<u>Locomotion and Performance in the Athletic Horse</u>

Dr. Hilary M. Clayton, BVMS, PhD, MRCVS
McPhail Dressage Chair in Equine Sports Medicine
Department of Large Animal Clinical Sciences
College of Veterinary Medicine, Michigan State University
East Lansing, MI 48824-1314

Locomotion can be considered the most important function of the horse's body. Without locomotion, the horse would not be able to feed, to breed or to take part in sporting events. The study of locomotion, or gait analysis, provides useful information for describing the individual horse's pattern of movement, for characterizing sporting performances, and for detecting the presence of gait asymmetries that might be indicative of lameness. In the McPhail laboratory, we use video analysis to study the horse's movements and force plate analysis to measure how the hoof pushes against the ground. We have developed custom software for combining the video and force data to calculate the torques around the joints and the generation and absorption of power across each joint. This paper will describe the techniques used in gait analysis and will describe the phases of the stride and their functional significance.

Gait Analysis Techniques

The primary tools used for equine gait analysis are video cameras and a force plate. Typically, the cameras track the movements of reflective markers attached to the horse's skin as the horse moves along a runway in which the force plate is embedded.

Motion Analysis

Reflective markers are attached to the horse's skin overlying the bones and joints. Our motion analysis system has six infra-red cameras that track the markers automatically as the horse moves along the runway. The resulting information describes the movement patterns of the horse in terms of the linear and angular displacements, velocities and accelerations. The study of movement patterns is known as **kinematics**.

Force Plate Analysis

A force plate is a metal plate, usually rectangular in shape that is embedded in a runway. Recordings are made as the horse moves back and forth over the force plate, either in hand or under saddle. Sometimes, but not always, one or more hooves step on the force plate as the horse passes over it. To get a good recording, there must be only one hoof on the force plate at a time. The force data indicate how the hoof pushes against the ground in terms of the magnitude of the force (how hard the hoof is pushing) and the direction in which the force acts. The study of the forces involved in locomotion is known as **kinetics**.

The forces between the hoof and the ground are measured in 3-dimensions (figures 1 and 2): vertical, longitudinal (from head to tail) and transverse (from side to side). The transverse forces are small in magnitude when the horse is moving in a straight line, but they are larger during turning or lateral movements. The vertical force is responsible for overcoming the effects of gravity which is always pulling the body downwards, and for projecting the horse into the air during gaits that have an airborne phase and during jumping. Development of the muscles that are responsible for increasing the vertical force produces more lofty gaits, allows the horse to achieve maximal stride length in the extensions, increases a horse's scope over fences, and avoids forging. The longitudinal force is concerned with braking (deceleration) and propulsion (acceleration) of the horse in a forward (or backward) direction. The longitudinal force normally shows negative and positive components during each stance phase as the horse's body passes forward over the limb. In the early part of the stance phase, the longitudinal force brakes the forward movement (negative longitudinal force), later in the stance phase it provides propulsion (positive longitudinal force).

Phases of the Stride

The trot is an important gait both for judging the quality of movement and for detecting gait asymmetries in lame horses, and the majority of our research is performed with horses moving at a trot. The trot is typically described as a "two beat gait in which the diagonal limb pairs move synchronously". When viewed in slow motion, however, there is often a dissociation of the diagonal limbs, so that either the forelimb or the hind limb of the pair makes ground contact and lift off earlier. Positive diagonal dissociation, in which the hind hoof contacts the ground before the diagonal fore hoof, is regarded as an indicator of good balance and is a positive selection criteria for judging gait quality.

The fact that the trot is a symmetrical gait implies equality of the movements and forces in the left and right limbs. It is the inherent symmetry of the trot that makes it so suitable for the detection of asymmetries that are indicative of lameness. However, left to right asymmetries sometimes occur in horses that are apparently sound and have been ascribed to a form of sidedness, which is similar to handedness in people. A horse's sidedness is recognized during the early stages of training by a crookedness that results in displacement of the hindquarters to one side and an uneven contact on the left and right reins. One of the objectives of training is to make the horse's body more symmetrical by strengthening the weak side and suppling the stiff side. During every stride of the trot each limb has a stance phase when it is in contact with the ground and a swing phase when it is moving through the air. The stance phase is more important in relation to the development of lameness due to the higher forces on the limb during stance. However, the swing phase is the primary contributor to the aesthetic quality of the gaits, and it is during the swing phase that deviations in the motion patterns are most apparent.

Stance Phase

The stance phase is the period during which the hoof is in contact with the ground. Each limb has a stance phase in every stride. The following parts of the stance phase can be recognized and measured or described during gait analysis: initial ground contact, impact phase, loading phase, and breakover.

Initial Ground Contact

The initial contact of the hoof with the ground at the start of the stance phase is classified as heel first, flat footed or toe first. The manner of contact is influenced by gait, speed, farriery, and lameness. The hind limbs show a greater tendency to heel first contacts than the forelimbs. Heel first contacts occur more frequently during high-speed locomotion and when horses are trimmed with an upright hoof angle. The frequency of toe first contacts increases when the hoof is trimmed with an acute angle. In some movements, such as piaffe, toe first contacts are normal due to the vertical trajectory of the hoof during the swing phase. With certain types of lameness an unusual and characteristic manner of hoof contact occurs as a means of reducing pain by shifting the loading away from the affected structures. The manner of initial ground contact is important because it affects the forces and accelerations applied to the limb during the subsequent impact phase.

Impact Phase

The impact phase occupies the first 50 milliseconds (1/20 second) after the hoof contacts the ground. During this time the hoof undergoes rapid deceleration that causes a shock wave to travel up the horse's limb. The shock wave is characterized by high amplitude and a rapid vibration frequency. These characteristics are particularly damaging to the bones and joints when they occur repeatedly, stride after stride, during locomotion. The impact phase has such a short duration that there is insufficient time for the muscles to respond to the impact forces in a manner that might protect the bones and joints.

During the impact phase the hoof is decelerated in both the vertical and horizontal directions. The fore hoof usually has a higher vertical velocity and lower horizontal velocity than the hind hoof at the instant of ground contact. This may explain why there is greater concussion, and may be one reason for the higher incidence of chronic lameness in the forelimbs. As the shock wave travels up the limb, it is attenuated by flexion of the joint and deformation of the soft tissues. The majority of injuries to the locomotor system occur, not as a result of a single catastrophic incident, but as a consequence of the cumulative damage that occurs from the many strides taken during training and competition. Impact is the most damaging phase of the stride for the bones and joints. Factors that affect the amplitude or frequency of impact shock include speed, surface, and farriery. Faster speeds are associated with higher impact shock and horses that train and compete at speed often develop fatigue fractures or bone sclerosis as a consequence. Fatigue fractures are small fracture lines in bones that have not adapted adequately to high impact loading. They precede complete fractures in the long bones. At the other end of the spectrum, bone sclerosis represents over-adaptation with the bone becoming excessively mineralized in response to high impact loading. Sclerosis occurs on the front of the carpal bones, and a slab fracture may develop as a result of shearing forces between the plate of highly mineralized sclerotic bone and the less mineralized underlying bone. Both fatigue fractures and bone sclerosis have been shown to precede complete fractures in racing Thoroughbreds.

A more chronic, impact-related problem is degenerative joint disease (osteoarthritis), which is the most common reason for premature retirement of sport horses. The repeated traumatic effect of impact shock during years of training and competing is a primary factor in the development of osteoarthritis, but the effects do not become apparent until permanent damage is present and the horse becomes lame. Therefore, trainers must make every effort to reduce the effect of impact shock throughout the horse's career. This means working on good surfaces and taking care of hoof balance and shoeing.

Loading Phase

Loading and unloading occupy the period from the end of the impact phase until breakover. During this phase, forces are applied more gradually than during impact and without the rapid vibrations. In trotting horses, the vertical force increases steadily as the limb accepts the horse's body weight, peaks in the middle of stance, and is then unloaded. The longitudinal force brakes the horse's forward motion in the first half of stance and provides forward propulsion in the second half of stance.

During the loading phase, the fetlock joint extends and the elastic structures that run down the back of the cannon region and over the fetlock joint are stretched. These structures, which include the deep and superficial digital flexor tendons and the suspensory ligament, store elastic energy as they lengthen. The magnitude of the peak vertical force determines the amount of fetlock joint extension.

Later in the stance phase, the vertical force declines steadily until the hoof leaves the ground. At the same time, the fetlock joint rises and flexes. During the unloading phase, reducing tension in the flexor tendons and the suspensory ligament, which recoil elastically. The release of elastic energy helps to flex the fetlock during the subsequent swing phase.

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 inferior check ligament acting through the deep flexor tendon, combined with tension in the ligaments that stabilize the navicular bone.

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 tendons 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 palmar 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

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 forelimbs than in the hind limbs, and this explains why the horizontal velocity at ground contact is lower in the forelimb than the hind limb.

During the swing phase the limbs act in a pendulum-like manner. The forelimb rotates with its pivot point in 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 lumbosacral joint (just in front of the croup) in the canter and gallop. The lumbosacral joint is the only part of the vertebral

column between the base of the neck and the tail that allows a significant amount of flexion (rounding) and extension (hollowing) of the back. At all the other vertebral joints the amount of motion is much smaller. Moving the point of rotation from the hip joint to the lumbosacral joint increases the effective length of the hind limbs and, therefore, increases stride length.
Movements of the upper limbs are driven by muscular action. Movements of the lower limbs tend to follow passively, that is without active muscular contraction, as a result of inertial forces. When the hoof leaves the ground, elastic recoil of the flexor tendons and suspensory ligament flexes the joints and this raises the hoof, pastern and cannon in early swing.
During locomotion energy is used to move the horse's bodyweight and to rotate the limbs back and forth relative to the body. The mass (weight) of the limb has a large effect on the energy used for limb rotation; as limb mass increases, more energy is needed to swing the limb back and forth. The distribution of the limb mass also plays a role in energy expenditure, the further the mass is located from the pivot point, the greater the energy expended to move it. Therefore, the weight of the shoe has a much larger effect on energy expenditure than the same amount of weight applied in a weight cloth. This is an important consideration in endurance sports.

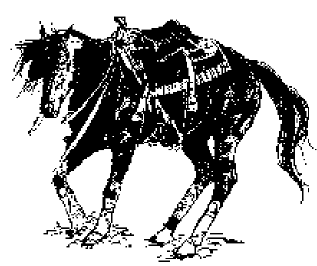

Figure Headings

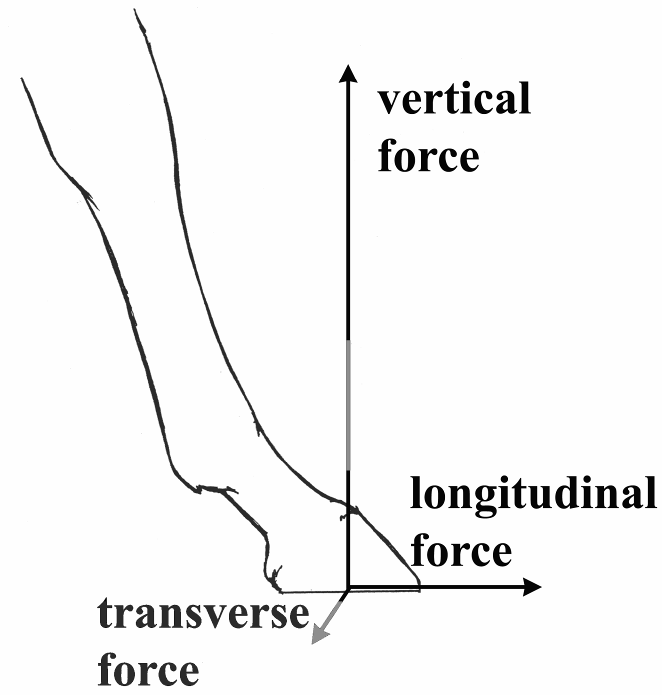

Figure 1: Vertical, longitudinal, and transverse components of the ground reaction forces.

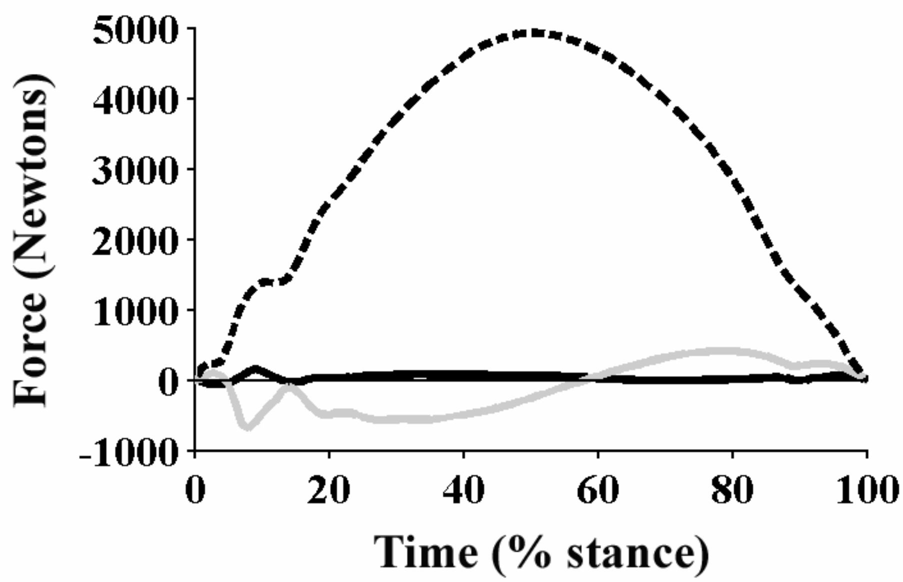

Figure 2: Vertical, longitudinal, and transverse ground reaction forces during a stance phase for a forelimb at the trot.