

Back kinematics of healthy trotting horses during treadmill versus over ground locomotion

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Summary

Reasons for performing study: Treadmill locomotion is frequently used for training of sport horses, for diagnostic purposes and for research. Identification of the possible biomechanical differences and similarities between the back movement during treadmill (T) and over ground (O) locomotion is essential for the correct interpretation of research results.

Objectives: To compare the kinematics of the thoracolumbar vertebral column in treadmill and over ground locomotion in healthy horses.

Methods: Six sound Dutch Warmblood horses trotted on a T and O during 10 s at their own preferred velocity (mean \pm s.d. 3.6 \pm 0.3 m/s T and 3.6 \pm 0.1 m/s O), which was the same in both conditions. Kinematics of the vertebral column was captured by infrared cameras using reflective skin markers attached over the spinous processes of selected vertebrae and other locations. Flexion-extension and lateral bending range of motion (ROM), angular motion pattern (AMP) and intravertebral pattern symmetry (IVPS) of 5 vertebral angles (T6-T10-T13, T10-T13-T17, T13-T17-L1, T17-L1-L3 and L1-L3-L5) were calculated. Neck angle, linear and temporal stride parameters and protraction-retraction angles of the limbs were also calculated.

Results: The vertical ROM (flexion-extension) was similar in both conditions, but the horizontal ROM (lateral bending) of the lumbar angles T17-L1-L3 and L1-L3-L5 was less during T locomotion (mean \pm s.d. difference of 1.8 \pm 0.6 and 1.7 \pm 0.9°, respectively, $P > 0.05$). During O locomotion, the symmetry pattern of the lumbar vertebral angles was diminished from 0.9 to 0.7 (1 = 100% symmetry) indicating increased irregularity of the movement ($P > 0.05$). No differences were found in the basic linear and temporal stride parameters and neck angle.

Potential relevance: Vertebral kinematics during treadmill locomotion is not identical to over ground locomotion, but the differences are minor. During treadmill locomotion lumbar motion is less, and caution should be therefore taken when interpreting lumbar kinematics.

Introduction

Research on equine biomechanics has increased substantially over the past decades. Most of the kinetic and kinematic studies are done on a treadmill due to the fact that this device offers a stable and controlled scenario for locomotion studies (Fredricson *et al.* 1983; Sloet van Oldruitenborgh-Oosterbaan and Clayton 1999; Weishaupt *et al.* 2002; Erickson 2006). Some of the topics that have been studied in the sound horse on a treadmill are ground reaction forces (Weishaupt *et al.* 2004), limb kinematics (Back *et al.* 1995a,b; Buchner *et al.* 1997, 2000; Peham *et al.* 1999) and back kinematics (Pourcelot *et al.* 1998; Faber *et al.* 1999; 2000; 2001a,b; 2002; Haussler *et al.* 2001; Licka *et al.* 2001; Johnston *et al.* 2004). However, to extrapolate the conclusions obtained from these studies to over ground situations it is necessary understand how the treadmill affects equine locomotion.

Biomechanical changes related to treadmill vs. over ground locomotion have been studied in several species, such as mice (Herbin *et al.* 2007), cats (Błaszczuk and Loeb 1993), horses (Fredricson *et al.* 1983; Barrey *et al.* 1993; Buchner *et al.* 1994), and primates (Nelson *et al.* 1972; Eliot and Blanksby 1976; van Ingen Schenau 1980; Frishberg 1983; Nigg *et al.* 1995; Stolze *et al.* 1997; Vogt *et al.* 2002; Dunbar 2004; Riley *et al.* 2008; among others). Several factors seem to affect the outcome of the comparison. Age differences have been reported to play a role in man, children having a larger increase in step frequency on a treadmill than adult subjects (Stolze *et al.* 1997). In the horse, the make of the treadmill has a certain influence; Jones *et al.* (2006) reported that the Mustang treadmill was >6 times stiffer than the Sätö and suggested that it costs less energy for horses to walk, trot or canter on a stiffer treadmill than on a more compliant treadmill.

Comparisons of treadmill vs. over ground locomotion in the horse have mainly investigated stride parameters. Buchner *et al.* (1994) compared the linear and temporal stride parameters and trunk vertical displacement of treadmill locomotion to 2 different track surfaces: a rubber surface and an asphalt track; they found increased stance duration of the forelimbs, diminished retraction of all limbs, and less vertical displacement of the trunk during treadmill locomotion compared to both types of track surface. Buchner *et al.* (1994) also found that the type of track surface

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affected the stride duration and hindlimb protraction angle. In contrast, Couroucé *et al.* (1999) did not find differences in locomotion parameters between 2 types of surface when measuring French Trotters over ground. Fredricson *et al.* (1983) reported shorter stride duration in one horse without experience on treadmills using a coir matted treadmill, while Barrey *et al.* (1993) reported longer stride duration in several horses on a treadmill compared to over ground locomotion.

The only finding more or less related to back motion of the horse is that described by Buchner *et al.* (1994). The reduction of the vertical displacement of the trunk found during treadmill locomotion in that study may have been due to the compliance of the treadmill used and therefore the lower workload provoked. It has been shown that workload on a treadmill is lower compared to over ground (Nelson *et al.* 1972; Barrey *et al.* 1993; Sloet van Oldruitenborgh-Oosterbaan and Barneveld 1995; Gottlieb-Vedi and Lindholm 1997; Couroucé *et al.* 1999). There are no data on the angular movement of the vertebral column in the report by Buchner *et al.* (1994).

The present study aimed to quantify the effect of treadmill locomotion on back kinematics in different planes compared to over ground locomotion in sound horses. It was hypothesised that there are differences in vertebral kinematics given the different nature of both types of locomotion and differences previously reported in temporal stride parameters; however, these differences are few and small.

Materials and methods

Horses

Vertebral kinematics was measured in 6 nonlame Dutch Warmblood horses, 2 horses and 4 mares, age mean \pm s.d. 11.7 ± 4.9 years with a height at the withers of 163 ± 3.6 cm, and a body mass of 567 ± 22.1 kg, while they were trotting over ground on a 15 m gravel track at their own preferred velocity and on a treadmill¹ at matched velocity. The horses had been previously accustomed to the treadmill. Velocity on the track was calculated from the distance covered and the time required recorded with a laser chronometer. The experimental protocol had been approved by the Animal Experimentation Committee of Utrecht University.

Data collection

Measurements were performed using the infrared-based ProReflex automated gait analysis system², operating at 240 Hz. Spherical infrared light reflective markers with a diameter of 19 mm were glued onto the skin overlying the spinous processes of the following vertebrae: thoracic (T) 6, 10, 13 and 17; lumbar (L) 1, 3 and 5, and sacral 3 (S3). Markers were also placed on the sacral tuberosities, the lateral sides of the left hooves below the coronary band and on the left wing of the atlas. Six infrared cameras recorded the marker locations while the horses were standing square and at trot on a treadmill and over ground without relocating the markers. Each recording session lasted 10 s. Measurements were started after one or 2 steps to allow the horses to reach a steady gait.

Data analysis

Qualisys Track Manager Software² and Matlab³ were used to capture and process the data. Data was presented as proportional to one stride cycle starting with the initial ground contact of the left

hindlimb. Angles were calculated in the 3 different planes to describe all the motions. All the vertebral movements were presented as angular motion patterns (AMP) during the stride cycle. The range of motion (ROM) was calculated for each AMP and was defined as the difference between maximal and minimal values of the AMP. Data captured in the square standing horse were used to determine the zero value in the AMPs in each horse. The vertebral angles were named after the central marker between 3 adjacent markers. Intravertebral pattern symmetry (IVPS) was the correlation coefficient calculated for each vertebral angle, it was scored from 0–1, 1 being 100% symmetrical. Pelvic axial rotation was calculated with help of the markers on the left and right sacral tuberosity and on S3. The neck angle was calculated as the angle of the line between the markers on T6 and on the atlas with the horizontal. Stride length and stride duration were calculated from the marker on the left hind hoof. Stance duration was calculated for the left hind and left fore hoof. The protraction-retraction (PR) angle was calculated for the fore and hindlimbs using the markers on the hooves and T6 for the left forelimb, and S3 for the left hindlimb. Data are presented as mean \pm s.d., ROM \pm s.d. and in the case of PR, maximal protraction and maximal retraction are included.

Treadmill vs. over ground parameters were tested for normality. If normally distributed, data were statistically analysed using ANOVA for repeated measures with Bonferroni correction. If data were not normally distributed a Wilcoxon signed rank test was used. The level of significance for all tests was set at $P < 0.05$.

Results

Due to a technical failure in the data capture, data of one horse had to be discarded, leaving 5 for analysis.

Velocity

The average velocity was 3.6 ± 0.3 m/s on the treadmill and 3.6 ± 0.1 m/s over ground.

Stride parameters

There were no significant changes in the temporal stride parameters. Stride length was 2.5 ± 0.5 m over ground and 2.5 ± 0.3 m on the treadmill. Stride duration was 0.70 ± 0.0 s over ground and on the treadmill. Stance duration was 0.4 ± 0.0 s for fore and hindlimbs in both conditions (Table 1).

Protraction-retraction angles

There were no differences in PR between the 2 conditions for any limb (Table 1).

Vertebral range of motion

There were no differences in range of motion (ROM) of flexion-extension of the vertebral column or in pelvic axial rotation (AR) ROM. Lateral bending (LB) ROM was significantly decreased on the treadmill at L1 (1.8°) and L3 (1.7°) (Table 1).

Vertebral angular motion patterns

Most of the vertebral angles were similar in pattern between over ground and treadmill locomotion. Only 2 mean vertebral angles

presented changes. On the treadmill, there was an increase at T10 of 0.5° in extension at the beginning of the stride and an increase of 2.3° in bending towards to the right during most of the stride. Over ground, the angle at L5 was 0.7° bent to the left during most of the stride.

Intravertebral pattern symmetry

The intravertebral pattern symmetry (IVPS) for all motions and vertebral angles was 0.9 ± 1.0 during treadmill locomotion, indicating a high degree of symmetry, and 0.7 ± 0.3 for flexion-extension motion during over ground; this difference was not statistically significant. IVPS of lateral bending motion was significantly diminished over ground compared to treadmill locomotion (on average for all vertebral angles 0.7 ± 2.0).

Neck angle

There were no statistical differences on the neck angle of the horses between treadmill and over ground locomotion (Table 1).

TABLE 1: Flexion-extension and lateral bending mean angular motion pattern and range of motion values of vertebral angles, axial rotation of the pelvis and neck angle in degrees; temporal stride parameters in m and s, and protraction retraction angles in degrees (mean \pm s.d.) of hind and fore (left) limbs at trot during overground and treadmill locomotion

			Overground	Treadmill
Flexion-extension	T10	Mean	1.5 \pm 0.9*	1.0 \pm 1.0*
		ROM	4.0 \pm 0.9	3.5 \pm 0.4
	T13	Mean	-2.5 \pm 0.3	-2.4 \pm 0.4
		ROM	2.3 \pm 0.5	2.4 \pm 0.4
	T17	Mean	-2.9 \pm 0.3	-2.5 \pm 0.5
		ROM	2.2 \pm 0.3	2.3 \pm 0.4
	L1	Mean	-2.9 \pm 0.7	-2.6 \pm 0.8
		ROM	3.2 \pm 0.5	3.2 \pm 0.7
	L3	Mean	-3.6 \pm 1.0	-2.6 \pm 1.0
		ROM	4.2 \pm 0.6	3.9 \pm 0.7
	L5	Mean	-1.2 \pm 0.9	-0.7 \pm 0.8
		ROM	3.9 \pm 0.4	2.9 \pm 1.0
Lateral bending	T10	Mean	2.1 \pm 0.9*	1.5 \pm 1.2*
		ROM	5.1 \pm 0.8	5.7 \pm 1.0
	T13	Mean	1.1 \pm 0.7	0.6 \pm 0.7
		ROM	4.4 \pm 0.9	4.1 \pm 0.8
	T17	Mean	0.2 \pm 0.6	0.0 \pm 0.5
		ROM	3.6 \pm 0.5	3.3 \pm 0.7
	L1	Mean	-0.8 \pm 0.6	0.0 \pm 0.6
		ROM	4.9 \pm 1.5*	3.1 \pm 0.9*
	L3	Mean	-0.1 \pm 0.8	0.2 \pm 0.9
		ROM	5.4 \pm 1.7*	3.7 \pm 0.8*
	L5	Mean	1.3 \pm 1.0*	0.1 \pm 1.5*
		ROM	4.6 \pm 2.3	4.9 \pm 1.4
Pelvic axial rotation	Mean	-0.3 \pm 3.9	-0.5 \pm 4.7	
	ROM	14.8 \pm 5.7	15.9 \pm 2.4	
Neck angle	Mean	-8.5 \pm 6.9	-8.2 \pm 8.9	
	ROM	4.8 \pm 2.2	4.6 \pm 0.9	
Stride duration (s)		0.7 \pm 0.0	0.7 \pm 0.0	
Stride length (m)		2.5 \pm 0.5	2.5 \pm 0.3	
Stance duration (s)	Hind	0.4 \pm 0.0	0.4 \pm 0.0	
	Fore	0.4 \pm 0.0	0.4 \pm 0.0	
Protraction (P)- retraction (R) angles	Hind	ROM	32.1 \pm 1.0	34.1 \pm 3.0
		Max P	20.1 \pm 0.6	21.7 \pm 2.7
		Max R	-12.1 \pm 1.2	-12.5 \pm 1.3
	Fore	ROM	34.7 \pm 1.1	36.7 \pm 1.5
		Max P	10.1 \pm 1.9	11.7 \pm 3.2
		Max R	-24.6 \pm 1.8	-25.1 \pm 1.7

*Statistically significant differences between overground and treadmill locomotion.

Discussion

Stride duration, stance duration and stride length were similar between treadmill and over ground locomotion. This is in accordance to the study by Buchner *et al.* (1994). However, in that study stance duration of the forelimbs was longer on the treadmill, which was not the case in our study. There are 2 possible explanations. First, the type of track material was different: the gravel surface used in our study is more compliant than the tarmac surface used by Buchner *et al.* (1994) and hence may come closer to the rubber of the treadmill belt. This is the reason why we have used this track material for our study. Second, our horses may have been more used to treadmill locomotion, making them more confident (Herbin *et al.* 2007). Also, in our study we found no differences on limb protraction-retraction in contrast to the study by Buchner *et al.* (1994), probably due to the same reasons.

Only slight and relatively few changes in vertical (flexion-extension) ROM of the back were found in our study. However, Buchner *et al.* (1994) described a decrease in vertical movement of the withers during treadmill locomotion compared to over ground locomotion on a rubber surface, which was attributed to the fact that the velocity of the belt decreased 9% during stance phase. Robert *et al.* (2001) also showed that velocity may affect flexion-extension motion because increasing velocity increases the activity of the *longissimus dorsi* and *rectus abdomini* muscles, which are involved in stabilising the vertebral column. Apparently, at the relatively slow velocities used in our study there were no influences on belt speed, or these velocities were not high enough to provoke changes in stance phase durations or in vertical vertebral kinematics.

The pattern of the angular motions of the back was slightly different between both types of locomotion. Mainly lateral bending was affected, but these changes were not consistent in more than one vertebral angle, therefore we do not consider it clinically relevant. In contrast, we think the consistent diminished horizontal (lateral bending) ROM of the lumbar area on the treadmill relevant. This observation is in agreement with the article of Vogt *et al.* (2002), where the oscillation amplitudes of the upper lumbar region and the pelvis in man were reduced on the treadmill. Quadruped and biped locomotion are not the same (Slijper 1946). Nevertheless, here a similar mechanism happens where the treadmill allows less freedom of movement of the lumbar back because velocity is imposed on the individuals. This seeming disadvantage of treadmill locomotion may be compensated by the marked advantage of smoother and more regular locomotion evident from the higher score of intravertebral pattern symmetry, resulting in a substantial reduction of noise on the treadmill.

It is concluded that the vertebral kinematics during treadmill locomotion is not identical to over ground locomotion, but the differences are minor. During treadmill locomotion lumbar motion is less, but also more symmetrical. Therefore, caution should be taken when interpreting lumbar kinematics. For all other aspects of thoracolumbar kinematics we can conclude that vertebral kinematics and stride parameters are similar between gravel track and treadmill locomotion.

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Manufacturers' addresses

¹Kaga AG, Fahrwangen, Switzerland.

²Qualisys Medical AB, Gothenburg, Sweden.

³The MathWorks, Natick, Massachusetts, USA.

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