Equine Exercise Physiology 3: 141–145, 1991

Velocity-dependent Changes in Intrinsic Stride Timing Variables of Quarterhorse Foals

G. D. MUIR,[1] D. H. LEACH, N. CYMBALUK[2] and S. DYSON[3]

[1]*Department of Veterinary Anatomy, Western College of Veterinary Medicine and* [2]*Department of Animal and Poultry Science, University of Saskatchewan, Saskatoon, Saskatchewan, Canada, S7N 0W0 and* [3]*Animal Health Trust, Newmarket, Suffolk, UK*

ABSTRACT. The purpose of this study was to determine changes in intrinsic stride timing variables as stride length and stride duration change with velocity. Alterations in intrinsic timing variables may influence limb effort and thus the overall energetics of locomotion. Stride length, stride duration, velocity and 10 intrinsic stride timing measurements (stance duration of each limb, 6 overlap measurements) were recorded from cine films of 10 genetically similar, 6 month old Quarterhorse foals moving at velocities between 1 and 10 m s^{-1}. Simple linear regression analysis, using stride duration as the independent variable and each intrinsic stride timing variable as the dependent variable, revealed high r^2 values (mean $r^2 = 0.94$). Logarithmic transformation of velocity measurements followed by regression analysis was used to describe the relationship between intrinsic stride timing measurements and velocity (mean $r^2 = 0.89$). Significant correlations ($p < 0.05$) were found between velocity, stride duration and all intrinsic stride timing variables analyzed. Any alterations in velocity, due to changes in stride duration and/or stride length, will clearly influence intrinsic stride timing variables.

Key words Horses; locomotion; velocity; stride duration.

INTRODUCTION

The relationship between velocity and stride characteristics has been studied in adult horses[2,4,5,7] and foals.[8] Stride length is linearly related to velocity at most gaits,[2,5,8] although may increase nonlinearly with velocity at the gallop.[5] For the foals used in the present study, stride length and velocity were linearly related through a velocity range of 1 to 10 m s^{-1}.[8] The relationship between stride frequency and velocity is more complex and has been explained by second- and third-order polynomial equations.[8] Stride frequency of the foals increased linearly with velocity through a velocity range of 1 to 4 m s^{-1} but the rate of increase decreased with increasing velocity through a velocity range of 5 to 10 m s^{-1}.[8]

The relationship between intrinsic stride timing measurements and velocity has not been examined in detail. High correlations have been found between certain intrinsic stride timing variables and velocity at the gallop over a velocity range of 10 to 15 m s^{-1}.[2] Scatter plots and line-fitting techniques have been used to describe the velocity-dependent effects on intrinsic stride timing measurements for galloping horses moving at velocities between 6 and 20 m s^{-1}.[7] Other studies which have measured intrinsic stride timing variables used a small range of velocities so that the examination of the relationship between velocity and intrinsic timing measurements was not possible.[4,9] Because these measurements are potentially useful in the biomechanical analysis of segmental motion and limb energetics, it was considered necessary to examine further the velocity-dependent changes of intrinsic stride timing measurements.

MATERIALS AND METHODS

Ten genetically similar, 6 month old male Quarterhorse foals were used in this study. All foals were in good body condition and maintained on a pelleted hay grain diet formulated to provide at least minimum nutritional requirements according to 1978 National Research Council standards.[10]

In preparation for filming, a stationary 16-mm camera (Locam model 164-DC, Red Lake Laboratories Inc, Santa Clara, CA, containing black and white film (Tri-X 7278 Reversal Film, Eastman Kodak Co, Rochester, NY), was positioned perpendicular to the line of motion and levelled horizontally. A framing rate of 200 frames s^{-1} was used. Before filming the gait sequences, a metre pole marked in 0.5 m segments was held in the line of motion to allow accurate scaling of distance measurements from film. Foals were filmed while moving over a level surface 15 m in length, allowing approximately 5 walk strides, 2–4 trot strides or 1–2 canter gallop strides in a single film sequence. The foals had a distance of 25 m to stabilize their gait pattern before entering the filming area and 25 m beyond the filming area in which to decelerate. Foals were led on a loose lead shank into the filming area for the walk, trot and slow canter sequences. For the remaining canter and gallop sequences, the foals were allowed to move unrestrained through the filming area. A total of 49 strides at the walk, 55 strides at the trot and 60 strides at the canter/gallop were analyzed for this study.

Stride length, stride duration, the stance phase duration of each limb, and 6 overlap measurements were recorded from film. Stride length was defined as the distance covered between separate hoof contacts of a single limb. Stride duration was defined as the time required to move a limb from a position in one stride to the same position in the next stride. Velocity was calculated by dividing stride length by stride duration. For the forelimbs, the stance phase duration was defined as time from initial hoof placement until heel lift-off (LFST = stance phase duration of the left forelimb, RFST = stance phase duration of the right forelimb). Hindlimb stance duration was defined as the time from initial hoof placement until the fetlock angle measured 180° (LHST = stance phase duration of the left hindlimb, RHST = stance phase duration of the right hindlimb). Overlap measurements were defined as the time throughout which the two limbs in question were in the stance phase simultaneously. The overlap measurements recorded were: left hind-right hind (LHRHOV), right hind-left fore (RHLFOV), left fore-right fore (LFRFOV), right hind-right fore (RHRFOV), left hind-left fore (LHLFOV) and left hind-right fore (LHRFOV).

Separate statistical analyses were carried out for each foal. Correlation matrices were produced using all variables and each correlation coefficient (r) was tested for significance.[11] Simple linear regression was performed using stride duration as the independent variable, and each intrinsic stride timing measurement as the dependent variable. To best describe the relationship between velocity and each stride timing variable, regression of stride timing variables, including stride duration, was carried out against logarithmically transformed velocity measurements. Mean regression coefficients (r^2) for both linear and log-transformed regressions were obtained by averaging the coefficients for all foals ($n = 10$). The fit of each regression equation produced for linear and log-transformed solutions was tested for significance using analysis of variance.

RESULTS

High correlations were found between all intrinsic stride timing variables and velocity, stride length and stride duration, all of which were significant ($r = 0.80$–0.99, $p < 0.05$). Mean r^2 values and standard deviations for the regression of each intrinsic stride timing variable against stride duration and velocity are presented in Table 1. Linear regression

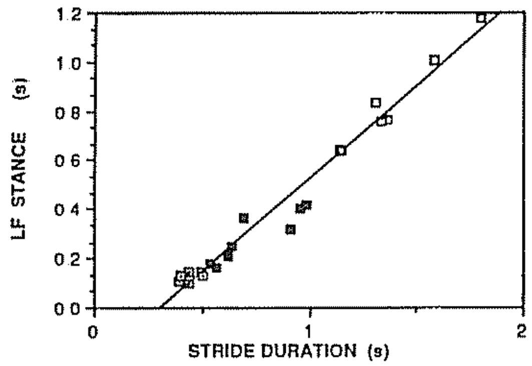

Fig. 1 Duration of the stance phase of the left forelimb (LFST) vs. stride duration for a typical foal. Plotted points are data values: □ = walk, ■ = trot, ⊡ = canter/gallop, solid line is fitted linear regression line. Regression coefficient = 0.97.

analysis revealed high r^2 values for all intrinsic stride timing variables (mean r^2=0.90–0.98) except for the duration of overlap of the forelimbs (mean r^2=0.74). Regression of velocity against stride duration resulted in relatively low r^2 values (mean r^2=0.69). All linear regression models were highly significant ($p<0.01$).

Logarithmic transformation and regression analysis resulted in high r^2 values for the regression of stride timing variables, including stride duration, against velocity (Table 1). Based on the r^2 values, the best fits for the log-transformed regression were obtained for stride duration, the stance phases of each limb and the diagonal overlap measurements between RHLF and LHRF (r^2 values between 0.93 and 0.96). r^2 values for the remaining overlap measurements are between 0.63 and 0.90. Analysis of variance showed that all log-transformed regression models were significant ($p<0.05$).

Fig. 1 shows the close linear relationship found between stride duration and the stance phase duration of the left forelimb for a typical foal. Fig. 2*a* and 2*b* show the logarithmic relationship between velocity and the stride duration and between velocity and stance phase duration of the left forelimb, respectively, for the same foal. The timing measurements decreased at a decreasing rate as velocity increased. Fig. 3*a* and 3*b* illustrate the relationship found between velocity and the overlap duration of the diagonal limbs, LHRF, and between velocity and the overlap duration of the forelimbs, LFRF, for the same foal. Overlap duration of diagonal limbs showed the same relationship with velocity as did the stride and stance phase durations in Fig. 2 (r^2=0.94). Measurements for the overlap duration of forelimbs did not occur at velocities between 2 and 6 m s^{-1}, and a log-transformed regression model does not fit this data well (r^2=0.50).

Table 1. *Regression coefficients obtained from regression of stride timing variables against stride duration and velocity*

Values in table are mean regression coefficients ± standard deviation (n=10)

	Independent variable	
Dependent variable	Stride duration[a]	Velocity[b]
Stride duration	–	0.95±0.02
Velocity	0.69±0.06	–
LHST	0.98±0.01	0.96±0.02
RHST	0.98±0.01	0.95±0.02
LFST	0.98±0.01	0.93±0.04
RFST	0.98±0.01	0.93±0.04
LHRHOV	0.90±0.23	0.82±0.11
RHLFOV	0.90±0.20	0.94±0.02
LFRFOV	0.74±0.29	0.63±0.28
RHRFOV	0.91±0.22	0.90±0.06
LHLFOV	0.92±0.15	0.85±0.18
LHRFOV	0.95±0.02	0.93±0.03

[a] Obtained by simple linear regression.

[b] Obtained by log-transformation of independent variable prior to regression.

DISCUSSION

Intrinsic stride timing measurements are linearly related to stride duration perhaps because these intrinsic measurements contribute directly to the total duration of the

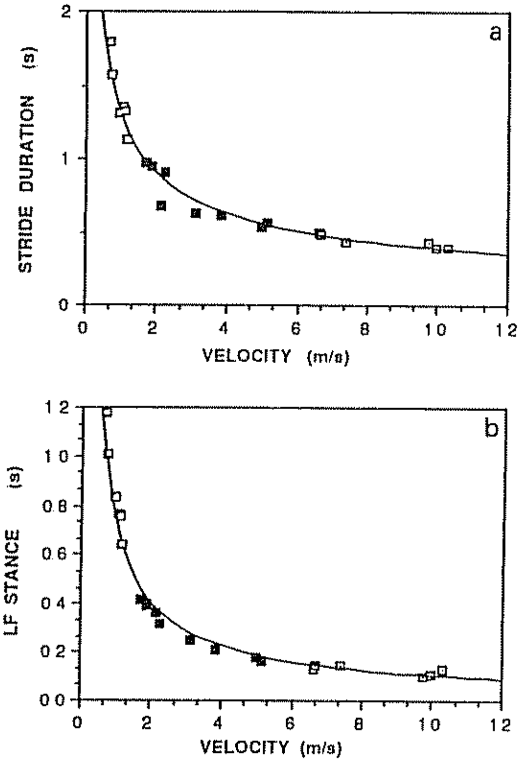

Fig. 2. (*a*) Stride duration versus velocity for a typical foal. Regression coefficient for fitted line = 0.98. (*b*) Duration of stance phase of the left forelimb (LFST) vs. velocity for a typical foal. Regression coefficient for fitted line = 0.98. Plotted points are data values: □ = walk, ▩ = trot, ⊡ = canter/gallop, solid lines are regression lines fitted by log-transformed regression.

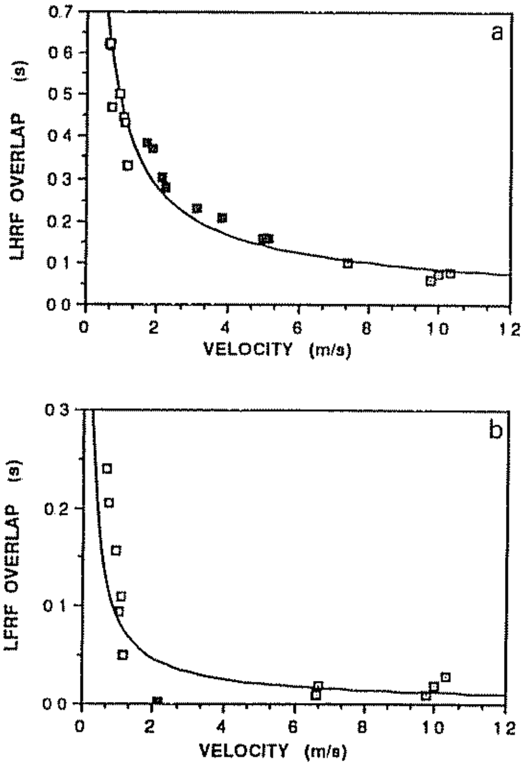

Fig. 3 (*a*) Duration of left hindlimb–right forelimb overlap (LHRFOV) vs. velocity for a typical foal. Regression coefficient for fitted line = 0.94. (*b*) Duration of left forelimb–right forelimb overlap (LFRFOV) vs. velocity for the same foal. Regression coefficient for fitted line = 0.50. Plotted points are data values: □ = walk, ▩ = trot, ⊡ = canter/gallop, solid lines are regression lines fitted by log-transformed regression

stride. The relationships between velocity and stride timing measurements are more complex. As velocity increases, the horse has less time with which to move the limb through the stride cycle, and therefore the duration of the stride and the time that each limb is on the ground, with or without other limbs, is reduced accordingly. However, the decrease is not linear (Figs. 2 and 3). There appears to be a limit to the rate with which the horse can reduce the time taken to move the limb through the stride cycle. This is shown by the ever decreasing rate with which stride duration, stance phase duration and the duration of most overlap measurements decrease with velocity (Figs. 2 and 3). Similar results have been found for other quadrupeds, such as cats, dogs and non-human primates.[12] As velocity increases, stride and stance duration decrease curvilinearly in the cat.[6] This limit to the reduction in stride duration with increasing velocity has been suggested to be caused by an inability to rapidly reduce the energy present in the limb during the swing phase in order to prepare for ground contact.[1]

In the present study, the use of regression analysis has revealed that the relationship between velocity and stride timing measurements is quite different from that between 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.

REFERENCES

1 Chapman, A. E and Caldwell, G E. (1983) Kinetic limitations of maximal sprinting speed J Biomech 16, 79–83.

2 Deuel, N R. (1985) A kinematic analysis of the gallop of the horse. Ph D thesis, Univ of Illinois at Urbana-Champaign.

3 Deuel, N R. and Lawrence, L M (1986) Gallop velocity and limb contact variables of Quarterhorses. J. Equine Vet Sci 6, 143–147

4 Drevemo, S , Dalin, G , Fredricson, I and Hjertén, G (1980) Equine locomotion. 1 The analysis of linear and temporal stride characteristics of trotting Standardbreds. Equine Vet J 12, 60–65.

5 Dusek, J., Ehrlein, H. J , von Engelhardt, W. and Hörnicke, H (1970). Beziehungen zwischen Trittlänge, Trittfrequenz und Geschwindigkeit bei Pferden Z Tierzuchtg Zuchtg Biol 87, 177–188

6 Goslow, G E., Reinking, R M. and Stuart, D. (1973) The cat step cycle: hind limb joint angles and muscle lengths during unrestrained locomotion J. Morphol 141, 1–41.

7. Hellander, J , Fredricson, I., Hjertén, G., Drevemo, S and Dalin, G (1983). Galoppaktion I—Basala gångartsvariabler i relation till hästens hastighet Svensk Veterinärtidning 35, Suppl. 3, 75–82

8. Leach D and Cymbaluk, N. (1986). Relationships between stride length, stride frequency, velocity, and morphometrics of foals. Am J Vet Res 47, 2090–2097.

9 Leach, D , Sprigings, E J and Laverty, W H (1987). A multivariate statistical analysis of stride timing measurements of nonfatigued racing Thoroughbreds. Am J. Vet Res 48, 880–888

10 *Nutrient requirements of horses* 4th ed. (1978) National Research Council—National Academy of Sciences, Washington, D C.

11 Snedecor, G. W. and Cochran, W G (1980). *Statistical Methods*, 175–193 Iowa State University Press, Iowa, 7th ed., pp. 175–193.

12 Vilensky, J. A (1987) Locomotor behavior and control in human and non-human primates: comparisons with cats and dogs Neurosci Biobehav Rev 11, 263–274.

Equine Exercise Physiology 3: 146–150, 1991

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

M. TOKURIKI and O. AOKI[1]

Department of Veterinary Physiology, Faculty of Agriculture, Yamaguchi City, Yamaguchi 753, and [1]Institute of Horse Shoeing, Setagaya-ku, Tokyo 155, Japan

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