The Veterinary Journal 198 (2013) e124–e129

Contents lists available at ScienceDirect

The Veterinary Journal

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

Discrimination of two equine racing surfaces based on forelimb dynamic and hoof kinematic variables at the canter

Nathalie Crevier-Denoix [a,b,*], Philippe Pourcelot [a,b], Laurène Holden-Douilly [a,b], Mathieu Camus [a,b], Sylvain Falala [a,b], Bérangère Ravary-Plumioën [a,b], Claudio Vergari [a,b], Loïc Desquilbet [c], Henry Chateau [a,b]

[a] Université Paris Est, Ecole Nationale Vétérinaire d'Alfort, USC 957 BPLC, F-94700 Maisons-Alfort, France
[b] INRA, USC 957 BPLC, F-94700 Maisons-Alfort, France
[c] Université Paris Est, Ecole Nationale Vétérinaire d'Alfort, F-94700 Maisons-Alfort, France

ARTICLE INFO

Keywords:
Equine
Force
Impact
Sink distance
Slip distance

ABSTRACT

The type and condition of sport surfaces affect performance and can also be a risk factor for injury. Combining the use a 3-dimensional dynamometric horseshoe (DHS), an accelerometer and high-speed cameras, variables reflecting hoof–ground interaction and maximal limb loading can be measured. The aim of the present study was to compare the effects of two racing surfaces, turf and all-weather waxed (AWW), on the forelimbs of five horses at the canter. Vertical hoof velocity before impact was higher on AWW. Maximal deceleration at impact (vertical impact shock) was not significantly different between the two surfaces, whereas the corresponding vertical force peak at impact measured by the DHS was higher on turf. Low frequency (0–200 Hz) vibration energy was also higher on turf; however high frequency (>400 Hz) vibration energy tended to be higher on AWW. The maximal longitudinal force during braking and the maximal vertical force at mid-stance were lower on AWW and their times of occurrence were delayed. AWW was also characterised by larger slip distances and sink distances, both during braking and at maximal sink. On a given surface, no systematic association was found between maximal vertical force at mid-stance and either sink distance or vertical impact shock. This study confirms the damping properties of AWW, which appear to be more efficient for low frequency events. Given the biomechanical changes induced by equestrian surfaces, combining dynamic and kinematic approaches is strongly recommended for a reliable assessment of hoof–ground interaction and maximal limb loading.
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Introduction

The type and condition of sport surfaces affect equine performance and can also be a risk factor for musculoskeletal injury (Nigg and Segesser, 1988; Williams et al., 2001). Despite the economic impact of injuries in horse racing and equestrian sports, investigations of the biomechanical effects of surfaces to date have been limited, mainly because of technological difficulties in performing dynamic measurements during equine high speed locomotion (Thomason and Peterson, 2008).

Most previous studies have used accelerometers to quantify the impact shock (sudden deceleration of the hoof following ground contact) and associated vibrations (Barrey et al., 1991; Ratzlaff et al., 2005; Gustås et al., 2006a,b; Chateau et al., 2009a, 2010). Provided that the range and acquisition frequency of the accelerometers are adapted to the studied phenomenon, this technique is relevant, since concussion and high frequency vibrations have been incriminated as a risk factor for damage to subchondral bone and joints (Radin et al., 1973; Serink et al., 1977; Gustås et al., 2001). However, accelerometers are not adapted to quantify the forces applied under the horse's hoof during the loading phase of support, although these forces, especially the peak vertical forces and the corresponding load rates, are likely to be the most critical factors contributing to musculoskeletal injuries (Cheney et al., 1973). This quantification is classically achieved using force plates, but this technique is not well adapted to working in the field under real training conditions.

Three-dimensional (3D) dynamometric horseshoes (DHS) allow measurement of the entire ground reaction force (GRF) over a large number of strides on various surfaces (Roepstorff and Drevemo, 1993; Kai et al., 2000; Roland et al., 2005; Chateau et al., 2009b). To date, only two models of DHS have been applied under field conditions. One model is based on the strain gauge technology and has been used to compare three racing surfaces (dirt, synthetic and turf) in Thoroughbred racehorses at the trot and slow canter (Setterbo et al., 2009). The other model uses piezoelectric force sensors and has only been used to date on harness trotters in

* Corresponding author. Tel.: + 33 1 43967106.
E-mail address: ncrevier@vet-alfort.fr (N. Crevier-Denoix).

1090-0233/$ - see front matter © 2013 Published by Elsevier Ltd.
http://dx.doi.org/10.1016/j.tvjl.2013.09.046

two studies comparing training surfaces: all weather waxed vs. crushed sand at 35 km/h (Robin et al., 2009); and wet firm vs. deep natural beach sand at 25 km/h (Crevier-Denoix et al., 2010).

Given the difficulties of direct dynamometric measurements, some studies have focussed on kinematic analysis of hoof landing and braking using high speed cameras (Hernlund et al., 2010). On a given surface (all-weather waxed track), Parsons et al. (2011) used high speed videography measurements of horizontal and vertical velocity of the hoof immediately prior to impact, and subsequent vertical sink and horizontal slip distances travelled by the hoof into the surface, to make indirect inferences about expected impact forces.

Combining all these approaches (3D DHS, accelerometer and high-speed cameras), the primary aim of the present study was to compare hoof–ground interaction and maximal loading in the forelimbs of five horses cantering on two racing surfaces. The secondary aim was to analyse the associations between the main variables measured, in order to gain insight into the most relevant approaches to characterise the effects of surfaces as possible factors in development of musculoskeletal injuries.

Materials and methods

Horses

Five saddle horses (2 geldings and 3 males, mean ± standard deviation, SD, body mass 567 ± 30 kg; age 12 ± 5 years) were used in this study. All horses were clinically sound, with no subjectively observed gait abnormality. The local Animal Care and Ethics Committee advised that no formal approval was required for this study.

Experimental set-up

After trimming by an experienced farrier, the right fore hoof of each horse was equipped with a DHS composed of four triaxial piezoelectric force sensors (Kistler 9251A) sandwiched between two aluminium plates (Robin et al., 2009; Chateau et al., 2009b; Crevier-Denoix et al., 2010) (Fig. 1). A horseshoe with matching height and weight was attached to the left fore and both hind hooves. The GRF was calculated as the sum of forces applied on each sensor. In this study, we considered only the longitudinal and vertical components of the GRF, designated Fx and Fz, respectively parallel (positive x in the palmaro-dorsal direction) and perpendicular (positive z directed downwards) to the solar surface of the hoof in the sagittal plane.

A triaxial piezoelectric accelerometer (PCB 356B20, frequency range 2–10,000 Hz) was also fixed rigidly to the dorsal hoof wall by use of a metal hull screwed into the horn (Chateau et al., 2010). The hoof angle was measured and used to express acceleration in a reference frame in which vertical acceleration was perpendicular to the hoof sole and longitudinal acceleration was palmaro-dorsal. Only the z acceleration was considered here; accelerations directed downward were denoted positive.

The DHS wires were secured to the limb and connected to charge amplifiers (Kistler 5073A411), then to an analogue-to-digital converter (NI-USB 6218), which also received the accelerometer wires; the converter was plugged in a mini-computer (Sony Vaio VGN-P11Z). A Wi-Fi connection enabled data to be acquired remotely. The total data acquisition system was placed behind the saddle in saddle-bags sewed on the saddle-cloth (Fig. 1). Acquisition was performed at 7.8 kHz. Reflective markers were placed on the right forelimb facing the main joints and a set square fitted with three reflective markers was screwed in the lateral hoof wall of the right foot. The horses' speed was measured and recorded by a global positioning system (GPS, Racelogic RLVBSS100) centred on an antenna glued to the horse's croup.

During the tests, each horse was filmed with two high-speed cameras (1000 Hz, Phantom v5.1, Vision Research) placed side by side 7 m from each other, filming the right side of the horse at a distance of about 10 m from the middle of the track. The resolution of each camera was 1024 × 512 pixels and its field of view was about 7 m. The films were synchronised with the DHS, accelerometer and speed data using the lighting of a light emitting diode (LED) placed on the right saddle-bag, from which the signal (V) was digitised by the same acquisition card as the other devices.

Recording protocol

Two linear corridors 70 m long were delimited on both racing tracks of the Deauville-La Touques Racetrack, France: one turf track (cut to ~8 cm height) and the other an all-weather waxed (AWW) surface (88.0% sand, 7.1% fibres and 4.9% paraffin; Novarea Laboratory). For each track, a 14 m long central portion of the 70 m long recording area equipped with two parallel series of markers (2.9 m apart) placed in face-to-face pairs every metre for kinematic measurements. All experiments took place from May to September, during a single afternoon for each horse (five afternoons of experiments in total). The average ambient temperature during the five experiments was 20.8 ± 4.7 °C (range 15–26 °C) and the turf track condition was judged 'good to soft' (personal communication from the track superintendent based on penetrometer measurements, recorded rainfall and maintenance operations).

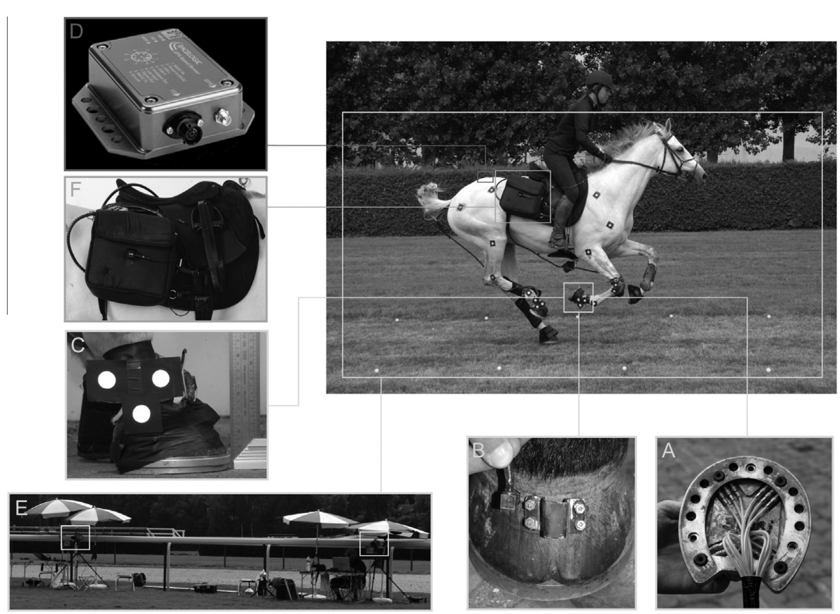

Fig. 1. Experimental set-up to study the effects of track surfaces on forelimb dynamic and hoof kinematic variables of horses at the canter. The right fore hoof is equipped with a 3D dynamometric horseshoe (A), a triaxial accelerometer fixed on the dorsal hoof wall (B) and a set square fitted with three reflective markers screwed in the lateral hoof wall (C). A global positioning system (GPS) system placed on the croup (D) allows the horse's speed to be measured. Two high speed cameras (1000 Hz) film the right side of the horse (E); films are a posteriori synchronised with the dynamic and speed recordings. Electronic devices are placed in saddle-bags (E). A Wi-Fi connection allows data to be acquired remotely.

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