The Veterinary Journal 198 (2013) e9–e13

Contents lists available at ScienceDirect

The Veterinary Journal

journal homepage: www.elsevier.com/locate/tvjl

Pressure plate analysis of toe–heel and medio-lateral hoof balance at the walk and trot in sound sport horses

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ARTICLE INFO

Keywords:
Hoof
Equine
Farriery
Gait analysis
Lameness

ABSTRACT

Empirically, equine distal limb lameness is often linked to hoof imbalance. To objectively quantify dynamic toe–heel and medio-lateral hoof balance of the vertical ground reaction force in sound sport horses, seven Royal Dutch Sport Horses were led at the walk and trot over a dynamically calibrated pressure plate. Forelimb hoof prints were divided into a toe and heel region and a medial and lateral zone. Toe–heel and medio-lateral hoof balance of the vertical ground reaction force were calculated throughout the stance. Toe–heel balance was highly symmetrical between contralateral limbs at both gaits. At the walk, medio-lateral balance of both forelimbs presented higher loading in the lateral part of the hoof throughout the stance. However, at the trot, left medio-lateral balance presented higher loading of the medial part of the hoof at impact, whereas the right limb showed higher loading of the lateral part of the hoof in all horses, and both limbs presented increased lateral loading at the end of the stance. This study provides objective data for toe–heel and medio-lateral hoof balance in sound sport horses.

Introduction

Hoof balance is a major concept in equine orthopaedics and involves not only the static geometry of the hoof, but also the dynamic interaction of the hoof with the track (Parks, 2011). Biomechanically, dynamic hoof balance comprises the hoof landing pattern and its trajectory throughout the stance phase, but also the distribution of forces over the contact area.

Empirically, equine distal limb lameness is often linked to hoof imbalance (Trotter, 2004; Parks, 2011). For example, medio-lateral hoof imbalance may predispose to quarter/heel cracks or pedal osteitis (Parks, 2011) whereas laminitis and navicular disease alter the toe–heel balance with an increase and decrease, respectively, in loading of the heel region (Wilson et al., 2001; McGuigan et al., 2005). Therefore, the assessment of static and dynamic hoof balance is essential during lameness examinations. However, hoof balance is traditionally evaluated by visual observation and, even for an experienced clinician, subtle abnormalities may not be readily observable, especially at gaits faster than the walk (Back, 2001; Parks, 2011). Occasionally, radiographs are made to help making trimming and shoeing decisions (Trotter, 2004; Parks, 2011), but this is only a static evaluation and therefore, does not reflect the dynamic hoof balance during locomotion.

There have been conflicting reports on the force distribution between the lateral and the medial side of the hoof. Balch et al. (1997) reported higher medial loading using an instrumented horseshoe, whereas Reilly (2010), using an in-shoe pressure measuring system, found a higher load on the lateral side at the walk and equivalent loading at the lateral and medial side at the trot. However, their analysis was limited to the limb-load at mid-stance and they did not report on hoof balance during the rest of the stance phase.

Pressure plate analysis has been described for the detailed study of the effect of trimming, normal shoeing and shoeing with a rolled toe on the hoof unrollment pattern at the trot (Van Heel et al., 2004, 2005, 2006b; Moleman et al., 2006). The latter studies have been focused on the trajectory of the centre of pressure from mid-stance to toe-off and variables derived thereof. However, direct translation into the clinical concept of hoof balance commonly referred to in a dorso-palmar and medio-lateral direction, may not be straightforward. Moreover, detailed information on hoof balance of the vertical ground reaction force during the complete stance phase, i.e. from impact to toe-off, has not been reported.

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http://dx.doi.org/10.1016/j.tvjl.2013.09.026

Therefore, the aim of this study was to explore the use of a pressure plate for the objective and dynamic analysis of toe–heel and medio-lateral hoof balance of the vertical ground reaction force at the walk and trot in sound sport horses during the complete stance phase. The hypothesis was tested that sound sport horses present a high degree of symmetry in hoof balance of the vertical ground reaction force between contralateral forelimbs.

Materials and methods

Horses

Seven Royal Dutch Sport Horses (mean age ± standard deviation, SD, 11 ± 4 years; body mass, BM, 539 ± 28 kg) were selected from the teaching herd of Utrecht University, The Netherlands. All horses were regularly used for pleasure riding by the student riding school; they were clinically sound and did not present any relevant contralateral hoof asymmetry (toe and heel angle alignment, hoof width) or conformational deficits. They were regularly trimmed towards a straight hoof–pastern axis and the fore hooves were shod with rolled-toe shoes (Mustad Equi-Librium) by two experienced farriers. Prior to each measuring session, each horse was adjudged healthy and sound by a veterinarian. The study was approved by the Ethical Committee of Utrecht University (approval number DEC 2010.III.09.105).

Measurement systems and data collection

The horses were led first at walk and subsequently at trot over a pressure-force plate combination (Footscan 3D 1 m-system, RsScan International; Z4852C, Kistler), embedded in the middle of a 20 m long track and covered with a 5 mm thick rubber mat (Oosterlinck et al., 2010b, 2012; Oomen et al., 2012). After 5 min of warming-up, the horses were led from their left side over the measuring system by an experienced handler, on a long lead rope, without interfering with horse's velocity or head motion.

The average velocity of each horse over the pressure-force plate combination was measured using two gates of photoelectric sensors with a 2 m interval centred over the measuring area. Although acceleration was not measured, the 20 m long track ensured that the effect of acceleration and deceleration at the start and end of each trial was minimised over the central measuring area. A trial was considered to be valid if the horse moved at a constant pace, looked straight ahead, the gait velocity was within a narrow preset range and the hoof of at least one forelimb fully contacted the plate surface. Five valid measurements of each forelimb were collected.

Data analysis

Only the data from five valid trials were analysed. Hoof prints were divided in a toe and heel region by a line through the maximal hoof width (Fig. 1a) and in a medial and lateral zone by a line through the central part of the toe and mid-way between the heels (Fig. 1b). The corresponding vertical forces (VF) were sampled at 250 Hz, and toe–heel and medio-lateral hoof balance were calculated as: $[(VF_{Toe/Medial} - VF_{Heel/Lateral})/0.5\ (VF_{Toe/Medial} + VF_{Heel/Lateral})] \times 100\%$. According to this method, a value of 0% indicates perfect balance in vertical ground reaction forces between the zones, whereas positive or negative values indicate relatively higher loading of the toe/medial or heel/lateral zone, respectively. Possible values range from −200% to 200%. Left and right hoof data are presented as mean ± SD curves throughout the stance phase.

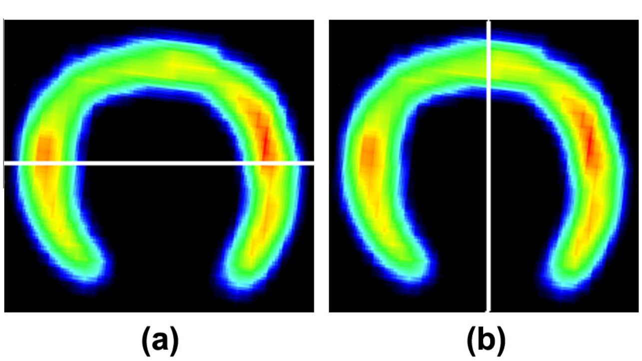

Fig. 1. Hoof prints were divided into a toe and heel region by a line through the maximal hoof width (a) and in a medial and lateral zone by a line through the central part of the toe and mid-way between the heels (b).

Hoof balance values of the vertical ground reaction force of the left and right limbs at three selected time points (impact, mid-stance and end of the stance phase) presented significant departures from a normal distribution, which could not be resolved using transformation. Therefore, these data were compared using a non-parametric Kruskal–Wallis test with post hoc comparisons using Dunn's test. Statistical analysis was performed using IBM SPSS Statistics 20, with statistical significance set at $P < 0.05$.

Results

Mean ± SD toe–heel balance curves are presented in Fig. 2. There were no significant differences in toe–heel balance of the vertical ground reaction force between the left and the right limb at impact, mid-stance and at the end of the stance phase; hence, toe–heel balance of the vertical ground reaction force presented a high degree of symmetry between contralateral limbs. Initially, the toe–heel balance curves presented higher loading of the heel zone, quickly changing to higher loading of the toe area during the first 5% of stance. Subsequently, the toe and heel regions were loaded equivalently, until a gradually increasing loading of the toe zone was observed, starting at around 60–65% of stance.

Mean ± SD medio-lateral balance curves are presented in Fig. 3. At walk, medio-lateral hoof balance of the vertical ground reaction force did not present significant differences between left and right limbs at impact, mid-stance and the end of the stance phase. The medio-lateral balance curves presented higher loading of the lateral part of the hoof throughout stance for both forelimbs. However, at trot, left medio-lateral hoof balance at impact was significantly higher than in the right limb ($P = 0.01$). The curve of the left limb presented higher initial loading of the medial zone, whereas the right limb curve presented initial higher loading of the lateral zone in all horses. At mid-stance and at the end of the stance phase, there were no significant differences between left and right limbs. Both limbs presented higher loading of the lateral part of the hoof at the end of stance.

Discussion

This study is the first to explore the use of a pressure plate for the detailed, dynamic evaluation of toe–heel and medio-lateral hoof balance of the vertical ground reaction force at the walk and trot in sound Warmblood horses. Recent studies have explored the use of this pressure plate as a clinical tool for the objective and dynamic evaluation of limb-loading symmetry (Oosterlinck et al., 2010a) and hoof contact area (Oosterlinck et al., 2011). Moreover, pressure-measuring systems with a high density of sensors distributed uniformly over the entire measuring area have the capacity for unravelling the pressure distribution underneath the hoof, unlike force plates with only four sensors near the four corners of the plate.

In a previous study on the toe–heel pressure distribution in horses shod with normal shoes and with shoes with a wide toe and smaller branches (Oomen et al., 2012), the comparison between the toe and heel region was based on maximal or total values during the stance phase. The dynamic evaluation of the loading on the toe vs. the heel region throughout the stance phase has not been performed; moreover, objective, dynamic data on medio-lateral balance of the vertical ground reaction force have not been reported.

The present study revealed characteristic curve patterns for toe–heel and for medio-lateral balance of the vertical ground reaction force at the walk and trot in sound sport horses. These hoof balance values presented limited inter-individual variability, illustrated by the small standard deviations in the study sample. The homogeneous appearance of hoof balance curves of the vertical