COMPARISON OF TWO PREPARATION PROCEDURES (HARROWING VS. ROLLING) APPLIED TO AN EQUESTRIAN SPORT ARENA: EFFECTS ON THE DYNAMIC VARIABLES IN 3 HORSES LANDING AFTER A JUMP

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The purpose of this study was to compare the dynamic variables recorded on 3 horses landing after a jump on an arena surface (sand & fibre mix) after application of two classical preparation procedures: harrowing and rolling. Each horse, equipped with a dynamometric horseshoe and an accelerometer on its right forehoof, performed 6 jumps alternatively on each prepared surface, landing alternatively at right and left lead. The maximal vertical deceleration and the energy of vibrations (>50Hz) at impact significantly decreased with harrowing, on both limbs. The braking force and braking loading rate were greater on the rolled surface but only in the leading limb. The vertical loading rate and, in the leading limb only, the maximal vertical force, were significantly larger on the rolled surface, which suggests that preparation affected the surface deeper than expected.

KEY WORDS: equestrian sport surface, impact, braking force, vertical force, loading rate, sand.

INTRODUCTION: Sand & fibre mixes are often used in surfaces designed for equestrian sports arenas. Although the optimal surface for a specific equestrian sport has not been established yet, it is generally accepted that the surface should minimise concussion through energy absorption, whilst still returning enough power to aid performance (Barrey et al., 1991). Sand & fibre mixes are intended to meet these requirements; however surface properties are affected by maintenance and preparation procedures. For instance harrowing a surface increases surface deformation and hence decreases substrate hardness and shear resistance (Setterbo et al., 2011), whereas rolling a surface is expected to produce the opposite effects. Northrop et al. (2013), using a Clegg impact hammer and an adapted torque wrench, compared both procedures (harrowing vs. rolling) applied to a waxed sand with fibres and did not find significant differences in surface hardness and surface traction. Tranquille et al. (2015) using the Orono Biomechanical Surface Tester (Peterson et al. 2008), observed a significant decrease of the maximum vertical deceleration and maximal vertical load post-harrowing of a surface made of waxed-sand with fibres. Unfortunately none of these devices has been correlated with dynamic measurements performed on horses exercising on the same surfaces.
Accelerometers have been used to quantify the impact shock (sudden deceleration of the hoof following ground contact) and associated vibrations during equine high-speed locomotion (Ratzlaff et al., 2005; Chateau et al., 2010a,b). However dynamometric horseshoes are required for measuring the forces applied under the horse's hoof during the support phase of the stance, especially when the tests are performed under training conditions on various surfaces, hardly compatible with the use of forceplates. A 3-D dynamometric horseshoe (DHS) has been developed and successfully applied to measure the hoof reaction forces (HRF) under various sport conditions (Chateau et al., 2009, 2010a; Robin et al., 2009; Crevier-Denoix et al., 2010; 2013a,c).
The aim of this study was to compare, using both an accelerometer and a DHS fixed on the forehoof, the dynamic variables measured on 3 horses landing after a jump on a sand & fibre mix surface successively rolled and harrowed. It was hypothesised that, as harrowing and rolling are supposed to only modify the mechanical properties of the surface cushion, they

would only influence the dynamic variables characterizing the onset of the stance phase (impact shock and braking phase), when the forces are relatively low, but not those characterizing the support phase.

METHODS: Three horses (geldings, Selle Français, mean ± standard deviation, body mass 599±19 kg, age 9±3 years), ridden by their own regular rider, were used. After trimming, the right forehoof of each horse was equipped with a DHS composed of 4 triaxial piezoelectric force sensors (Kistler 9251A) sandwiched between two aluminium plates (Chateau et al., 2009b). A horseshoe with matching height and weight was attached to the left fore and both hind hooves. The HRF was calculated as the sum of forces applied on each sensor. In this study we only considered the longitudinal and vertical components of the HRF (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) was also rigidly fixed to the dorsal hoof wall (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. A complete description of the acquisition devices can be found in Crevier-Denoix et al. (2013c). A wifi-connection enabled to remote-control the data acquisition. Acquisition was performed at 7.8 kHz. The horse's speed was measured and recorded by a global positioning system (GPS, Racelogic RLVBSS 100) centred on an antenna glued to the horse's croup. The complete acquisition system was placed in saddle-bags.
A linear corridor was delimited in the centre of an outdoor arena made of 12.5 cm of a sand & fibre mix (Normandie drainage*), laid on 15 cm of a draining sand (0-4), placed on a 30 cm silty clay foundation. Two preparations of the surface were obtained using: (1) a vibratory roller (Bomag BW 80 AD-5, 1550 kg, 2 wheels 58 cm diameter) and (2) a harrow (Arena Master, Cousins & Martin Collins). The surface was first prepared with the roller, then a 1.2 m height straight fence was placed mid-length of the corridor, and the horse performed a first series of tests consisting of jumping the fence in straight line (within the corridor) cantering alternatively at both right and left leads (3 jumps at each lead). Then the fence was removed and the surface was harrowed to 4 cm depth; the fence was installed again (at the same place) and a second series of tests were performed (6 jumps at each lead). Lasty, the fence was removed again and the surface was rolled. After placing back the fence, a third series of tests were recorded (3 jumps at each lead).
Only the landing stride was analysed here. A total of 18 landing strides (3 horses x 6 jumps) were analysed for each preparation and for each lead (when the equipped right forelimb was the leading limb (LL), i.e. at right lead, and when it was the trailing limb (TL), i.e. at left lead). To delimit the stance phase, the threshold was set to 100 N vertical force.
Customised programmes developed in Matlab (MathWorks) were used to determine peak forces, average loading rate (Fx max and Fz max divided by the corresponding time), impulses (integral of force over time), peak vertical acceleration and temporal parameters of each event. The power density spectrum of the z accelerometric signal (during the hoof braking phase) was calculated for each stride using a Fast Fourier Transform. The spectral density curves were then integrated for several frequency ranges (0-50, 50-100, 100-150, 150-200 Hz) to give vibration energy values that could be compared between surfaces.
To compare the two preparations, harrowed (H) vs. rolled (R), with respect to the dynamic variables, linear mixed-effects regression models were used taking into account repeated measurements within each horse (SAS version 9.2). Left and right leads were treated separately. Significance level was set at $P < 0.05$.

RESULTS: Speed of the horses was not significantly different between H and R (18.5 ± 1.4 km/h, and 18.7 ± 1.3 km/h, respectively). The maximal vertical acceleration at impact was higher (in absolute value) on R, at both leads (+30%, p=0.04 in the TL; +52%, p=0.007 in the LL). Energy of low frequency vibrations (< 50 Hz) was not significantly different between preparations whereas for frequencies between 50 and 200 Hz, the energy was higher on R at both leads (+319% in average, p<0.02 on the TL; +537%, p<0.0003 on the LL). Maximal longitudinal force (braking force) and average longitudinal loading rate were not significantly different between R and H on the TL whilst higher on R in the LL (+8%, p=0.04; +51%, p<0.0001, respectively). Although the maximal vertical force (Fz max) was not significantly different in the TL, the average vertical loading rate tended to be higher on R in this limb (+4%, p=0.06). Both variables were significantly affected on the LL (respectively +5%, p=0.01 for Fz max, and +17%, p=0.02 for the vertical loading rate). Although stance duration was not significantly different between preparations, on both leads, there was a tendency for the longitudinal braking impulse to be lower (-18%, p=0.06) and for the vertical impulse to be higher (+4%, p=0.09), on R, in the LL; no difference was observed in the TL.

DISCUSSION: This study first confirms that the leading and the trailing forelimbs should be separately considered when analysing biomechanical measurements of horses landing after a jump, as the interaction of both limbs with the surface is obviously different. Loading differences between both limbs at landing have been described (Crevier-Denoix et al., 2013a), as well as differences in the kinematic variables at the canter (Crevier-Denoix et al., 2013b). In the present study, the leading limb was more affected by the preparation of the surface than the trailing limb. The obliquity of this limb at ground contact and its longer retardatory (positive Fx) phase during stance are likely responsible for these differences. The maximal vertical deceleration and the energy of vibrations (>50Hz) characterizing the impact phase were strongly affected by the preparation, i.e. decreased with harrowing (or increased with rolling), on both limbs, as expected (Chateau et al., 2010a). The decrease of the braking force and loading rate with harrowing compared with rolling (in the LL) was not a surprise either, as harrowing is intended to decrease the shear resistance of the surface. However the increase in vertical loading rate and above all, of the maximal vertical force (significant in the LL only) with rolling, was unexpected (Northrop et al., 2013). A stiffer (rolled) cushion likely induces a more rapid vertical loading of the limb during stance. However complementary kinematic data, especially information on the vertical displacement and orientation of the hoof and limb to the surface during stance, are required to further interpret the results regarding maximal vertical force.

CONCLUSION: Classical preparation procedures such as harrowing and rolling significantly affect not only the impact phase but also the longitudinal and vertical loading of the limb during stance. As loading rates are likely critical variables for injury prevention, regular harrowing should be recommended for surfaces that are prone to compaction. However a kinematic analysis is now required to more completely assess the respective effects of the two preparation procedures on the hoof and limb joint motion.

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