**Evidence-based shoeing in healthy feet: biomechanical considerations**

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The way a horse’s hooves are trimmed and shod can have a significant influence on limb movement and loading. Medio-lateral and dorso-palmar/-plantar balancing in particular, as well as mechanical features of the horseshoe are crucial in maintaining a healthy hoof. Evidence based farriery can also be used to correct individual conformational shortcomings of the limb or to address certain pathologies of the hoof and distal limb (see the subsequent abstract text by Oosterlinck et al.). Over the last decades, biomechanical tools such as kinetic and kinematic analysis have shed light on the basic mechanics of trimming and shoeing.

**Limb protraction**

How the hoof impacts the ground and is loaded depends directly on the protraction phase of the limb. The flight arc of the foot is influenced by the conformation of the limb as well as by the angle of the dorsal hoof wall1 and weight of the hoof. Hooves that are artificially weighted by attaching weighted boots, using heavy horseshoes, pads and packing material or by letting them grow unnaturally long lead to a higher limb action2,3, higher limb impulse and increased difference between horizontal hoof velocity at impact and the ground which results in higher braking forces4.

**Limb impact**

The hoof’s impact with the ground can be divided into two phases; the primary impact phase representing the initial ground contact, characterised by rapid vertical deceleration and resulting in high-frequency oscillations; and the secondary impact phase, during which the vertical force gradually increases while the hoof is braking in a horizontal direction to become firmly placed on the track. The primary impact phase lasts around 30ms, which is less than proprioceptive reactivity and therefore makes neuromuscular adaptive corrections impossible. Peak vertical impact deceleration can amount to 400*g* and horizontal deceleration to 200*g* depending on the horseshoe and ground surface properties5. Shoeing decreases the natural damping properties of the hoof. To reduce the concussive loads on the distal limb and compensate for hard ground surfaces, impact dissipation can be achieved with horseshoes, pads and packing material with viscoelastic properties. Partial energy dissipation can be effective if the hoof is allowed to slide during the secondary impact phase. The degree of slip depends on the gait and is determined by the hoof impact angle as well as by the ground surface and/or the grip of the horseshoe.
Medio-lateral loading of the hoof during impact should ideally be equal. However, pressure measurements have shown that during the landing phase, around 60% of fore hooves and almost all hind hooves land on the lateral heel wall and first load their lateral wall6,7. Furthermore, these measurements revealed that even in balanced hooves landing flat visually, forces are unevenly distributed across the hoof-track interface with the lateral part of the hoof subjected to higher loading. This might be even more pronounced in horses, which tend to place their limbs towards the centre of gravity in a slightly base narrow way.

**Support phase**

The ground reaction forces (GRF) can be divided into a vertical, a longitudinal and a transverse component. Although vertical stride impulse decreases with increasing velocity due to shorter stride durations, there is an inversely proportional increase in peak vertical force due to the shorter stance duration8. The duty factor (stance duration as a percentage of stride duration) decreases from 75% at walk to 25% at gallop. Peak vertical forces occur at trot and canter/gallop around midstance, reach bodyweight at trot and increase to up to 2.5-times bodyweight at the gallop depending on velocity of the horse and ground surface properties. Vertical forces are higher in fore- compared to hind limbs because of the proximity of the body centre of mass to the forehand. In horses with uneven pairs of fore hooves GRF measurements showed that the hoof with the lower hoof angle experiences higher horizontal braking and peak vertical forces9. Horizontal braking forces are more dominant in the forelimbs compared to the hind limbs. At fast trot and gallop, peak braking forces amount to 30-60% bodyweight10,11. In the second half of the stance phase, this force becomes propulsive. The transverse force has large inter-individual variability and the smallest amplitudes of the three components.
All forces acting between the hoof and the ground can be summed up in one single GRF vector. The point of application of this vector is the centre of pressure, which is initially localised at the point of first contact moving rapidly to the central part of the hoof where it remains for most of the support phase before moving toward the toe during breakover.

As the horses’ limbs are rarely perfectly straight, the hooves will usually experience some degree of medio-lateral imbalance12. Axial deviations such as bow-legs (carpus varus) or knock-knees (carpus valgus), axial rotations resulting in a toe-in or toe-out conformation, or base wide or base narrow limb conformation can directly influence the loading of the hoof capsule, the interphalangeal joints and the tendons and ligaments in the distal limb. Uneven loading of the hoof capsule can over time lead to changes in the shape of the hoof due to uneven growth of the hoof walls. Besides the vertical forces, shear, tensile and compressive forces may contribute to uneven loading resulting in the distortion of the hoof capsule. Typical signs are unevenly angled quarter walls, flares in the distal third of the hoof walls, a white line that is distorted and uneven in width, crooked or wry hooves, sheared heels or quarter cracks. The most important points to consider when attempting corrective shoeing for this type of imbalance are: length of the hoof walls; the relationship of the solar surface of the hoof to the axis of the limb (T-Balance); how the horse lands (base narrow, base wide, medial/lateral landing); and orientation of the hoof during landing and pushing-off (e.g. inwards rotation of the toe in bow-legged hind limb (hock varus) conformation). Several studies have shown that in hooves with uneven walls, the centre of pressure is shifted towards the side of the longer wall. Accordingly, the interphalangeal joints will experience more load on that side and the joint capsule and collateral ligaments on the other side will come under greater tension. The same phenomenon applies to wedges when the horse moves on hard surface. Wedging the palmar/plantar part of the hoof will shift the force vector (centre of pressure) towards the heel walls; a unilateral wedge will influence the medio-lateral load distribution at the level of the hoof and in the distal limb, moving the force vector (centre of pressure) to the side of the wedge. The same applies for an extension but with the horse weight bearing on deformable ground13. In hooves with weakened hoof walls, redistributing the force with the help of wedges or extension will not be effective as the walls cannot support the extra pressure. In these cases, using other structures apart from the bearing edge to bear weight should be considered. For instance using straight- or heart-bar shoes or pads in combination with packing material might help to redistribute load to structures such as the frog or the sole.
When considering medio-lateral imbalance, another important point to bear in mind is the condition of the terrain on which the horses is predominantly exercised. This point is of particular relevance in horses which are required to travel long distances over unyielding ground: endurance horses competing over 100-160 km (160 km equates to around 64’000 steps taken!) on uneven or hard terrain are far more likely to feel the strain of a medio-lateral imbalance than horses working for short periods on predominantly soft ground.

Dorso-palmar/-plantar balance of the hoof and the related phalangeal alignment are relevant at impact, midstance and breakover. Trimming for a straight hoof-pastern axis and a positive palmar/plantar angle (angle between the solar margin of the coffin bone and the bearing edge)14 as well as the placement of the breakover point of the shoe relative to the centre of rotation of the distal interphalangeal joint (DIPJ) are decisive features affecting how the palmar/plantar structures of the hoof are loaded, especially on compacted ground.

On soft ground, mechanical features of the horseshoe in the form of toe extensions or bars affect the dorso-palmar/-plantar stability of the hoof during stance. A hoof shod with a normal horseshoe with a uniform width of the web will tend to sink into the ground more in the toe part. This is minimised if the horseshoe is forged with a toe extension. The opposite is achieved by supporting the caudal part of the hoof with a bar shoe, which allows the toe to sink in to a greater extent relative to the heels. As a consequence strain is relieved from the deep digital flexor tendon and adjacent structures however with the downside of potentially overstraining other structures15. Although dynamic hoof balance during locomotion cannot be reflected by hoof radiographs, latero-medial and dorso-palmar/plantar views provide useful information on the position of the P3 within the hoof capsule (e.g. palmar/plantar angle).

Hoof breakover (from heel-off to toe-off) occurs during approximately the last 15% of the stance phase. Several studies have demonstrated that long toe, low heel conformation prolongs breakover time16,17. Furthermore, the horizontal distance between the breakover point at the toe to the centre of rotation of the DIPJ (the cranial lever arm) significantly affects the joint moment especially at initiation of breakover18. Accordingly, changes in hoof conformation during an 8-week shoeing interval leads to increased DIPJ extension and consequently to increased loading of the deep digital flexor tendon19. In Icelandic horses shod for competition with high and long hooves, a 23% increase in length of the cranial lever arm resulted in a 13-15% increase of DIPJ moment20. The break-over movement of the hoof can be facilitated by trimming back the toe, applying shoes with toe modifications (rolled toe, rocked toe) or by setting back the shoe16,18; all effective in decreasing the cranial lever arm. In the same way, medial and lateral breakover of the hooves in horses circling on compacted ground may be facilitated by setting back the outer edges of the branches at the ground surface.

A further important biomechanical aspect is the deformation of the hoof capsule during a stride. The hoof mechanism plays an important role in shock absorption by dissipating the impact energy21 and supporting venous return with its pumping action22. During the stance phase, the sole and frog move distally23 and the proximal part of the dorsal hoof wall moves caudally24. Most deformation is observed at the level of the heels, which are most elastic and experience most mechanical load25,26. In the shod situation heel expansion is limited to the horizontal plane whereas vertical heel movement can be substantial in the unshod hoof on uneven ground. Heel expansion results from distal and caudal movement of the second phalanx21 and occurs in the first 70-80% of the stance phase, whereas heel contraction occurs during breakover27. Heel expansion increases with speed associated with higher vertical GRF28. Heel expansion and consequently shock absorption properties are less developed in club feet compared to hooves with low heel conformation24.

**Conclusions**

The basis of normal shoeing and any corrective intervention is always the careful balancing of the hoof through trimming; in the best case, this may be the only form of correction necessary. Good medio-lateral and dorso-palmar/-plantar balance is essential for a functional and healthy hoof and limb, and therefore must be given special consideration at each shoeing. Correspondingly, the application of farriery modifications or corrective shoes must always be considered on a case-by-case basis taking into account the surface conditions on which the horse is exercised and the type and intensity of work the horse is asked to do, being in full training/competition or in a period of rehabilitation. Whatever modifications are applied, the principles of medio-lateral or dorso-palmar/-plantar balancing and hoof stability during maximal weight bearing should always be borne in mind. Careful evaluation of all influencing factors is required before any steps are taken to redistribute weight within the hoof’s contact surface especially when using extensions and wedges to modify lever arms and angulation of the distal phalanx. Furthermore, any shoeing modification should restrict the hoof mechanism as little as possible. Finally, it is important to remember that all changes to the biomechanics of hoof need to be done gradually and in small steps.

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