steel shoes increase the amplitude of impact shock on the hoof wall, whereas certain shoes and pads reduce both the amplitude and frequency of the impact accelerations (Benoit et al., 1993). The amplitude also increases with the density of the surface material, but is reduced when the surface has a higher content of water or organic material (Barrey et al., 1991).

### Loading Phase

The carpus rapidly snaps into the close-packed position after initial ground contact, and this allows the forelimb to act as a propulsive strut throughout most of the stance phase. The fetlock joint and the palmar soft tissues behave like an elastic spring to conserve energy. In the early part of the stance phase the fetlock joint extends as it sinks toward the ground, reaching maximal extension at midstance, which corresponds with the time when the cannon bone is vertical. As the fetlock joint extends, the palmar soft tissues are stretched. After midstance the fetlock rises, allowing the elastic structures to recoil, thereby releasing elastic energy that was stored during the stretching process. This energy helps to flex the distal joints during the swing phase.

The limbs accept the body weight in the early part of stance then push off against the ground in the later part of stance. Limb loading can be evaluated using a force plate, which measures the magnitude, direction and point of application of the ground reaction force (GRF) vector. This is resolved into three perpendicular force components: vertical, longitudinal (from head to tail) and transverse (side-to-side). When a horse moves in a straight line, the transverse force is small and relatively unimportant compared with the vertical and longitudinal forces. The vertical force is responsible for overcoming the effects of gravity and for raising the body mass. At the trot, the vertical force peaks at midstance, when the cannon bone is vertical and the fetlock is at its lowest position. Maximal fetlock extension is directly correlated with peak vertical force. The longitudinal force, which is concerned with braking (deceleration) and propulsion (acceleration) of the horse in a forward direction, shows negative and positive components during each stance phase. In early stance, the longitudinal force retards the forward movement, later in the stance phase it provides propulsion. The direction of the longitudinal force changes around the time of midstance.

Strains in the tendinous structures of the distal limb have been measured directly using strain gages. They can also be calculated from a knowledge of the GRFs and limb kinematics. The extensor branches of the suspensory ligament orient the hoof for contact and prevent buckling forward of the interphalangeal joints during early stance. As the limb accepts weight, the superficial digital flexor (SDF) muscle generates tension to stiffen the limb. Consequently, peak tension in the SDF occurs during the loading phase. The suspensory ligament (SL) together with the sesamoid bones and the distal sesamoidean ligaments acts as a passive system to support the fetlock. Since it has no muscular component, SL strain depends entirely on the angle of the fetlock joint. As the fetlock extends, SL strain increases and reaches its maximal value at midstance. The deep digital flexor tendon (DDFT) reaches peak strain later in the stance phase around the time when the propulsive force is maximal. The DDF is thought to be involved in providing forward propulsion. Since it has no muscular component, strain in the distal check ligament of the DDFT (DCL) depends on the angles of the fetlock, pastern and coffin joints. Maximal strain corresponds with the start of breakover. Due to its dependence on coffin joint angulation, the DCL is particularly sensitive to changes in hoof angle and toe length, and to different surface types particularly with regard to the ability of the hoof to rotate during the stance phase. The DCL is maximally strained at the start of breakover.
The entirely passive structures (SL, DCL) are loaded and strained more than the DDFT and SDFT which have an active muscular component that adjusts tension in the tendons. Maximal strains in the SDFT and DDFT are higher when the horse carries a rider, moves on a hard surface or travels at higher speed.

**Breakover**

Breakover begins when the heels leave the ground and start to rotate around the toe of the hoof, which is still in contact with the ground. Breakover is initiated by tension in the distal check ligament (DCL) acting through the deep digital flexor tendon (DDFT), combined with tension in the navicular ligaments. The initiation of breakover is an important part of the stride, especially in horses with caudal heel pain, since it is at this time that tension in the heel region is maximal. On a hard surface, the hoof remains flat on the ground until heel off. On a softer surface the toe rotates into the surface prior to heel off which reduces tension in the DCL-DDFT and navicular ligaments. This, in turn, reduces pressure in the navicular region. Therefore, a surface that allows the toe to dig in during push off is usually beneficial in horses with navicular syndrome or other types of caudal heel pain. Toe off is the instant at which the toe leaves the ground, after which the elastic tendons and ligaments are able to recoil in an unrestrained manner.

**Swing Phase**

During the swing phase the flight arc of the hoof reaches its highest point soon after lift off with a second, smaller elevation coinciding with an upward flip of the toe at the time of maximal protraction. This gives a slightly biphasic flight arc.

In the swing phase the limb is initially protracted (pulled forward) then, in the final part of the swing phase, it is retracted (pulled backwards) prior to initial ground contact. The purpose of this "swing phase retraction" is to reduce the horizontal velocity between the hoof and ground at initial ground contact. The swing phase retraction has a considerably longer duration in the fore limbs than in the hind limbs (Back et al. 1995). The longer retraction period explains why the horizontal velocity is lower in the fore limb than the hind limb at ground contact.

During the swing phase the limbs act in a pendulum-like manner. The fore limb rotates around the upper part of the scapula. Since horses do not have a clavicle or a shoulder girdle, the whole scapula is free to rotate back and forth on the side of the chest wall. The hind limb rotates around the hip joint in the walk and trot, and around the lumbar sacral joint in the canter and gallop. The reason the site of rotation changes is that, in the canter and gallop, the two hind limbs are moving forward at the same time, which allows the whole pelvis to swing forward. This has the effect of increasing the effective length of the hind limbs and, therefore, increasing the stride length. The lumbar sacral joint is the only part of the vertebral column from the base of the neck to the root of the tail that allows a significant amount of flexion (rounding) and extension (hollowing). At all the other joints the amount of motion is much smaller.

Movements of the upper limbs are the result of muscular action. Movements of the lower limbs tend to follow passively, that is without active muscular contraction. When the hoof leaves the ground, elastic recoil of the flexor tendons and suspensory ligament raises the hoof, pastern and cannon to initiate flexion of the carpal joint. Toward the end of the swing phase, forward movement of the upper limb is slowed by muscular contraction while the momentum of the lower limb tends to increase as it advances to maximal protraction. In some horses this produces a whiplash-like effect that causes the toe to flip up at full protraction. In the hind limb, movements of the stifle, hock and fetlock joints are coupled so that the three joints flex and extend in synchrony due to the action of the reciprocal apparatus.

For horses to excel in sports that require the maintenance of speed over a distance, efficient energy transfers are particularly beneficial. Since efficiency of movement is such a complex phenomenon, manipulation of factors, including farriery and tack, may easily disturb a horse's natural coordination, reduce the efficiency of movement, and have deleterious effects on performance. In other sports, such as dressage, economy of movement is not an issue. The subjective nature of the judging requires movement that is aesthetically pleasing.
References


