The Veterinary Journal 198 (2013) e27–e32

Contents lists available at ScienceDirect

The Veterinary Journal

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

Hoof accelerations at hoof-surface impact for stride types and functional limb types relevant to show jumping horses

Elin Hernlund [a,*], Agneta Egenvall [b], Michael L. Peterson [c], Christie A. Mahaffey [c], Lars Roepstorff [a]

[a] Swedish University of Agricultural Sciences, Unit of Equine Studies, Uppsala, Sweden
[b] Swedish University of Agricultural Sciences, Department of Clinical Sciences, Uppsala, Sweden
[c] Mechanical Engineering, University of Maine, Orono, ME 04469, USA

ARTICLE INFO

Keywords:
Equine
Hoof impact
Acceleration
Jump
Surface

ABSTRACT

Increased knowledge of the influence of stride type on hoof impact accelerations for fore and hind limbs could lead to a more complete picture of hoof–ground interactions in equine athletes. Hoof accelerations were quantified for each hoof of five show jumping horses using two orthogonal single axis ± 250 *g* accelerometers. Accelerations were recorded when cantering horses jumped fences of varying types (upright and oxer) and heights (90–130 cm) on three different surface conditions. Strides were identified as normal canter strides, take-off strides and landing strides. Descriptive hoof impact parameters were maximal vertical deceleration (MaZ), range of maximum fore-aft acceleration and deceleration (RaX), quotient of acceleration vectors (arctangent for RaX/MaZ) and hoof breaking duration (time from MaZ to first level of <0.042 *g* absolute fore-aft acceleration). The highest hoof impact accelerations occurred during the take-off stride (mean MaZ over limbs 52.6–91.6 *g* vs. all-stride mean 39.8 *g*; mean RaX 63.9–80.5 *g* vs. all-stride mean 50.7 *g*). At the jump landing, the forelimbs also experienced high MaZ (46.8 and 49.0 *g*) of the same order of magnitude as the forelimbs at the take-off. Non-lead limbs had higher MaZ in the normal canter stride, comparing within forelimb and hind limb pairs, and the reverse relationship occurred for RaX and for the quotient of acceleration vectors. The systematic variation introduced by limb and stride type suggests that these gait parameters are important to understand in a sport-specific context for horse surfaces, especially in the development of standardised testing equipment that simulates horse–surface interactions.

Introduction

The hoof–ground interaction is crucial for performance and in development of injuries in horses. At the horse–surface interface, the properties of the granular surfaces generally used in equestrian sport are non-linear and strain rate dependent. Data on this stress–strain relation are crucial for development of sport-specific surface testing equipment. To date, methods of evaluation of the mechanical properties of surfaces used for equine sport have been limited to racetracks and racing training grounds (Zebarth and Sheard, 1985; Ratzlaff et al., 2005; Peterson and McIlwraith, 2008; Peterson et al., 2008, 2010; Chateau et al., 2009, 2010; Robin et al., 2009; Setterbo et al., 2009).

Nigg (1990) critically reviewed test procedures for evaluation of sport surfaces for human athletes. Most procedures were deemed not to be relevant and one major conclusion was that surface interactions representing actual situations during sport activities were lacking. Also, surface testing of equine sport surfaces is limited by the extent of information on the mechanical demands of a horse on specific surfaces. Studying hoof ground interactions addresses this need.

The stance phase is initiated by a primary and a secondary impact between the horse and the surface (Thomason and Peterson, 2008). Factors that affect accelerations and loads in these events can be related to the horse, e.g. fore or hind limb (Gustås et al., 2004; Oosterlinck et al., 2011), the shoe (Benoit et al., 1993; Roepstorff et al., 1999, 2001; Back et al., 2006; Schaer et al., 2006; Harvey et al., 2012) and the surface (Barrey et al., 1991; Kai et al., 1999; Chateau et al., 2009, 2010; Robin et al., 2009; Setterbo et al., 2009). In show jumping, the horse challenges the surface with a seemingly wide range of accelerations and loads, quickly changing speed, stride frequency and direction, taking off over fences and landing. To increase knowledge about the range of challenges imposed on both the horses and the surfaces of this sport, the specific horse–surface interface in show jumping must be described further.

Previously, we described kinematic hoof landing parameters in the jump landing of elite show jumping horses (Hernlund et al., 2010). The aim of the present study was to describe hoof

* Corresponding author. Tel.: +46 18672145.
E-mail address: Elin.Hernlund@slu.se (E. Hernlund).

1090-0233/$ - see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.tvjl.2013.09.029

accelerations from first impact to hoof standstill for different strides and for functional limb types relevant to the show jumping horse. Different surfaces were included in the study design to enable control of their effects, but in-depth discussion of surface effects was not the scope of this study.

Materials and methods

Experimental design, horses and riders

An experiment to study kinematic parameters of hoof impact with accelerometers mounted on all four hoofs of horses cantering and jumping was performed. Surface conditions, obstacle height and obstacle type were varied. Five Warmblood show jumpers (3 geldings and 2 mares) with mean age ± standard deviation (SD) 10.6 ± 2.9 years, participated in the study. Three riders rode the same one or two horse(s) throughout the experiment. Horses wore regular steel shoes. The mean ± SD summed weight of horse, rider and equipment was 668 ± 64.5 kg. The horses were equipped and then warmed-up by jumping low fences before data collection commenced. After this, riders took turns cantering their horse onto a straight line and jumped over the fence, aiming for two successful jumps per fence type and height. The ethical committee for animal experiments in Uppsala, Sweden approved the study (approval number C146/11).

Accelerometers, logger and data acquisition

Two single axis ± 250 g accelerometers (ADXL193, Analog Devices) were attached to each hoof's lateral wall by a metal fixture (Fig. 1a and b). The accelerometers were placed orthogonally on the fixture in vertical and fore-aft (aligned with the shoe) direction. The fixture was attached to the hoof using a polyurethane hoof adhesive (Equi-Thane SuperFast, Vettec). Accelerometers were glued to the metal by the same adhesive. The added weight of material fixed to each hoof was 22 g. Electric wires from the accelerometers were plugged into a 14-bit data logger (DataLOG MWX8, Biometrics) carried by the rider in a waist bag. The wires were fixed to the horses' limbs by padded elastic straps with hook-and-loop fasteners and glued to the croup and back with adhesive bandage (Animal Polster, Snøgg AS). The sampling rate was set to 1 kHz.

Arenas

The experiment was performed in two indoor arenas, one with a sand–fibre top layer over a conventional gravel base. The sand–fibre surface was measured in two sessions with different maintenance conditions. The surface was allowed to dry out for a week before being used for the first measurement. The same surface was then watered with 5.82 L/m^2 over 58 min the night before the second session. The second arena had a sand–woodchip top layer and a base with a 15 cm layer of rubber pieces placed on top of levelled gravel. The moisture content of the surfaces' top layers was calculated by comparing the weight of soil samples before and after being dried at 45 °C to a constant mass. This is a modification of soil standards (ASTM, 2005) with lower temperature and longer time due to synthetic material contents.

Fences

Fence maximum height was comparable to the competition level of each horse. Each session started with horses jumping fences with a height 20 cm under their set maximum level, moving to 10 cm below this level, and then finally fences of their individual maximum height. Upright fences and oxers were built in a random order for each height.

Data processing

Fifteen strides around the jumps were selected with a custom written Matlab script (version 2009a, MathWorks). The signal was filtered with a fourth order forward–backward low pass Butterworth filter with a cut-off frequency of 400 Hz. The digital filter transition frequencies were in the same range as the filter, which was integrated into the sensors (Analog Devices, 2010). The signal bandwidth was defined by a 20 dB drop from the spectral peak showing the highest frequency value of 150 Hz from the hardest surface tested in this work. According to the Nyquist–Shannon sampling theorem, the sampling rate of this experiment ensures a faithful reconstruction of the analogue signal. The filter selection was used to ensure that noise from the relatively high sampling rate of the signal did not affect the results for peak values.

In the impact complex at the beginning of the stance, the maximum vertical deceleration (MaZ) was identified. The range (RaX) between maximal horizontal deceleration and acceleration was used as a measure of the magnitude of horizontal ground interaction during the same period. The quotient of the acceleration vectors (QAV) was calculated as the arctangent of RaX/MaZ, avoiding the problem of values moving toward infinity when MaZ moves toward zero. The QAV parameter reflects the relation between the horizontal and vertical ground interaction in the early hoof-surface interface. Break duration was calculated as time (ms) from MaZ to first level of <0.042 *g* absolute horizontal acceleration and deceleration. Each step was classed as leading or non-leading forelimb (LdF and NLdF, respectively) or hind limb (LdH and NLdH, respectively) by comparing timing of impact between contralateral limbs for each stride. Steps with disturbance in the signal, due to mechanical or electronic failure, were excluded. Steps were further identified as belonging to normal canter strides, approach strides (not analysed), take-off strides and landing strides. We defined the take-off stride as the forelimb steps from the stride before the jump stride and the hind limb steps from the jump stride. Normal canter strides started with NLdH steps and ended after LdF steps.

Statistical analysis

Mixed models were created using the MIXED procedure in SAS to take account of several fixed effects simultaneously within the repeated design. Response variables modelled were MaZ, RaX, QAV and break duration. Data were Box–Cox transformed to find a transformation close to normality. The functional limb types (LdF, NLdF, LdH and NLdH), side type (normal canter, take-off and landing) and arena (wet sand–fibre, dry sand–fibre and sand–woodchip) were entered as fixed effects. Random effects were the horse–rider combination and repetition within arena. The covariance structure was modelled as compound symmetry. The variation from the rider/horse combinations was assessed using this variance parameter estimate and dividing it by the sum of the estimate and the residual variance (the compound

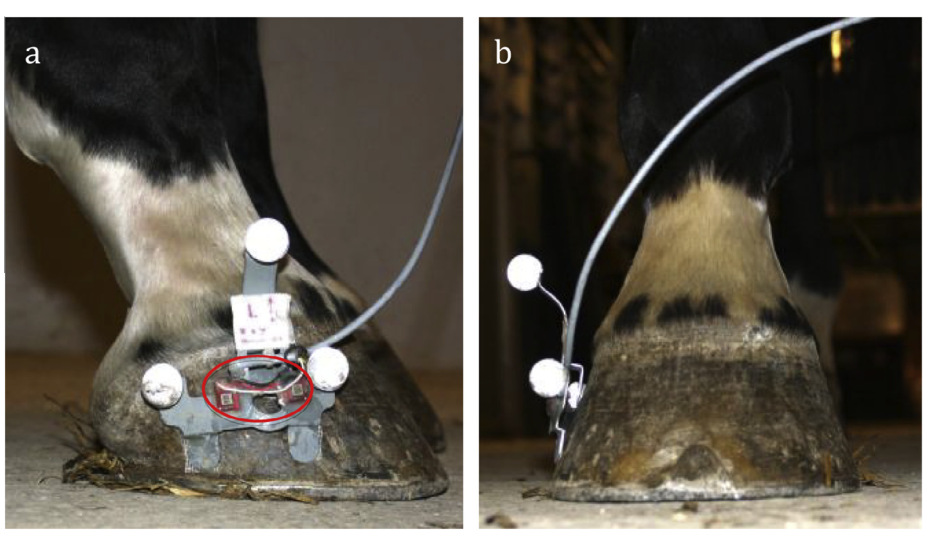

Fig. 1. Hoof mounted accelerometers in lateral (a) and dorsal (b) view. The metal fixture was designed to enable attachment of accelerometers (circled) and reflective markers (not used for this study).