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Analysis of trotter gait on the track by accelerometry and image analysis

C. LELEU*, E. GLORIA, G. RENAULT† and E. BARREY†

Pégase Mayenne, Département de médecine du Sport, Centre Hospitalier, 53 015 Laval; and †INRA, Station de Génétique Quantitative et Appliquée, 78352 Jouy en Josas, France.

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Summary

The aim of this study was to describe the correlation between the phases of the limb cycle of trotters on the track and specific points on the acceleration curves obtained from a new gait analysis system. We compared kinematic data obtained by video image analysis and 3-dimensional acceleration recordings made on 3 French trotters in training. They trotted on a race track at speeds of 8.33, 10 and 11.66 m/s, with a final stretch at maximum speed. Their locomotion was recorded with a synchronised video camera at a frame frequency of 200 Hz and with the Equimétrix gait analysis system. The gait variables were calculated using 3-dimension acceleration data recorded at the sternum (dorso-ventral, longitudinal and lateral axes) at a sampling rate of 100 Hz.

Three phases of the stride were clearly identified on the dorsoventral acceleration signal: hoof-landing, midstance phase and toe-off. Braking and propulsion phases were identified on the corresponding longitudinal acceleration signal. The weight-bearing diagonal was identified by observing the lateral signal. The stride temporal variables (stride, stance, braking and propulsion durations for both diagonals), measured by video analysis and by acceleration signal analysis, were not significantly different (P>0.05). The identification of specific points on the acceleration pattern allowed an accurate temporal analysis of the stride. Potential applications could be the determination of locomotor factors related to racing performance or assessment of locomotor disorders at high speed.

Introduction

Locomotion analysis is being used increasingly to assess horses in training. Gait analysis may help in the evaluation of lameness (Buchner *et al.* 1995, Deuel *et al.* 1995), of the effect of training (van Weeren *et al.* 1993; Johnston *et al.* 1999) or selection of young animals (Back *et al.* 1994, 1995). Many studies on the locomotion of trotters on the track were carried out in Sweden in the 1980s (Fredricson *et al.* 1980; Drevemo *et al.* 1980a), including studies on interlimb coordination and the reproductibility of the trot at high speed (Drevemo *et al.* 1980 b,c). While high speed cinematography provides a great deal of information, it is time consuming and cannot be used routinely to assess training. A gait analysis system[1], based on accelerometry measurements, has been used to determine locomotor variables reflecting the performance of racing trotters and Thoroughbreds (Barrey *et al.* 1995, 2001). Our present knowledge of the acceleration signals and advances in signal analysis have allowed the development of this tool for application in early selection and in training. This study used this method of gait analysis on the track to describe the correlation between the phases of the limb cycle and specific points on the acceleration curves. We compared certain stride temporal variables obtained with the accelerometry device and by video image analysis.

*Author to whom correspondence should be addressed.

Materials and methods

Horses

The study was carried out on 3 French trotters, age 3, 4 and 5 years, in full training. They were clinically sound and driven, using the same harness and sulky, by an experienced driver. White anatomical markers (2 x 2 cm) were glued onto the horse's skin in a standard pattern.

Forelimb: Markers were placed on the proximal hoof, lateral collateral ligament of the metacarpophalangeal joint, lateral styloid process of the radius, lateral collateral ligaments of the elbow joint, caudal part of the greater tubercle of the humerus and distal end of the scapular spine.

Hindlimb: Markers were placed on the hoof and metatarsus as for the forelimb. Other markers were placed on the lateral malleolus of the tibia, at the attachment of the lateral collateral ligament of the stifle joint, on the cranial part of the greater trochanter and upper tubercle of the iliac spine. The horses trotted in a straight line on a sand track at speeds of 8.33, 10, 11.66 m/s and at maximal speed. The driver used a tachymeter to measure the speed of the horse.

Accelerometric gait analysis system

The gait analysis system Eqimetrix[1] consisted of an accelerometric transducer fixed at the sternum and connected to a small data logger. The accelerometric transducer contained 3 orthogonal accelerometers measuring acceleration along the dorsoventral, longitudinal and lateral axes of the horse (Fig 1). Positive values were obtained when accelerations were in the dorsal, cranial and left directions, respectively. The transducer, enclosed in a small box (4.0 x 2.2 x 1.7 cm), was placed in a leather pocket on the harness girth. Its sternal location, between

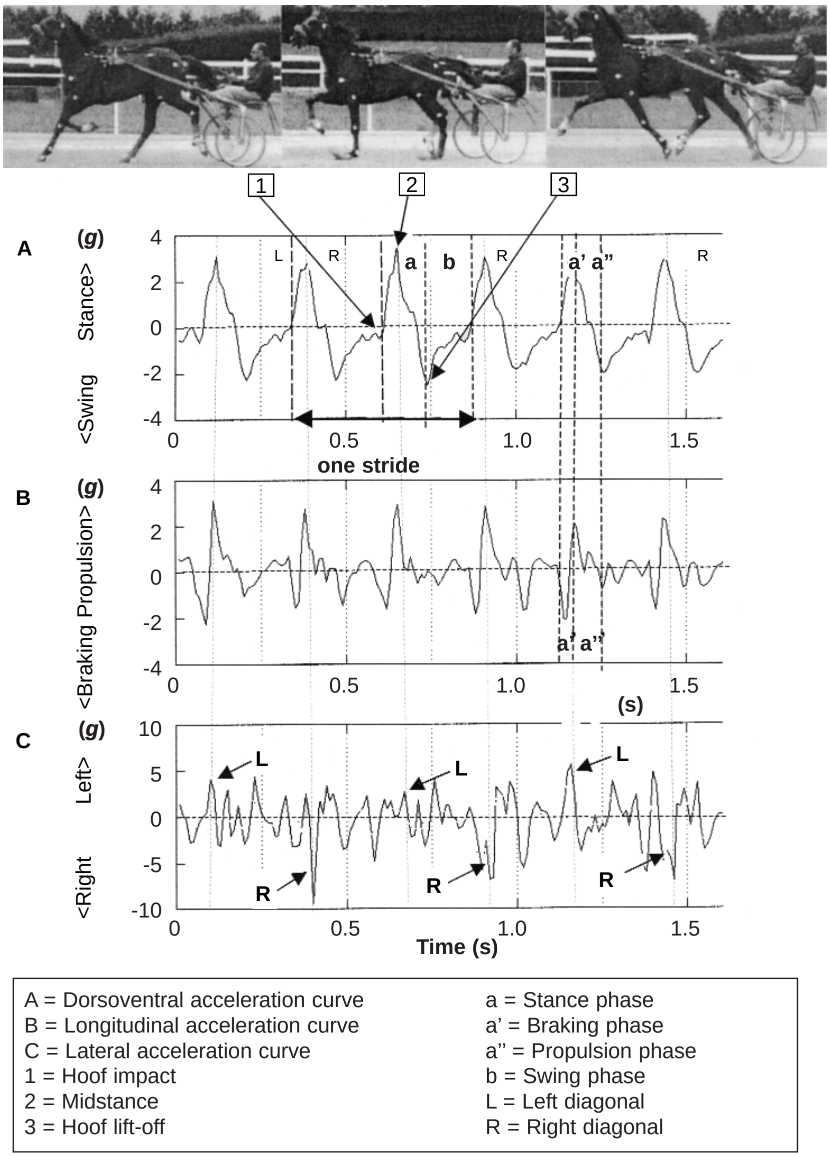

Fig 1 : Correspondence between video images and the 3 axial acceleration curves.

the *pectoralis ascendens* muscles, ensured that the transducer was close to the horse's centre of gravity and provided a good stability against the body of the horse. The range of accelerations recording was ± 10 ***g***. The transducer was connected to a data logger fixed on the shaft of the sulky. This recorder was equipped with an event marker that could detect a flash of light. Data were acquired continuously, at a sampling rate of 100 Hz, and filtered with a low pass filter (cut-off frequency 50 Hz) to avoid aliasing. The data logger was removed from the horse at the end of the test and its data transfered to a laptop computer.

Video recording

Horses were filmed from left side with a stationary high-speed camera (Memocam C25 Sony)[2] at a frame frequency of 200 Hz. The recording distance of 40 m allowed analysis of 6 to 10 strides. An event marker device was used to synchronise the video images and accelerometric recordings. The video films were converted to digital images for use with a computer programme that plotted acceleration curves synchronised with the images. The main events of the limb cycle were identified on the 3 acceleration curves.

Accelerometer data analysis

Data from the 3 acceleration signals were analysed using scientific software (Matlab 5)[3] to calculate temporal stride variables. All the variables were calculated for a trot sample of 20.48 s at constant speed. The temporal variables measured were:

Stride duration (S): The trot at constant speed can be considered as a sum of stationary periodic motions. This preliminary assumption allows Fourier analysis of the dorsoventral signal. Stride frequency (SF) was deduced from the frequency of the main peak of the power spectrum calculated by Fast Fourier Transform of the dorsoventral acceleration signal (Barrey *et al.* 1994). Stride duration was calculated the reciprocal of SF.

Specific points (hoof landing, mid-stance and toe-off) of the dorsoventral and lateral acceleration curves were identified (see below). Six stride temporal variables were measured on the acceleration curves for both the right an left diagonals:

Right stance duration (RS): time between the right diagonal hoof landing and the same diagonal toe-off.

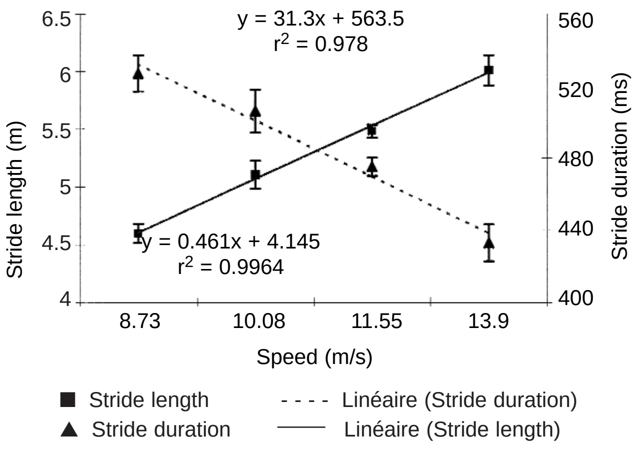

Fig 2: Evolution of stride length and stride durtion with speed.

Left stance duration (LS): time between the left diagonal hoof landing and the same diagonal toe-off.

The stance phase was divided into braking and propulsion phases. The braking lasted from the hoof landing to the mid-stance position, ie, for the forelimb, when the metacarpus was in a vertical position. The propulsion stage was the remainder of the stance phase, from the mid-stance position to toe-off. The 4 following variables were measured using these definitions:

Right diagonal braking stage duration (RB): time between the right forelimb hoof landing and the right mid-stance position.

Left diagonal braking stage duration (LB): time between the left forelimb hoof landing and the left mid-stance position.

Right propulsion stage duration (RP): time between the mid-stance position and the right forelimb toe-off.

Left propulsion stage duration (LP): time between the mid-stance position and the left forelimb toe-off.

Temporal stride analysis on video image

The duration of each phase (stance, braking and propulsion) was also measured visually from the video sequence recordings. The image corresponding to hoof landing was defined as the last one before any extension movement of the distal limb. The image corresponding to mid-stance was defined as the one in which the metacarpus or metatarsus was vertical. The image corresponding to lift-off was defined as the last one in which the toe was in contact with the ground.

Statistical analysis

Relationships between stride temporal variables measured by Equimetrix and those measured from the video analysis were studied by an analysis of variance (GLM procedure)[4]. The relative errors of the accelerometric method were calculated using the video method as reference i.e. differences of duration obtained by the 2 methods divided by the video one. The effects of speed and horses on the stride temporal variables were also tested. A significance of $P<0.05$ was used for all the tests.

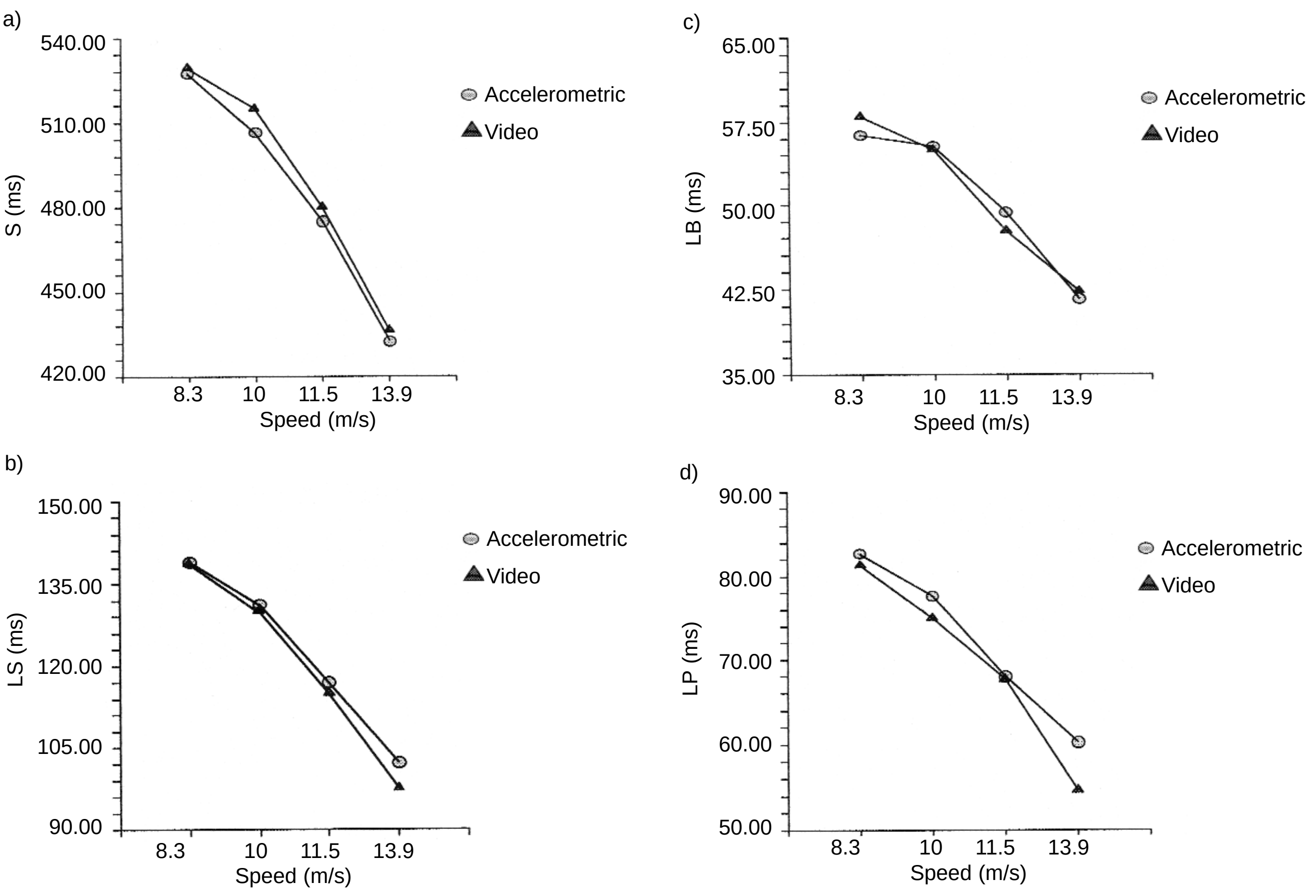

Fig 3: (a) Stride (S), (b) Left stance (LS), (c) Left braking (LB) and (d) Left propulsion (LP) durations at increasing speed measured by accelemetric or video method.

TABLE 1: Temporal variables measured by accelerometric analysis and video analysis at different speeds (mean and (s.d.)). n = 3

	Accelerometric analysis (ms)							Video analysis (ms)						
Speed (m/s)	S	LS	RS	LB	RB	LP	RP	S	LS	RS	LB	RB	LP	RP
8.73 (0.1)	527 (10)	140 (4)	135 (12)	56 (5)	56 (15)	83 (9)	79 (6)	529 (11)	138 (4)	140 (5)	58 (2)	58 (3)	81 (5)	84 (5)
10.08 (0.16)	508 (12)	132 (3)	132 (8)	56 (4)	52 (2)	78 (8)	76 (10)	515 (9)	130 (1)	130 (1)	55 (3)	52 (3)	75 (2)	78 (2)
11.55 (0.13)	475 (5)	117 (7)	123 (5)	49 (10)	47 (5)	68 (6)	76 (9)	480 (5)	115 (1)	115 (5)	48 (5)	47 (4)	68 (3)	69 (2)
13.9 (0.23)	433 (10)	102 (8)	102 (5)	42 (3)	46 (1)	61 (8)	56 (3)	436 (13)	98 (1)	97 (5)	42 (0)	38 (4)	55 (2)	59 (1)

S = stride duration; LS and RS = left and right stance durations; LB and RB = left and right braking durations; LP and RP = left and right propulsion durations.

Results

Identification of the limb cycle on acceleration curves

The images were used to identify precisely hoof contact, midstance phase and hoof lift-off on the corresponding points of the acceleration curves. Figure 1 shows the images and the dorsoventral (A), longitudinal (B) and lateral acceleration (C) of a horse trotting at 8.33 m/s. The time and duration of each phase of the stride cycle were determined from the dorsoventral acceleration curve (A) - stance phase (a) including hoof impact (1), braking phase (a’), midstance phase (2), propulsion phase (a’’) and hoof lift-off (3), - swing phase (b).

The phases of braking (a’) and propulsion (a’’) were determined from the longitudinal curve (B), depending on whether the signal was respectively positive or negative.

The signal from the lateral acceleration curve (C) was used to determine whether the right or left diagonal was in the stance phase. A positive acceleration at the midstance phase conventionally indicated that the left diagonal was in stance (L), and a negative one that it was the right one (R).

Correlation between speed and stride duration and length

The relationships between stride duration and speed, and stride length and speed, obtained by the accelerometric method, are shown in Figure 2. A linear model was used to fit the stride length and stride duration. The relationship between stride caracteristics and speed was linear (r^2 = 0.99 for stride length and r^2 = 0.97 for stride duration).

Comparison of stride temporal variables measured by accelerometry and video image analysis

Table 1 shows the temporal variables measured by accelerometry and video analysis. Analysis of variance showed no significant differences between the 2 methods (P>0.05). There was also no ‘horse’ effect. Figure 3 shows the velocity-linked changes in the temporal variables (S, LS, LB, LP) measured by accelerometry and by video analysis. The relative errors of the accelerometry analysis compared to video image analysis were calculated for the stride temporal variables. The means of the relative errors (%) were 0.5 for S, 2.2 for LS, 2.5 for RS, 0.9 for LB, 1.4 for RB, 5.2 for LP and 1.5% for RP. Taking all variables into account, the mean of the relative errors at obtained speed of 8.73, 10.08, 11.55 and 13.9 m/s were 2.3, 0.4, 3.3 and 5.1%, respectively.

Discussion

We have verified the agreement between data obtained by accelerometry and that obtained by video imaging in real conditions of horse training, i.e. on the track at high speed. We have also compared the temporal variables obtained by accelerometry and video imaging. The limb cycle phases correlated perfectly with specific points on the 3 axial acceleration curves for each horse and at each speed. Consequently, the 2 methods produced identical stride temporal variables. However, there was little horse-to-horse variation because of the small sample size (n = 3). The measurements made at ‘maximum speed’ were also approximate because the horses could hardly reach their maximum speed as they were not under competition conditions. The accelerometric method of gait analysis is easy to use in field condition and data analysis is rapid. The measurements of acceleration at the sternum provides some basic information on the stride temporal variables and other variables that describe the kinetics of the horse centre of gravity, but they give no information about joint and limb segment kinematics. The overall shape of the acceleration patterns is a biomechanical constant of the trot. However the acceleration curves for each horse had some specific characteristics which should be further investigated. This variation in the locomotor patterns between individuals has also been reported for kinematic variables (van Weeren *et al.* 1993; Sloet van Oldruitenborh-Oosterbaan *et al.* 1996). The image analysis with the high speed camera provides other temporal information about brief events, such as diagonal advanced placement. However its main limitations appear to be the precise visual determination of events of hoof landing and take-off. An accelerometer mounted on the hoof could have overcome this difficulty for hoof impact (Barrey *et al.* 1993; Benoit *et al.* 1993; Burn *et al.* 1997). The estimates of the right diagonal variables were less accurate, although this was not significant. This might be because the video camera was placed laterally, giving better visualisation of the left diagonal than the right one. There were greater relative errors in the estimation of propulsion phase variables than in the braking ones, perhaps because of problem with determining exact occurrence of the hoof take-off. The lack of precision in determining this particular event makes it difficult to calculate propulsion and stance phases.

The agreement between the limb cycle and dorsoventral acceleration in the present study correlates well with a preliminary study of a trotting horse on a treadmill (Barrey *et al.* 1993). The same thoracic location was used, but the accelerometry device had only 2 accelerometers (a vertical and a longitudinal one) and acquired data at 500 Hz for 5 s. An accelerometer fixed to the hoof wall detected hoof impact and lift-off precisely. The horse, trotting at 4.2 m/s on a treadmill, was simultaneously filmed (25 frames/s). The images obtained in the present study were more accurate because of the higher frame rate and the better synchronisation with the acceleration measurement. The latest version of the accelerometry gait system[1] provides an additional lateral axis, which allows determination of the side of the diagonal in stance phase. Pulling a load does not seem to interfere with signal interpretation and the speed does not limit the calculation of locomotion variables.

The stride temporal variables measured in this study are very close to those measured at high speed on a track (Drevemo *et al.* 1980a; Barrey *et al.* 1995; Johnston *et al.* 1995). Measurements made on 24 standardbred horses at 12 ± 0.25 m/s by Drevemo *et al.* (1980a,b,c) gave a stride duration of 455 ± 8 ms, a left stance duration of 109 ± 4 ms, a left braking duration of 43 ± 4 ms and a left propulsion duration of 66 ± 3 ms. Barrey *et al.* (1995) observed stride durations of 476 ± 11 and 429 ± 11 ms for trotters at 10.5 and 12.7 m/s, while Johnston *et al.* (1995) measured a stride duration of 502 (481–527) ms and a stance duration of 133 (127–140) ms for horses trotting at the speed of 10.2 ± 0.2 m/s. Stride length increased linearly with the speed of the trot (Leach and Drevemo 1990; Barrey *et al.* 1995). Linear regression analysis was suitable for describing velocity-related changes in stride length. Leach and Drevemo (1990) found that polynomial model fits the relationship between stride duration and speed best but, our measurements at only 4 speeds could not be used to test a nonlinear regression model.

In conclusion, we have shown a close correlation between the limb cycle events and 3 axial acceleration curves for fast trotting harnessed horses. The identification of specific points on the acceleration pattern allowed an accurate temporal analysis. This new accelerometry device[1] works well under race track conditions and provides data on basic temporal stride parameters and other kinetic variables not described in the present study. This tool may have many practical applications. It could be used for testing young trotters and finding locomotor factors related to racing performance. It might also be useful for assessing locomotor disorders at high speed.

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Manufacturers' addresses

[1]Patented by INRA, services distributed by Centaure Métrix, Avon-Fontainebleau, France.
[2]Memocam C25 Sony, Tokyo, Japan.
[3]The MathWorks Inc., Natick, Massachusetts, USA.
[4]NCSS, Kaysville, Utah, USA.

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