stride duration and intrinsic timing measurements. This is despite highly significant and similar correlations found between all of these variables. The calculation of correlation coefficients alone may thus provide incomplete information about the relationship between variables.

The overlap measurements which did not fit the log-transformed regression model as closely as did most duration measurements were contralateral limb overlap (LFRFOV, LHRHOV) and ipsilateral limb overlap (LHLFOV, RHRFOV). Values for these overlap measurements were generally not available for velocities between 2 and 6 m s^{-1}. Overlap between the indicated limbs does not occur at the trot, which is the gait most foals used within this velocity range. The absence of these measurements may have contributed to the relatively low r^2 values obtained for the log-transformed regression equations for these variables.

Previous analyses of the relationship between velocity and intrinsic stride timing measurements have been performed with data taken from galloping horses.[3,7] Horses moving at velocities between 6 and 20 m s^{-1} showed a nonlinear decrease in stride duration and stance phase duration as velocity increased, similar to the relationship found here.[7] Although the duration of overlap appeared to decrease linearly with velocity, it is uncertain which limbs are considered in the overlap measurement.[7] A study on four 2 year old Quarterhorses galloping at velocities between 10 and 15 m s^{-1} revealed relatively low r^2 values for the linear regression of hindlimb overlap and forelimb overlap duration against velocity ($r^2=0.77$ and 0.72, respectively).[3] These were similar to the linear regression values obtained for intrinsic timing measurements against velocity for the data of the present study. However, in the former study, linear regression of velocity against stride frequency revealed high r^2 values ($r^2=0.94$),[3] unlike the results obtained in the present study (Table 1, $r^2=0.69$).

The difference in velocity range used in the former studies, as compared to the data presented here, limits the degree to which results can be compared. The more detailed analysis of a wide velocity range in this study allows the nonlinear relationship between velocity and stride timing measurements to be revealed, and provides a logical explanation for the pattern of velocity-dependent changes in stride timing variables.

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Neck Muscles Activity in Horses during Locomotion with and without a Rider

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ABSTRACT. The activity and movement of the neck were investigated electromyographically and kinematically in 4 horses with and without a rider during the walk, trot and canter. Electromyograms (EMGs) of the neck muscles (splenius and sternomandibularis) and a forelimb muscle (brachiocephalicus), and hoof strains were recorded telemetrically and synchronized with 16-mm high speed film. In the standing horse only the splenius had any tonic activity. The splenius and sternomandibularis had EMG activity twice during a step cycle in the symmetrical gaits but only once at the canter. Both muscles had activation on both sides irrespective of gait. The splenius began activity in the walk after landing of the forefoot, in the trot just around landing of the forefoot and in the canter before landing of the forefoot, probably to resist falling of the head and neck. The sternomandibularis had a reciprocal activity to the splenius. This muscle was only active at the walk when horses were ridden. The brachiocephalicus had EMG activity once a step cycle at any gait, which indicated that the muscle is not a neck muscle, but a forelimb muscle.

Key words: Horses, neck muscles, locomotion, electromyogram.

INTRODUCTION

Analyses of electromyograms (EMGs) of skeletal muscles during locomotion in the horse have been focused on the limb muscles,[1,6,7] and few papers have documented electromyographic (EMG) activity of the neck muscles. However, these muscles play an important role in locomotion,[3–5] and have rhythmic EMG activity in accordance with the step cycle of the forelimbs at all gaits in the dog. The horse has a long neck and uses it to control and balance the head and forequarters during locomotion. It is important to analyze EMG activity of the neck muscles during locomotion in the horse with or without a rider in order to understand neck function during locomotion and to gain an insight into the effect of a rider. A rider can achieve control of a horse in two ways; by moving his position and center of gravity and by regulating the horse's head and neck movement with the reins. The purpose of this experiment was to investigate the effect on EMG activity of the neck muscles of the rider alone. The horses were therefore ridden with a loose rein so as to prevent any restriction of head and neck movement.

MATERIALS AND METHODS

Horses

The electrodes positions for the splenius, the sternomandibularis and the brachiocephalicus were determined in 2 horses recently destroyed with a barbiturate overdose.

Four clinically normal Thoroughbreds, weighing 430 to 478 kg, used as riding horses were recorded by EMG and high speed photography. The horses were saddled without a rider and were led at the walk, trot and canter over a hard soil straight track. After this, a 65 kg rider mounted and rode the horse over the same course with a loose rein so as not to restrain the natural movement of the horse's head and neck.

Kinematic studies

Circular marks (2 cm diameter) were glued to the left side of the upper nostril, zygomatic process of the temporal bone, proximal spine of the scapula and the coxal tuber. Marks were photographed with a 16 mm camera (Model 16-1PL, Photo-Sonics Inc, CA, USA) at 200 fps during locomotion. Each film frame was analyzed with a motion analyzer (Model Sportias 2000, Nac Co, Tokyo, Japan) to identify the swing and stance phases of the forelimb and to determine the angular changes between the head and neck, and the neck and trunk during the walk, trot and canter.

EMG studies

Three muscles were investigated; the splenius, an epaxial muscle, the sternomandibularis (or sternocephalicus), a hypaxial one, and the brachiocephalicus, a forelimb muscle.[2] A multi-stranded stainless steel wire with Teflon insulation (Type No. 7915, A-M Systems Inc., WA, USA) was inserted into a 27 gauge needle, and 0.5 cm of the tip was bent back against the needle shaft. Wires used as bipolar electrodes were inserted into the muscles with a needle that was quickly removed and the electrode terminal connected to a lead line. The distance between the bipolar electrodes was 3 cm. The presence of the electrodes did not cause any pain to the horses.

Each experiment was repeated at least 3 times to record EMG activity of each muscle in each horse.

Measurements of hoof strain

The hoof was rubbed down with sandpaper and cleaned with ethyl ether to remove any fatty material. Paper strain gauges (Type N22-FA-5120-11VS3, Showa Kogyo Inc., Tokyo, Japan) were glued firmly on the dorsal midline, mid-way between the coronary band and the weight-bearing surface in each forehoof. Hoof strain caused by contact with the ground was detected by gauges and was used to mark the onset and end of the stance phase.

Measuring equipment

A 4-channel transmitter (Type 271, NEC San-ei Sokki Inc, Tokyo, Japan) with a frequency response of 34–500 Hz was used to transmit 4 EMG signals. EMGs of left and right muscles were always transmitted simultaneously. Another 2-channel transmitter (Type NK-7690, NEC Co, Tokyo, Japan) with a frequency response of 0–3 000 Hz was used to send electrical signals from the strain gauges glued to the toe wall of each forehoof. Transmitters were attached to a saddle of the riderless horses or to a waist belt of the rider. A pulse generator (Type 5L37ME, NEC San-ei Sokki Inc, Tokyo, Japan) emitted a signal of about 20 milliseconds (ms) duration every 100 ms. The signal was fed into a small neon light bulb located just over the sound track of the film in the 16 mm camera and was fed into the 8-channel recorder to synchronize frames and EMG data on the record.

RESULTS

In standing horses the splenius showed tonic EMG activity with and without a rider, but the sternomandibularis and brachiocephalicus were electromyographically silent.

Splenius activity

During the walk the splenius was active from the early mid-stance phase to the late mid-stance phase of each forelimb. During the trot, however, EMG activity occurred immediately before or after contact of each forelimb with the ground and ceased at around the mid-stance phase of each forelimb (Figs. 1 and 2). Changes of the angles measured from the ventral side between the longitudinal axis of the neck and the trunk decreased maximally in the mid-stance phase during symmetrical gaits. The splenius had a burst

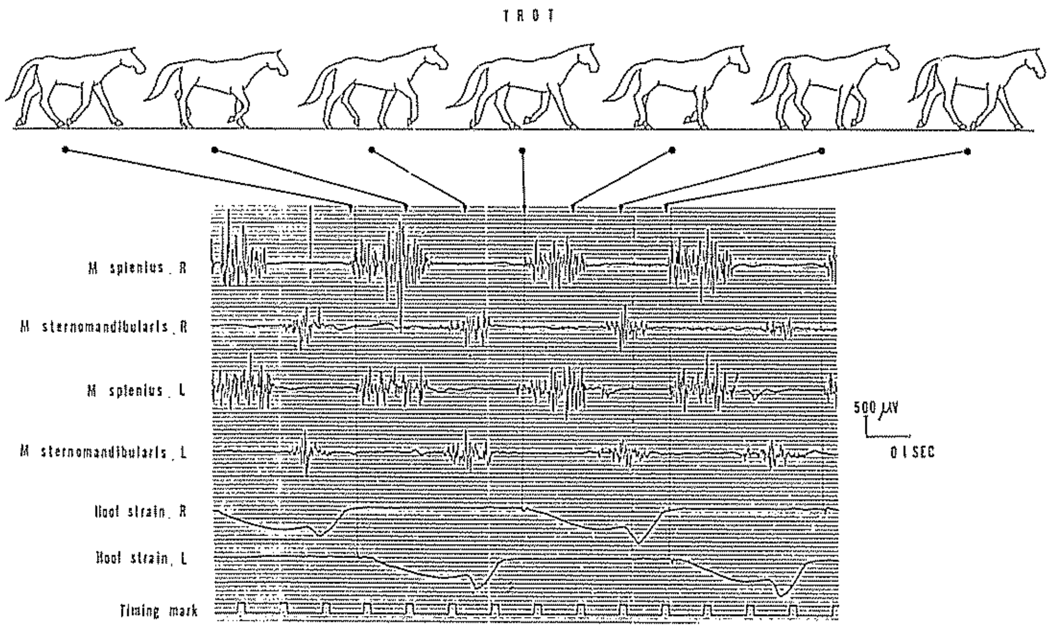

Fig 1 The electromyographic activity of the splenius and sternomandibularis and strain curves of forehooves in horses without a rider during the trot. R = right side, L = left side. Timing mark at the bottom is the signal that synchronizes tracings with a 16 mm film. The lowest peak of the strain curve indicates that the heel of the forehoof has just left the ground. The following inflection point of the curve is the instant of lifting the forehoof from the ground. The vertical lines indicate the instant of contact of the forehoof with the ground.

of EMG activity twice in a step cycle during the symmetrical gaits. The activity of the muscle during the stance phase of the contralateral forelimb tended to be of a higher intensity than that in the stance phase of the ipsilateral forelimb. During the canter the splenius had activity only once in a step cycle. The EMG activity on the side of the trailing forelimb began in the late swing phase of the trailing forelimb, continued through the stance phase and ceased in the early swing phase. Whereas the activity on the side of the leading forelimb was active from the middle swing phase of the leading forelimb to the middle stance phase. The muscles on both sides exhibited coactivation irrespective of gait. There was little difference in activity phase of the splenius between horses with and without a rider during any of the gaits investigated, although locomotion velocity in each gait was different between or among horses with and without a rider.

Sternomandibularis activity

During the walk, the sternomandibularis was silent or had little activity in any of the 4 horses without a rider, but was active twice a step cycle in the late periods of the stance phase of each forelimb in 3 of the horses when ridden. During the trot the muscle was active in the latter half of the stance phase of each forelimb with and without a rider (Figs. 1 and 2). During the canter the sternomandibularis on both sides had EMG activity once a step cycle. Activity of the muscle on the side of the trailing forelimb was active almost throughout the swing phase of the trailing forelimb, whereas activity of the muscle on the side of the leading forelimb began in the mid-stance phase of the leading forelimb and ceased in the mid-swing phase. At all

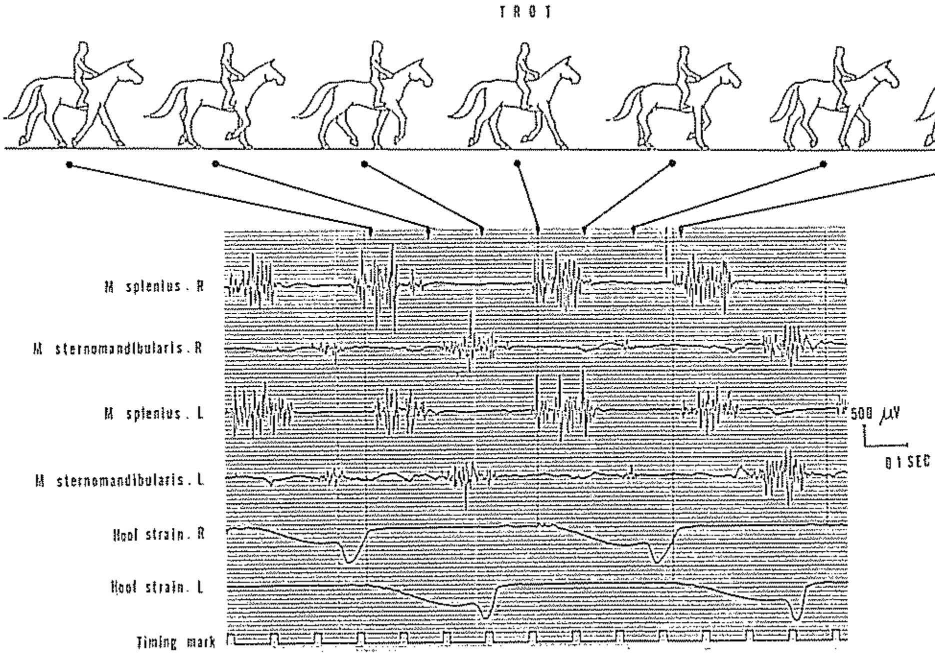

Fig. 2. The electromyographic activity of the splenius and sternomandibularis and strain curves of forehooves in a horse with a rider during the trot. R = right side, L = left side. Timing mark at the bottom is the signal that synchronizes tracings with a 16 mm film. The lowest peak of the strain curve indicates that the heel of the forehoof has just left the ground. The following inflection point of the curve is the instant of lifting the forehoof from the ground. The vertical lines indicate the instant of contact of the forehoof with the ground.

gaits, the activity of the sternomandibularis on both sides had coactivation reciprocal to activity of the splenius. The sternomandibularis had similar EMG activity in horses with and without a rider during the trot and canter.

Brachiocephalus activity

The brachiocephalicus had activity once a step cycle irrespective of gait in all 4 horses. The muscle was active from the mid- or late stance phase of the ipsilateral forelimb to the mid- or late swing phase during the trot and canter. It had a shorter period of burst activity before and after landing of the ipsilateral forelimb on the ground during the walk in 4 horses with a rider and in 2 without a rider. Continuity of burst activity of the muscle was often interrupted with an interposition of short silent periods.

DISCUSSION

The splenius, as an epaxial muscle, was active in the standing position, presumably acting to stabilize the neck and prevent falling of the horse's heavy head. Activity of the splenius begins immediately before or after landing of each forelimb at all gaits in the dog[3–5] and the cat (Tokuriki, unpublished data), because this muscle resists falling of the head and neck due to impact of landing of the forelimb on the ground. Activity of the splenius in horses began in the early mid-stance phase of the forelimb during the walk, immediately before or after contact of the forehoof with the ground during the trot and before contact of the trailing forelimb with the ground during the canter. The onset of its activity seemed to move forward in the step cycle with a change to a faster gait. It remains to be investigated why this occurs, but neck rigidity may be necessary to resist falling of the head and neck in earlier period of the step cycle with increasing locomotion velocity.

It is possible that other epaxial neck muscles may have different activity phases and different actions during locomotion in the horse. However, all epaxial neck muscles investigated in the dog[3–5] and cat had similar activity phase during any gaits. Other epaxial muscles, such as the large semispinalis capitis consisting of the biventer cervicis and the complexus, the longissimus capitis and the multifidus cervicis, may also have the same type of activity pattern as the splenius in the horse.

The presence of the rider had an effect on sternomandibularis activity during the walk. When there is no weight on the horse's back, ventroflexion of the neck at the walk occurs simply due to gravity. However, hypaxial muscle activity appears to be required when there is a rider in place. Ventroflexion of the neck indicates that the horse has changed the center of gravity of the body. The addition of the rider's weight seems to accentuate the movement of the neck and alter its center of gravity.

The brachiocephalicus had a long active period during locomotion in horses, which might indicate that this muscle has a complex function because of its extended position from the neck to the forelimb. The finding that the brachiocephalicus always had EMG activity before and after lifting of the ipsilateral forelimb from the ground, confirms that it plays a role as an extensor of the shoulder joint as documented from an anatomical point of view.[2]

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