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Velocity-dependent Changes in Stride Frequency and Length of Trotters on a Treadmill

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ABSTRACT The purpose of this study was to describe velocity-dependent changes in stride length and stride frequency of horses trotting on a treadmill. Eight trained, fit horses were trotted at 15 increments of increasing treadmill speed. Velocity, stride length and stride frequency were determined by counting and measuring the number of strides occurring over a set number of revolutions of a coir treadmill mat marked off at known distances. Cine films were taken concurrently to verify measurements, if required. Mean values of the ranges were 1.6–10.0 m s^{-1} (velocity), 1.1–2.18 strides s^{-1} (stride frequency), and 1.48–4.62 m (stride length). There was a strong linear relationship between stride length and velocity, as shown by a mean r^2 of the regression equation of 98.0%. The slopes of the stride length-velocity lines differed ($p<0.05$) between most horses as determined by analysis of covariance. The relationship between stride frequency and velocity was nonlinear and was described by a first (1 horse), second (6 horses) or third (1 horse) degree polynomial equation. It was concluded that stride length increases linearly, and stride frequency nonlinearly, with increases in velocity in horses trotting on a treadmill.

Key words Horses; locomotion; treadmill.

INTRODUCTION

Equine exercise physiologists take measurements of horses moving on treadmills under the assumption that these animals are moving in a manner comparable to that seen in overground locomotion. However, a preliminary study which included comparison of a horse moving on a treadmill and moving overground at either 6.5 or 8.5 m s^{-1} found significant differences in stride length, stride frequency and a number of interlimb timing and distance measurements.[4] The present understanding of how horses locomote on treadmills is incomplete as velocity-dependent changes in stride characteristics have not been described.

Evaluation of any locomotor performance requires an understanding of the interrelationships between velocity, stride length and stride frequency.[8] The purpose of this study was to examine velocity-dependent changes in stride length and stride frequency of horses trotting on a treadmill.

MATERIALS AND METHODS

Eight Swedish Standardbred trotters were used for this study. The average weight of horses was 451 kg. All horses were relatively fit, unshod, clinically sound and familiar with moving on a treadmill. Notes were taken of any hoof trimming modifications or abnormalities present.

The treadmill used is described elsewhere.[4] There was a mark on the coir treadmill mat from which calculations of velocity and stride length were made. The marks on the treadmill were 16.14 apart. The time required for 2, 3 or 4 revolutions of the mat were timed with a stopwatch. Stride frequency was determined visually by counting strides made over 30 second intervals. As a

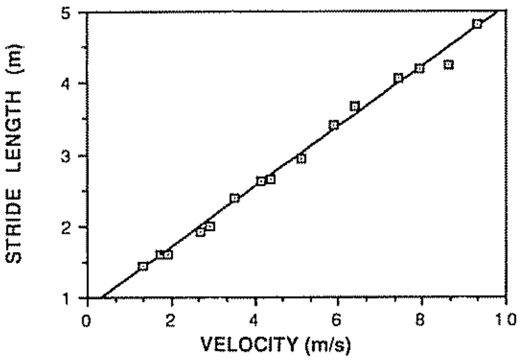

Fig 1 Graph of stride length (m) and velocity (m s^{-1}) data for horse 8. The first degree polynomial regression line is shown.

backup to data collection, horses were filmed with a cine camera (Locam 164-5 DC, Red Lake Laboratories, Santa Clara, CA) at either 125 or 250 frames $second^{-1}$, depending on horse velocity. To verify film speed the camera was fitted with an internal timing light generator set at 250 Hz.

After an adequate warm-up period on the treadmill, each horse was trotted at an average of 15 increments of increasing treadmill speed, from the slowest speed at which the horse used a trot to the fastest trot that the horse could exhibit with safety. After the measurement period was completed the horses were cooled off by gradually decreasing treadmill speed.

A polynomial-regression analysis, based on the least-squares method of line fitting, was done on stride length or stride frequency (dependent variable) and velocity (independent variable) data. The selection of the appropriate degree of polynomial equation was based on comparing the calculated F value of each of the first 4 degrees of polynomial equations with tabular F values for the 0.05 probability level.[11] The coefficient of determination (expressed as percentage), r^2, slope, and standard error were calculated for each selected regression equation of stride length versus velocity. Comparison of regression slopes was done using analysis of covariance, using an F test, at the 5% level of significance.[11]

RESULTS

The range of mean velocities used was 1.6 to 10.0 m s^{-1}, the range of mean stride frequencies was 1.1 to 2.18 strides s^{-1} and range of mean stride lengths was 1.48 to 4.62 m.

Stride length For each of 8 horses in the study the relationship between velocity and stride length was linear with little deviation of data from the regression line (Fig. 1). The regression analysis of stride length and velocity selected a linear regression line with a mean r^2 of 98.0%. The mean slope of the regression line using stride length as the dependent variable and velocity as the independent variable, was 0.39, and the standard error of this line was 0.015. Analysis of covariance of regression lines revealed 2 groups and one individual with significant differences in slope: the first group (Horses 1, 2, 4) had an average slope of 0.43, the second group (Horses 5, 6, 7, 8) an average slope of 0.37, and the individual horse (Horse 3) had a slope of 0.32. Slopes of horses within each group did not differ significantly ($p<0.05$).

Stride frequency. The relationship between stride frequency and velocity was described by a first degree (1 horse), second degree (6 horses), or third degree (1 horse) polynomial equation (Figs. 2–4). The r^2 of the second

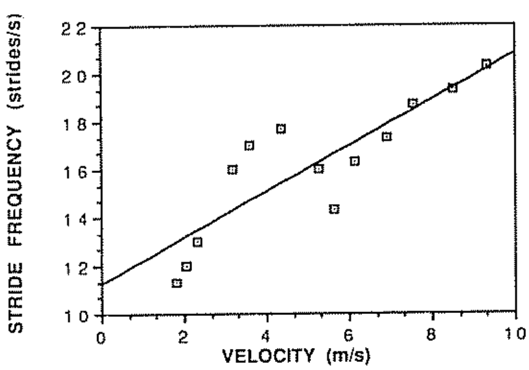

Fig 2. Graph of stride frequency (strides s^{-1}) and velocity (m s^{-1}) data. The line of best fit (a first degree polynomial regression line) is also graphed. This horse (no 2) exhibited interference at velocities between 4 and 7 m s^{-1}.

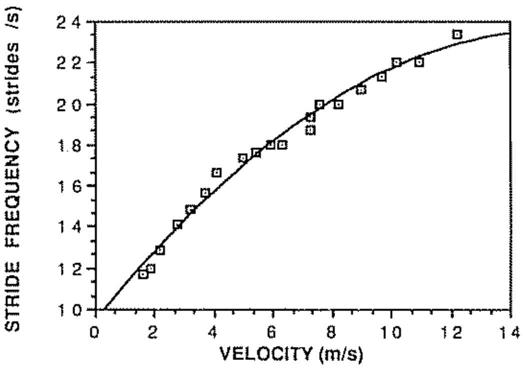

Fig. 3 Graph of stride frequency (strides s^{-1}) and velocity (m s^{-1}) data for horse 8. The line of best fit was a second degree polynomial equation.

degree polynomial equations selected to describe the relationship stride frequency vs. velocity of 6 horses was 95.9%. The r^2 for the first and third degree equations was 73.8% and 95.2%, respectively.

The stride frequency-velocity graph of the horse with a first degree polynomial exhibited scatter of points in velocities between 4 and 7 m s^{-1} (Fig. 2). At velocities when scattered data points occurred, this horse was experiencing limb interference problems, as detected by the clicking sound of the hindlimb hitting the opposite forelimb. The front feet of this horse had been trimmed with a shortened toe as a possible attempt to correct for the interference problem. The stride frequency-velocity graph of the horse requiring a 3rd degree polynomial (Horse 4) flattened out in the mid-velocity range and then increased at faster velocities (Fig. 4).

DISCUSSION

Stride length

Stride length of horses moving overground is known to increase linearly with increases in velocity in foals[10] and adult horses of various breeds.[2,7] The results of the present study of horses locomoting on a treadmill also exhibited a strong linear relationship. Stride length of horses moving on a treadmill is reported to be significantly shorter than that of horses moving overground.[4] Future analysis of intrinsic stride measurements may give us additional information to determine why this occurs.

Stride frequency

Stride frequency of horse 2 was described by a first degree polynomial equation. This horse exhibited varying stride frequency measurements at velocities between 4 and 7 m s^{-1} apparently due to velocity-dependent interference (possibly forging) occurring at those speeds.

The velocity-stride frequency data of horse 4 described by a third degree polynomial equation may represent an attempt by this horse to use a preferred stride frequency over a middle velocity range of approximately 4 to 8 m s^{-1}. A similar nonlinear relationship and interpretation has been reported previously.[1,2] It was suggested that the horse may be attempting to use a stride frequency which would demand the least amount of energy expenditure.[1] It has been suggested that the metabolic costs of locomotion are proportional to stride frequency, since stride frequency reflects the speed at which forces must develop and decay during each stride.[12] In horses there is a velocity at the walk, trot

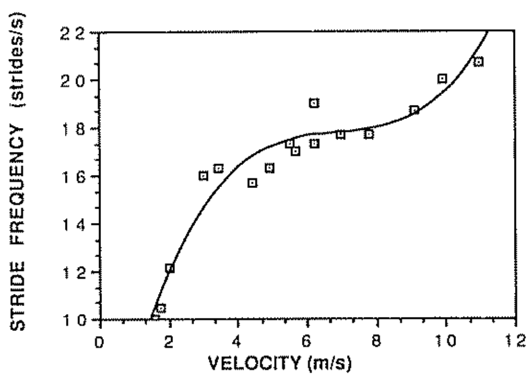

Fig. 4 Graph of stride frequency (strides s^{-1}) and velocity (m s^{-1}) data for horse 4. The line of best fit was a third degree polynomial equation.

or gallop at which the expenditure of energy reaches a minimum value for each gait and which a horse will choose preferentially.[5,6] The selected velocity may involve use of a preferred stride length, stride frequency, or both measurements.[9]

A comprehensive study should be done comparing treadmill locomotion and overground locomotion. The differences detected in a previous study[4] included decreases in stride length, swing phase duration, time between placement of the limbs of a diagonal limb pair (diagonal dissociation) at lift off and distance between forelimb placement (forestep length), and increases in stride frequency, duration of the limb deceleration phase (at 8.5 m s^{-1}), and a marked increase in the distance between limbs of each diagonal limb pair of horses on a treadmill. The authors suggested that these differences could be due to variability between recording sessions.

It may be unacceptable to carry out physiological experiments on horses moving on a treadmill by setting a standard velocity and assuming that all horses are moving similarly and expending comparable energy.[9] The basis of this comment is data reported in Fedak et al.[3] of a pony on a treadmill which showed that, at a velocity of 7.6 m s^{-1}, 38–40% of the mass-specific rate at which this animal consumes energy is used to accelerate the limbs and other segments relative to the center of mass. This percentage would be greater at faster velocities. It is therefore feasible that different patterns of moving the limbs, such as those typically seen in a group of horses, would result in distinctly different energy costs and consequently, different levels of metabolic measurements. It has been suggested that a different method of standardizing movement analysis should be devised. For example, one study evaluated stride length taken at a standard stride frequency of 2 strides s^{-1}.[10] Other researchers standardize measurements to stance phase duration.

It would be valuable to know velocity-dependent characteristics of velocity, stride length, and stride frequency prior to initiating a treadmill based experiment so as to detect idiosyncracies, or unique locomotor features, such as those determined for stride frequency of Horses 2 and 4 in the present study.

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