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Development of locomotor parameters of the flying pace of Icelandic Horses after application of weights to the palmar aspect of the hoof

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Summary

The study was aimed at obtaining kinetic and timely data of the flying pace of Icelandic Horses and evaluating the influence of weights applied to the palmar aspect of the hooves of both forelimbs on variables tested. Seven Icelandic Horses were ridden in flying pace, once without and once with added weights. Force at impact, force at end impact, force at lift off, cycle duration, stance phase duration, swing phase duration, swing phase length and overlap were recorded using computerkinematographic devices on the metacarpal and metatarsal region of each limb. Data was analyzed using a generalized linear model, type III sums of squares to determine F- and p-values, with significance threshold of $p \leq 0.05$, post-hoc analyses were performed as t-tests over least square means. Mean values with standard deviations were obtained, when looking at all horses together, weights influenced force at impact, force at end impact and force at lift off significantly, as well as the overlap, resulting in greater gait-uniformity. Great individual differences were noted. The effect was greatest in less experienced horses. Insight into effects of the widely practiced use of weight-application to the distal forelimbs in Icelandic Horses is given. Conclusively, this use might be most beneficial in less experienced horses, but be less effective in horses well-trained in performing the flying pace.

Keywords: Icelandic Horse / flying pace / biomechanics / weight / gait analysis

Einfluss von Ballengewichten auf biomechanische Parameter des Rennpasses von Islandpferden

Mit der Studie wurden einerseits kinematische und zeitliche Daten des Rennpasses von gerittenen Islandpferden erfasst und zum anderen der Einfluss von an den Ballen beider Vorderbeine angebrachter Gewichte auf die zuvor verwendeten Parameter evaluiert. Sieben Islandpferde wurden jeweils einmal ohne und einmal mit Ballengewichten 100m auf einer geraden Strecke mit festem ebenem Untergrund im Rennpass geritten. Mittels computerkinematographischer Sensoren am lateralen Metacarpus bzw. -tarsus aller vier Gliedmaßen wurden die verwendeten Parameter Beschleunigungen zum Zeitpunkt des ersten Aufsetzens, des vollständigen Bodenkontakts und des Abhebens vom Boden, Dauer eines Bewegungszyklus, der Stützphase und der Schwingphase, sowie Dauer des gemeinsamen Bodenkontakts der ipsilateralen Beinpaare (Overlap) während beider Läufe aufgezeichnet. Statistische wurden die Daten unter Verwendung eines verallgemeinerten linearen Modells Typ III Quadratsummen zur Bestimmung der F- und p-Werte mit einem Signifikanzwert von $p \leq 0{,}05$, post hoc-Analysen in Form von t-tests unter Verwendung der Least square-Mittelwerte analysiert. Für die Parameter wurden Mittelwerte mit der jeweiligen Standardabweichung ermittelt. Alle Pferde zusammen betrachtet beeinflusste der Einsatz der Ballengewichte die Parameter force at impact, force at end impact und force at lift off für jeweils drei Beine signifikant, ebenso den Overlap sowohl des rechten als auch des linken ipsilateralen Beinpaares. Die Veränderungen führten zu einer größeren Uniformität des Gangbildes, wobei eine starke individuelle Ausprägung der Auswirkungen erkennbar wurde. Der stärkste Effekt konnte bei im Rennpass unerfahrenen Pferden beobachtet werden. Durch die Ergebnisse werden Daten zum weit verbreiteten Einsatz von Ballengewichten im Islandpferdesport geliefert. Dieser Einsatz scheint den größten Einfluss auf den Gang bei weniger erfahrenen Pferden zu haben, bei Rennpass-erprobten Pferden hingegen von geringerem Effekt zu sein.

Schlüsselwörter: Islandpferd / Rennpass / Biomechanik / Gewicht / Ganganalyse

Introduction

The Icelandic Horse is known for its two special gaits, the tölt and the flying pace. Most research concerning biomechanical strains to date has been performed on racehorses or Warmbloods (*Holmström* et al. 1993, *Vilar* et al. 2008, *Setterbo* et al. 2009, *Oosterlinck* 2010), therefore little is known about the specific features of these two special gaits. Also their influence on the prevalence on certain orthopedic problems has not been studied to a broad extent (*Biknevicius* et al. 2004a). The use of weights for the purpose of enhancing the quality of the gait is widely distributed, but little is known about its consequences in regard to possibly detrimental effects on the musculoskeletal system. In accordance with the rules for Icelandic Horse sport events (FEIF 2011), 250g of protective equipment can be applied above the sole of the hoof of each leg.

In other breeds research has been done concerning different aspects using systems measuring the accelerative forces acting on the limbs (*Dallap Schaer* et al. 2006). The measuring system used in this study has been validated as a tool for gait analysis in horses (*Falaturi* 2001) and has also been utilized to characterize the motion pattern in jumping horses (*Falaturi* et al. 2001).

Two studies dealt with the racing gait of Standardbred pacers in order to determine factors influencing the racing speed (*Wilson* et al. 1988a, *Wilson* et al. 1988b). The effects of the weight of the shoeing and changes in hoof length were the topic of another study of interest (*Balch* et al. 1996), and one tested the influence of the shoeing on kinematic parameters (*Singleton* et al. 2003).

A study performed with Standardbred trotters trotting on a treadmill examined the effects of weights applied to the dorsal hoof wall of the horses (*Willemen* et al. 1994). It was shown that the weights had higher effects in horses with lower gait qualities. In these animals the parameters evaluated – namely the maximal flexion of the carpal joint, the length of pro- and retraction of the front limb – were influenced positively. The length and duration of the stride and relative duration of stance and suspension phase were not altered. The addition of 600g to the distal part of all four limbs resulted in an elongation of the stride period in the trot on a treadmill, but no changes in time of contact or duty factor (*Wickler* et al. 2004). The range of motion of the forelimbs of these horses was not influenced, that of the hindlimbs was increased by the weights. Another finding of this study was the increase of the metabolic rate of the animals by 6.7%. The authors hypothesized that the addition of weights might bear a higher risk of injury through exhaustion.

Icelandic Horses have also been the subject of a few studies. One study evaluated walk, trot, canter, tölt and flying pace using accelerometric devices in order to classify gait patterns biomechanically (*Robilliard* et al. 2007). The tölt of Icelandic Horses was the concern of two other studies; the devices used were a force plate and videographic capturing (*Biknevicius* et al. 2004a, *Biknevicius* et al. 2004b). The data collected are of a different nature than those acquired using accelerometric devices, which will provide new information about the characteristics of the gait. Another study dealt with the consequences of different velocities on the stride phases in the tölt (*Zips* et al. 2001). It was found that the clear four-beat without a suspension phase was altered with increasing speed to become a more laterally pronounced gait with a distinguishable suspension. Finally, the combined influence of speed and the addition of weight on the beginning and duration of the stance phase in tölting Icelandic Horses were investigated (*Pecha* et al. 2011). The influence of two different weights (170g and 280g) applied to the hooves of the forelimbs at two different speeds was tested by kinematic analysis, and it was found that overall the weights reduced the tendency to show a pronounced ipsilateral stance phase, but considerable individual differences in reaction to the combinations of speed and weight applied were observed.

A study with the same setup as the aforementioned one looked into the influence of speed and weight addition on the motion of the limbs during tölt (*Rumpler* et al. 2010). It was found that both significantly changed the potential energy, with higher values at higher speed as well as heavier weights. Also the height of the flight arc of the forelimbs was correlated positively with speed and weights with significant differences, whereas this parameter did not change in the hindlimbs. Further positive correlations were found between the different conditions and the minimum angle of the forelimb fetlock and carpal joints, but these were not significant.

The biomechanical characteristics of the flying pace were of interest in the present study and were determined by means of computerkinetomatic devices applied to all four limbs of the horses. Of special interest in this study was the influence of weights applied to both hoofs of the forelimbs on their palmar aspect.

Methods

Horses

Seven trained five-gaited Icelandic Horses, aged five to 16 years (mean±standard deviation (SD), 9.29±4.31 years); four geldings, one mare, two stallions; height at the withers 1.34 to 1.52m (1.43±0.09 m); body weight of 254 to 386 kg (328.14±52.35 kg), measured with a measuring tape (Horse and Pony height-weight tape, Feeding and Conditioning Guide, The Coburn Company, Inc., Whitewater, USA), were ridden by one experienced rider down a 100 m long straight track with a firm surface. Only clinically normal horses without any signs of musculoskeletal disorders were included.

Equipment and measurements

During all trials the horses were wearing computerkinematographic devices (marquis®CKG, marquis Tiermedizintechnik GmbH, Steinheim, Germany; weight 150g, size 90x60x35mm) on the lateral metacarpal/-tarsal aspect of all four limbs held in place by standard bandages (Stallbandagen, Eskadron, Werther, Germany; weight 30g). Each horse was ridden down the track at least twice, once wearing only bell boots as protective material (Springglocken, DMS-Reitsport, Rotenburg/F, Germany; weight 30g) on the pastern and hoof region (defined as lap 1), and once wearing protective boots with additional weight (Topreiter Lederballenboots, Topreiter, Neustadt, Germany; weight 210g) on the palmar aspect of the hooves (defined as lap 2) (Fig.

Fig 1 Preparation of the distal forelimb. (a) Horse wearing the accelerometric devices fastened to the limb using standard bandages, protective bell boots; (b) Horse wearing the accelerometric devices and weighed boots (210g) attached to the palmar aspect of the hooves.
Ausrüstung der distalen Vordergliedmaße. (a) Für Lauf 1: Beschleunigungsmess-Sensoren mittels Bandage befestigt, Springglocken als Schutzmaterial; (b) Für Lauf 2: Beschleunigungsmesssensoren mittels Bandage befestigt, Ballengewichte (210g) in Form von Ballenboots.

1a, b). If one of the aforementioned trials could not be used for data collection due to gait changes during the measuring period, a third lap was performed following the same protocol as the one not evaluable. The data were stored in the computerkinematographic devices and read out to the hard disk of a computer after each horse. Data processing and evaluation was performed using DIAdem 11.10f3806 TDM (National Instruments Ireland Resources Limited, Newbury, Ireland) and windows Excel (Windows Microsoft® Office Excel® 2007 SPS MSO, Microsoft Corporation, Redmond, Washington, USA).

Data collection and analysis

For each lap 14 consecutive stride cycles were evaluated. The limbs were defined as left (LH) and right (RH) hindlimb and left (LF) and right (RF) forelimb. Three different qualities of variables were evaluated. First those describing the accelerations and decelerations acting on the distal part of each limb during one stance cycle, measured as multiples of the gravitational acceleration [g], which in this study are represented by the force at impact (FI), defined as the moment when the heel bulb of the hoof makes first contact with the ground, the force at the end of impact (FEI), which describes the moment when the complete hoof is in contact with the ground, and the force at lift off (FLO), which means the instance when the tip of the hoof leaves the ground.

The second sets of variables are those related to timely relations between the different phases of a cycle. These were measured in seconds [s] and are the duration of the complete cycle (CD), measured from one moment of impact until the following, stance phase duration (Stance PD), lasting from the moment of impact until the moment of lift off, and the duration of the swing phase (Swing PD), which in contrast is defined as time between the moment just after lift off till until just before the next moment of impact. Another variable measured as a function of time was the overlap, which is defined as the time that the ipsilateral limbs synchronously spend in contact with the ground and was measured as the difference between the impact of the forelimb and the moment of lift off of the ipsilateral hindlimb and recorded for the left respectively right side of the body of the horse.

The last category of variable qualities was utilised to measure the length of the swing phase (Swing PL) in metres [m].

Statistical analysis

Statistical data evaluation was carried out with SAS (SAS Institute Inc., Cary, NC, USA; version SAS 9.1.3 Service Pack 4). The data were analyzed by a generalized linear model (GLM procedure), including fixed effects and random effect (horse). This model allows seeing the influence of various parameters on the studied variables. Furthermore, a test of correlation was made between some analyzed variables. First the influence of the parameters leg, lap, speed each and the influence of the interaction between run and leg on the variables FI, FEI, FLO, CD, Stance PD, Swing PD and Swing PL were evaluated with the factor horse as random effect. Type III sums of squares were obtained to achieve the F-values and their p-values. The significance threshold was set to 0.05. Post-hoc analyses were carried out using t-tests over the least square means (LSM). The mean values and their standard deviation were assessed. In a second step the aforementioned procedures were repeated to test the effect of the left respectively right pair of limbs and of the parameter run on the variable overlap.

Results

The number of laps performed by each horse and their use for further analysis were recorded (Table 1). The mean values and their standard deviations for the variables tested are shown in relation to the leg and lap number (Table 2) respectively side of the body and lap number (Table 3). The test of the LSM was done for the parameters leg, lap, the combination of leg and lap (leg*lap) and for the combined influence of side and lap (side*lap).

Looking only at the effect of the legs comparing the hind- respectively forelimbs with each other, significant differences comparing the LH and RH could only be found concerning FI ($p<0.0001$). The forelimbs significantly differed in the values for Stance PD ($p=0.0003$), Swing PD ($p<0.0001$) and swing PL ($p<0.0001$). For FEI, FLO and CD no significant differences could be found between the pairs of interest. Concerning

Table 1 Number of laps performed in each horse, indicating the laps used for further analysis / *Anzahl der von jedem Pferd durchgeführten Läufe, mit Kennzeichnung der für die weitere Analyse verwendeten Läufe*

Horse No.	Lap 1	Lap 2	Lap 3
1	★	+	●
2	+	★	†
3	★	★	–
4	★	★	–
5	★	+	●
6	★	★	–
7	★	★	–

Lap 1: First lap, with the horse only wearing protective bell boots, Lap 2: Second lap, with the horse wearing weighted boots, Lap 3: Third lap, only performed when needed to collect valid data. ★ = lap used for further analysis, + = recorded lap, data not used for analysis, ● = lap repeating the measurement with bell boots, data used for analysis, † = lap repeating the measurement with weight boots, data used for analysis, – = no third lap was undertaken.

Lap 1: Erster Lauf, bei dem das Pferd Schutzglocken trägt, Lap 2: zweiter Lauf, das Pferd trägt Ballengewichte, Lap 3: Dritter Lauf, der nur im Bedarfsfall durchgeführt wird, um valide Daten zu erhalten. ★ = für weitere Analyse verwendeter Lauf, x = aufgezeichneter Lauf dessen Daten nicht zur Analyse verwendet wurden, ● = Wiederholungslauf mit Schutzglocken, Verwendung der Daten zur Analyse, † = Wiederholungslauf mit Ballengewichten, Verwendung der Daten zur Analyse, - = ein dritter Lauf wurde nicht durchgeführt.

Table 2 Mean values ± standard deviations (X±SD) of the variables evaluated in relation to leg and lap in Icelandic Horses ridden in flying pace / *Mittelwerte ± Standardabweichungen (X±SD) der untersuchten Variablen von im Rennpass gerittenen Islandpferden im Bezug auf Bein und Lauf*

Leg	Lap	FI (X±SD)	FEI (X±SD)	FLO (X±SD)	CD (X±SD)	Stance PD (X±SD)	Swing PD (X±SD)	Swing PL (X±SD)
LH	1	4.4999 ±3.0803	41.4911 ±15.2266	−13.9994 ±8.7762	0.4104 ±0.0450	0.1495 ±0.0394	0.2633 ±0.0179	2.2768 ±0.3659
	2	4.5286 ±2.6715	43.0070 ±10.5271	−17.1489 ±8.6751	0.4000 ±0.0172	0.1341 ±0.0188	0.2671 ±0.0123	2.5526 ±0.2662
RH	1	2.6352 ±4.9017	42.5966 ±16.5295	−12.7934 ±9.0175	0.4075 ±0.0355	0.1470 ±0.0361	0.2604 ±0.0219	2.2570 ±0.4015
	2	0.2352 ±6.2612	44.3245 ±11.0220	−14.5026 ±8.8847	0.4931 ±0.0275	0.1313 ±0.0148	0.2700 ±0.0114	2.5786 ±0.2441
LF	1	1.2829 ±4.1979	28.5636 ±9.8743	−14.8800 ±10.8168	0.4033 ±0.0275	0.1587 ±0.0562	0.2457 ±0.0439	2.1300 ±0.4621
	2	−3.3461 ±6.4727	31.7230 ±6.5237	−14.1978 ±12.3691	0.3985 ±0.0234	0.1399 ±0.0286	0.2609 ±0.0297	2.4812 ±0.2839
RF	1	−0.5555 ±4.4574	31.0510 ±9.7369	−13.9363 ±9.5199	0.4068 ±0.0353	0.1425 ±0.0251	0.2655 ±0.0257	2.2727 ±0.2421
	2	−2.1408 ±5.4976	32.5283 ±7.1439	−12.0380 ±10.0577	0.4010 ±0.0222	0.1400 ±0.0278	0.2608 ±0.0287	2.4829 ±0.2900

LH: left hindlimb, RH: right hindlimb, LF: left forelimb, RF: right forelimb, FI: force at impact [g], FEI: force at end of impact [g], FLO: force at lift off [g], CD: cycle duration [s], Stance PD: stance phase duration [s], Swing PD: swing phase duration [s], Swing PL: swing phase length [m]; n= 7 Icelandic Horses.
LH: linke Hintergliedmaße, RH: rechte Hintergliedmaße, LF: linke Vordergliedmaße, RF: rechte Vordergliedmaße, FI: force at impact [g], FEI: force at end of impact [g], FLO: force at lift off [g], CD: cycle duration [s], Stance PD: stance phase duration [s], Swing PD: swing phase duration [s], Swing PL: swing phase length [m]; n= 7 Islandpferde.

Table 3 Mean values ± standard deviations (X±SD) of the variable overlap in relation to side of the body and lap in Icelandic Horses ridden in flying pace / Mittelwerte ± Standardabweichungen (X±SD) der Variable Overlap von im Rennpass gerittenen Islandpferden im Bezug auf Körperseite und Lauf

Side	Lap	Overlap X±SD)
L	1	0.1437 ±0.1387
	2	0.0904 ±0.0271
R	1	0.0517 ±0.0854
	2	0.1405 ±0.1099

L: left hind- and forelimb, R: right hind- and forelimb, Overlap: overlap [s]; n= 7 Icelandic Horses. / *L: linke Vorder- und Hintergliedmaße, R: rechte Vorder- und Hintergliedmaße, Overlap [s]; n= 7 Islandpferde.*

the lap number, values of all four limbs combined differed significantly between lap 1 and lap 2 for FI ($p<0.0001$), FEI ($p=0.0015$), FLO ($p<00001$) and stance PD ($p=0.0108$). CD, swing PD and swing PL did not show p-values ≤ 0.05. When looking at the combined influence of leg and lap, the following results were obtained: For FI significant differences between the laps were found for RH ($p<0.0001$), LF ($p<0.0001$) and RF ($p<0.0001$), the values for LH were not significantly different, but show a p-value of 0.0556. The FEI values differed for LH ($p=0.0207$), RH ($p=0.0300$) and RF ($p=0.0193$). The RH ($p=0.0002$), LF ($p<0.0001$) and RF ($p<0.0001$) showed significant differences concerning FLO, whereas CD values only differed significantly between the laps for RH ($p=0.0157$), the Stance PD values only for RF ($p<0.0001$).

Swing PD values were significantly influenced for LF ($p=0.0073$) and RF ($p=0.0026$), the same which is true for swing PL, with LF ($p=0.0255$) and RF ($p=0.0091$).

The LSMs test applied to the combination of side and lap, looking at the overlap resulted in significant differences for L ($p<0.0001$) as well as R ($p<0.0001$).

Discussion

The seven horses used in this study were five-gaited, in good health and ridden by one experienced rider. Nevertheless, the obtained data show a specific individual pattern of each horse, not only during lap 1, but also during lap 2. These differences were described in the literature (*Willemen* et al. 1994, *Dallap Schaer* et al. 2006, *Pecha* et al. 2011) and might be explicable with the influence of the differences in the conformation of the horses, the training status, especially concerning the flying pace, since the older horses could be expected to be more experienced in performing this gait under the rider, or other individual factors such as temperament of the horse, speed of the lap or overall gait quality (*Willemen* et al. 1994, *Dallap Schaer* et al. 2006).

Other studies concerning the influence of addition of weight to the distal limbs on the biomechanics of different gaits used considerably heavier loads on each limb, ranging 365 to 600g (*Willemen* et al. 1994, *Singleton* et al. 2003, *Wickler* et al. 2004). In the present study, the added weights were chosen to be in coherence with the present rules for Icelandic Horse tournaments (FEIF 2011) in order to be able to provide information concerning the practiced use of palmarly added weights.

In regard of the kinematic data, i.e. CD, Stance PD, Swing PD and Swing PL, the following observations were made in this study: Looking at the Stance PD of the hind- versus the forelimbs, no consistent pattern could be found as to which pair of limbs would stay in contact with the ground longer. When all horses were evaluated together, for lap 1 the Stance PD of the hind- and forelimbs were nearly the same, for lap 2 a tendency towards a longer Stance PD of the forelimbs could be noted. At the level of the individual horse, significant differences and tendencies could be found; three horses had longer ground-contact with the forelimbs, whereas in four horses Stance PD was longer in the hindlimbs. The pattern whether a horse left its hind- respectively forelimbs in longer contact with the track stayed the same with and without weights, in four horses the tendencies shown during lap 1 were emphasized by the weights; in the three remaining horses the tendency was decreased. It has to be noted however, that in the five fastest laps – regardless to lap number – a significant difference between hind- and forelimb Stance PD could be observed, for the four fastest laps the Stance PD of the forelimbs was significantly longer than that of the hindlimbs. Since these four laps were run by two horses with and without weights, the preference of the fore- over the hindlimbs could be due to the individual footfall pattern of these horses rather than to the speed. These findings contrast those found in the literature for Standardbred pacers, where it was stated, that the hindlimbs tend to stay on the ground longer than the forelimbs, especially in high order finishing individuals (*Wilson* et al. 1988a, *Wilson* et al. 1988b). A study performed using Icelandic Horses also found that the stance time of the hindlimbs was longer than that of the forelimbs, but they also noted a considerable variation in fore- and hindlimb ratios and that the values for the stance times and ratios were more variable in the hindlimbs (*Robilliard* et al. 2007). Concerning the tölt of Icelandic Horses, two different weights did not have a significant effect on the stance phase duration of the forelimbs (measured as % of the cycle duration) at slow speed, whereas at faster speed the difference between the stance phase duration was significant between the lighter and heavier weights (*Pecha* et al. 2011).

Another finding in the aforementioned study by Robilliard et al. was a tendency to significant differences between subsequent cycles in the flying pace, which resulted in a broader distribution of footfall ratios than found in other gaits of the Icelandic Horse (*Robilliard* et al. 2007). This was also noted in this study. Also a tendency for an asymmetry between left and right side was stated as described by significant differences between the Stance PD (*Robilliard* et al. 2007). In regard to the data material of this study, this phenomenon was not found. The differences between the sides of the body were not significant. Since the data in this study were collected with the horses running down a straight track, an effect of bends was avoided, which might explain the different findings, since the horses used in the cited study were ridden on an oval track, where the flying pace is ridden starting at the end of the bend following the short side of the track and ending before entering the next bend (FEIF 2011). Therefore the assumption of a more apparent handedness in the flying pace cannot be supported concerning this parameter.

On the other hand, a significant discrepancy between left and right side was observed when focusing on the overlap. The left side of the body showed longer overlap times than the right. This might be an expression of the above-mentioned handedness, which seems to be more apparent concerning the overlap than the Stance PD when evaluating horses running down a straight track.

The influence of weights applied to the forelimbs has been described to have different effects on the parts of the limbs. The proximal parts above the carpus were found to show a greater range of motion through enhancement of the elbow movement, whereas the distal parts are driven by force of inertia, which is increased by the additional weight (*Balch* et al. 1996, *Singleton* et al. 2003). This results in a change of the flight arc of the limb during the swing phase, which has been studied in Standardbred trotters in relation to racing performance (*Willemen* et al. 1994). It was found that the effect of the weights applied to the dorsal hoof wall was most beneficial in horses with lower gait qualities, described by limb motion, imbalance and finishing order during a race. In Icelandic horses it also was shown that the addition of weights changes swing phase characteristics of the tölt (*Rumpler* et al. 2010). Other studies also found important individual influences on the tested impact of different shoeing material (*Dallap Schaer* et al. 2006) resp. the added weights (*Pecha* et al. 2011). In a study focussing on gait changes of the tölt through speed and addition of weights it was found that the ratio of diagonal to ipsilateral overlap did not change with the application of different weights when compared between speeds (*Pecha* et al. 2011), implicating a characteristic gait pattern. These individual patterns could also be observed in the present study. The effect of the weights on the palmar aspect of the hooves of the forelimbs varied, ranging from almost no observable differences to significant influences on the kinematic and timely variables. The most apparent changes could be seen in those horses with more pronounced variations of the variables during lap 1. These variations could be observed looking at the acceleration forces as well as for the timely parameters. They implicate an inhomogeneity of the gait pattern and are interpretable as a poorer gait quality than that of horses showing more consistent profiles. In the horses with greater variations during lap 1 the weights provoked a more uniform appearance of the values. Therefore the weights seem to influence the balance of the gait in horses with a lower quality of the flying pace. In this study, those horses were the ones with less experience performing the flying pace, whereas the influence seemed to be less pronounced in the horses more adept. This might implicate that the weights have a higher effect during the training of the gait than on the well-versed horse. Further studies with a greater study population would be necessary to corroborate this impression.

Overall, the weights had significant influences on a number of the parameters evaluated. Most influenced was the right forelimb, for which of the seven variables six were significantly changed, only CD was not affected. The left forelimb was also affected regarding its impact and lift off forces and the swing phase parameters. In the hindlimbs the right limb also was more affected. This apparently greater influence of the weights on the right limbs of the horses in this study might again be explicable with a handedness of the animals, but it also was observed that the rider more often was shifting his weight to the right side of the saddle in order to keep the horse from changing into gallop. The preference of sitting to the right can be explained with the aids used to change from canter to flying pace. Next to other aids with reins and legs, the rider will shift his weight to the side opposite to leading forelimb in the canter/gallop, i.e. to the right side when starting from a left-lead in canter (*Feldmann* and *Rostock* 1997). Most horses were ridden in left-lead canter before changing into flying pace. This might explain the higher incidence of significant differences concerning the right limbs. In a study concerning the influence of left and right rising trot on the kinematics and kinetics a clear effect towards an asymmetry through the action of the rider was observed (*Roepstorff* et al. 2010). The findings of that study may be applicable to the situation found in the present study.

Also the speed seemed to be influenced by the application of the weights in this study. A similar pattern was found as with the kinematic variables, again for the horses showing a lower quality of the gait greater changes were observed. This might be related to the above described effects on the other variables, which resulted in a more efficient performance with better speed generation. In Standardbred pacers stride length, total suspension length and overlap time were found to be discriminants of pacing speed (*Wilson* et al. 1988b). Another possibility might be the effect of repetition, since the horses might show more enthusiasm during lap 2, which might be more pronounced in horses with less routine.

Conclusion

Conclusively, the findings of the present study are consistent with those from previous studies concerning the influence of weights on the biomechanics of the limbs. On the other hand, new specific assessments could be made concerning the flying pace of the Icelandic Horse. The influence of the weights seems to be dependent on the gait quality of the horse, being more pronounced in horses with a lower quality. Further studies might be indicated to validate the possible effect of age respectively training status of the horse.

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Animal welfare statement

The project was approved by the Animal Care and Welfare Committee of Schleswig Holstein, Germany. Registration number: 33.12-42502-04-07/1398.

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