The Effects of Inclination (Up and Down) of the Treadmill on the Electromyogram Activities of the Forelimb and Hind limb Muscles at a Walk and a Trot in Thoroughbred Horses

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It is important to know the effects of the inclination of a slope on the activity of each muscle, because training by running on a sloped track is commonly used for Thoroughbred racehorses. The effects of incline (from −6 to +6%) on the forelimbs and hind limbs during walking and trotting on a treadmill were evaluated by an integrated electromyogram (iEMG). The muscle activities in the forelimbs (5 horses) and hind limbs (4 horses) were measured separately. Two stainless steel wires were inserted into each of the brachiocephalicus (Bc), biceps brachii (BB), splenius (Sp), and pectoralis descendens (PD) in the forelimb experiment and into the longissimus dorsi (LD), vastus lateralis (VL), gluteus medius (GM), and biceps femoris (BF) in the hind limb experiment. The EMG recordings were taken at a sampling rate of 1,000 Hz. At a walk, the iEMG values for the forelimb were not significantly different under any of the inclinations. In the hind limb, the iEMG values for the GM and BF significantly decreased as the inclination decreased. At a trot, the iEMG values for the Bc in the forelimb significantly decreased as the inclination of the treadmill decreased. In the hind limb, the iEMG values for the LD, GM, and BF significantly decreased as the inclination decreased. Uphill exercise increased the iEMG values for the Bc, LD, GM, and BF, while downhill exercise resulted in little increase in the iEMG values. It was concluded that the effects of inclination on the muscle activities were larger for the uphill exercises, and for the hind limb muscles compared with the forelimb muscles.

Key words: electromyogram, forelimb, hind limb, inclination, Thoroughbred

There are fewer training methods for Thoroughbred racehorses than for humans. Thoroughbred racehorses are mainly trained by running on a track, although swimming training is sometimes also used. Resistance training is often done by humans as a way to strengthen individual muscles. Training methods similar to this resistance training have not been developed for racehorses.

It has been reported that variation in the running speed or type of surface changed the workload of each limb in running training [9, 10, 15]. Uphill training is commonly carried out in the training of racehorses. Therefore, it is important to know the effect of the degree of slope on the activity of each muscle. It has been reported that uphill training increases the activity of the muscles used for propulsive force compared with training on flat ground [2, 7, 8]. However, only one study has reported the effects of a downward slope on the activity of muscles in the hind limb [2]. An understanding of the effects of uphill or downhill running on the activity of muscles may contribute to the development of new training methods to strengthen each muscle effectively.

Thoroughbred race horses usually train for 90 to 120 min at the training center of the Japan Racing Association (JRA). Walking and trotting exercise account for the great majority of training (walk for 60–80 min, trot for 5–15 min). It is important to know the effect of inclination during these
exercises. The purpose of this study was to evaluate the effects of inclination of the treadmill on the electromyogram activities of the forelimb and hind limb muscles at a walk and a trot.

**Materials and Methods**

The muscle activities in the forelimbs and hind limbs were measured separately. Five gelding Thoroughbred horses (ages 5–7 year, weight 468–535 kg) were used in the forelimb experiment, and four gelding Thoroughbred horses (ages 5–7 year, weight 468–544 kg) were used in the hind limb experiment. These horses were familiar with running on upward and downward inclined treadmills. Two Teflon-coated stainless steel electrodes (A-M Systems Inc., Carlsborg, WA, U.S.A.) with 1 cm of the tip bared were inserted into a 23G needle of 6 cm in length, and 1 cm of the tip was bent back and twisted around the needle shaft [12]. The electrodes were inserted into the splenius (Sp) at the level of the second cervical vertebra at a depth of 20 mm, the middle point of muscle belly of the brachiocephalicus (Bc) at a depth of 20 mm, the middle point of the biceps brachii (BB) at a depth 50 mm, and the middle point of the pectoralis descendens (PD) at a depth of 20 mm in the forelimb experiment; in the hind limb experiment, they were inserted into the longissimus dorsi (LD) at the level of the first lumbar vertebra at a depth of 50 mm, the biceps femoris (BF) in the upper third portion of the muscle at a depth of 60 mm, the middle point of muscle belly of the vastus lateralis (VL) at a depth of 80 mm, and the middle point of the gluteus medius (GM) at a depth of 40 mm. The distance between bipolar electrodes was 3 cm. Electromyography (EMG) data were collected from right and left side muscles (Type 271 NEC San-ei Sokki Inc., Tokyo, Japan; frequency response of 32 to 500 Hz). Strain gauges (N22-FA-10-120-11-VS3; NEC San-ei Instruments, Ltd., Tokyo, Japan) were attached with glue to the dorsal midline of the fore or hind hooves in the applicable experiment, and they were connected to dynamic strain measuring instruments (DP-612B, Kyowa Electronic Instruments, Tokyo, Japan). EMG and strain gauge data were recorded with PC using the WINDAQ software (DATAQ, Akron, OH, U.S.A.). Software at a sampling rate of 1,000 Hz. The horses performed a designated exercise protocol consisting of walking (1.6 m/sec) and trotting (3.5 m/sec) on a treadmill (SÄTO AB, Knivsta, Sweden) at five gradients (−6%, −3%, 0%, +3%, +6%). Because the inclination of the slope for uphill training is 3 to 3.5% at the training center of the JRA, the range of inclination was determined by doubling the value in ordinary use. The sequence of the gradients was randomized between subjects. Each condition was continued for about 1 min. The methods and procedures were approved by the Institutional Animal Care and Use Committee.

The EMG signal and strain gauge data were filtered with software (BIMUTUS, Kissie Comtec Co., Ltd., Nagano, Japan) using a high-pass Butterworth filter with a 10 Hz cutoff point and a low-pass Butterworth filter with a 40 Hz cutoff point, respectively. Stride time and duty factor (the percentage of stance to stride time) were determined by the strain gauge data from randomly selected right or left hooves. The integrated electromyogram (iEMG) values for each muscle in each stride were calculated from the EMG data. One recording on the right or left side of the EMG signal was selected depending on the signal condition. Each value was the average for five consecutive strides under each condition. All data are presented as the mean and SD. Comparisons between conditions were made using repeated measures analysis of variance (R 3.0.2, R Core Team (2013). R: A language and environment for statistical computing. R, Foundation for Statistical Computing, Vienna, Austria. URL http://www.R-project.org/). Where significant differences (P<0.05) were identified, a pair-wise Ryan test was applied.

**Results**

In the forelimb experiment, stride time and duty factor at a walk and a trot were not significantly different under any of the inclinations of the treadmill (Fig. 1). On the other hand, in the hind limb experiments, stride time on the −6% incline was significantly shorter than that on the 0% and +3% inclines during walking (Fig. 1). Stride time on the −6% incline was also significantly shorter than that on the 0%, +3%, and +6% inclines during trotting (Fig. 1). Duty factor at a walk and trot were not significantly different under any of the inclinations of the treadmill (Fig. 1).

At a walk, the iEMG values for the muscles in the forelimb were not significantly different under any of the inclinations of the treadmill (Fig. 2). In the hind limb at a walk, the iEMG values for the LD and VL were not significantly different under any of the inclinations of the treadmill, while the iEMG values for the GM at all inclinations other than +6% were significantly less than that at +6% inclination (Fig. 2). The iEMG of the BF significantly decreased as the inclination of the treadmill decreased. There was a significant difference between each different inclination with the exception of between −6% and −3% (Fig. 2).

At a trot, the iEMG values for the Bc at the −6%, −3%, and 0% inclines were significantly less than that at the +6% incline (Fig. 3). The iEMG values for the other three muscles in the forelimb were not significantly different under any of the inclinations of the treadmill at a trot (Fig. 3). In the hind limb at a trot, the iEMG values for the VL were not significantly different under any of the inclinations of the treadmill, while the iEMG values for the LD at the −6%
and −3% inclines were significantly decreased compared to that at +3% and +6% inclination. The iEMG of the GM at −6% and −3% inclines were also significantly decreased compared with that at +6% inclination. The iEMG values for the BF at all inclinations other than +6% incline were significantly decreased compared with that at +6% inclination (Fig. 3).

**Discussion**

In the hind limb experiment, stride time at a walk and trot shortened as the inclination decreased, while stride time was not different under any of the inclinations in the forelimb experiment. In theory, stride time does not change whether it is measured in the forelimb or hind limb. In this study, the average stride time at a walk in the hind limb at a −6% incline was reduced by 0.035 sec (3.3%) compared with that at a 0% incline. At a trot, the average stride time in the hind limb at a −6% incline was also reduced by 0.024 sec (3.5%) compared with that at a +3% incline. Because the effect of inclination on stride time was very little, the results might be different between the forelimb and hind limb experiments.

In previous reports, the effects of inclination on stride time at a walk and trot were also inconsistent [2, 5–7, 11, 13].

The iEMG values changes by horse and the position of the electrodes in each muscle. Repeated measurement ANOVA was used for analysis to compensate these variations. This method evaluated the effect of incline within each horse. In the BB at a trot, a statistical comparison could not be performed because EMG data were only recorded for 2 horses. In some muscles at a walk and trot, EMG data could not be recorded for 1 or 2 horses. The statistical powers of the test were low in these muscles.

In the muscles of the forelimb, the effects of the inclines were observed through the iEMG values for the Bc at a trot, which decreased as the incline decreased. The iEMG values for the Bc, which protracts the forelimb [1], decreased on the downward slope possibly because gravity assisted the protraction of the forelimb. On the other hand, iEMG values for the Bc increased on the upslope possibly because gravity retracted the forelimb downward. This result was consistent with a previous report in which the iEMG values for the Bc increased on an upslope at a trot [5]. There was no influence at a walk and trot on the iEMG values for the BB, which acts
as an antigravity muscle [1], although it was reported that the vertical ground reaction force in the forelimb decreased on an upslope [3]. In the PD, which has a similar function as the Bc, there was no difference in the iEMG values. The iEMG values for the Sp, which supports the head [1], were not influenced by the inclination because the movement of the head was not influenced by the inclination of the treadmill.

In the hind limb muscles, the iEMG values for the GM and BF decreased as the incline decreased at a walk and trot [2, 7]. These muscles produce the propulsive force [1]. The iEMG values for these muscles decreased because the propulsive force decreased as the incline decreased. The LD bends the back [1]. The inclination had no effect on the bending of the back at a walk, while the iEMG values for the LD increased significantly as the inclination increased. The VL is an antigravity muscle like the BB [1]. It was reported that the vertical ground reaction force in the hind limb increased on an upslope [3]. It was assumed from these studies that the hind limb force decreases on a downslope. However, the iEMG values for the VL were not influenced by the inclination, as reported by Crook et al. [13], although this was different from the predicted result based on the previous report about the vertical ground reaction force. A +10% inclination was used in that report [3]. The inclination of +6% might not be enough to influence the effect of the vertical ground reaction force on the iEMG values for the VL.

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**Fig. 2.** Mean (± SD) iEMG values for the forelimb (left; Bc n=5, BB n=3, Sp n=4, PD n=5) and hind limb (right; LD n=3, VL n=3, GM n=4, BF n=4) during downhill (−3, −6%), level (0%), and uphill (+6, +3%) walking. Significant differences (P<0.05) are indicated by different letters.

**Fig. 3.** Mean (± SD) iEMG values for the forelimb (left; Bc n=4, BB n=2, Sp n=3, PD n=5) and hind limb (right; LD n=3, VL n=4, GM n=4, BF n=4) during downhill (−3, −6%), level (0%), and uphill (+6, +3%) trotting. Significant differences (P<0.05) are indicated by different letters.
It was reported that heart rate and oxygen demand increased as the inclination increased [4, 6, 14]. The iEMG values for the Bc, GM, and BF on an upslope were higher than those on flat ground, while the iEMG values for any muscles on a downslope were not different from those on flat ground. The rate of oxygen consumption was increased by about 250% on the 10% upslope compared with trotting on level ground and was only reduced by about 50% on a −10% downslope [4, 6, 14]. The present data suggested that the increased rate of oxygen consumption reflected the increased muscle activities.

In conclusion, in the forelimb, the iEMG values for the Bc increased on an upslope at a trot, while the iEMG values for the muscles that were measured did not change on a downslope at a walk and trot. In the hind limb, the iEMG values for the GM and BF increased on an upslope, while the iEMG values for these muscles did not change or decreased on a downslope. The effects of the inclination on the muscle activities were larger on an upslope and in the hind limb muscles compared with the forelimb muscles. New training methods should be developed for strengthening the muscles of the forelimb.

Reference