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DOI: https://doi.org/10.3920/cep180002

Originally published at:
Rhodin, M; Byström, A; Roepstorff, L; Hernlund, E; van Weeren, P R; Weishaupt, Michael A; Egenvall, A (2018). Effect of different head and neck positions on kinematics of elite dressage horses ridden at walk on treadmill. Comparative Exercise Physiology, 14(2):69-78.
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Comparative Exercise Physiology, 2018; 14 (2): 69-78

Effect of different head and neck positions on kinematics of elite dressage horses ridden at walk on treadmill

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Received: 15 January 2018 / Accepted: 8 March 2018

RESEARCH ARTICLE

Abstract

The debate on proper head and neck positions (HNP) in horse training is lively, but little is known about the biomechanical effects of various HNPs in horses ridden at walk. The aim was to quantify the influence of different HNPs on the kinematics of horses ridden at walk. The standard competition position (HNP2) was compared to a free, unrestrained position (HNP1), more flexed positions (HNP3, HNP4), a raised extended position (HNP5) and a forward-downward extended position (HNP6). An experimental study in seven high-level dressage horses ridden at walk on a treadmill was designed. Kinetic and kinematic measurements were obtained with different HNPs. HNP2 was used as a speed-matched reference. Kinematics were measured from skin-fixed markers recorded by high-speed video cameras. The kinetics of the limbs were measured by the force-measuring instrumentation of the treadmill. In HNP1, compared to HNP2, the lumbar back and the pelvis were more horizontally positioned (more extended), and fore- and hindlimb pro- and retraction increased, with increased caudal rotation of the femur during the second half of hindlimb stance. HNP6 induced similar changes as HNP1, but caused larger increases in forelimb pro- and retraction. In HNP3, HNP4 and HNP5 the pelvis was more angled (less extended) compared to HNP2 at hindlimb midstance, and in HNP3 and HNP4 also in early hindlimb stance. All three HNPs caused increased maximum flexion of the tarsus, stifle and metatarsophalangeal joint during the swing phase. HNP3 and HNP5, but not HNP4, had a decreasing influence on fore- and hindlimb pro- and retraction, and decreased caudal rotation of the femur during the second half of hindlimb stance.The main limitation was that horses were not ridden overground and the number of horses was small. Our conclusion was that changes in head and neck position can markedly affect the horse's movement pattern at walk.

Keywords: equine, kinematics, back, rider

1. Introduction

The walk is the slowest equine gait with an alternation between two- and three-limb support with large overlaps between the consecutive stance phases and no suspension. The Fédération Equestre Internationale (FEI) recognises four different variations of walk in dressage competitions: free, collected, medium and extended. These are characterised by different head and neck positions (HNPs), apart from differences in speed and stride length. In free and in extended walk the horse should stretch the neck forward and downward with the mouth approaching a horizontal line through the point of the shoulder. In collected walk the horse should arch and raise the neck with the poll high and the bridge of the nose should be slightly in front of the vertical. Medium walk is in between free and collected (Anonymous, 2017).

The effect of different head and neck position on the performance and health of riding horses has been debated for centuries (Baucher, 1852; De la Guerniére, 1733). Over the recent decades (1992-2008) a head position with the bridge of the nose behind the vertical has become more prevalent at dressage competitions (Lashley *et al.*, 2014), and in the last two decades hyperflexion has been debated (Van Weeren, 2013). A variety of studies have addressed physical, psychological and welfare aspects of different HNPs (e.g. Christensen *et al.*, 2014; Kienapfel *et al.*, 2014). In a comprehensive biomechanical study (Weishaupt *et al.*, 2006), the effects of various HNPs on kinetics and temporal gait parameters were investigated at walk and trot in a group of seven high-level dressage horses ridden on an force-measuring treadmill. Less restrained HNPs led to redistribution of the vertical impulse to the forelimbs and increased stride length at walk, and to decreased relative stance duration in the hindlimbs at both gaits, compared to the competition position. A raised extended position redistributed the vertical impulse to the hindlimbs, but increased forelimb vertical peak force at both walk and trot. A low overflexed position caused relatively few changes, but increased the first peak in hindlimb vertical force at walk. Kinematic data were recorded simultaneously, and results have been published for trot (Rhodin *et al.*, 2009) but not for walk. Since a typical riding session will include both walk, trot and canter, and since riding in walk is frequently recommended during rehabilitation, it is important to know whether the horse's head and neck position has similar or different influences in the different gaits.

The aim of this study was to quantify objectively the influence of different HNPs on the kinematics of horses ridden at walk, using data from the above mentioned study. It was hypothesised that the more restrained positions (either in flexion or in extension, i.e. HNP 3, 4 and 5; Figure 1) would induce changes opposite in magnitude to those provoked by the less restrained positions (HNP1, 6).

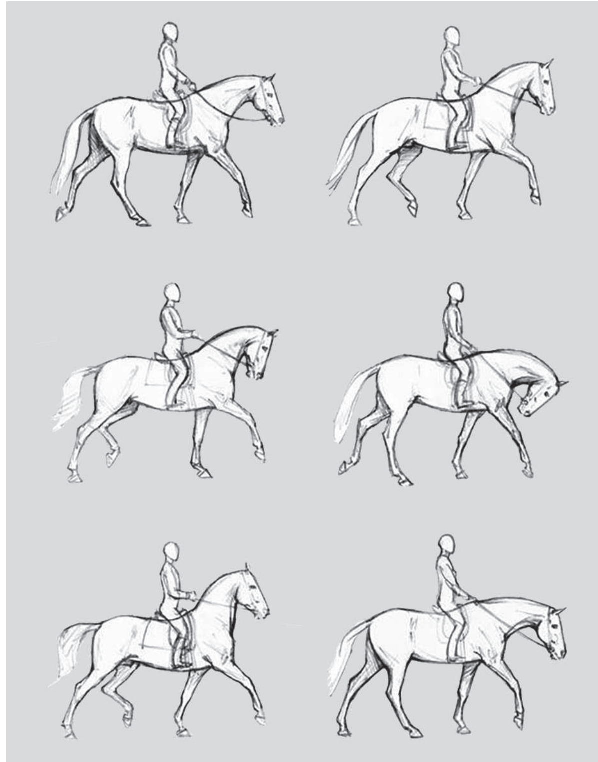

Figure 1. Head-neck positions (HNPs) studied. Short descriptions: HNP1 free position, HNP2 competition position, HNP3 flexed poll position, HNP4 overflexed position, HNP5 extended raised position and HNP6 forward downward position. For full descriptions see text. Illustration: Matthias Haab, University of Zurich, Switzerland.

2. Material and methods

Horses

Seven Warmblood dressage horses of typical conformation competing at Grand Prix (n=6) or intermediate (n=1) level, six geldings and one stallion, 14±4.3 years of age, with a height at the withers of 1.7±0.07 m (range 1.64-1.85 m), and a body mass of 609±62.3 kg (range 616-788 kg), were included in the study. At clinical examination the horses were judged to be free from lameness and pain or dysfunction of the limbs and back. Prior to the study, the horses were accustomed to treadmill locomotion with and without rider. The horses were ridden by their own rider wearing their own saddle and bridle with a normal snaffle bit. The fit of the saddles was evaluated by a member of the research team experienced in saddle fitting; all saddles were deemed to fit appropriately. The Animal Health and Welfare Commission of the canton of Zürich (188/2005) approved the experimental protocol. For all procedures carried out, written consent was obtained from the animal owner.

Experimental set-up

An experimental study was designed. Horses were measured on a high-speed treadmill (Karga AG, Fahrwangen, Switzerland) with an integrated force measuring system (Weishaupt *et al.*, 2002). This system determines hoof positions during stance on the treadmill and decomposes the vertical ground reaction forces at the multiple bearing points of the treadmill platform into vertical ground reaction forces for the loaded limbs. Spherical reflective markers (Ø 19 mm, ProReflex, Qualisys, Gothenburg, Sweden), were glued to defined anatomical landmarks on the head, at the spinal processes of T6, L3, L5, S3 and S5, on the tubera coxae and over the joints of the limbs (Appendix A). Kinematic data were collected by twelve infrared high-speed video cameras (ProReflex, Qualisys, Gothenburg, Sweden) at sampling rates of 140 Hz (four horses) and 240 Hz (three horses). The lower sampling rate was selected because of technical issues with the kinematic system. Kinetic data were sampled at 420 Hz (four horses) and 480 Hz (three horses), i.e. even multiples of the kinematic sampling rates.

Head-neck positions (HNPs)

Horses were measured ridden at walk with the head and neck in six different HNPs (Figure 1):

HNP1: free or natural; voluntarily acquired position, unrestrained with loose reins (free position).

HNP2: neck raised, poll high and bridge of the nose slightly in front of the vertical; reference position (competition position). This position was used as reference position as this is the ideal high-level dressage HNP, e.g. prescribed at competition, according to FEI (Anonymous, 2017).

HNP3: neck raised, poll high and bridge of the nose slightly behind the vertical (flexed poll position).

HNP4: neck lowered and flexed, bridge of the nose considerably behind the vertical (overflexed position).

HNP5: neck extremely elevated and bridge of the nose considerably in front of the vertical (extended raised position).

HNP6: neck and head extended forward and downward (forward downward position).

The overflexed position, HNP4, was achieved with a combination of ordinary reins and draw-reins; all other positions with ordinary reins only. After a warm-up on the treadmill of approximately 10 min, the horses were ridden in each HNP until steady (1-5 min) before measuring. The correctness of each HNP was verified by an international dressage judge. Reference recordings were first made in HNP2 at walk at speed intervals of 0.1/ms to provide speed-matched controls for each of the other HNPs, for which the speeds were adapted to the individual preference of each horse. HNPs other than HNP2 were then applied in random order.

Kinematic analysis

Proprietary software (QTrack, ProReflex, Qualisys, Gothenburg, Sweden) was used to capture data and to reconstruct the 3D movement of each marker. Raw x-, y-, and z-coordinates were exported to Matlab (The Math Works inc., Natick, MA, USA) for calculation of the following variables (illustrated in Supplementary Figure S1): the angle of the neck with respect to the horizontal plane; the vertical position of T6 and L5; the angles of the lumbar back (L3-L5) and sacrum (S3-S5) with respect to the horizontal plane; axial rotation of the pelvis (left and right tuber coxae with respect to the horizontal plane); lateral bending of the lumbo-sacral area (T6-L5-S5 projected in the horizontal plane); the angle of the femur with respect to the horizontal plane; the stifle, tarsal and metatarsophalangeal joint angles; and the pro- and retraction angles of the left fore- and hind hooves in relation to the elbow joint and L5, respectively. The elbow joint was selected as a reference for forelimb pro- and retraction to avoid influence from possible forward-backward motion in the sagittal plane of the T6 marker between different HNPs.

Kinematic variables were normalised to 101 points, 0-100% of the stride defined by first contact of either the left forelimb (neck angle and forelimb pro- and retraction) or the left hindlimb (all other variables), using data on stance start and end times from the treadmill force measuring system. Pro- and retraction angles were also normalised to 0-100% of fore- or hindlimb stance, respectively. The stride curves for the angles of the lumbar back, sacrum and femur with respect to the horizontal plane, and the tarsal joint angle were averaged over the available strides for each horse and condition and represented as graphs. Of the remaining variables, maximum, minimum and/or range of motion (ROM), were determined and averaged over available strides (see Table 1 for specifications), as was the transverse distance between stance positions of contralateral hooves on the treadmill. Hoof distance was measured from the center of the hoof, as calculated from the treadmill system.

Statistical analysis

The 101 point of the stride normalised mean curve or mean ROM, stride mean, minimum and maximum values for each variable (detailed above) were compared pair-wise between a speed-matched measurement in the reference position (HNP2) and each of the other HNPs using a paired nonparametric test (Wilcoxon signed rank in Matlab) similar to previous studies (Rhodin *et al.*, 2009). All data were considered potentially non-normally distributed, based on the difficulty to evaluate normality in small samples. Differences were considered to be significant at $P<0.05$. For the curves, a conservative decision was made that only significances with a duration of five or more consecutive data points were considered. Standard deviations (SDs) presented are group means of the intra-individual, trial-level SDs. Neither the Bonferroni correction nor any equivalent method, was applied because this is only valid if a general null hypothesis is tested (Perneger, 1998). In our case, if a HNP had no significant influence on e.g. forelimb protraction, there is no reason to reject the hypothesis that HNP affects the stifle angle.

3. Results

Over all trials and all horses, speed varied from 1.35 to 1.74 m/s. None of the experimental-control comparisons had a speed difference >0.02 m/s. Speed ranged between horses as follows; HNP1 1.57-1.74 m/s; HNP3 1.45-1.63 m/s; HNP4 1.45-1.57 m/s; HNP5 1.36-1.46 m/s and HNP6 1.57-1.74 m/s. The median number of stride cycles used for evaluation was 12, maximum 13 and minimum eight per trial.

Table 1. Stride mean, range of motion (ROM), maximum (max) and minimum (min): group mean difference (with SD) from 'control' HNP2 to HNP1 and HNP6 (a positive difference equals a larger value for the 'test' HNP), and group mean value for the speed-matched control measurement (in HNP2).

Variable			HNP1			HNP6		
			Diff/Mean	SD	*P*-value	Diff/Mean	SD	*P*-value
Neck angle (degrees)	Mean	Diff	**9.33**	**(2.07)**	b	**15.74**	**(1.37)**	a
		Control	-5.79	(0.55)		-7.43	(0.52)	
	ROM	Diff	-1.03	(1.46)		-0.82	(1.35)	
		Control	9.96	(0.63)		9.90	(0.54)	
Vertical position T6 (mm)	ROM	Diff	**8.83**	**(1.63)**	b	**10.46**	**(1.71)**	a
		Control	36.22	(1.04)		35.40	(1.61)	
	Max	Diff	2.52	(1.30)		4.08	(0.64)	
		Control	1,786.5	(0.46)		1,785.8	(0.70)	
	Min	Diff	**-6.22**	**(2.00)**	a	-6.37	(1.16)	
		Control	1,750.2	(0.88)		1,750.4	(1.12)	
Vertical position L5 (mm)	ROM	Diff	0.04	(1.47)		3.66	(1.45)	
		Control	72.76	(1.05)		71.15	(1.34)	
	Max	Diff	-2.17	(1.51)		-1.10	(1.33)	
		Control	1,730.1	(0.70)		1,729.8	(0.91)	
	Min	Diff	-2.32	(1.75)		-4.61	(1.43)	
		Control	1,657.3	(0.86)		1,658.6	(1.50)	
Stride protraction/retraction forelimb (degrees)	ROM	Diff	-7.30	(0.49)		**2.29**	**(0.70)**	a
		Control	56.37	(0.36)		56.11	(0.36)	
Stance protraction/retraction forelimb (degrees)	ROM	Diff	**2.46**	**(0.65)**	b	**2.71**	**(1.33)**	a
		Control	54.08	(0.51)		53.72	(0.47)	
	Max	Diff	**1.53**	**(0.42)**	b	**1.54**	**(1.20)**	a
		Control	113.38	(0.09)		113.11	(0.10)	
	Min	Diff	**-0.96**	**(0.47)**	b	**-1.25**	**(0.58)**	
		Control	59.34	(0.59)		59.40	(0.55)	
Stride protraction/retraction hindlimb (degrees)	ROM	Diff	**1.30**	**(0.44)**	b	**1.13**	**(0.17)**	a
		Control	39.54	(0.21)		39.68	(0.16)	
Stance protraction/retraction hindlimb (degrees)	ROM	Diff	**1.28**	**(0.40)**	a	**1.11**	**(0.21)**	a
		Control	39.11	(0.30)		39.20	(0.27)	
	Max	Diff	**0.85**	**(0.32)**	a	0.49	(0.20)	
		Control	119.48	(0.21)		119.76	(0.15)	
	Min	Diff	**-0.45**	**(0.11)**	a	**-0.61**	**(0.18)**	c
		Control	80.38	(0.11)		80.55	(0.14)	
Lateral bending (degrees)	ROM	Diff	-0.24	(0.27)		-0.28	(0.11)	
		Control	12.01	(0.18)		11.95	(0.20)	
Axial rotation (degrees)	ROM	Diff	0.55	(0.20)		**0.83**	**(0.27)**	b
		Control	10.14	(0.20)		9.96	(0.24)	
Metatarsophalangeal angle (degrees)	Range	Diff	-2.90	(4.87)		0.84	(4.46)	
		Control	75.21	(4.05)		75.19	(4.00)	
	Max	Diff	0.59	(3.19)		1.44	(3.16)	
		Control	222.90	(3.16)		222.79	(3.18)	
	Min	Diff	3.54	(3.21)		0.55	(3.12)	
		Control	147.70	(2.75)		147.62	(2.68)	
Stifle angle (degrees)	ROM	Diff	-1.29	(0.72)		-0.63	(0.78)	
		Control	36.20	(0.67)		36.27	(0.62)	
	Max	Diff	0.41	(0.27)		0.00	(0.30)	
		Control	166.80	(0.19)		166.78	(0.17)	
	Min	Diff	**1.65**	**(0.69)**	c	0.64	(0.63)	
		Control	130.63	(0.63)		130.49	(0.69)	
Lateral distance fore hooves (m)	Mean	Diff	**0.01**	**(0.01)**	a	-0.04	(0.06)	
		Control	0.11	(0.03)		0.16	(0.05)	
Lateral distance hind hooves (m)	Mean	Diff	0.01	(0.01)		**0.02**	**(0.01)**	a
		Control	0.17	(0.06)		0.16	(0.05)	

[1] HNP = head and neck position; HNP1 = free position; HNP2 = dressage competition position; HNP6 = forward downward position; control standard deviations (SD) are means of the SDs from the individual trials. Significant differences ($P<0.05$) compared to the 'control' HNP2 are marked in bold.

[2] In the *P*-value column [a] equals $P=0.016$, [b] $P=0.031$ and [c] $P=0.047$. A negative value for the neck angle means a position of the neck above the horizontal plane.

Comparing HNP1 ('free position') and HNP6 ('forward downward position') to HNP2 ('competition position')

Mean and ROM for the neck angle was larger in HNP1 and HNP6 compared to HNP2, i.e. the neck was held lower. In HNP1, compared to HNP2, the lumbar back was more horizontal during the three-limb support phases including the two hindlimbs, and the sacrum was more horizontal (more extended) at hindlimb midstance (Figure 2). Further, fore- and hindlimb pro- and retraction increased (decreased minima/increased maxima, Table 1). This was accompanied by increased ROM and a lower minimum for the vertical movement of T6, increased caudal rotation of the femur (increased angle with respect to the horizontal plane) during the second half of hindlimb stance, decreased flexion of the tarsus in early swing (Figure 2) and decreased maximum flexion of the stifle during swing (larger stride minimum angle, Table 1). Additionally, the fore hooves were placed slightly wider apart.

HNP6 induced similar changes as did HNP1. However, HNP6 caused larger increases in forelimb pro- and retraction, but no significant increase in hindlimb retraction at lift off (Table 1). ROM for the axial rotation of the pelvis was increased compared to HNP2, but the increase in sacral extension and reduction in tarsal and stifle swing flexion were not significant (as it was for HNP1). Additionally, the hind hooves, rather than the front hooves, were placed wider apart, compared to HNP2.

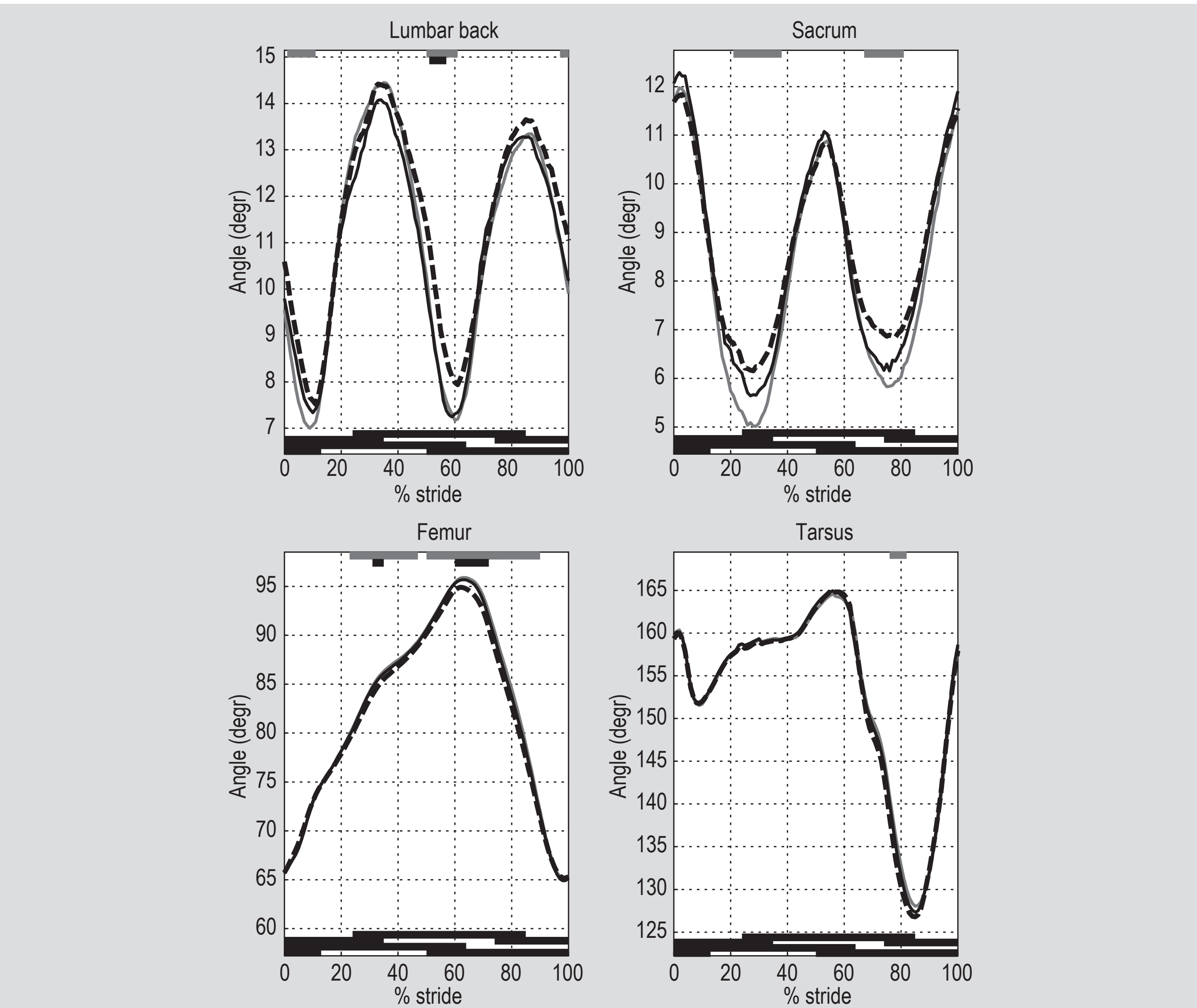

Figure 2. Group mean curves for selected variables with the stride normalised to 101 points, 0-100%, in horses ridden at walk with the head and neck in three different head and neck positions (HNP); HNP1 (solid grey line), HNP6 (solid black line) and a mean of the speed-matched HNP2 (dash-dotted heavy black line). The horizontal bars at the top indicate significant differences (*P*<0.05) between a speed-matched measurement in the reference position (competition) HNP2 and HNP1 (grey bar) or HNP6 (black bar). The horizontal bars at the bottom represent stance phases of (from top to bottom) the left and right forelimbs (black bars) and left and right hindlimbs (grey bars).

Comparing HNP3 ('flexed poll position'), HNP4 ('overflexed position') and HNP5 ('extended raised position') to HNP2 ('competition position')

The mean neck angle was significantly smaller in HNP3 and HNP5, and larger in HNP4, compared to HNP2. In all three positions, the sacrum was less extended (decreased angle with respect to the horizontal plane) at hindlimb midstance (Figure 3), and the maximum vertical position of L5 was increased compared to HNP2 (Table 2). In HNP3 and HNP4 the pelvis was also more flexed at the beginning of hindlimb stance. Further, all three HNPs caused decreased tarsal extension during the first part of hindlimb stance, and increased maximum flexion of the tarsus (Figure 3), stifle and metatarsophalangeal joint (Table 2) during swing, compared to HNP2.

HNP3 and HNP5, but not HNP4, had an influence on fore- and hindlimb pro- and retraction. HNP3 decreased protraction as well as stance ROM in the forelimb and decreased retraction, stance and stride ROM in the hindlimb, compared to HNP2. HNP5 decreased all pro- and retraction variables (Table 2). For both positions, this was accompanied by decreased extension of the stifle at the beginning of hindlimb stance (smaller stride maximum angle, Table 2) and decreased caudal rotation of the femur during the second half of hindlimb stance (Figure 3). In HNP3 the minimum vertical positions of T6 and L5 were higher, in HNP5 there was a non-significant tendency (for both $P=0.08$). Additionally, the hind hooves were placed closer together in HNP3 and the front hooves in HNP5 (Table 2).

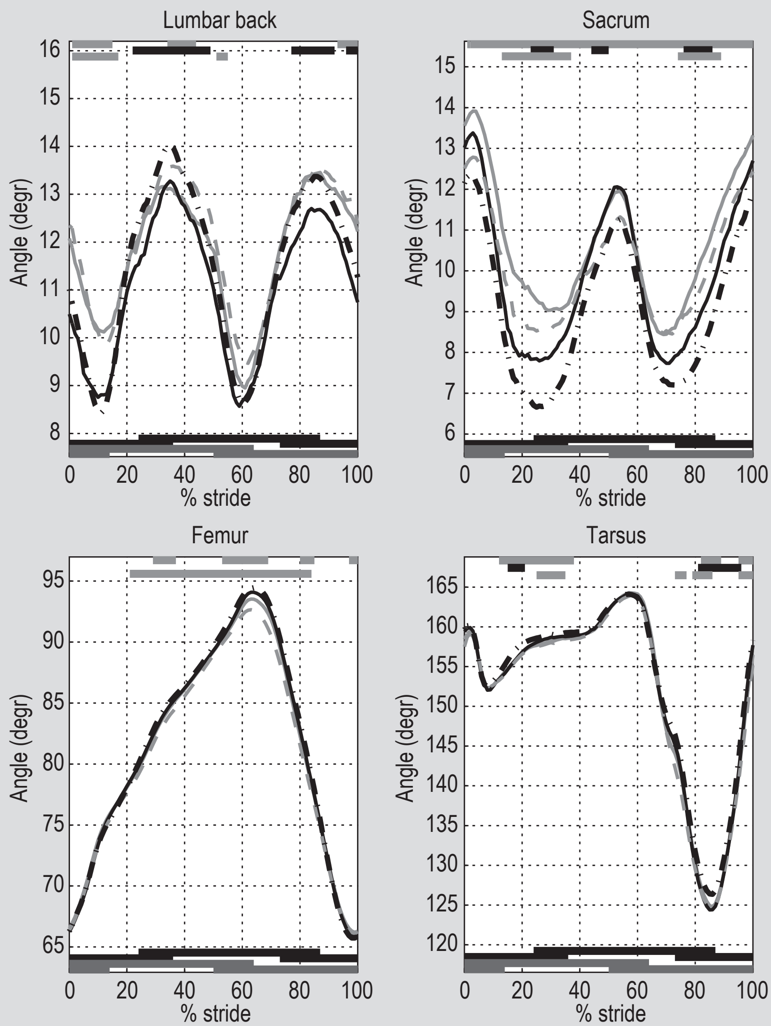

Figure 3. Group mean curves for selected variables with the stride normalised to 101 points, 0-100%, in horses ridden at walk with the head and neck in four different head and neck positions (HNP); HNP3 (solid grey line), HNP4 (solid black line), HNP5 (dashed grey line) and a mean of the speed-matched HNP2 (dash-dotted heavy black line). The horizontal bars at the top indicate significant differences (*P*<0.05) between a speed-matched measurement in the reference (competition) position HNP2 and HNP3 (upper grey bar), HNP4 (black bar) or HNP5 (lower grey bar). The horizontal bars at the bottom represent stance phases of (from top to bottom) the left and right forelimbs (black bars) and left and right hindlimbs (grey bars).

Table 2. Group mean ± standard evaluation for stride mean, range of motion (ROM) and maximum (max) and minimum (min) values for kinematic variables for HNP3, HNP4 and HNP5, comparing to HNP2.

Variable			HNP3			HNP4			HNP5		
			Diff/Mean	SD	*P*-value	Diff/Mean	SD	*P*-value	Diff/Mean	SD	*P*-value
Neck angle (degrees)	Mean	Diff	**4.32**	**(1.44)**	a	**15.67**	**(1.10)**	a	**-10.67**	**(1.11)**	a
		Control	-6.74	(0.86)		-7.21	(0.86)		-6.96	(0.75)	
	ROM	Diff	-0.11	(1.16)		-1.15	(0.86)		0.98	(1.26)	
		Control	8.52	(0.47)		8.91	(0.59)		7.66	(1.19)	
Vertical position T6 (mm)	ROM	Diff	-3.60	(1.87)		0.18	(3.09)		0.38	(2.27)	
		Control	33.15	(1.31)		31.56	(1.46)		29.49	(1.04)	
	Max	Diff	4.35	(1.33)		**7.91**	**(0.80)**	b	4.73	(2.49)	
		Control	1,787.1	(0.68)		1,785.5	(0.76)		1,788.4	(0.85)	
	Min	Diff	**7.85**	**(1.00)**	b	**7.80**	**(1.97)**	a	4.51	(1.62)	
		Control	1,754.0	(1.50)		1,754.0	(1.45)		1,758.9	(1.27)	
Vertical position L5 (mm)	ROM	Diff	1.43	(1.09)		**6.27**	**(0.98)**	a	-1.59	(2.18)	
		Control	66.59	(1.41)		66.82	(1.29)		60.54	(1.89)	
	Max	Diff	**8.43**	**(0.99)**		**6.20**	**(1.44)**	a	**5.91**	**(1.71)**	c
		Control	1,728.9	(0.84)		1,728.7	(0.76)		1,730.0	(0.61)	
	Min	Diff	**7.24**	**(2.15)**	b	0.09	(1.47)		7.55	(2.45)	
		Control	1,662.2	(1.04)		1,661.8	(1.04)		1,669.4	(2.72)	
Stride protrac/retrac forelimb (degrees)	ROM	Diff	-2.01	(0.87)		-0.41	(0.88)		**-3.21**	**(0.46)**	
		Control	55.12	(0.69)		55.04	(0.69)		53.72	(0.40)	
Stance protrac/retrac forelimb (degrees)	ROM	Diff	**-2.22**	**(0.89)**	c	-0.24	(0.84)		**-3.80**	**(0.77)**	a
		Control	52.82	(0.81)		52.67	(0.88)		51.43	(0.73)	
	Max	Diff	-1.18	(0.87)		-0.17	(0.95)		**-2.46**	**(0.12)**	
		Control	112.57	(0.71)		112.52	(0.72)		111.85	(0.29)	
	Min	Diff	**1.08**	**(0.84)**	a	0.06	(0.84)		**1.28**	**(0.62)**	a
		Control	59.75	(0.76)		59.87	(0.80)		60.45	(0.75)	
Stride protrac/retrac hindlimb (degrees)	ROM	Diff	**-1.45**	**(0.14)**	a	-0.20	(0.30)		**-2.46**	**(0.45)**	a
		Control	38.77	(0.10)		38.68	(0.32)		37.61	(0.10)	
Stance protrac/retrac hindlimb (degrees)	ROM	Diff	**-1.48**	**(0.07)**	a	-0.29	(0.26)		**-2.41**	**(0.29)**	a
		Control	38.37	(0.18)		38.32	(0.32)		37.14	(0.25)	
	Max	Diff	**-1.12**	**(0.21)**	a	-0.27	(0.24)		**-1.88**	**(0.27)**	a
		Control	119.10	(0.16)		119.03	(0.30)		118.37	(0.40)	
	Min	Diff	0.37	(0.20)		0.00	(0.18)		**0.56**	**(0.19)**	
		Control	80.72	(0.15)		80.70	(0.14)		81.19	(0.10)	
Lateral bending(degrees)	ROM	Diff	-0.60	(0.24)		**-0.80**	**(0.38)**	b	-0.55	(0.32)	
		Control	11.83	(0.18)		11.79	(0.19)		11.47	(0.15)	
Axial rotation (degrees)	ROM	Diff	-0.56	(0.25)		0.06	(0.30)		**-1.12**	**(0.32)**	c
		Control	9.40	(0.36)		9.47	(0.26)		8.53	(0.17)	
Metatarsophalangeal angle (degrees)	Range	Diff	**7.84**	**(3.01)**	a	**8.02**	**(4.18)**	b	**1.19**	**(1.19)**	a
	(Control)	Control	75.33	(3.05)		72.12	(3.64)		0.61	(0.61)	
	Max	Diff	0.60	(0.90)		1.50	(3.11)		**0.56**	**(0.56)**	c
	(Control)	Control	224.10	(0.99)		222.83	(3.11)		0.66	(0.66)	
	Min	Diff	**-7.30**	**(2.94)**	a	**-6.60**	**(3.39)**	a	**0.82**	**(0.82)**	a
	(Control)	Control	148.79	(0.33)		150.71	(3.07)		0.62	(0.62)	
Stifle angle (degrees)	ROM	Diff	0.44	(0.21)		**1.18**	**(0.35)**	a	0.62	(0.21)	
		Control	36.34	(0.46)		36.32	(0.38)		36.13	(0.42)	
	Max	Diff	**-1.46**	**(0.23)**	a	-0.60	(0.65)		**-1.53**	**(0.44)**	a
		Control	166.88	(0.36)		166.86	(0.35)		166.72	(0.39)	
	Min	Diff	**-1.88**	**(0.27)**	a	**-1.88**	**(0.34)**	a	**-2.10**	**(0.47)**	b
		Control	130.54	(0.29)		130.54	(0.28)		130.58	(0.30)	
Lateral distance fore hooves (m)	Mean	Diff	-0.04	(0.05)		-0.05	(0.05)		**-0.06**	**(0.06)**	b
		Control	0.16	(0.05)		0.16	(0.05)		0.16	(0.05)	
Lateral distance hind hooves (m)	Mean	Diff	**-0.01**	**(0.01)**	c	0.00	(0.02)		-0.06	(0.06)	
		Control	0.16	(0.05)		0.16	(0.05)		0.16	(0.05)	

[1] HNP = head and neck position; HNP2 = dressage competition position; HNP3 = flexed poll position; HNP4 = overflexed position; HNP5 = extended raised position; control standard deviations (SD) are means of the SDs from the individual trials. Significant differences (P<0.05) compared to the 'control' HNP2 are marked in bold.

[2] In the *P*-value column [a] equals P=0.016, [b] P=0.031 and [c] P=0.047. A negative value for the neck angle means a position of the neck above the horizontal plane.

HNP4 increased T6 maximum vertical position and ROM for the vertical movement of L5 compared to HNP2 (Table 2). Additionally, the lumbar back angle was decreased at hindlimb midstance (Figure 3) and ROM for lateral bending of the lumbosacral area was decreased (Table 2).

4. Discussion

In the freely walking horse, the head and neck have a pendular motion cycle. During forelimb propulsion the head moves upwards and the neck rotates upwards while the withers are lowered, during hindlimb propulsion the head is lowered and the neck rotates downwards while the withers move upwards (Denoix and Audigié, 2001). In normal walk there is a difference in the depth of the midstance dip in the vertical ground reaction force curve between forelimbs and hindlimbs (deeper for the hindlimbs). In a modeling study this could only be explained when taking the head dynamics into account (Gan *et al.*, 2016). Further, at walk the horse moves with substantially less muscle activity in the lower back and abdomen (Wakeling *et al.*, 2007; Zsoldos *et al.*, 2010), and with larger lateral movement of the body center of mass, compared to trot (Buchner *et al.*, 2000). Maintaining a defined, non-natural, HNP alters neck muscle activity compared to the free position (Kienapfel, 2014), which may affect the coordination between the neck and trunk movements and necessitate increased core muscle tension. Both effects influence the normal gait mechanics of the walk, as evidenced by the finding in this and earlier studies that a restrained HNP decreases stride length at this gait (Gómez *et al.*, 2006; Rhodin *et al.*, 2005; Weishaupt *et al.*, 2006).

Both increased poll flexion, HNP3, and increased neck flexion, HNP4, caused more changes to the horse's movement pattern at walk compared to trot. When the horses were ridden in trot there were no significant changes in any joint angle compared to HNP2, except for a slight decrease in stifle joint extension at the beginning of hindlimb stance in HNP3, and a slight increase in femur angle in the first part of hindlimb stance in HNP4 (Rhodin *et al.*, 2009). The effects on sacral (pelvic) flexion and extension and swing phase flexion of the hindlimb joints seen in both positions at walk were not seen at trot. This illustrates the higher susceptibility of walk kinematics to a restrained HNP. In HNP4, a contributing factor may also be that the group mean for the neck angle was twice as low at walk compared to trot, suggesting that it was easier for the riders to achieve an overflexed position at walk than at trot. With regards to limb protraction and retraction, there were both similarities and differences between the two gaits. HNP3, but not HNP4, had an influence on pro- and retraction at both walk and trot. However, HNP4, but not HNP3, was associated with a decrease in stride length at trot, whereas the opposite was true for walk walk (Weishaupt *et al.*, 2006). This could be the reason why HNP3 caused a marked increase in pelvic flexion at ridden walk, but not in ridden trot. It also illustrates the differences in mechanics between the two gaits, where stride length at walk is directly dependent on limb protraction and retraction, whereas at the bouncing trot push-off force also has a significant influence.

The raised extended position, HNP5, caused obvious and similar changes to the horse's movement pattern at both walk and trot. With respect to kinetics, it has been shown for both walk and trot that in this HNP vertical impulse was re-distributed to the hindlimbs, while vertical peak forces increased in the forelimbs (walk first force peak), and stride length decreased, compared to HNP2 (Weishaupt *et al.*, 2006). The kinematic changes observed at HNP5 at walk were also similar to those observed at trot: the lumbar back was more extended at midstance, sacral (pelvic) flexion was increased, the caudal rotation of the femur was reduced in the second half of the stride, and the stifle, tarsal and metatarsophalangeal joints were all more flexed during the swing phase (Rhodin *et al.*, 2009). At walk the horses placed the fore hooves markedly closer together, while this was not evaluated at the trot. A possible reason for these similarities could be that a raised, extended head neck position disturbs the horse's ability to maintain its balance, which would be troublesome for the horse irrespective of gait.

In the free and the forward down positions, HNP1 and HNP6, lowering of the head and neck was accompanied by increased lumbar back flexion and sacral (pelvic) extension, resulting in an overall more horizontal top line. Increased pro- and retraction of the fore- and hindlimbs were accompanied by increased ROM for the sacral (pelvic) angle (only significant for HNP1) and pelvic axial rotation (only significant for HNP6). Previous studies in unmounted horses have indicated that HNP1 increased back movements also in the thoracolumbar back, compared to HNP2 (Gómez *et al.*, 2006; Rhodin *et al.*, 2005). The common perception amongst riders that HNP1 is a useful position in training is likely related to these increased limb pendulations and back movements. In HNP6 the neck was more stretched out forwards compared to HNP1. Also in HNP6 forelimb protraction/retraction ROM was increased, whereas in free walk (HNP1) the mean value was numerically (though not significantly) lower, compared to HNP2. Taken together, these data suggest that both HNPs have roughly similar effects, but that, if the rider wants to improve forelimb protraction and retraction HNP6 may be slightly more advantageous.

The findings of this and previous studies suggest that the use of different HNPs may profoundly influence the effect of training in horses. More relaxed positions, like HNP1 and HNP6, are probably well suited for warm-up and cool-down before and after training and likely for rehabilitation, if the horse's temperament allows. The background of the use of a raised position (HNP5) may vary from deliberate use in correcting a horse hanging on the bit, to being the result of the rider's inability to work the horse in an intended lower position, e.g. in a riding school situation. Deliberate use of accentuated poll flexion, HNP3, and neck overflexion, HNP4, is likely more common among advanced riders, but the posture of HNP3 or HNP4 also resembles the situation where the horse drops the bit and works without contact with the rider's hand, as often described (German National Equestrian Federation, 1997). Riders should also be aware that the training effects from using different HNPs may vary between gaits, as illustrated by the differences in HNP3 and HNP4 between ridden walk and ridden trot (Rhodin *et al.*, 2009). This may be a reason why transitions are often considered useful in horse training. For example, walk-trot transitions are often gradual, especially in non-advanced horses, and contain intermediate steps likely to engage both trot and walk mechanics (Argue and Clayton, 1993).

This study does not answer any questions of whether HNP3, HNP4 or HNP5 are suitable for usage in rehabilitation, but none of these three positions seem to have effects particularily desirable for rehabilitation.

Care was taken to optimise the experimental design of this study as much as possible. It was a deliberate choice to use upper level dressage horses and to have an international dressage judge independently verify correctness of the HNP positions. Further, horses were well accustomed to work on the treadmill and horses were performing at their own individual preferred speed with a speed-matched control. However, there are limitations as well. The number of horses was low and treadmill locomotion allows for standardised and repeatable measurements, but is not identical to overground locomotion and forcibly only permits measuring on the straight in very steady state conditions. Stride length in walk has been shown to differ comparing overground to treadmill locomotion (Barrey *et al.*, 1993). As protraction/retraction is coupled to stride length, this may have introduced an offset to our results but is considered less likely to have affected the differences between HNPs. Use of skin fixated markers always includes the risk of skin displacement errors. However, with each horse acting as its own control, the skin displacement should not affect the differences observed between different head and neck positions.

5. Conclusions

It can be concluded that in horses ridden at walk both the unrestrained and forward-downward extended HNPs increased limb protraction and retraction, and pelvic ROM. Three more restrained positions, including an overflexed position and two positions with raised neck, caused rather substantial kinematic changes compared to the competition position. We therefore conclude that interventions influencing head and neck position can markedly affect the horse's movement pattern at walk, which is not necessarily always innocuous and has to be taken into account when designing training protocols for riding horses.

Supplementary material

Supplementary material can be found online at https://doi.org/10.3920/CEP180002.

Figure S1. Kinematic variables and marker placement.

Acknowledgements

The authors wish to thank Sören Johansson, Katja von Peinen and Thomas Wiestner for excellent technical assistance and all riders and horse owners who generously lent us their horses for this study. This study was supported by grants from Swedish Foundation for Equine Research, Sveland Insurance Company, Sweden and Ulla Håkansson.

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