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8 authors, including:

Michael A. Weishaupt
University of Zurich

Katja Geser-von Peinen
University of Zurich

Lars Roepstorff
Swedish University of Agricultural Sciences

Paul René van Weeren
Utrecht University

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Effect of head and neck position on vertical ground reaction forces and interlimb coordination in the dressage horse ridden at walk and trot on a treadmill

M. A. WEISHAUPT*, T. WIESTNER, K. VON PEINEN, N. WALDERN, L. ROEPSTORFF†, R. VAN WEEREN‡, H. MEYER§ and **C. JOHNSTON†**

Equine Hospital, University of Zurich, CH-8057 Zurich, Switzerland; †Department of Veterinary Anatomy and Physiology, Swedish University of Agricultural Sciences, 75007 Uppsala, Sweden; ‡Department of Equine Sciences, Utrecht University, 3584 CM, Utrecht, The Netherlands; and §Am Wisselsbach 22, 52146 Würselen, Germany.

Keywords: horse; kinetics; GRF; limb loading; rider interaction; riding

Summary

Reasons for performing study: **Little is known in quantitative terms about the influence of different head-neck positions (HNPs) on the loading pattern of the locomotor apparatus. Therefore it is difficult to predict whether a specific riding technique is beneficial for the horse or if it may increase the risk for injury.**

Objective: **To improve the understanding of forelimb-hindlimb balance and its underlying temporal changes in relation to different head and neck positions.**

Methods: **Vertical ground reaction force and time parameters of each limb were measured in 7 high level dressage horses while being ridden at walk and trot on an instrumented treadmill in 6 predetermined HNPs: HNP1 - free, unrestrained with loose reins; HNP2 - neck raised, bridge of the nose in front of the vertical; HNP3 - neck raised, bridge of the nose behind the vertical; HNP4 - neck lowered and flexed, bridge of the nose considerably behind the vertical; HNP5 - neck extremely elevated and bridge of the nose considerably in front of the vertical; HNP6 - neck and head extended forward and downward. Positions were judged by a qualified dressage judge. HNPs were assessed by comparing the data to a velocity-matched reference HNP (HNP2). Differences were tested using paired *t* test or Wilcoxon signed rank test ($P<0.05$).**

Results: **At the walk, stride duration and overreach distance increased in HNP1, but decreased in HNP3 and HNP5. Stride impulse was shifted to the forehand in HNP1 and HNP6, but shifted to the hindquarters in HNP5. At the trot, stride duration increased in HNP4 and HNP5. Overreach distance was shorter in HNP4. Stride impulse shifted to the hindquarters in HNP5. In HNP1 peak forces decreased in the forelimbs; in HNP5 peak forces increased in fore- and hindlimbs.**

Conclusions: **HNP5 had the biggest impact on limb timing and load distribution and behaved inversely to HNP1 and HNP6. Shortening of forelimb stance duration in HNP5 increased peak forces although the percentage of stride impulse carried by the forelimbs decreased.**

Potential relevance: **An extremely high HNP affects functionality much more than an extremely low neck.**

Introduction

The main goal of dressage schooling is to achieve a well balanced horse able to show its individual gait qualities. Optimal load distribution between fore- and hindlimbs allows the development of regularity and expressiveness of movements. One suggested way of achieving this is by altering the position of the neck and head.

Increasing collection and self-carriage is often associated with an increase in elevation of the neck and flexion at the poll (Anon 2003; "The neck should be raised, the poll high and the head slightly in front of the vertical"). It is commonly believed that the higher the HNP, the more load is shifted to the rear. Collection is associated with increased stride duration and fore- and hindlimb stance duration while speed and stride length are usually reduced (Clayton 1994, 1995; Holmström *et al.* 1995). Prolonged stance duration is associated with better balance which enables the horse to accomplish more advanced movements such as Passage and Piaffe. Furthermore, the range of pendular motion of the hindlimbs is reduced and strides become more elevated. During the stance phase the hindlimbs are more flexed, indicating storage of elastic strain energy (Holmström and Drevemo 1997). It is therefore proposed that elevation of the head and neck allows a more effective transfer of propulsive forces from the hindquarters to the body and increases the efficiency of movement under the rider (Holmström *et al.* 1995). Higher collection leads to greater demands on the musculoskeletal system of the back and hindquarters. Kinematically, collection achieved by the application of side reins has demonstrated a decrease of the movement of the back, indicating increased stability of the caudal back (Rhodin *et al.* 2005).

Alternative methods of training, with a low position of the neck and a strongly flexed head have been suggested to augment the gymnastic ability of the horse (Jansen 2003). The opposing orientation of the head and neck to that of the traditional approach implies a different balance between forehand and hindquarters. Currently, there is no objective information supporting or opposing the influences of head-neck orientation on force distribution. Roepstorff *et al.* (2002) have demonstrated that the use of equipment such as draw reins in combination with normal rein can induce a reduction of forces in the forelimb.

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*Author to whom correspondence should be addressed.

The aim of this study was to objectively assess the influence of different HNPs on the load distribution between fore- and hindlimbs.

Materials and methods

Horses and rider

Six Grand Prix dressage horses and 1 dressage horse competing at intermediate level (breed: 5 Swiss Warmbloods and 2 Westfalian Warmbloods; sex: 6 geldings, 1 stallion; age mean ± s.d. 14.0 ± 4.3 years; bwt: 609 ± 62.3 kg; wither height: 1.70 ± 0.07 m) were selected for this study after passing a thorough clinical examination by an experienced clinician, in which they were judged to be free from lameness or pain or dysfunction of the back. All horses were in training. Horses were ridden by their own expert rider using their own fitted saddle and a bridle with a normal snaffle bit.

Horses were fully accustomed to the treadmill[1] beforehand, with and without the rider. At the end of the treadmill training period riders confirmed that their horses were moving in the different HNP at appropriate speeds and in a manner equivalent to their normal gait.

Experimental design

Horses were measured at walk and sitting trot in 6 predetermined head-neck positions (Fig 1):

HNP1 - Free or natural; voluntarily acquired position, unrestrained with loose reins

HNP2 - Neck raised, poll high and bridge of the nose slightly in front of the vertical; reference position

HNP3 - Neck raised, poll high and bridge of the nose slightly behind the vertical

HNP4 - Neck lowered and flexed, bridge of the nose considerably behind the vertical

HNP5 - Neck extremely elevated and bridge of the nose considerably in front of the vertical

HNP6 - Neck and head extended forward and downward

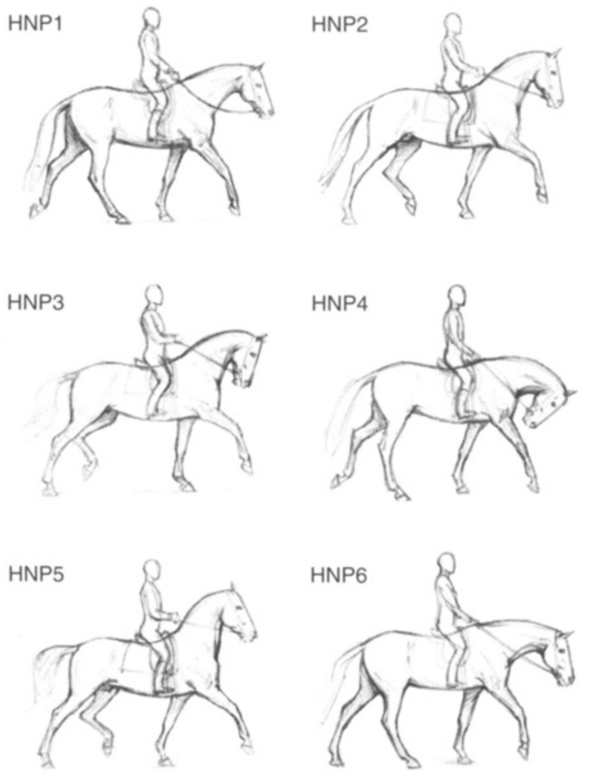

Fig 1: Head-neck positions.

At the trot, HNP6 was only ridden in rising trot and therefore not included in this analysis.

Speed variations are a known source of interference when performing kinematic and kinetic gait analysis and comparing different observations. (McLaughlin *et al.* 1996; Khumsap *et al.* 2001a,b, 2002). The different HNPs were performed at the speed at which horse and rider performed at ease. In order to have a precise speed-match control, data of the reference position HNP2 were collected over a range of velocities to include the velocities of the other HNPs. Data interpolation to the velocities measured in the respective HNPs was performed based on the speed trial data sets. The speed trial was first conducted at the walk where measurements were made at intervals of 0.1 m/sec and, after a short break, at the trot where the speed interval was 0.2 m/sec.

After a warm-up period of 15 min at walk and trot, positions were carried out successively, each position first at the walk then at the trot. The measurement was started when the horse was moving at a regular pace and the HNP corresponded to the protocol. The correctness of the HNP was judged by an international dressage judge. The measurements were documented by simultaneously recording the trials on video from the left side, from in front and behind.

The experimental protocol had been approved by the Animal Health and Welfare Commission of the Canton of Zurich.

Data acquisition and analysis

Vertical ground reaction force and time parameters of each limb were measured with a treadmill instrumented with a force measuring system (Weishaupt *et al.* 2002). This system decomposes the reaction force response at the multiple bearing points of the treadmill platform into the 4 vertical hoof forces and determines the hoof positions during stance phase on the treadmill. Data were sampled at 480 Hz during 20 sec. The velocity of the treadmill belt was measured on the front coil of the treadmill using an inductive revolution counter. The accuracy of this speedometer is ± 0.8% at 3.5 m/sec belt speed.

The following parameters were determined from the force curves and the limb positional data using custom-made software[2] programmed in C++: stride duration (SD), stance duration (StD); diagonal and ipsilateral step duration at the walk ($StpD_{diag}$, $StpD_{il}$); suspension duration (SpD), time of diagonal advanced placement (TAP; time dissociation between diagonal limbs at initial ground contact) and time of diagonal advanced completion (TAC; time dissociation between diagonal limbs at toe-off) at the trot; vertical stride impulse (Iz_{SD}; sum of the 4 vertical limb impulses during an entire motion cycle), vertical force peaks 1 and 2 at the walk (Fz_{P1}, Fz_{P2}) and peak vertical force (Fz_{peak}) at the trot. To assess an average load distribution between fore- and hindlimbs during an entire stride cycle, vertical impulse of both forelimbs were expressed as proportion of Iz_{SD} (Iz). This enabled the estimation of shifts in body centre of mass.

All temporal parameters were expressed as proportion of SD. Force and impulse parameters were normalised to the combined weight of the horse and rider. The walk and the trot are symmetrical gaits. On the assumption that horses were not lame, data of the contralateral limbs are reported as a forelimb and hindlimb mean.

Statistics

Statistical analysis was performed with SigmaStat 2.0[3]. Normality of data was tested with the Kolmogorov-Smirnov test. Changes resulting from the different HNPs were assessed by comparing the data to the velocity-matched reference position HNP2. Differences were tested using paired *t* test or Wilcoxon signed rank test depending the result of the normality test. Significance level was set at P = 0.05.

Results

Mean treadmill belt velocities for the different HNPs are reported in Table 1. In both gaits, HNP1 and HNP6 were conducted at the fastest speeds whereas in HNP3, HNP4 and HNP5 the speeds were slower by 0.2–0.3 m/sec.

HNP-related changes of the walk and trot trials are summarised in Tables 2 and 3, respectively. At the walk, vertical impulse was redistributed from the hindquarters to the forehand in HNP1 and HNP6 and inversely in HNP5 (Fig 2). At the trot, only HNP5 changed the impulse distribution, shifting weight away from the fore- to the hindlimbs (Fig 3). The most obvious changes were observed for HNP5 where almost all parameters changed compared to the reference position HNP2. Changes showed the same tendencies in HNP3 but did not reach significance in all parameters. In general, changes in HNP1 and HNP6 led to a shift in the opposite direction, from the hind- to the forelimbs.

TABLE 1: Mean ± s.d. treadmill belt velocities (m/sec) for different head-neck positions

	HNP1	HNP3	HNP4	HNP5	HNP6
walk	1.63 ± 0.08	1.52 ± 0.08	1.52 ± 0.06	1.43 ± 0.05	1.62 ± 0.06
Trot	3.15 ± 0.15	3.01 ± 0.06	2.95 ± 0.04	2.97 ± 0.09	-

Discussion

This study investigated the influence of different head-neck positions on the weight distribution between fore- and hindlimbs in high-level dressage horses ridden at the walk and trot. Summarising Tables 2 and 3, HNP5 showed the most conspicuous impact on limb timing and load distribution in both investigated gaits. Furthermore, in the other HNPs changes were more obvious at the walk than at the trot.

Changes at the walk

At the walk, regardless of the statistical significance, virtually all changes of force and temporal parameters showed a concurrent direction in HNP1 and HNP6, and a concurrently opposite direction in HNP3 and HNP5.

Vertical impulse was redistributed from the hindlimbs to the forelimbs in HNP1 and HNP6 and in the opposite direction in

TABLE 2: Mean ± s.d. of temporal, vertical force and linear parameters at the walk (n = 7). Below in brackets mean ± s.d. of the reference HNP2 at the corresponding velocity and percentage difference

Parameter			HNP1	HNP3	HNP4	HNP5	HNP6
SD [s]			1.167 ± 0.026	1.111 ± 0.037	1.140 ± 0.045	1.109 ± 0.072	1.155 ± 0.031
		(control)	(1.134 ± 0.037)	(1.168 ± 0.029)	(1.166 ± 0.036)	(1.191 ± 0.036)	(1.132 ± 0.047)
		Δ[%]	2.87% *	-4.89% *	-2.17%	-6.89% *	2.05%
StD [s/s]	forelimbs		0.626 ± 0.007	0.623 ± 0.014	0.630 ± 0.010	0.624 ± 0.015	0.630 ± 0.009
		(control)	(0.620 ± 0.011)	(0.630 ± 0.013)	(0.629 ± 0.013)	(0.637 ± 0.014)	(0.620 ± 0.011)
		Δ[%]	0.91%	-1.09%	0.12%	-2.02% *	1.51% *
	hindlimbs		0.634 ± 0.013	0.648 ± 0.019	0.645 ± 0.017	0.655 ± 0.019	0.634 ± 0.015
		(control)	(0.638 ± 0.016)	(0.644 ± 0.018)	(0.643 ± 0.015)	(0.648 ± 0.018)	(0.638 ± 0.015)
		Δ[%]	-0.76% *	0.64% *	0.38%	1.14% *	-0.65% *
StpD$_{diag}$ [s/s]			0.266 ± 0.020	0.249 ± 0.035	0.249 ± 0.031	0.251 ± 0.025	0.266 ± 0.018
		(control)]	(0.261 ± 0.025)	(0.264 ± 0.026)	(0.265 ± 0.025)	(0.267 ± 0.026)	(0.261 ± 0.023)
		Δ[%]	2.15%	-5.74%	-6.07%	-5.86% *	1.98%
StpD$_{il}$ [s/s]			0.234 ± 0.021	0.251 ± 0.035	0.251 ± 0.031	0.249 ± 0.025	0.233 ± 0.018
		(control)	(0.239 ± 0.025)	(0.236 ± 0.026)	(0.235 ± 0.025)	(0.233 ± 0.026)	(0.239 ± 0.023)
		Δ[%]	-2.37%	6.49%	6.70%	6.63% *	-2.27%
Iz$_{SD}$ [Ns/kg]			11.5 ± 0.26	10.9 ± 0.36	11.2 ± 0.45	10.9 ± 0.70	11.3 ± 0.31
		(control)	(11.1 ± 0.37)	(11.5 ± 0.29)	(11.4 ± 0.36)	(11.7 ± 0.36)	(11.1 ± 0.46)
		Δ[%]	2.87% *	-4.89% *	-2.17%	-6.89% *	2.05%
Iz [Ns/Ns]	forehand		0.601 ± 0.012	0.589 ± 0.015	0.591 ± 0.014	0.583 ± 0.014	0.600 ± 0.012
		(control)	(0.594 ± 0.014)	(0.594 ± 0.012)	(0.593 ± 0.011)	(0.593 ± 0.009)	(0.594 ± 0.014)
		Δ[%]	1.18% *	-0.84%	-0.30%	-1.60% *	0.98% *
Fz$_{P1}$ [N/kg]	forelimbs		6.08 ± 0.16	6.28 ± 0.22	6.06 ± 0.24	6.50 ± 0.32	5.88 ± 0.24
		(control)	(6.16 ± 0.19)	(6.14 ± 0.26)	(6.10 ± 0.23)	(6.11 ± 0.33)	(6.15 ± 0.19)
		Δ[%]	-2.11%	2.31%	-0.73%	6.35% *	-4.41% *
	hindlimbs		4.26 ± 0.26	4.16 ± 0.35	4.26 ± 0.38	3.93 ± 0.24	4.31 ± 0.14
		(control)	(4.21 ± 0.25)	(4.01 ± 0.26)	(4.03 ± 0.25)	(3.84 ± 0.17)	(4.22 ± 0.23)
		Δ[%]	1.32%	3.73%	5.70% *	2.43%	2.22% *
Fz$_{P2}$ [N/kg]	forelimbs		6.52 ± 0.32	6.22 ± 0.30	6.32 ± 0.34	6.23 ± 0.44	6.53 ± 0.33
		(control)	(6.32 ± 0.36)	(6.20 ± 0.36)	(6.18 ± 0.37)	(6.09 ± 0.35)	(6.34 ± 0.36)
		Δ[%]	3.26% *	0.36%	2.25%	1.98%	3.08% *
	hindlimbs		4.07 ± 0.13	4.03 ± 0.20	3.95 ± 0.19	4.08 ± 0.18	3.99 ± 0.16
		(control)	(4.15 ± 0.18)	(4.08 ± 0.15)	(4.08 ± 0.15)	(4.02 ± 0.14)	(4.13 ± 0.15)
		Δ[%]	-1.94% *	-1.43%	-2.99%	1.39%	-3.52% *
SL [m]			1.90 ± 0.12	1.69 ± 0.12	1.73 ± 0.10	1.58 ± 0.12	1.88 ± 0.09
		(control)	(1.85 ± 0.14)	(1.77 ± 0.12)	(1.77 ± 0.09)	(1.70 ± 0.07)	(1.84 ± 0.13)
		Δ[%]	2.93 *	-4.77% *	-2.05%	-6.96% *	2.11%
OR [m/m]			0.111 ± 0.050	0.011 ± 0.084	0.035 ± 0.070	-0.029 ± 0.087	0.101 ± 0.048
		(control)	(0.083 ± 0.064)	(0.058 ± 0.066)	(0.061 ± 0.051)	(0.037 ± 0.059)	(0.082 ± 0.063)
		Δ[%]	33.9% *	-81.5% *	-42.7%	-186.7% *	23.3%

SD, stride duration; StD, stance duration relative to SD; StpD$_{diag}$, diagonal step duration relative to SD; StpD$_{il}$, ipsilateral step duration relative SD; Iz$_{SD}$, stride impulse; Iz, percentage of stride impulse carried by the forehand; Fz$_{P1}$, first force peak; Fz$_{P2}$, second force peak; SL, stride length; OR, overreach distance relative to stride length. * Significant difference (P<0.05) compared to reference position HNP2.

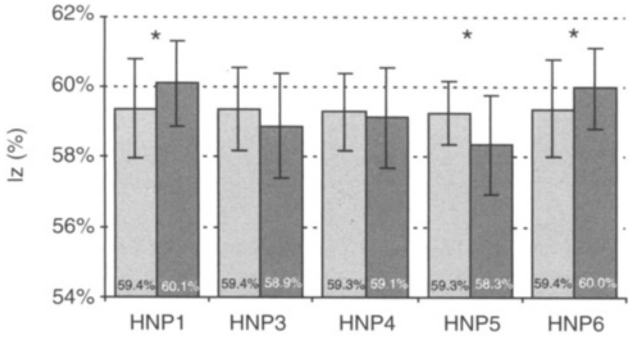

*Fig 2: Vertical impulse distribution between forehand and hindquarters at the walk. Iz, percentage of stride impulse carried by the forehand. Light grey, mean ± s.d. of reference position 2 at the corresponding velocity; grey, mean ± s.d. of the respective head-neck position; * significant difference (P<0.05).*

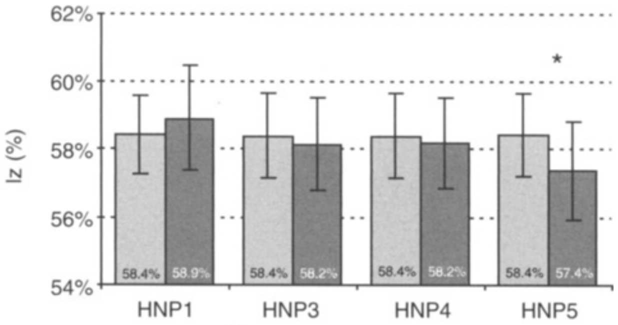

*Fig 3: Vertical impulse distribution between forehand and hindquarters at the trot. Iz, percentage of stride impulse carried by the forehand. Light grey, mean ± s.d. of reference position 2 at the corresponding velocity; grey, mean ± s.d. of the respective head-neck position; * significant difference (P<0.05).*

HNP5 (Table 2). This appears to correspond to the extended neck in HNP1 and HNP6 where the centre of mass (COM) of the neck-head segment is shifted cranially; whereas the shortened and elevated neck in HNP5 shifts the COM of the neck-head segment caudally. In HNP1 and HNP6, the general forward-downward motion is characterised by longer SL. Both these positions represent the horizontal type of motion a horse assumes of its own free will moving forward in the most efficient way. Rhodin *et al.* (2005) and Gómez Alvarez *et al.* (2006) documented similar results in unridden horses where the SL of a low neck position (HNP1, HNP6) was longer compared to an elevated position (HNP2). Therefore, changes in SL at the walk are directly comparable between the studies with and without rider. Retrospective analysis of the video sequences showed that HNP1 and HNP6 did not always differ conspicuously in every horse; this might explain the similarity of the changes.

HNP3, and more clearly HNP5, showed a clear intervention of the rider's action on the horse's movement patterns. The general

TABLE 3: Mean ± s.d. of temporal, vertical force and linear parameters at the trot (n=7). Below in brackets mean ± s.d. of the reference HNP2 at the corresponding velocity and percentage difference

Parameter			HNP1	HNP3	HNP4	HNP5
SD [s]			0.807 ± 0.038	0.824 ± 0.040	0.843 ± 0.049	0.860 ± 0.055
		(control)	(0.814 ± 0.043)	(0.823 ± 0.039)	(0.826 ± 0.038)	(0.825 ± 0.035)
		Δ [%]	-0.82%	0.23%	2.03% *	4.13% *
StD [s/s]	forelimbs		0.450 ± 0.016	0.433 ± 0.019	0.442 ± 0.018	0.407 ± 0.028
		(control)	(0.435 ± 0.010)	(0.445 ± 0.007)	(0.448 ± 0.007)	(0.446 ± 0.009)
		Δ [%]	3.50% *	-2.67%	-1.26%	-8.75% *
	hindlimbs		0.395 ± 0.020	0.398 ± 0.017	0.397 ± 0.018	0.395 ± 0.020
		(control)	(0.393 ± 0.017)	(0.399 ± 0.016)	(0.401 ± 0.016)	(0.401 ± 0.017)
		Δ [%]	0.62%	-0.18%	-0.99%	-1.51% *
TAP [s/s]			-0.008 ± 0.012	-0.002 ± 0.016	-0.005 ± 0.018	0.011 ± 0.025
		(control)	(-0.003 ± 0.013)	(-0.007 ± 0.012)	(-0.009 ± 0.011)	(-0.008 ± 0.012)
		Δ [%]	247.5%	-90.0%	-45.1%	-259.7% *
TAC [s/s]			0.044 ± 0.013	0.032 ± 0.015	0.038 ± 0.020	0.024 ± 0.018
		(control)	(0.037 ± 0.015)	(0.037 ± 0.015)	(0.036 ± 0.015)	(0.036 ± 0.016)
		Δ [%]	19.0% *	-13.2% *	6.13%	-33.5% *
SpD [s/s]			0.047 ± 0.014	0.059 ± 0.012	0.051 ± 0.013	0.072 ± 0.016
		(control)	(0.060 ± 0.008)	(0.052 ± 0.007)	(0.049 ± 0.007)	(0.050 ± 0.008)
		Δ [%]	-21.5% *	14.9%	3.63%	44.5% *
Iz_{SD} [Ns/kg]			7.92 ± 0.37	8.09 ± 0.39	8.27 ± 0.48	8.43 ± 0.53
		(control)	(7.98 ± 0.42)	(8.07 ± 0.38)	(8.10 ± 0.38)	(8.10 ± 0.35)
		Δ [%]	-0.82%	0.23%	2.03% *	4.13% *
Iz [Ns/Ns]	forehand		0.589 ± 0.015	0.582 ± 0.014	0.582 ± 0.014	0.574 ± 0.015
		(control)	(0.584 ± 0.012)	(0.584 ± 0.012)	(0.584 ± 0.011)	(0.584 ± 0.012)
		Δ [%]	0.86%	-0.40%	-0.36%	-1.78% *
Fz_{peak} [N/kg]	forelimbs		10.14 ± 0.54	10.39 ± 0.36	10.21 ± 0.41	10.97 ± 0.49
		(control)	(10.44 ± 0.43)	(10.22 ± 0.26)	(10.15 ± 0.24)	(10.19 ± 0.27)
		Δ [%]	-2.84% *	1.63%	0.63%	7.64% *
	hindlimbs		8.45 ± 0.49	8.52 ± 0.43	8.57 ± 0.45	8.69 ± 0.40
		(control)	(8.57 ± 0.37)	(8.49 ± 0.36)	(8.46 ± 0.37)	(8.47 ± 0.38)
		Δ [%]	-1.34%	0.32%	1.38%	2.59% *
SL [m]			2.54 ± 0.15	2.48 ± 0.12	2.49 ± 0.15	2.55 ± 0.22
		(control)	(2.56 ± 0.14)	(2.47 ± 0.13)	(2.44 ± 0.12)	(2.45 ± 0.16)
		Δ [%]	-0.73%	0.27%	2.07% *	4.17%
OR [m/m]			-0.017 ± 0.020	-0.037 ± 0.022	-0.036 ± 0.022	-0.033 ± 0.032
		(control)	(-0.019 ± 0.019)	(-0.035 ± 0.024)	(-0.041 ± 0.022)	(-0.040 ± 0.027)
		Δ [%]	-13.2%	5.54%	-13.6% *	-17.8%

SD, stride duration; StD, stance duration relative to SD; TAP, diagonal advanced placement relative to SD; TAC, diagonal advanced completion relative to SD; SpD, suspension duration relative to SD; Iz_{SD}, stride impulse; Iz, percentage of stride impulse carried by the forehand; Fz_{peak}, peak force; SL, stride length; OR, overreach distance relative to stride length.* Significant difference (P<0.05) compared to reference HNP2.

idea behind raising the neck and head is to create a greater degree of elevation by redirecting the horizontal movement towards a more vertical direction. Accordingly, we observed a shift in weight to the hindquarters and a shortening of SL and OR. Increased s.d. of SD and OR suggested that the horses were moving inconsistently. During the trial, it was obvious that the horses had difficulties coping with these HNPs, especially with HNP5. Further evidence of this phenomenon is the significantly reduced range of movement and symmetry of movement of the thoracolumbar back, seen in simultaneous kinematic measurements (Gómez Alvarez *et al.* 2006). The reduction of SL and OR found at walk is in agreement with the mechanism that underlies the bow-and-string principle of equine back biomechanics (Slijper 1946), in which hindlimb protraction is supposed to result in a tensing of the bow, i.e. flex the back. An extension of the back can thus be expected to result in a reduction of hindlimb protraction (van Weeren 2004). The awkward orientation of the head and neck may promote stiffness of the forehand, which is reflected by a decrease in StD and a concomitantly increased Fz_{peak} in the forelimbs. Peak forces or the rate at which the force develops determines the way the rider is accelerated upwards and, therefore, how comfortable the horse's movement is to ride.

Although the impulse redistributions between the forehand and the hindquarters seen in HNP1, HNP6 and HNP5 were statistically significant, it should be noted that these load shifts were small (between 1–1.8%). Similarly small shifts in load to the hindquarters (<1.8%) are reported by Roepstorff *et al.* (2002) comparing horses ridden with normal reins and with a combination of normal and draw reins at the trot. In a 2 segmental model (head/neck, trunk) lowering or raising the head-neck segment had an even smaller effect on the cranio-caudal position of the COM (Vorstenbosch *et al.* 1997). In contrast to the different HNPs in the present study, the constant neck length and smaller range of vertical head-neck excursion in the model may have limited influence on the cranio-caudal orientation of the COM of the head-neck segment.

The additional weight of a rider alters ground reaction forces by increasing the fraction of vertical impulse in the forelimbs and decreasing it in the hindlimbs (Schamhardt *et al.* 1991; Clayton *et al.* 1999). A skilled rider can redistribute the load to the hindlimbs (Schamhardt *et al.* 1991). Warmbloods, when trotting freely without rider on the treadmill at 3.5 m/sec have a weight distribution of around 56% of Iz_{SD} on the forehand (Weishaupt *et al.* 2004b); with the rider and dependent on the HNP, 57.4–58.9% of the weight was carried by the forehand. At the ridden walk 58.3–60.1% of the weight was carried by the forehand. This indicates that despite raising the head and neck to extremely high positions, the riders were not able to recreate the weight distribution between forehand and hindquarters of the freely moving, unridden horse. The biggest shift of weight and, therefore, of the centre of mass towards the hindquarters was observed in HNP5 at the walk as well as at the trot. However, it must be emphasised that when the higher peak forces in the forelimbs and restricted movements of the limbs and back induced by HNP5 are taken into account, this position can not be recommended. It is believed that working the horse with a high elevated neck and the back in extension definitely contributes to degenerative pathologies of the back (Johnston *et al.* 2002).

Although not always statistically significant, differences in $StpD_{il}$ and $StpD_{diag}$ followed the general trend, with HNP1 and HNP6 following a similar pattern and HNP3 and HNP5 a similarly opposing one. An irregular 4-beat rhythm of lateral couplets ($StpD_{il}$ shorter than $StpD_{diag}$, pacing rhythm) was observed for the reference position and in HNP1 and HNP6. Clayton (1995) also found that a majority of national level dressage horses showed lateral couplets in all type of walk (collected, medium extended and free). Riding the horse in HNP3, HNP4 and HNP5 corrected the rhythm to a regular 4-beat. Therefore, it seems unreasonable to aim for a perfectly regular 4-beat gait under all circumstances as our study suggests that HNPs in which the regular beat was observed all involved certain restrictions to the horse's range of movement.

At the walk, HNP4 showed surprisingly few differences to the reference position HNP2. Reviewing the video sequences showed that although all horses had the bridge of the nose considerably behind the vertical, two of the seven horses carried their necks higher than in the heavily debated 'rollkur' position. Generally, it seems that the height of the neck influences the movement more than the flexion at the poll. Therefore, HNP4 in these horses would not very differ biomechanically from HNP2.

Changes at the trot

Redistribution of Iz_{SD} occurred only in HNP5 where the load was shifted towards the rear (Table 3). This reflects a generally higher tonus of the horse's trunk at the trot in all HNPs and consequently a better overall balance when compared to the walk.

SD and consequently Iz_{SD} changed only in HNP4 and HNP5 relative to HNP2. However, the increase of Iz_{SD} seemed to affect the dynamics of the trot in 2 different ways. In HNP5, the 4.1% increased Iz_{SD} in combination with a shorter StD were directly reflected in higher Fz_{peak}. The higher Fz_{peak} prolonged the airborne phase of the stride (SpD). The overall impression was that the horses' movements were less compliant but more impulsive than in HNP2.

In HNP4, Iz_{SD} was increased by 2.0% without concomitant changes in Fz_{peak} and SpD. The significant reduction of OR implicates an increased extension of the lumbar back. This could be demonstrated in the back kinematics of the same horses (Gómez Alvarez *et al.* 2006). HNP4 was associated with increased flexion in the cranial thoracic region and increased extension in the caudal back. A well stabilised caudal back in extension is favourable for horizontal propulsion. Roepstorff *et al.* (2002) and Byström *et al.* (2006) showed that riding the horse in a HNP4-like position with a combination of normal and draw reins increases maximal push-off forces and impulse. Interestingly, gait quality is related to a more horizontal orientation of the pelvis (Holmström *et al.* 1994). Horses with a more inclined pelvis show increased mobility at the lumbar-sacral joint (Johnston *et al.* 2002). This suggests that increase in horizontal propulsion and in SL at the trot is related to extension of the caudal back and this again can be induced by HNP4.

In HNP1, Iz_{SD} did not change while StD and Fz_{peak} in the forelimb increased and decreased respectively. This suggests a rather compliant adjustment of the forelimbs. Consequently, the overall decrease in Fz_{peak} resulted in a shortened SpD. An overall loss of impulsion is also typically observed in lame horses. Gait adaptations such as prolonged StD of the lame and contralateral limb with resulting reduced Fz_{peak} and SpD are part of the strategy to compensate for weight-bearing lameness (Weishaupt *et al.* 2004a, 2006).

Positive diagonal advanced placement - where the hindlimb contacts the ground before the diagonal forelimb - is considered to be indicative of a good balance and characteristic for horses moving with an elevated forehand in high collection (Holmström *et al.* 1995). On the treadmill, the majority of horses impact first with their forelimbs (negative TAP) or simultaneously with their diagonal limbs (Buchner *et al.* 1994; Weishaupt *et al.* 2004b). The mean TAP of the 7 horses was negative in all HNPs with the exception of HNP5. In HNP5, the hindlimb impacted before the forelimb indicating increased weight-bearing function of the hindquarters. Good dressage performers tend to have a longer TAP while at lift-off these limbs tend to leave the ground closer together (Deuel and Park 1990). In this study, lift-off of diagonal limbs were closer in HNP3 and HNP5 than in HNP1 and HNP2. This is interpreted as expression of a greater reliance of the hindlimbs for support. As suggested by Holmström *et al.* (1994), HNP5 showed that positive diagonal placement was indeed related to increased maximal forces and relative impulses in the hindlimb. However, this occurred in what was intended to be the trot with the least balance in this study. Collection may, therefore, be a reflection of an increased vertical impulse of the body that indicates a more impulsive gait. The decreased StD promotes a faster build-up of force, increased Fz_{peak} and results in prolonged SpD. Perhaps the perceived shift in weight due to a reorientation in movement direction towards the vertical as is indicated by the concomitant increased loading of the fore- and hindlimb. We therefore suggest that the impulse shift to the hindlimb is a compensatory mechanism. To achieve the redirection of the resultant force vector acting on the centre of gravity of the horse into a more vertical direction, the body has to increase stiffness. This reasoning is supported by the decrease in range of movement of the whole thoracic back (T10-T17) in HNP5 (Gómez Alvarez *et al.* 2006).

In conclusion, no impressive shifts in load distribution between forehand and hindquarters caused by changing the HNP were observed. However, in the unrestrained position and in the position with the neck and head extended forward, load was shifted at the walk towards the forelimbs, whereas in the extremely elevated position load was shifted to the hindquarters at walk and trot. A shift of impulse from the forehand to the hindquarters is not necessarily associated with a reduction of Fz_{peak} in the forelimbs. In a movement pattern where forelimb StD decreases, as observed in HNP5, higher peak forces are to be expected. The experiment demonstrated that an extremely high neck affects functionality much more than an extremely low neck.

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Manufacturers' addresses

[1]Mustang 2200, Kagra AG, Fahrwangen, Switzerland.
[2]HP2, University of Zurich, Zurich, Switzerland.
[3]SigmaStat, SPSS Inc, Chicago, USA.

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