Equine vet. J. (2000) **32** (4) 312-317

The effects of treadmill inclination and speed on the activity of two hindlimb muscles in the trotting horse

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Keywords: horse; surface electromyography (EMG); treadmill; speed; incline; trot

Summary

Electromyographic activity (EMG) was used to determine how hindlimb muscle activation patterns vary with speed and incline in the horse. EMG was recorded using surface electrodes over the *gluteus medius* and *tensor fasciae latae* muscles during treadmill locomotion at trot for different combinations of speed (3.5 to 6 m/s) and inclination (0, 3 and 6%). Raw EMG signals were processed to determine stride duration, activity onset and end, and integrated EMG (IEMG). Stride and stance phase duration decreased linearly with increasing speed. Stride duration was not influenced by the slope. Onset and end of muscle activity came significantly earlier in the stride cycle when speed increased and later when inclination changed from 0 to 6%. The relative duration of the burst (percentage of stride duration) increased as running speed increased, but tended to decrease with increasing slope. The IEMG of the muscles increased with increasing speed and slope, the largest increase being observed in the *tensor fasciae latae*. It is concluded that both increases in speed and inclination lead to an increase in the integrated electromyographic activity and hence to a higher workload of the 2 hindlimb muscles investigated.

Introduction

It has been reported that exercising uphill strengthens the hindlimbs (Clayton 1991) and increases muscle and conditioning (Marcella and Leimbach 1998). Work during an ascent would require synergistic and concentric work on the extensors of the hip and back (Denoix and Pailloux 1997) usually used during propulsion. In racehorses, conventional training is conducted on flat tracks at high speeds. In experimental studies on treadmills, the running speed or inclination are usually increased to increase workload. Sloet *et al.* (1997) suggested that working on an incline might recruit muscles differently than on a horizontal treadmill.

Kinematic investigations (Leach and Drevemo 1991; Rooney *et al.* 1991; Kai *et al.* 1997; Sloet *et al.* 1997) and exercise physiology studies (Barrey *et al.* 1993; Hiraga *et al.* 1995; Ratzlaff *et al.* 1995) have been previously conducted on the effect of the speed and inclination of the treadmill. Electromyographic activity of several muscles during different gaits has been documented in horses on track and treadmill (Wentink 1978; Tokuriki and Aoki 1995; Cheung *et al.* 1998; Robert *et al.* 1998). However, the pattern of change in muscle activity in relation to the increase in speed and inclination is still unclear.

Our aim was to determine the detailed effects of speed and inclination on hindlimb muscular activity in the horse and to provide empirically based guidelines in text books with a scientific background. This investigation was focused on the periods of muscle activity and the integrated EMG of 2 muscles: *gluteus medius* and *tensor fasciae latae*.

Materials and methods

Subjects

Four healthy mature horses (3 Selle Français, 1 Trotteur Français) with mean bodyweights 525 ± 25 kg, withers height 1.65 ± 0.02 m and average age of 8 ± 2.5 years were studied. These horses were free of lameness. They were used 6 days a week as saddle horses in a riding school and had been previously accustomed to trotting on a high speed treadmill.

Electromyographic computing

The motor points of the *gluteus medius* (GM) and *tensor fasciae latae* (TFL) were detected in each horse by a stimuli-detection method. The skin of each site was shaved, cleaned with spirit, and ether was applied to improve adhesiveness; then, 2 pregelled (Ag/AgCl) surface electrodes[1] were placed over each muscle belly with a 2.5 cm interelectrode distance (Fig 1). A single ground electrode was placed over the right *tuber sacrale*. Each pair of electrodes was connected to a snap fastener[2]. A piezoelectric accelerometer[2] was taped on the lateral wall of the hoof of the left hindlimb to obtain impact acceleration peak for detection of the landing and toe off. Both the EMG and accelerometer signals were transmitted by an 8 channel transmitter[2] with a sampling frequency of 1200 Hz to a microcomputer[3].

Exercise test

Prior to the experiments, horses followed a warm-up period of 10 min walk and 10 min working trot. Then, they were instrumented before recordings were made. The exercise test consisted in trotting at 3.5, 4, 5 and 6 m/s on a high speed treadmill[4] at different slopes (0, 3 and 6%). The sequences of combined speed and slope were randomly determined for each subject.

TABLE 1: Mean (s.d.) stride parameters and periods of muscle activity in 4 saddle horses exercising on a 0, 3 and 6% inclined treadmill at different speeds

Variables	Slope (%)	Speed (m/s) 3.5	4	5	6
Stride parameters					
Stride duration (ms)	0	728.7 (17.8)[1]	712.9 (26.4)	661.6 (16.3)	606.6 (9.6)
	3	742.1 (30.8)	713.9 (20.5)	667.2 (16.3)	615.5 (28.8)
	6	736.6 (24.1)	713.1 (23.1)	670.2 (28.0)	617.1 (21.6)
Stance duration[2]	0	30.6 (1.8)	29.2 (1.4)	27.0 (1.8)	26.1 (0.7)
	3	31.3 (1.2)	29.5 (0.7)	27.6 (1.3)	26.3 (0.3)
	6	32.2 (1.3)	30.0 (0.7)	28.4 (0.7)	26.2 (0.8)
Gluteus medius					
Beginning[2]	0	71.8 (2.7)	70.7 (2.6)	68.9 (1.7)	63.5 (5.3)
	3	72.8 (2.7)	71.4 (2.3)	68.2 (6.1)	66.1 (4.2)
	6	74.7 (1.7)	73.2 (1.1)	71.9 (1.7)	69.9 (1.8)
End[2]	0	16.5 (1.3)	15.3 (2.1)	14.3 (2.5)	14.2 (1.8)
	3	17.9 (3.5)	16.2 (2.3)	16.7 (3.3)	16.3 (3.6)
	6	18.9 (2.6)	17.3 (3.3)	15.9 (2.7)	15.7 (7.0)
Duration[2]	0	44.7 (3.1)	44.6 (1.8)	45.4 (1.8)	50.7 (6.6)
	3	45.0 (4.3)	44.8 (2.6)	48.5 (8.3)	50.2 (5.9)
	6	44.2 (1.4)	44.1 (3.0)	44.0 (1.8)	45.8 (6.2)
Tensor fasciae latae					
Beginning[2]	0	13.1 (3.1)	11.3 (3.1)	7.8 (3.5)	3.8 (0.7)
	3	13.8 (1.8)	12.8 (1.2)	8.9 (1.2)	5.9 (2.0)
	6	16.0 (2.5)	14.5 (2.6)	12.4 (2.0)	7.1 (1.9)
End[2]	0	67.0 (5.5)	66.7 (5.2)	65.6 (5.8)	63.0 (4.3)
	3	67.6 (6.3)	67.0 (5.0)	62.1 (3.7)	62.2 (4.7)
	6	70.5 (3.6)	68.9 (3.5)	68.8 (4.7)	63.9 (3.3)
Duration[2]	0	53.9 (5.8)	55.4 (4.6)	57.8 (6.2)	59.2 (3.6)
	3	53.8 (4.5)	54.1 (3.9)	53.2 (4.3)	56.3 (2.7)
	6	54.5 (1.9)	54.4 (2.7)	56.4 (3.0)	56.9 (3.0)

[1]mean (s.d.); [2]in percentage of stride duration (0% = landing).

Measurements

Data were collected for 15 consecutive strides at each speed/slope combination. Raw electromyograms and accelerometer signals were analysed using Myodata software[2]. The signal of the accelerometer enabled detection of the initial ground contact and heel raising as well as the calculation of the duration of the stride, stance and swing phase. Onset and end of muscle activities were defined with reference to the hindlimb landing obtained from the signal of the accelerometer. The mean EMG activity onset, end and duration were calculated for ten consecutive stride cycles for each muscle as a percentage of the stride duration (0% = landing).

EMG were also full-wave rectified on 10 successive strides and the integrated EMG (IEMG) were calculated on the same strides. Statistical analyses were carried out to identify any differences in the timing and IEMG variables for each muscle between speeds and slopes. The beginning, end, duration of activity and IEMG of both muscles were compared using an analysis of variance (GLM procedure[5]) with a significance level set at $\alpha = 0.05$. Correlation between IEMG, temporal parameters and speed or slope was also examined by linear regression and correlation analysis.

Results

Mean ± s.d. values for the temporal variables measured in this study are presented in Table 1. The patterns of EMG activity of Horse 1 at 6 m/s/0% and 3.5 m/s/6% speed/slope are shown in Figure 2. For all 4 horses, the range of stride duration was 601 to 771 ms and the hindlimb stance duration varied from 25 to 34% of the stride duration. The EMG activity of the GM always began in the second part of the swing phase (57.5 to 76.3% of the stride duration) and continued until midstance (10.6 to 23.7%). As a result, the mean burst duration represented 40.1 to 60.8% of total stride duration. The TFLactivity began in the first part of the stance phase (3.4 to 19.2%) and ended when the GM appeared to be active (58.0 to 74.4%). It was active for more than half of the stride duration (48.7 to 66.8%). The 2 muscles showed great differences in their IEMGs (Fig 3). The mean value for one horse varied from 9.3 to 24.7 mVper stride for the GM and from 41.1 to 109.1 mV for the TFL.

Effects of speed

Regardless of the slope of the treadmill, the values of stride and stance phase duration decreased linearly ($R^2 \geq 0.99$ and 0.95 respectively) with increasing speed.

The beginning of electrical activity came earlier ($P<0.01$) for the 2 muscles studied when speed increased (Table 1). The relationship between speed and mean activity onset was linear for the GM ($R^2 \geq 0.93$) and TFL($R^2 \geq 0.96$) with little deviation of data from the regression line for each slope. This linear

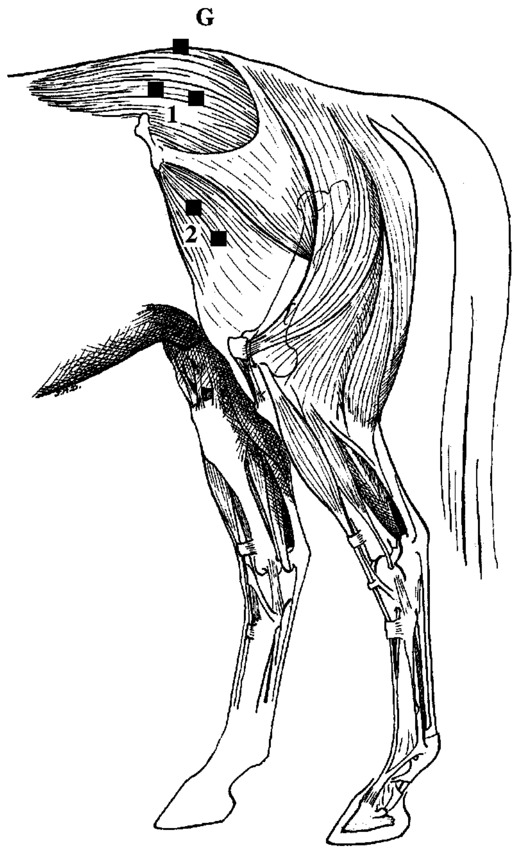

Fig 1: Position of the electrodes over the 2 muscles investigated. 1 = Gluteus medius *muscle, 2 =* Tensor fasciae latae *muscle, G = Ground electrode.*

relationship appeared in all horses for both muscles. EMG activity ceased significantly earlier (P<0.05 for the GM and P<0.01 for the TFL) as speed increased (Table 1). For the GM, the relationship between end of activity and speed was not linear. The end of activity of the TFL tended to happen linearly earlier ($R^2 \geq 0.84$) as the speed increased.

Individual muscle activity duration varied considerably from one horse to the others and with treadmill slope. In both muscles studied, the mean value of the burst duration was related directly (P<0.01) to the speed, and increased as running speed increased.

Further evidence of modified muscle activity was demonstrated by IEMG. With increasing speed, the IEMGs showed higher levels (P<0.01) of activity in the TFL and a slighter but significant (P<0.01) increase in the GM (Fig 3). The relationship between IEMG, and speed for each slope, was linear ($R^2 \geq 0.88$ for the GM and $R^2 \geq 0.97$ for the TFL).

Effects of slope

The individual and mean values of stride duration were not significantly affected by treadmill slope. The stance phase duration increased significantly with slope (P<0.01). The mean stance value calculated for the 4 horses increased linearly ($R^2 \geq 0.98$) with slope independently of the speed (Table 1).

The GM and TFL were activated later in the stride cycle (P<0.01) as the slope increased from 0 to 6%. The relationship between the start of activity and slope was linear for the GM ($R^2 \geq 0.93$ except at 5 m/s speed) and the TFL ($R^2 \geq 0.92$). The end of activity came significantly later in the stride cycle when the slope increased (P<0.05 for the GM and P<0.01 for the TFL). Activity duration of the TFLwas not significantly influenced by slope whereas the GM activity duration decreased (P>0.05) with increasing slope.

The major effects of an increasing inclination were seen in the IEMG (Fig 3). For the GM, the activation per stride was significantly higher (P<0.01) at higher inclines at all speeds. Changing the treadmill inclination also resulted in increasing the mean IEMG of the TFL. However, because of the low level of electrical activity in the GM, the absolute changes on EMG amplitude were much smaller than those observed in the TFL, but the relative changes were greater.

EMG variations

Minimal and maximal values of EMG temporal parameters are presented in Table 2. They were calculated from all the recordings on the 4 horses and for all the speed/slope combinations.

Changes in the speed/slope combination lead to variations in the beginning, end and duration of muscle activity. In the population of horses considered in this study, the variations for one parameter can represent up to 20.8% of the stride duration (interindividual variations). For the same animal (intraindividual variations), variations in electromyographic periods of activity can reach 18.1% (mean 13.3%) of the total stride duration.

TABLE 2: Variations in temporal parameters of muscles activity with subjects, speed and slope in percentage of stride duration (0 = landing)

	Interindividual variations (found between all the recordings of the 4 horses and the speed-slope combinations)			Intraindividual variations (observed in the 4 horses between the extreme values of a same subject)	
	Earliest value (a)	Latest value (b)	Difference (b-a)	Minimal variation	Maximal variation
Gluteus medius					
Beginning	57.5	76.3	18.8	3.8	18.1
End	10.6	23.7	13.1	4.3	9.4
Duration	40.1	60.8	20.8	4.2	14.6
Tensor fasciae latae					
Beginning	3.4	19.2	15.9	10.0	14.6
End	58.0	74.4	16.4	7.3	9.3
Duration	48.7	66.8	18.2	6.7	13.7

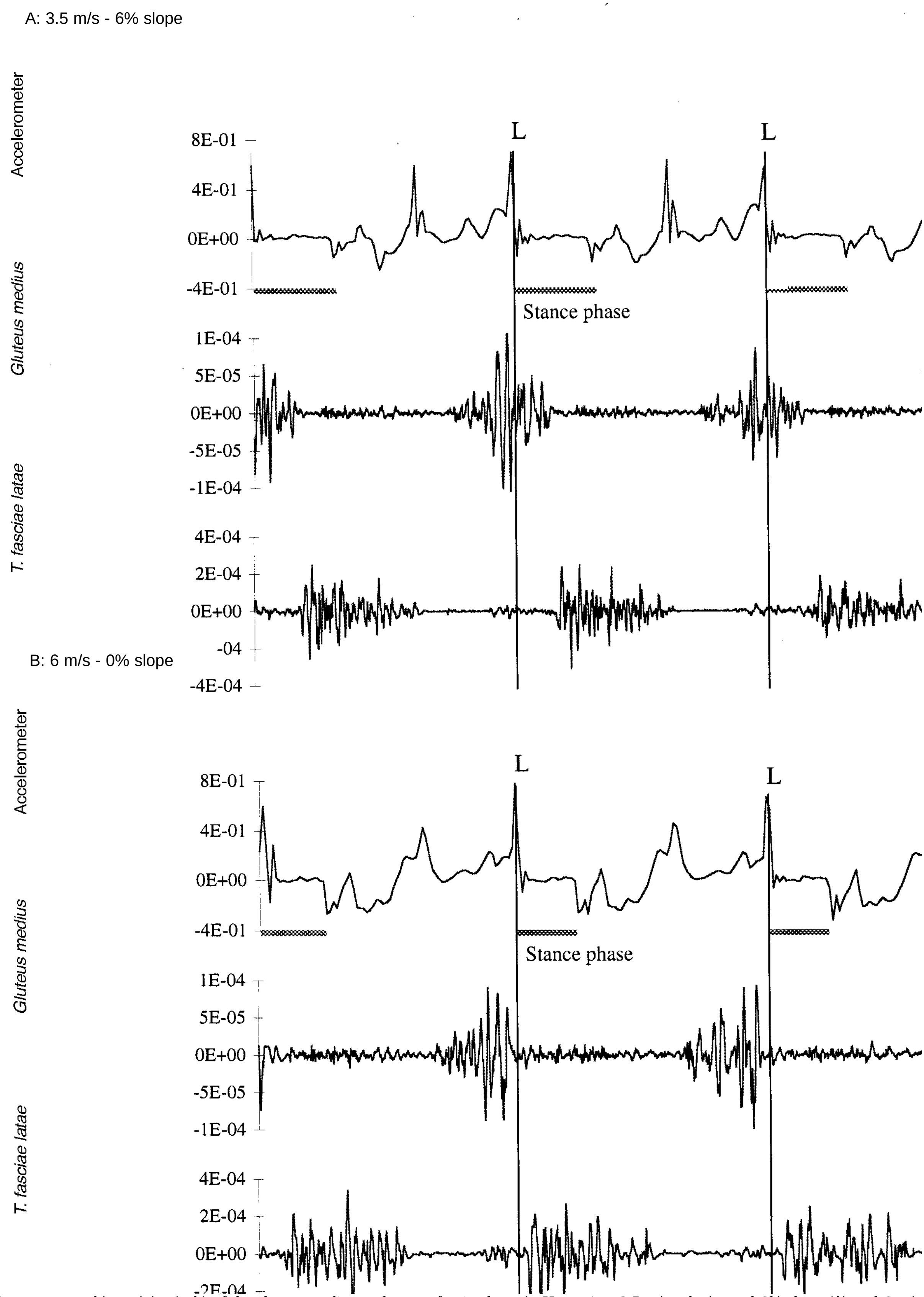

Fig 2: Electromyographic activity (volt) of the gluteus medius *and* tensor fasciae latae *in Horse 1 at 3.5 m/s velocity and 6% slope (A) and 6 m/s velocity and 0% slope (B) during 3 consecutive strides. L = landing of the ipsilateral hindfoot.*

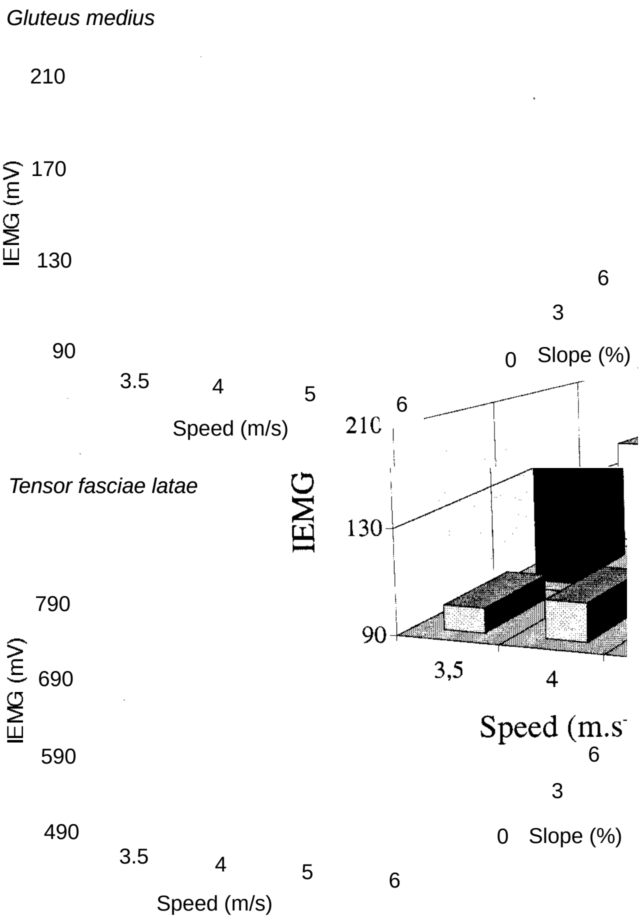

Fig 3: Variations of IEMG with speed and slope (mean values of the 4 horses in mV, calculated for 10 consecutive strides).

Discussion

The objective of this study was to quantify periods of activity and activation levels of 2 hindlimb muscles for different treadmill speeds and inclinations.

Effects of speed

Stride duration decreased as speed increased. Similar results were also found in dressage horses when comparing collected (3.20 m/s) and extended (4.93 m/s) trot (Clayton 1994). Stride frequency increased with speed in horses trotting on a treadmill (Leach and Drevemo 1991; Rooney *et al.* 1991; Barrey *et al.* 1993). On the track, no significant relationship was found between speed and stride duration (Drevemo *et al.* 1980). As previously documented (Holmström *et al.* 1995; McLaughlin *et al.* 1996), a significant negative linear correlation was found between subjects'speed and stance duration.

Recorded EMG patterns were similar to previously reported data (Wentink 1978; Tokuriki and Aoki 1995; Robert *et al.* 1998). The changes in muscle activity in relation to speed were similar in all 4 horses. The relative duration of activity (in percentage of stride duration) of both muscles studied increased with speed. As reported in the cat (Rasmussen *et al.* 1978; Pierotti *et al.* 1989) and rat (Canu and Falempin 1997), these modifications could be correlated with differences in the relative duration of the stance phase with speed. The GM, for instance, was mainly active during the stance phase and stopped before the lift-off. While speed increased, the hindlimb stance phase duration shortened and muscle activity ceased proportionally earlier.

Considering both the amplitude and duration of activation, the integrated EMG reflects the total amount of activity per stride in each muscle. In this study, the EMG activity levels increased with speed. Such alterations have been reported in man (Yang and Winter 1984; Mero and Komi 1987; Wolf *et al.* 1997) and cat (Goslow *et al.* 1973). But, in the horse, EMG amplitude has only been correlated to fatigue or training (Cheung *et al.* 1998; Hyyppä and Hänninen 1998). Changes with speed could be related to the mechanical function of the muscles involved. In horses trotting at 6 to 9 m/s, van Weeren *et al.* (1993) reported that the maximal and minimal values of hip and stifle angles tended to diverge when speed increased. Greater trotting speeds are associated with greater vertical ground reaction forces (Barr *et al.* 1995) and require increased muscle activity. The increase in GM IEMG observed at high speeds might be related to a greater hip extension and a need for greater power to propel the animal during a shorter contact phase. The higher TFL IEMG is associated with greater hip flexion and stifle extension.

Movements of the skin and consequently electrodes position may change with speed and be responsible for variations of muscle activity observed. However, amplitude of skin displacement generally do not differ much at the trot and walk for the proximal part of the hindlimb (van Weeren *et al.* 1990) and it can be assumed that skin movements are similar between 3.5 and 6 m/s.

Effects of slope

The constant stride duration on both flat and inclined treadmill is in agreement with earlier results (Barrey *et al.* 1993; Kai *et al.* 1997), but in contrast with the findings of Sloet *et al.* (1997). The latter authors found a nonsignificant tendency for stride duration to increase with treadmill slope.

In the present study, stance duration tended to increase with treadmill slope. This has already been reported, with a greater increase in the hindlimbs than in the forelimbs (Sloet *et al.* 1997). Barrey *et al.* (1993), however, found that the inclination of the treadmill did not significantly influence the stride parameters.

The influence of slope on the timing of muscle activity has never been evaluated in the horse. On the inclined treadmill, a delayed activity was observed in the rear end muscles, probably because the hindlimbs have to carry more weight and provide greater propulsion. Sloet *et al.* (1997) found that the impulse and propulsion generated by the hindlimbs are increased on a uphill slope (6%) and are correlated with an increased retraction angle.

As in man (Lange *et al.* 1996), the present study showed increasing the slope resulted in increasing EMG activity levels. Slope could require higher propulsive force in the hindlimb (Kai *et al.* 1997) as muscles have to act against the backward component of gravity.

GM activity appeared more altered by the slope than TFL EMG. The major function of the GM is the propulsion of bodyweight during the stance phase. On the incline, stance time is lengthened and a considerable amount of energy is required to raise the body upward in addition to moving forward (Hiraga *et al.* 1995). The GM provides the additional power required during more time per stride. On the contrary, TFL activity is less influenced by slope and more by speed. This muscle acts in the retraction and protraction of the hindlimb during the swing phase and has to act against mass acceleration when speed increases.

Combined effects of speed and slope

Combined effects of speed and slope have never been investigated for muscle activity in the horse. Physiological studies of cardiopulmonary function indicate a linear increase with speed and incline (Barrey *et al.* 1993; Hiraga *et al.* 1995).

Increasing the speed results in shortening the duration of the stride and stance, bringing beginning and end of activity earlier, lengthening the relative duration of activity and increasing the IEMG especially for the TFL muscle. Increasing the treadmill slope does not influence temporal stride parameters, but delays the beginning and the end of activity. It also maintains or decreases the total muscle activity duration and increases the IEMG, especially for the GM. Consequently, temporal EMG parameters are affected differently by speed and slope, whereas IEMG increases with either speed or slope. A similar level of IEMG could therefore be obtained with combinations of low speed/steep slope or high speed/slow slope, each combination resulting in different periods of muscle activity.

In order to increase the workload in training conditions, simultaneous increases in speed and slope would be adequate to maintain constant periods of activity and to keep the coordination between flexor and extensor muscles. The increase in IEMG is associated to constant or shorter burst duration on the incline, whereas it results from lengthening of the burst duration at fast trot. On the slope, it is likely that a higher electromyographic activity requires recruitment of additional motor units whereas the increase in speed could be associated to a longer contraction phase. As a result, it is not of benefit to train racehorses on a slope. On the contrary, horses used to slow gaits, like dressage horses, would benefit from exercise on the incline, as stance and muscle activity duration are maintained with increased IEMG.

This study confirmed that a significant correlation exists between speed and muscle activity in clinically normal horses at trot on a treadmill. Speed is an important factor to allow comparison between studies. A linear relationship between EMG and slope during exercise was also demonstrated. In conclusion, treadmill speed and incline both increase the workload, but each through separate mechanisms. As a result, the choice between the 2 exercise protocols (speed vs. incline) is likely to be relevant to the type of training intended for a particular horse. However, further investigations are needed to confirm these results in the field.

Manufacturers' addresses

[1]COMEPA, Saint Denis, France.
[2]Mazet Electronique, Le Mazet Saint Voy, France.
[3]Compaq Computer Corporation, Compaq France, Issy-les-Moulineaux, France.
[4]Säto, Raymore, Missouri, USA.
[5]SAS Institute, Cary, North Carolina, USA.

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Received for publication: 4.5.99
Accepted: 30.7.99