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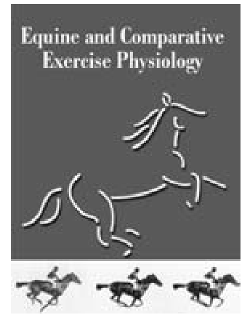

Ground reaction force and hoof deceleration patterns on two different surfaces at the trot

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Research Paper

Abstract

The objective of the present study was to compare the hoof deceleration and ground reaction forces following impact on two different surfaces. Seven unshod Standardbreds were trotted by hand at 3.0–5.7 m s^{-1} over a force plate covered by either of the two surfaces, sandpaper or a 1 cm layer of sand. Impact deceleration data were recorded from one triaxial accelerometer mounted on the fore- and hind hooves, respectively. Ground reaction force data were obtained synchronously from a force plate, sampled at 4.8 kHz. The differences between the two surfaces were studied by analysing representative deceleration and force variables for individual horses. The maximum horizontal peak deceleration and the loading rates of the vertical and the horizontal forces were significantly higher on sandpaper compared with the sand surface ($P < 0.001$). In addition, the initial vertical deceleration was significantly higher on sandpaper in the forelimb ($P < 0.001$). In conclusion, it was shown that the different qualities of the ground surface result in differences in the hoof-braking pattern, which may be of great importance for the strength of the distal horse limb also at slow speeds.

Keywords: accelerometer; horse; impact; kinematics; kinetics; locomotion

Introduction

The distal limbs of the trotting horse are subjected to repeated impulsive loadings[1–3], suggested to be important factors behind the mechanical stress. Mechanical stress is characterized by the presence of large peak decelerations in combination with high loading rates[4] and may end up in subchondral bone damage followed by degenerative changes in the joints as described in animal models[5–8]. The characteristics of the horizontal hoof braking have been suggested to be of importance to impact forces and hoof decelerations at the trot[9,10].

The movements of the hoof at impact can be described as a series of peak decelerations[2,9–11] associated with development of the ground reaction forces (GRFs)[2,9,10] causing transients or shockwaves that transmit through the hoof and bone tissue of the distal limb[9,12,13]. The attenuation of these transients has been suggested to be related to the time lapse of the horizontal hoof braking[9].

At a slow trot, the transients were reported to be attenuated distal to the proximal phalanx[12] or distal to metacarpus[9,13]. *In vitro* studies of hoof impact have shown that the frequency attenuation of the impact-related shock waves occurs mainly in the soft tissues of the hoof, while the attenuation of amplitudes seems to be related to the skeleton and to the interphalangeal joints[13,14].

The aim of the present study was to describe the kinematics and kinetics of the hoof on two different ground surfaces and carry out a comparison between fore- and hind limbs. It was hypothesized that a sandpaper surface may introduce higher loading rates and impact decelerations and a shorter period of hoof

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deceleration compared with a sand surface. It was also expected to find differences in the deceleration patterns between the fore- and hind limbs.

Materials and methods

This study was approved by the Ethical Committee for Animal Experiments, Uppsala, Sweden.

The horses

Seven unshod and clinically sound Standardbred trotters (mean bodyweight 504 kg, SD 38) were used in the study. Each of the horses was trained to trot over the force plate on the different surfaces at least on one occasion before the recordings.

Laboratory equipment and data acquisition

Two 14-g triaxial piezoelectric accelerometers (Brüel & Kjaer® type 4504; Brüel & Kjaer, Naerum, Denmark) were used. The accelerometers were mounted on a triangular aluminium plate[9,10] attached to the lateral wall of the right fore- and hind hooves with a two-component glue (Equilox®; Equilox International, Pine Island, MN, USA) with one axis perpendicular to the ground at the standing position.

The GRFs were recorded by the use of a strain gauge-based force plate (Bertec® type 6090-15; Bertec Corporation, Columbus, OH, USA) mounted in the concrete floor, halfway along a 40 m indoor track with a concrete surface. To protect the original aluminium surface of the force platform, it was covered with a 3 mm-thick aluminium plate.

Two different surfaces were used to cover the force plate in order to modify the hoof and ground interaction properties. One surface consisted of sandpaper, which was glued to the aluminium plate. The second surface consisted of a 1 cm-thick layer of sand (particle size 0–5 mm), spread out over a sheet of non-woven, covering the sandpaper.

The joint angles were calculated from spherical markers, 11 mm in diameter, glued to the skin over well-defined anatomical structures of the fore- and hind limbs[15,16], recorded by a 240 Hz video system with three infrared cameras (Proreflex®; Qualisys Medical AB, Gothenburg, Sweden). The speeds were calculated from a marker attached to the lateral side of the chest.

Force plate and accelerometer data were sampled at 4.8 kHz using a 16 bit A/D-converter together with a synchronizing signal from the video system. Acquisition and processing of data were carried out in the LabVIEW® (National Instruments, Austin, TX, USA) software package.

Protocol

The horses trotted by hand over the force plate, first covered by sandpaper and thereafter by sand. A total of 10–16 successful right fore- and hind hoof ground contacts were measured on each surface at different speeds for each horse. Between each trial, the horses walked back.

The minimum range between the lowest and the highest speed in individual horses was $0.6\,\mathrm{m\,s^{-1}}$ and the maximum was $1.6\,\mathrm{m\,s^{-1}}$. The speed range in the whole group of horses was $3.0–5.7\,\mathrm{m\,s^{-1}}$.

Data processing

Force plate data were filtered back and forth using a digital third-order low-pass Butterworth. After visual examination, the appropriate cut-off frequency of the filter was decided to be 85 Hz. The natural frequency of the force plate was tested to be 175 Hz.

The accelerometer data were initially filtered back and forth using a tenth-order low-pass Butterworth filter with the cut-off frequency set to 2399 Hz (just below the Nyqvist frequency) in order to get an entire frequency resolution of the acquired signals[17]. The frequency content of the accelerometer data was determined for each of the orthogonal acceleration components separately.

The frequency content was determined from a power spectrum analysis, computed in accordance to the formula:

$$(\mathrm{FFT}^{*}(\mathrm{signal}) \times \mathrm{FFT}(\mathrm{signal}))/N^{2}$$

in which FFT is a fast Fourier transform, * denotes complex conjugate and N is the number of points in the signal. The power spectrum was integrated to estimate the frequencies at 50 and 90% of the signal power[14]. According to the power spectrum analysis, 85% of the signal power was below 1200 Hz.

As described in earlier studies with similar methods[9,10], the accelerometer data were filtered back and forth also with a second-order digital low-pass Butterworth filter at a cut-off frequency of 1200 and 400 Hz, respectively. The type of filter was chosen in order to avoid temporal changes in the deceleration pattern, even if it influenced the frequency content below the cut-off frequency, compared with a steeper filter. The filtering procedure made the absolute amplitudes of the signal suitable only for comparisons between the limbs and the surfaces, respectively.

The data originating from three different synchronized kinematic and kinetic recording systems were sampled at different frequencies. Kinematic data from the video system were cubic spline interpolated and resampled at 4.8 kHz in order to be comparable with the accelerometer and force plate signals.

The GRF was split into its vertical, cranio-caudal horizontal and transverse horizontal components, and the decelerations were separated into the vertical (along the vertical axis of the hoof), cranio-caudal horizontal (cranio-caudal axis of the hoof) and transverse horizontal (medio-lateral axis of the hoof) components at the standing position. Only the vertical and cranio-caudal horizontal components were considered in the study. Decelerations and GRFs directed upwards and backwards were denoted positive and the accelerations were marked negative in the figures.

Variables

The general patterns of the GRF- and accelerometer curves were identified by visual examination. Amplitudes and times for a number of typical and consistent maxima and minima were used as representative variables[10,11] and automatically identified by definitions specified in the LabVIEW® (National Instruments) software package.

First contact was normally defined from accelerometer data as the beginning of the first vertical deceleration peak[2]. In some cases when this peak was not evident, first contact was defined as the onset of the vertical GRF[18].

The first and second distinct vertical deceleration peaks at hoof impact were defined as z_1 and z_2, respectively. The time for the dip between z_1 and z_2 was determined from the signal filtered at 400 Hz. The amplitude of z_1 was then defined in the 1200 Hz signal as the maximal deceleration occurring between the first contact and the time of the dip between z_1 and z_2.

The minimum horizontal deceleration following z_1 was denoted as y_{min}, and y_{max} was the maximum in the following peak retardation complex.

The end of the horizontal hoof braking was identified from the horizontal deceleration curve as the time when the amplitude of the following 75 samples deviated less than $25\,m\,s^{-2}$ from the arithmetic mean.

In the vertical force signal, there were well-defined local maxima on sandpaper. As these maxima were shown only occasionally on sand, the maximum loading rates (i.e. the local maxima of the time derivate, DF_{z1} and DF_{z2}) were used instead to describe the vertical force development[19].

The maximum cranio-caudal GRF was denoted as F_{ymax} and the following absolute minimum was F_{ymin}. The maximum loading rate to F_{ymax} is DF_{ymax}. The time for the first contact was set to zero and the offset variation in the accelerometer data was set close to zero at first contact[10].

Statistical methods

The statistical analyses were carried out in the STATISTICA® (StatSoft Inc, Tulsa, OK, USA) software package. The Wilcoxon matched pairs test was used to analyse whether there were significant ($P < 0.05$) differences in the frequency distribution below 50 and 90% of the signal power, between the two surfaces and between the fore- and hind limbs, respectively.

The correlations between speed and the different variables were studied with scatter plots. The differences between the sandpaper and the sand surfaces were analysed for each horse and limb to minimize the influence of inter-individual variation[20]. The data were first paired within each horse and limb for the respective surface, for runs at as similar speed as possible, mean speed difference between paired observations being $0.2\,m\,s^{-1}$ (SD 0.2, range $0–1.3\,m\,s^{-1}$). Mean and standard deviations were calculated for the differences. Significant differences ($P < 0.05$) between horses for each variable and limb were assessed using one-way ANOVAs.

The 95% confidence intervals of the differences were plotted for each horse and variable to study the distribution round zero. The normal distribution ($P < 0.05$) was investigated with Shapiro-Wilk's W-test for each variable. For variables with a normal distribution, a single sample t-test was used to assess for differences between sand and sandpaper surface data. For variables that were not normally distributed, a Wilcoxon matched pairs test was used. Variables with the majority of the confidence intervals for each horse on one side of zero, together with $P < 0.001$ from the Wilcoxon or t-tests, were considered to be significantly different.

Results

Significantly higher frequencies in the vertical (Fig. 1) and horizontal decelerations were seen on the sandpaper surface compared with sand. On sandpaper in five out of the seven horses, a dominating part of the signal density was concentrated to the lower frequencies in the forelimb, when compared with the hind limb. However, the accelerometer data did not show any significant differences between fore- and hind limbs.

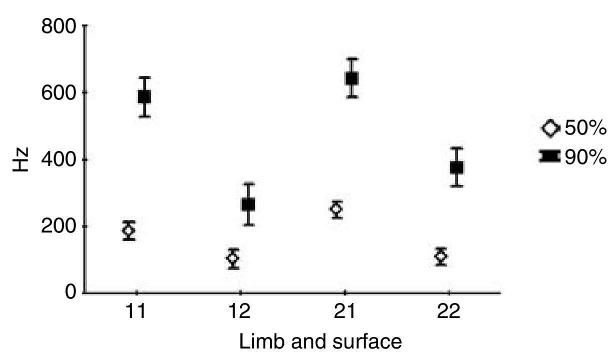

FIG. 1 Vertical bars show the 95% confidence intervals of the levels for 50 and 90% of the frequency content of the vertical deceleration for each limb and surface. 11, forelimb on sandpaper; 12, forelimb on sand; 21, hind limb on sandpaper; 22, hind limb on sand

No correlations were found between the speed and the different variables.

The characteristic decelerations during the hoof-braking period were more distinct on sandpaper than on sand in all horses (Fig. 2).

Significant differences were seen in the deceleration patterns between the two surfaces, and means and standard deviations are summarized in Tables 1 and 2.

A shorter time between first contact and z_1, and a higher y_{max} were observed on sandpaper compared with sand (Table 1). In addition, z_1 in the forelimb was significantly higher on sandpaper. An initial complex of peaks was seen in the horizontal deceleration signal, which was most prominent on sandpaper.

The vertical load was characterized by a slow onset and the following fast increase started earlier on sandpaper compared with the sand surface (Fig. 2c and f). On sand, the F_z curve showed inflections following both DF_{z1} and DF_{z2}, while the corresponding events were seen as distinct and consistent local maxima and minima on sandpaper in the majority of the recordings.

Significant differences were observed for times and magnitudes of GRF variables between the two surfaces (Table 2). DF_{z1} was higher in the forelimb (and showed a tendency to be higher also in the hind limb). The maximum horizontal force appeared significantly earlier and showed higher magnitude on sandpaper compared with sand in the hind limb.

DF_{ymax} was higher on sandpaper compared with sand in both fore- and hind limbs.

F_{ymax} was located between DF_{z2} and the following inflection on sand was seen earlier in the recordings on sandpaper. F_{ymin} appeared after the inflection followed after DF_{z2} on both surfaces (Fig. 2c and f).

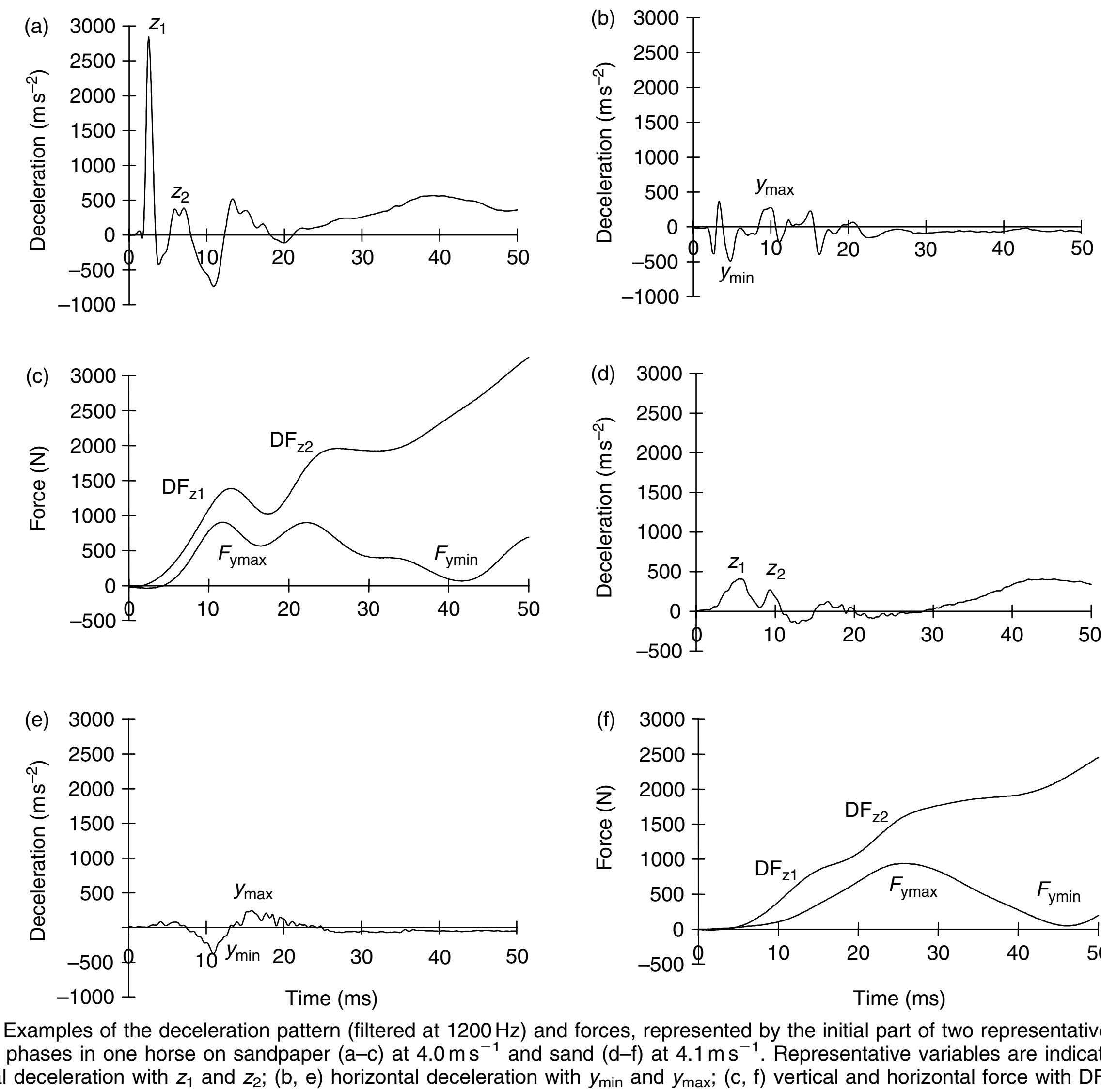

Fig. 2 Examples of the deceleration pattern (filtered at 1200 Hz) and forces, represented by the initial part of two representative forelimb stance phases in one horse on sandpaper (a–c) at 4.0 m s^{-1} and sand (d–f) at 4.1 m s^{-1}. Representative variables are indicated. (a, d) Vertical deceleration with z_1 and z_2; (b, e) horizontal deceleration with y_{min} and y_{max}; (c, f) vertical and horizontal force with DF_{z1}, DF_{z2}, F_{ymin} and F_{ymax}

Table 1 Accelerometer variables recorded at the hoof wall for horses 1–7 and means for all horses

		z_1		z_2		y_{min}		y_{max}	
Horse	*N*	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Differences between forelimb sandpaper and sand surface amplitudes and times									
Amplitude ($m\,s^{-2}$)									
Mean	61	1026.5*	822.1	401.4	650.8	−41.2	242.6	321.9*	204.5
1	9	1938.1	378.2	119.0	190.4	−90.4	164.1	168.1	159.5
2	8	514.8	399.7	−49.2	553.5	119.1	228.3	323.7	86.5
3	7	797.0	339.1	806.8	1238.5	−71.5	223.8	466.7	302.0
4	7	713.9	575.1	80.7	429.4	9.4	151.6	235.1	139.3
5	10	1603.7	246.8	636.8	227.1	−13.2	99.7	453.1	252.7
6	10	562.3	461.0	708.0	686.3	−159.0	324.1	344.7	176.2
7	10	882.1	1367.4	414.9	500.4	−49.7	346.2	264.5	111.6
Time (m s)									
Mean	61	−2.6*	2.2	−3.4*	3.7	−3.3	3.6	−3.3	7.2
1	9	−2.9	1.5	−3.7	1.5	−5.4	2.9	−4.4	1.8
2	8	−1.5	1.2	−1.1	1.6	−0.9	2.6	2.0	6.5
3	7	−2.6	2.2	−2.2	4.5	−3.6	2.8	−5.5	8.7
4	7	−1.8	0.9	−4.4	3.5	−5.8	3.5	−2.1	0.9
5	10	−5.8	1.7	−7.7	4.1	−6.6	1.9	−5.3	10.7
6	10	−1.9	2.2	−2.3	3.2	0.1	3.3	−4.3	6.4
7	10	−1.1	0.9	−2.2	2.6	−1.5	2.1	−2.8	7.9
Differences between hind limb sandpaper and sand surface amplitudes and times									
Amplitude ($m\,s^{-2}$)									
Mean	69	269.4	453.4	689.8	1018.4	−159.1	381.4	423.8*	492.2
1	11	110.6	254.8	1156.3	800.9	−134.7	309.4	377.7	185.9
2	9	701.4	324.7	240.6	90.1	59.6	123.3	871.7	603.3
3	9	721.7	151.5	713.5	644.0	−123.7	266.4	264.5	209.8
4	9	291.4	827.4	1729.8	1319.1	−119.2	361.1	869.2	860.7
5	10	227.1	273.1	1128.8	636.6	−714.9	158.9	273.7	202.6
6	11	35.8	178.4	−461.4	1003.5	250.6	265.3	128.2	237.8
7	10	−72.3	166.4	451.1	479.8	−345.2	242.3	289.1	296.6
Time (m s)									
Mean	69	−1.8*	2.0	−1.9	2.7	−2.2	5.1	−3.9	6.3
1	11	−2.2	1.4	−2.2	2.5	−2.3	2.1	−3.7	3.0
2	9	−1.6	2.0	0.2	2.2	−9.9	4.3	−4.7	11.4
3	9	−2.5	1.4	−3.3	1.3	−2.3	2.5	−4.6	3.3
4	9	−2.8	2.0	−4.8	2.0	−2.7	4.7	−7.9	4.4
5	10	−3.1	1.8	−1.8	2.5	−0.2	4.5	−8.0	3.9
6	11	−0.8	0.9	−0.2	2.5	−2.2	3.8	−1.7	2.6
7	10	−0.1	2.4	−1.6	2.3	3.6	3.0	2.1	6.2

z_1 and z_2, first two main vertical deceleration peaks; y_{min} and y_{max}, minimum and maximum values in the horizontal deceleration curve; *N*, number of strides for the group of horses and for each horse in the group. As sand surface data were subtracted from sandpaper data, negative differences were obtained when the sand surface variables had higher values.

*Significant differences between sandpaper and sand surface values ($P < 0.001$).

In the kinematic data, in a majority of the impacts on sand there were missing values. This was from the first contact and through the initial part of the hoof braking, probably due to dust covering the markers. There were not enough data for a complete analysis to be considered. However, the complete recordings revealed a pattern of the fetlock joint angle in accordance with the angle–time diagrams presented by Back *et al.*[21,22] and Johnston *et al.*[15,16], with a short period of slow movement of the fetlock joint angle before the rapid extension of the joint at a time that seemed to be in accordance with the rapid increase in the vertical load.

Discussion

The present study was designed to describe differences in kinematics and kinetics of the hoof on two different ground surfaces. The low resonance frequency of the force plate rendered it unable to measure the details in the ground reaction force associated with the transient events of high frequency described *in vivo* and *in vitro* from accelerometer studies on the hoof impact[9–15,18]. Furthermore, the absolute values of the force plate–as well as the accelerometer variables–were influenced by the filtering methods[10,18]. However, the magnitudes of the variables presented were of interest for relative comparisons. With the method used to study the difference between hoof impacts on the two surfaces within each individual, influencing factors were set as constant as possible[10,20].

The kinematic and kinetic data, describing the initial part of the stance phase, were recorded at slow trot. The speed was varied, with the purpose of studying the correlations between speed and magnitudes of the different variables; however, no correlation was found. In other studies, the correlations between

Table 2 Force plate variables of horses 1–7 and means for all horses

Horse	N	DF_{z1} ($N s^{-1}$) Mean	SD	DF_{z2} ($N s^{-1}$) Mean	SD	Fy_{max} (N) Mean	SD	Fy_{min} (N) Mean	SD
Differences between forelimb sandpaper and sand surface amplitudes and time									
Amplitude									
Mean	61	11.5*	9.9	3.2*	6.8	4.8	155.1	−152.2*	141.8
1	9	15.1	6.2	8.2	7.7	80.5	115.2	−121.8	91.1
2	8	6.0	17.1	2.9	4.2	20.8	133.0	−131.2	202.5
3	7	13.5	4.2	4.8	5.3	−76.6	248.9	−197.1	196.6
4	7	17.4	14.3	2.5	9.2	31.9	115.5	−155.9	189.7
5	10	11.1	4.6	3.2	6.0	40.1	113.2	−222.2	56.1
6	10	12.2	5.0	0.9	8.2	−48.8	155.6	−97.7	126.7
7	10	6.5	10.0	0.9	4.7	−20.1	174.7	−147.0	118.6
		DF_{z1} (m s)		DF_{z2} (m s)		Fy_{max} (m s)		Fy_{min} (m s)	
Time									
Mean	61	−1.2	3.4	−1.7	3.4	−7.5	14.8	−4.9*	5.8
1	9	−2.1	1.5	−1.8	1.5	−13.2	2.4	−5.7	3.2
2	8	−2.0	3.1	−3.2	3.4	−10.8	4.5	−6.3	4.9
3	7	−0.3	2.4	−0.8	2.3	4.3	19.1	−3.2	5.8
4	7	1.9	5.1	1.1	4.3	−9.9	1.9	−2.5	5.1
5	10	−4.3	2.4	−5.2	2.8	−17.3	14.6	−11.4	7.0
6	10	0.7	3.5	−0.3	3.6	−8.3	6.4	−2.7	5.0
7	10	−1.1	1.5	−0.7	1.9	4.3	23.0	−1.5	2.9
Differences between hind limb sandpaper and sand surface amplitudes and times									
		DF_{z1} ($N s^{-1}$)		DF_{z2} ($N s^{-1}$)		Fy_{max} (N)		Fy_{min} (N)	
Amplitude									
Mean	69	18.4	14.1	9.7*	12.7	332.1*	199.5	−112.2	157.3
1	11	24.0	7.2	24.2	14.1	352.7	190.2	−137.5	91.3
2	9	−2.8	11.9	17.2	9.3	236.2	193.5	−337.0	166.3
3	9	9.3	7.3	1.3	4.9	174.9	89.4	5.3	92.5
4	9	36.0	9.8	12.4	9.6	445.6	229.7	−95.0	151.6
5	10	25.6	8.0	9.3	8.1	457.2	191.6	−29.3	53.3
6	11	16.3	11.6	1.9	12.9	353.9	224.6	−166.4	146.2
7	10	19.0	4.3	1.0	5.2	286.0	113.7	−26.3	117.0
		DF_{z1} (m s)		DF_{z2} (m s)		Fy_{max} (m s)		Fy_{min} (m s)	
Time									
Mean	61	−1.6	4.4	−0.6	4.9	−9.9*	4.8	−5.3	8.8
1	9	−1.3	2.7	−2.2	2.0	−15.9	5.1	−13.6	3.1
2	8	−8.0	7.4	−6.0	7.8	−7.8	5.7	−10.8	5.6
3	7	−1.9	1.8	0.0	5.1	−9.0	2.6	−4.0	7.1
4	7	−1.3	2.0	0.0	1.8	−11.7	2.8	1.6	13.9
5	10	−1.0	3.3	0.3	4.2	−10.9	4.3	−2.4	7.8
6	10	0.9	3.6	1.9	4.5	−5.9	1.5	−7.0	1.6
7	10	0.3	1.7	1.3	3.0	−8.0	2.2	0.5	7.4

DF_{z1} and DF_{z2}, local maxima of the time derivative of the vertical ground reaction force (GRF); F_{ymax}, maximum of the cranio-caudal GRF, followed by a local minimum F_{ymin}; N, number of strides for the group of horses and for each horse in the group. As sand surface data were subtracted from sandpaper data, negative differences were obtained when the sand surface variables had higher values.
*Significant differences between sandpaper and sand surface values ($P < 0.001$).

speed and acceleration peaks[11], as well as between the speed and the vertical force, have been reported[23,24]. In the latter studies, however, the maximum force was compared and not the impact characteristics, as in the present study.

The higher frequency content and amplitudes in the sandpaper measurements are thought to have been caused by a higher friction between hoof and ground compared with the sand surface (Fig. 1).

In connection with this and based on the earlier studies[25,26], it is plausible to suggest that high friction between hoof and ground, as in the case with the sandpaper, also increases the transients which transmit through the distal limb, resulting in a higher mechanical stress and risk for injury. However, studies on the hoof impact reported by Lanovaz *et al.*[14] suggest that the soft tissues in the hoof function as a low-pass filter and that most of the transients are attenuated in the hoof or distal to the proximal phalanx[12] or the fetlock joint[9,13].

The sand surface was assumed to allow relatively free and normal hoof movements following first contact[25] and the sandpaper surface was chosen to simulate high friction to the unshod hoof, resulting in a faster horizontal hoof breaking. The overall characteristic patterns of the vertical and cranio-caudal GRFs and decelerations, during the hoof-braking period described earlier on the sand surface[10], were evident also on the sandpaper surface (Fig. 2). However, significant differences in the results between the two surfaces indicate that the distal limb was subjected to higher mechanical stress on the sandpaper as compared with sand.

On sandpaper, there was a shorter time between first contact and z_1, which is suggested to be caused by an earlier onset of the hoof braking. The higher magnitude of z_1 in the forelimb may be an effect of a combination of the higher friction and the relative higher vertical landing velocity compared with the hind limb[27].

The maximum horizontal deceleration $y_{\max}$ was higher on sandpaper and corresponded to time with the increase in the F_z slope.

In the hind limb, the maximum of the horizontal force appeared significantly earlier and showed a higher magnitude on sandpaper, while $DF_{y\max}$ was higher for both fore- and hind limbs.

These results were expected on the surface with high hoof-braking properties.

Some differences in the force variables were observed between fore- and hind limbs, indicating a difference in the mechanical behaviour as well as in the stress subjected to the respective limb, which is in accordance with the earlier studies[10].

The fetlock joint angle has been described as a kinematic expression of the loading of the limb[28,29]. When the lateral fetlock joint angle was studied together with the force plate and accelerometer data on both surfaces there was only little, if any, movement measured during the period of low increase in force following first contact, which can also be seen in the joint-angle diagrams reported by Back *et al.*[21,22] and Johnston *et al.*[15,16]. This may be explained by the slow onset of the vertical and horizontal load and the successive disto-proximal loading of the limb[2].

The hoof deceleration could be divided into two main parts. The first part consists of z_1, which was always in the period of slow loading and fetlock joint movement. The second part followed at the increase of load and fetlock joint movement. Due to the loading pattern, the first part of the hoof braking probably involves only structures below the fetlock joint, but the second part may involve the entire distal limb. This is supported by the observed attenuation of impact-related shockwaves distal to the third metacarpal bone[9].

In conclusion, it was shown that high friction between the hoof and ground may cause increased mechanical stress to the structures of the distal limb also at a relatively slow trotting speed. In this study, however, there were no changes in the impact pattern with speed and the hoof deceleration was similar in the fore- and hind limbs. This paper contributes to the basic knowledge on the importance of the interaction between the hoof and the ground to the orthopaedic health of the horse.

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