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The effect of trimming of the frog on the impact accelerations of the equine hoof during walk and trot

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May 2009

Report 255

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Science Shop Wageningen UR
May 2009

Report 255

Colophon

TITLE
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of the equine hoof during walk and trot

COMMISSIONER
Working group Natural Balance Netherlands

FINANCIAL SUPPORT
Science Shop Wageningen University

PROJECT CO-ORDINATION
Hugo Hoofwijk, De Groene Link

PROJECT IMPLEMENTATION
Experimental Zoology Group, Wageningen University and Research Centre and
the Dutch Equestrian Vocational Education Centre, in cooperation with working group
Natural Balance Netherlands

LAY-OUT
Hildebrand DTP, Wageningen

PHOTOGRAPHS
De Groene Link, Johan van Leeuwen, Monique Haazelager, Natural Balance Working Group

CITATION
Further distribution of the report and citation are encouraged, provided that the source is
properly cited

ISBN
978-90-8585-186-8

SCIENCE SHOP WAGENINGEN UNIVERSITY
Report number 255, May 2009, www.wetenschapswinkel.wur.nl

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Working group Natural Balance Netherlands

The working Group Natural Balance is an organisation formed by Natural Balance farriers living and working in the Netherlands. The members are working according to the Natural Balance principles. This method originates in the United States and is developed by Gene Ovnicek.

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Preface

In Dutch farrier practice, some controversy exists about the most appropriate technique of trimming (and shoeing) horses. Besides the conventional, traditional, way of trimming, some groups advocate other trimming methods (e.g. Natural Balance, 'Natuurlijk bekappen', Ramey and Strasser). The conventional and each of the alternative groups claim that their way of trimming is the best for the horse's health. Their often lively debate seems to be based more on emotions than on scientific data. Several alternative trimming methods (such as Natural Balance) advocate a well developed frog as a prerequisite for an optimal landing and a more even distribution of the loads that are transmitted through the hoof and distal phalanx. A well developed frog could help to reduce the shear loads between the hoof wall and the underlying epithelium, and might also lead to lower impact accelerations.

To shed some light on this issue, we describe in this report a pilot study that addressed the effects of the trimming of the frog of the equine hoof on the impact accelerations during walking and trotting on a treadmill.

Table of contents

Abstract

When hooves are conventionally trimmed, the frog will not or barely have contact with the ground surface. The energy absorbing function of the frog will be reduced or absent. We hypothesize that a hoof of which the frog has full contact with the ground surface will have lower accelerations at impact than a hoof of which the frog has no or barely contact with the ground surface. To test this hypothesis, 10 clinically sound Dutch Warmblood horses received successively three treatments 1. Untrimmed (control); 2. Hoof wall trimmed + frog untrimmed; 3. Hoof wall trimmed + frog trimmed.

The accelerations were measured with a tri-axial accelerometer, placed at the left fore hoof. The horses walked at 5.6 km/h and trotted at 7.4 km/h on a treadmill. From the acceleration data, the acceleration at impact, the stride frequency and duty factor were determined.

There was no significant difference ($p \geq 0.05$) between the three treatments for acceleration at impact (walk: 32.4±0.4 g and trot: 87.1±8.3 g), stride frequency (walk: 0.87±0.01 strides/s and trot: 1.35±0.01 strides/s) and duty factor (walk: 0.64±0.01 for all treatments and trot: 0.42±0.01, 0.43±0.01, 0.42±0.01 for treatments 1, 2, 3, respectively).

For these parameters, with the current experimental set-up, there is no significant statistical difference between the effects of a high frog-ground contact level and a reduced frog-ground contact level on the acceleration amplitudes of the hoof. There seemed to be no effect of trimming of the frog on the measured parameters. We cannot exclude, however, that a different experimental set up (for example with a concrete floor) could yield significant differences.

Samenvatting

Bij conventioneel bekapte hoeven heeft de straal niet tot nauwelijks contact met de grond. Het wordt verondersteld dat de energieabsorberende functie van de straal hierbij gereduceerd is of mogelijk zelfs vrijwel afwezig is. Het valt te verwachten dat een hoef waarvan de straal een goed contact maakt met de ondergrond een geringere impactversnelling zal hebben dan een hoef waarvan de straal niet of nauwelijks de grond raakt. Om deze hypothese te testen ondergingen 10 klinisch gezonde warmbloedpaarden drie achtereenvolgende behandelingen; 1. Onbekapt (controle meting); 2. Bekapte hoefwand + onbekapte straal; 3. Bekapte hoefwand + bekapte straal.

Versnellingen zijn gemeten met een tri-axiale versnellingsopnemer die op de laterale zijde van de linker voorhoef was geplaatst. De paarden stapten met een snelheid van 5.6 km/h en draafden met een snelheid van 7.4 km/h op een lopende band. Met behulp van de versnellingsgegevens zijn de impactversnelling, de pasfrequentie en de relatieve sta-fase bepaald.

Er was geen significant verschil ($p \geq 0.05$) tussen de drie behandelingen voor de impactversnelling (stap: 32.4±0.4 g en draf: 87.1±8.3 g), de pasfrequentie (stap: 0.87±0.01 passen/s en draf: 1.35±0.01 passen/s) en de relatieve sta-fase (stap: 0.64±0.01 en draf respectievelijk: 0.43±0.01, 0.42±0.01 en 0.43±0.01 voor de drie behandelingen).

Voor deze parameters bij deze proefopzet is geen significant verschil gevonden tussen een hoge en geringe mate van straal-grond contact; het bekappen van de straal lijkt geen invloed te hebben op bovenstaande parameters. Het is echter niet uit te sluiten dat er bij een andere proefopzet (bijvoorbeeld bij lopen op een betonvloer) wel verschillen gevonden kunnen worden.

1 Introduction

1.1 The equine industry

The last decades, the Dutch equine industry has rapidly increased in size and is still growing. At the end of 2006, 456,000 people were active in the horse industry and about 60,000 people were active in competitive equestrian sports [1].

With this growth, the demand for animal health and welfare increases in the Dutch horse industry. Lameness is one of the most common health problems in horses and is a major cause of wastage of horses [2,3]. Improper hoof care and hoof related problems are factors that may contribute to, and even cause lameness. A large proportion of the lameness seen today could have been prevented or treated through good farriery [4]. Proper hoof care is essential to prevent lameness [5].

Due to the common housing conditions (23 h/day in a stable), nutrition, and the way in which the horses are used, the hoofs need to be trimmed. Usually every 6-8 weeks, a farrier comes to trim or shoe the horses. Trimming is necessary when the growth is greater than the wear, shoeing is necessary when the wear is greater than the growth. Due to growth and wear, the length of the toe of the hoof increases with approximately 8-10 mm/month, the quarters with 6-8 mm/month and the heels with 4-5 mm/month [6]. Even the conformation of the legs might be corrected by trimming and/or shoeing.

1.2 The hoof

The bony skeleton of the hoof consists of the distal phalanx (P3) (or coffin bone), the navicular bone and part of the middle phalanx (P2) (or short pastern bone). These three bones together form the distal interphalangeal joint, also known as coffin joint (figure 1) [6].

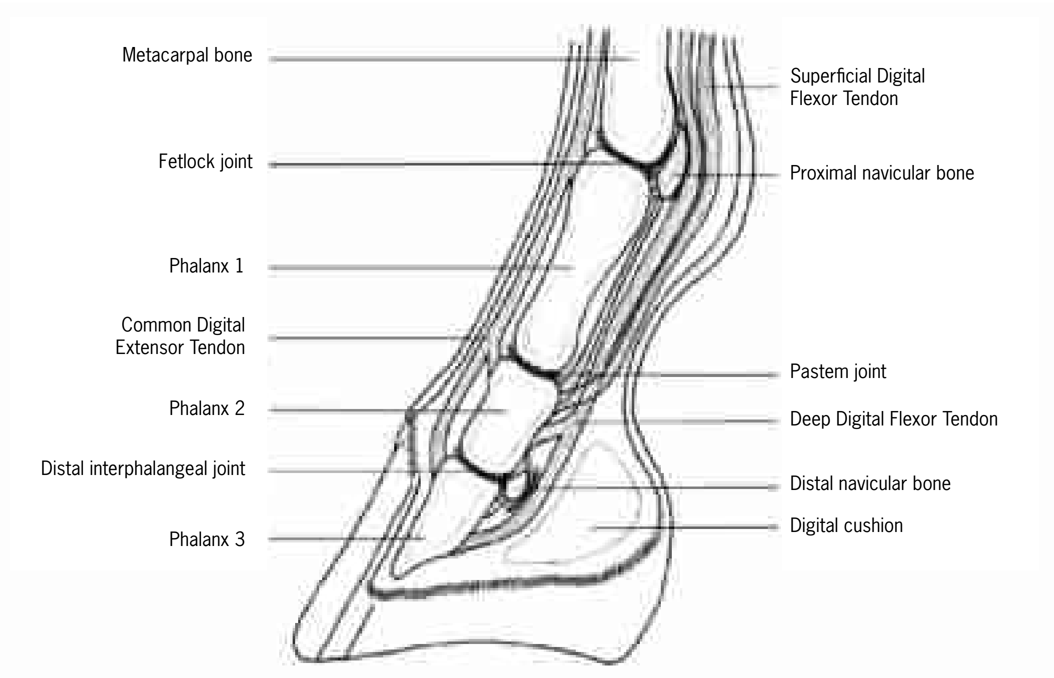


Figure 1. Sagittal section of the equine distal lower limb [7].

The hoof capsule of the horse consists of horn, belonging to the claw of the third digit. It can be divided in five parts: the coronet, the horn wall, the sole, the frog and the heels (figure 2) [6]. The frog is located on the palmar/plantar (bottom) side of the hoof, has approximately the shape of a triangle and is elastic. The digital cushion overlies the frog and is partly placed between the ungual cartilage (C-shaped cartilage on both lateral sides of the distal phalanx within the hoof capsule). The digital cushion consists of a meshwork of collagen and elastic fiber bundles, with small areas of adipose tissue (fat). Owing to its viscoelastic properties, the digital cushion absorbs and dissipates energy of the work done by the impact forces, when the hoof hits the ground surface, but functions also as a spring. The digital cushion bulges into the bulbs of the heel that are separated superficially by a central shallow sulcus (groove in the underside of the horse's hoof, in the middle of the frog) [8].

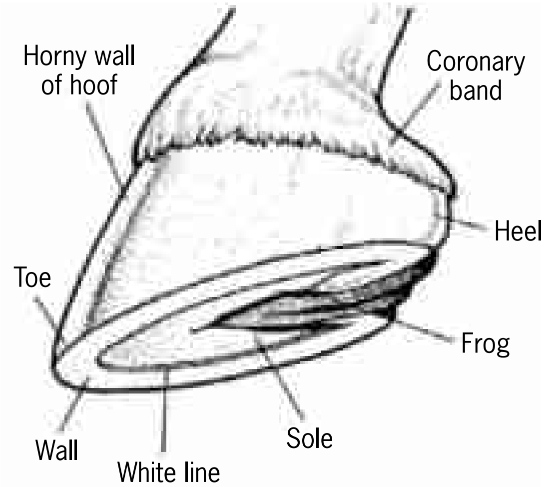


Figure 2. The different structures of the hoof. [9]

1.3 The mechanism of the hoof complex

Different theories exist about the deformation of the hoof and the underlying tissues during the landing and support phase. A commonly accepted version is described below.
When the hoof hits the ground surface, a mediolateral expansion of the hoof wall in relation to the inner bony skeleton, the vascular network, elastic and connective tissues and damping tissues (e.g. digital cushion) takes place. The moving and bending of the elastic horn of the heels absorbs energy. At the same time, the pastern is rotating downward, pressing the second phalanx down and back upon the digital cushion. The digital cushion expands outward, pressing against the cartilages of the digit, spreading the quarters even more [10]. The frog becomes slightly wider and more flattened. The opposite happens when the hoof is lifted. Deformation of the hoof enables the hoof to act as a pump for the blood circulation [5]. This process is known as the hoof complex mechanism (figure 3). During full ground-frog contact, the frog will absorb energy directly at the first contact of the hoof with the ground surface. When the hooves are conventionally trimmed (and shod), the frog will not or barely have contact with the ground surface. The energy absorbing function of the frog is supposed to be reduced or absent as a result of this treatment. A combined loading of the hoof wall and the frog will presumably result in a lower load of the hoof wall (compared to an unloaded frog), and hence to lower shear stresses (the load per unit area parallel to a surface) on the hoof lamellae. Unfortunately, it is impossible to measure the internal stresses in the hoof and underlying tissues.

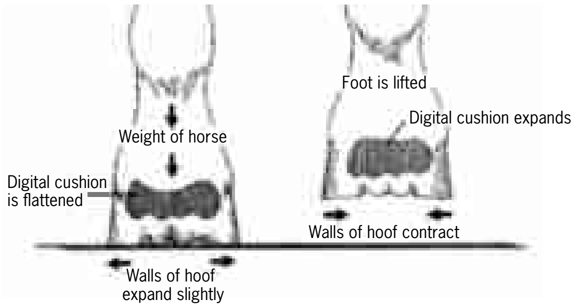


Figure 3. Commonly accepted mechanism of the hoof complex. A mediolateral expansion of the hoof wall in relation to the inner bony skeleton, the vascular network, elastic and connective tissues and damping tissues [11].

1.4 Hypothesis

The mechanism described above leads to the hypothesis that a hoof of which the frog makes full contact with the ground surface, will have lower accelerations at impact than a hoof of which the frog makes no or barely contact with the ground surface. To test this hypothesis, the accelerations at impact were determined of horses that were firstly trimmed such that the frog has full contact with the ground surface and were secondly trimmed such that there was reduced contact with the ground surface.

Acceleration of the hoof

Photographs

Frog - ground contact area

2 Material and Methods

2.1 Experimental set up

This experiment was approved by the Wageningen University Animal Experimental Committee (Dier Experimenten Commissie). Data were collected from horses owned by 'The Dutch Equestrian Vocational Education Centre'.

Ten clinically sound Dutch Warmblood horses with an age of 14±2 years and withers height of 1.65±0.02 m were selected. The horses successively obtained three different treatments by a farrier at three different days:

1. *Untrimmed.*
   The horseshoes of the four hooves were removed but no trimming occurred. The horses were last trimmed 4-8 weeks before the experiment. This treatment was meant as a reference measurement.
2. *Hoof wall trimmed + frog untrimmed.*
   The hooves were trimmed according to the conventional hoof trimming method, while creating as much frog-ground contact as possible. The latter is not always the case in conventional trimming.
3. *Both hoof wall and frog trimmed.*
   The hooves had still the conformation as obtained from treatment 2, except that now the frog was trimmed in order to minimize the frog-ground contact area.

The day after the treatment, the horses walked (5.6 km/h) and trotted (7.4 km/h) at the treadmill for maximally ten minutes, during which accelerations were measured. The horses were measured 24 h after the treatment in order to give the horses time to adapt to the new situation. After the measurements, the horses directly obtained their new treatment.

2.2 Data collection

Three sets of data were collected during the experiment:

Acceleration of the hoof	Accelerations were measured using an tri-axial accelerometer. *A video recording of the acceleration measurement can be found at http://www.wetenschapswinkel.wur.nl/NL/projecten/Projecten2009/hoefverzorging+paarden/*
Photographs	Pictures were made from the front and lateral side of the hoof, to determine the position of the accelerometer.
Frog - ground contact area	A print of the latex painted palmar side of the hooves was made, to get an impression of the frog-ground contact area.

2.3 Measurement equipment

The accelerations were measured using a tri-axial ceramic shear accelerometer (type 8763A500, Kistler, Kistler Instrument Corporation, Amherst, NY). This accelerometer has a sensitivity of x=10.49 mV/*g*, y=9.91 mV/*g*, z=10.55 mV/*g*, a transverse sensitivity of 5.0 %, a range of 500 *g*, a maximum range of 1,000 *g*, and a frequency response of 1 to 12,000 Hz, where *g* is magnitude of the acceleration of gravity. Its mass is 3.3 grams and its size is 10.2 x 10.2 x 17.5 mm.

The accelerometer was firmly attached to its casing (figure 4a) byscrews. This casing was screwed to a round plate, which in turn was mounted to the lateral side of the left forehoof (figure 4b and 4c). Mounting was done with a two component epoxy adhesive (Super Mix, Pattex, Henkel Nederland B.V. Nieuwegein, The Netherlands) after thoroughly sanding the hoof. The plate was firmly attached to to the hoof before the experiment started and removed with a chisel after the last experiment had been conducted.

The data cable (length 4 m) was attached to the limb by some tape and lead out the treadmill where it was attached to the power supply/signal conditioner (Piezotron® Coupler, Type 5134B Kistler, Kistler Instrument Corporation, Amherst, NY). The signal was amplified ten times in the x-, and y-directions and 5 times in the z-direction and filtered with a 1 kHz low pass filter. Data were digitized at 2.5 kHz via a commercial data acquisition card (Multifunction DAQ, model USB-6008 National Instruments, Austin,TX).

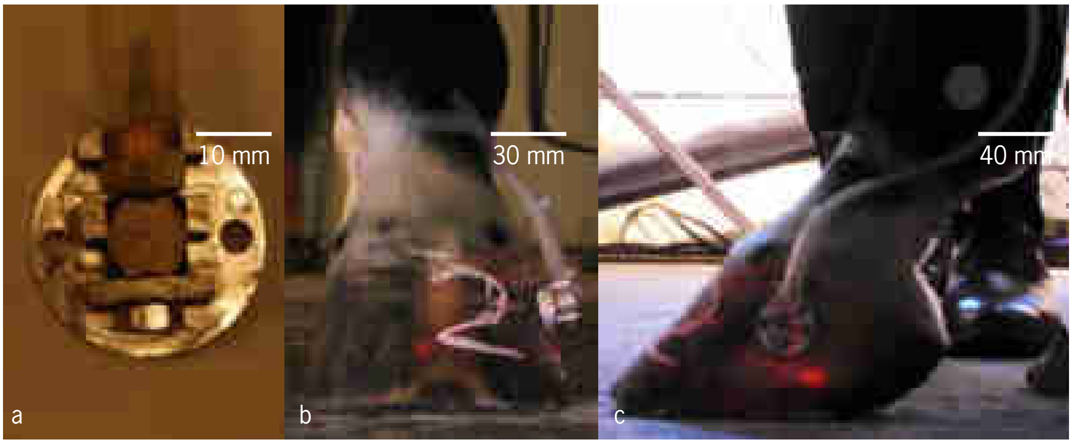


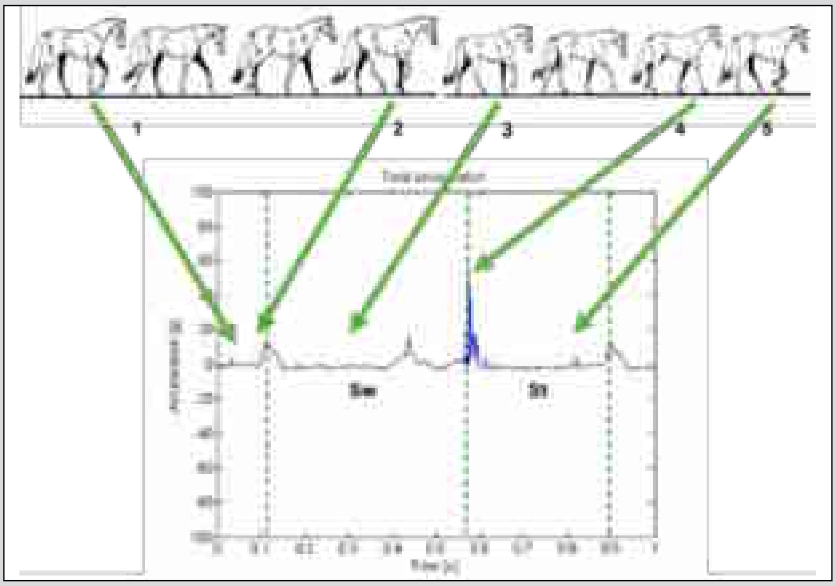
Figure 4. Placement of the accelerometer. (a) The accelerometer attached to a casing by a screw. (b, c) The accelerometer with casing attached to the lateral side of the equine left fore hoof.

2.4 Data analysis

Data were recorded, analyzed and viewed using customized software (Matlab 7.3.0.267, The Mathworks Inc., Natick, Massachusetts). The acceleration of the hoof is completely characterized if both the linear acceleration at at least one location (with three components) and the rotational acceleration (also with three components) could be measured. In the present study, we have measured only the linear acceleration components at one location (lateral side of the hoof). The amplitude of the acceleration vector was calculated from the acceleration components along the *x*-axis, *y*-axis and *z*-axis, defined in the frame of the accelerometer (and hence the hoof because of the rigid connection between the two):

Amplitude of the acceleration = $\sqrt{(a_x^2 + a_y^2 + a_z^2)}$

From the acceleration amplitude, five parameters were derived[1]:

Acceleration at impact	The acceleration at the time the hoof hits the ground. The data are normalized with respect to the magnitude of the acceleration of gravity *g*.
Stride frequency	Stride frequency is the number of strides per second.
Stance phase & Swing phase	During a stride, each limb has a stance phase (St) and a swing phase (Sw). The stance phase is the period of hoof contact with the ground, the swing phase is the period when the hoof has no contact with the ground as it swings forward in preparation for the next stance phase [12]. The determination of the stance and swing phase from the acceleration data is shown in figure 5. The unit of measure for the stance phase and the swing phase is seconds (s).  *Figure 5. Acceleration data of 1 stride cycle of 1 horse at walk. The horse has his hoof on the ground (1), after which it will leave the ground. It moves it a little backwards, after which it will bring it forward (2). It will move it back (3) and hit the ground (4). It will keep it's hoof on the ground (4) until it will move it up again (5). The moments where the toe gets off and on the ground are defined.*
Duty factor	Duty factor is the relative amount of time the hoof spends on the ground. It is calculated by: $\text{Duty factor} = \frac{\text{Stance phase}}{\text{Total stride time}}$ A decrease in the duty factor will generally lead to higher peak loads during the landing and stance phase.

A change in the stride parameters (stance phase and swing phase, duty factor and stride frequency), could indicate that a change in locomotion pattern has occurred.

[1] For each of these parameters, 20 strides per horse were analysed and averaged.

2.5 Statistics

It was investigated whether the data were normally distributed by the application of a Kolmogorov-Smirnov test. The dataset was considered to be normally distributed when $p \geq 0.05$. Because the dataset was indeed found to be normally distributed, a repeated measures test with a post-hoc Bonferroni approach was used to test for differences between the three different treatments. Differences were considered significant when $p < 0.05$.

Kolmogorov-Smirnov test	With this test, the samples are standardized and compared with a standard normal distribution.
Repeated measures test	The repeated measures test tests the equality of means. It is used when all members of a random sample are measured under a number of different conditions. As the sample is exposed to each condition in turn, the measurement of the dependent variable is repeated.
Post-hoc Bonferroni test	When multiple comparisons are made, this test is used to protect against making type I errors (falsely rejecting the null-hypothesis).

3 Results

3.1 Frog-ground contact area

An impression of the frog-ground contact area after each treatment, as described in paragraph 2.1, is shown in figure 6. A difference can be observed in frog-ground area between the three different treatments. The prints seem to suggest that the frog-ground area is reduced after trimming of the frog.

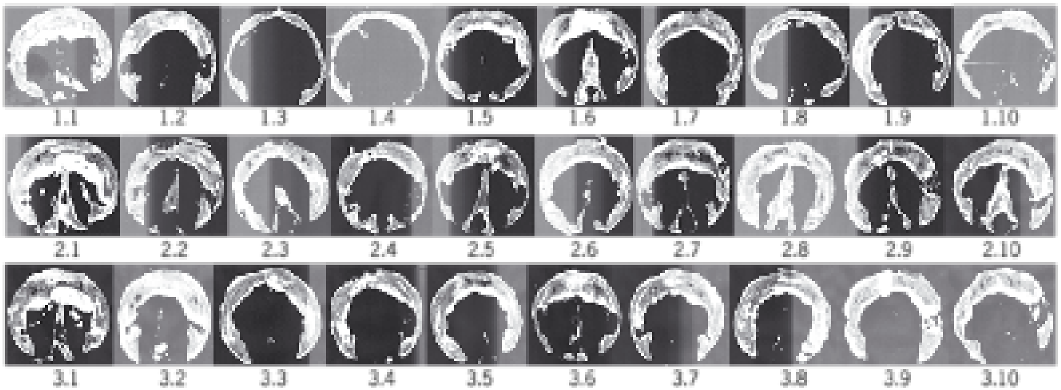


Figure 6. An impression of the frog-ground area of then horses after treatment 1.Untrimmed 2.Trimmed + frog untrimmed and 3.Trimmed + frog trimmed.

3.2 Acceleration at impact

At walk and at trot, there was no significant difference between the three different treatments for the acceleration at impact. At walk, acceleration at impact was 32.2±4.9 *g*, 32.1±10.1 *g*, and 32.8±11.9 *g* for the three treatments respectively. During trot, the acceleration at impact was 78.5±11.2 *g*, 94.7±16.7 *g*, and 90.0±24.4 *g* for the three treatments respectively.

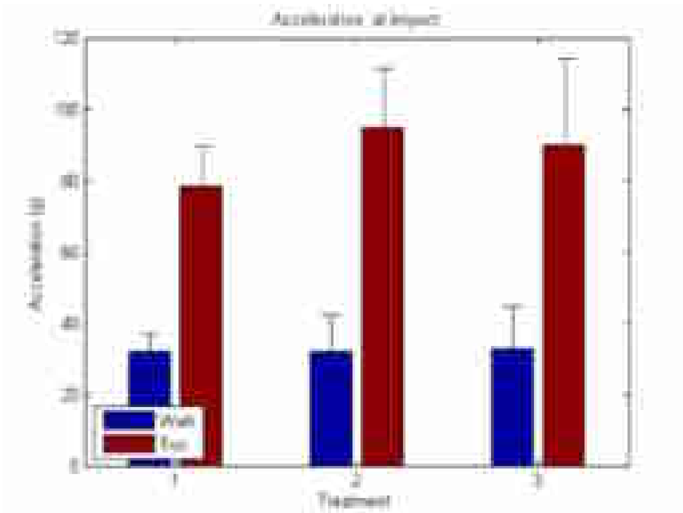


Figure 7. Peak acceleration at impact with standard deviation for walk and trot, after treatment 1. Untrimmed 2. Trimmed + frog untrimmed and 3. Trimmed + frog trimmed.

3.3 Stride frequency

The stride frequency was not different for the three treatments at both speeds (figure 8). The stride frequency for treatment 1 was 0.85±0.04 strides/s, for treatment 2 0.87±0.04 strides/s and for treatment 3 0.88±0.03 strides/s at walk. At trot, the stride frequency was 1.33±0.03 strides/s, 1.35±0.02 strides/s, and 1.36±0.03 strides/s for the three treatments respectively.

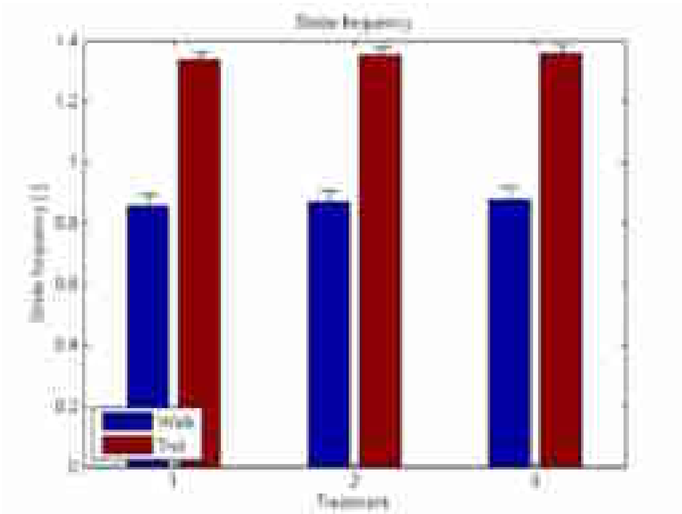


Figure 8. Stride frequency with standard deviation for walk and trot,
-after treatment 1. Untrimmed 2. Trimmed + frog untrimmed and 3. Trimmed + frog trimmed.

3.4 Duty factor

For both walk and trot, the duty factor was not significantly different for the three different treatments (figure 9). The duty factor during walking was 0.64±0.01, 0.64±0.01 and 0.64±0.01 for the three treatments respectively. At trot, the duty factor for treatment 1 was 0.43±0.01, for treatment 2 0.42±0.01, and for treatment 3 0.43±0.01.

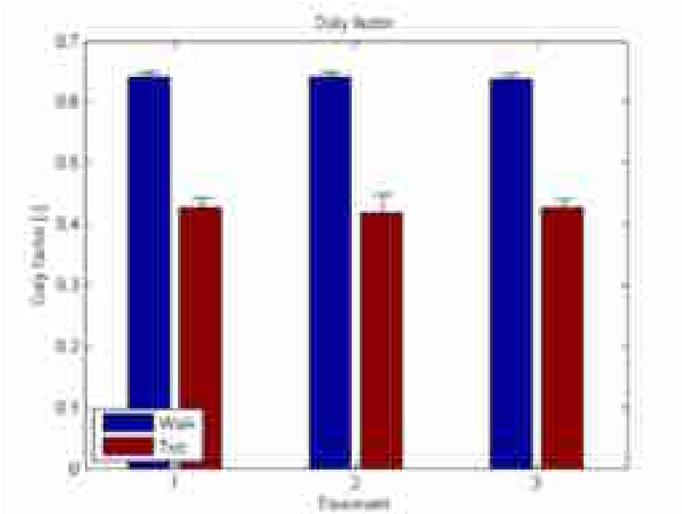


Figure 9. Duty factor with standard deviation for walk and trot,
after treatment 1. Untrimmed 2. Trimmed + frog untrimmed and 3. Trimmed + frog trimmed.

4 Discussion

4.1 Study design

The objective of this study was to determine the differences in acceleration at impact of the equine fore hoof with a high level of frog-ground contact area and a low level of frog-ground contact area. The hooves of the horses were treated in the following order: 1. untrimmed, 2. trimmed, but frog untrimmed and 3. trimmed, including the frog. To determine whether there was really less ground-frog contact area after treatment 3 compared to treatment 2, a print of the latex painted palmar side of the hooves was made. The amount of latex painted under the hoof, contact time of the hoof on the paper and load of the hoof on the paper, determines the amount of latex on the paper, and are all subject to influences by man and horse. However in this registration, the main factor responsible for the printed amount of contact area of the frog (in relation to the total contact surface of the hoof) is the amount of frog tissue in contact with the ground. Therefore this method should be considered as giving an impression of the frog-ground contact area, but its results should be interpreted with caution.

The accelerometer was placed at a metal plate, which was glued to the hoof. In this way, the accelerometer could be placed at the same location at each measurement. Unfortunately, the plates did not always remain attached to the hoof: six times the plate came off. When the plate came off, the adhesive remained attached to the hoof, not to the plate. Probably, the plate was not degreased enough and had too smooth a surface. In future experiments, this could be prevented by sand-blasting the plate and degreasing it with acetone. Also another mounting adhesive could be considered to prevent loosening of the plate. Because the total acceleration vector was calculated, the slight change in position and orientation after replacement did not significantly influence the parameters determined. One time, the plate remained attached to the hoof, but the connection of the accelerometer to the hoof was not strong enough. This resulted in unusable data that had to be excluded from the dataset.

In this study, the horses walked on a treadmill. The band of the treadmill is made of rubber and between the band and the ground surface there is some space, reducing the impact generated. The energy absorbing capacity of the band might be higher than the energy absorbing capacity of the frog. This could overshadow the effect of frog-trimming on the accelerations at impact. Walking on another substrate could have yielded different results than presented in this study.

The sample size was small and there was much variation in the accelerations at impact of one measurement at one speed of one horse. This might influence the statistics. However, we do not think that increasing the number of horses would make the difference between treatment 2 and 3 significant, owing to the small differences in average values and relative large standard deviations.

With the current approach, tissue loads of the hoof and underlying tissues cannot be determined.

4.2 Frog-ground contact area

The latex prints suggest that the frog-ground area was reduced after trimming the frog. This indicates that when comparing treatment 2 and 3, indeed a high frog-ground contact level and a reduced frog-ground contact level are compared.

4.3 Acceleration at impact

A slight decrease in the average peak acceleration at impact could be observed after treatment 3, compared to treatment 2. This could indicate that minimizing the frog-ground contact level would decrease impacts. However, this decrease is not significant and a larger dataset and other substrate should be considered. The (non significant) decrease may also be caused by the visco-elastic properties of the treadmill.

The accelerations at impact during walk (32.4±0.4 *g*) and trot (87.1±8.3 *g*) are higher compared to literature (trot 54.0±22.9 *g*) [13,17]. In our study, the horses walked on a treadmill instead of an asphalt tract and operated at a lower trotting speed. We would therefore expect lower accelerations at impact rather than higher accelerations. On the other hand, the (horizontal) friction between the hoof and the rubber surface of the treadmill was probably quite high, and might in fact be higher than the acceleration between an ion horse shoe and asphalt. This problem requires further research for a decisive answer.

4.4 Stride frequency and duty factor

There was no significant difference between high frog-ground contact level and reduced frog-ground contact level for both the stride frequency and the duty factor. According to these parameters, the frog-ground contact level had no effect on the locomotion pattern of the horses.

The stride frequency at walk 0.87±0.01 strides/s and trot 1.35±0.01 strides/s were comparable to literature (walk 0.87 strides/s [14], 0.93 strides/s [15]; trot 1.36 [13], 1.32 strides/s [14], 1.44 strides/s [15], 1.49 strides/s [16]). The duty factor was also comparable to literature for walk (0.64±0.00) and trot (0.60±0.01) (walk 0.67 [15], 0.61 [16]; trot 0.47 [12], 0.39 [15], 0.40 [16]).

5 Conclusion

For this experimental set-up, the accelerations at impact, the stride frequency and the duty factor did not differ significantly between a high frog-ground contact level and a reduced frog-ground contact level. There seemed to be no significant effect of trimming of the frog on these parameters. It is important to consider that the horses walked on a treadmill and the sample size was small. To exclude the effect of the treadmill, it would be interesting to study free walking and trotting of the horses on an asphalt track in a future work.

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