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Relationships between biomechanical variables and race performance in French Standardbred trotters

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Abstract

Summary. Little information is available about gait characteristics and the level of performance in racehorses. The aim of that cross-sectional experiment was to study the relationships between some locomotor variables and the level of performance of trotter racehorses. A total of 104 horses from 3 to 7 years old performed a four-step locomotor test on the track with an accelerometric device: Equimetrix™. The population was divided into two groups on the basis of their official performance index: Index of TRot (ITR). These two groups were: an elite performers group (n=52) and a medium performers group (n=52). Locomotor variables: stride frequency, stance and propulsion durations, stride length, symmetry, regularity, dorsoventral, longitudinal and lateral activities were calculated at four different speeds (8.5, 11, 11.7 m/s and maximal speed). The variables were compared between two performance groups by an analysis of variance. The main results indicated that elite performers presented significantly higher stride frequency, longer stance and propulsion durations at submaximal and maximal speed. In conclusion, biomechanical characteristics of trotter racehorses, such as stride frequency and propulsion duration, might be useful criteria to quantify gait efficiency in trotter racehorses.

Keywords: Gait; Performance; Biomechanics; Trot; Racehorse

1. Introduction

Measuring stride characteristics of Standardbred trotters in track condition has been undertaken by means of ongulography (Bayer, 1973), cinematographic methods (Fredricson et al., 1972a,b; Drevemo et al., 1980a,b,c) or by accelerometry (Barrey et al., 1995). However, little is known about the relationships between locomotion and race performance. A high stride frequency has already been described as a factor of performance (Bayer, 1973; Barrey et al., 1995). In most experiments, the relationships between stride characteristics and performance were studied with horses measured at maximal speed.

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The aim of that cross-sectional experiment was to study the relationships between some locomotor variables and the level of performance of trotter racehorses at submaximal and maximal speed. One-hundred and four horses, divided into two performance groups, underwent a four-step locomotor test on the track. The locomotor variables were compared between the performance groups defined as an elite group and a medium performers group.

2. Materials and methods

2.1. Horses

A total of 104 horses from 3 to 7 years old were studied in this cross-sectional experiment. They were all French Trotters, in full training, clinically sound. The population was composed of horses aged 3 (n=42), 4 (n=29) and 5 and over (n=33). Before the test, all horses were also measured at withers. Table 1 shows the characteristics (means of age, height at withers and performance index) of the population studied.

2.2. Performance indices

The horses were divided into two groups in accordance with their annual index of performance [Index of TRot (ITR)].

Elite performers should have an equal or higher than 115 ITR and medium performers should have a lower than 115 ITR.

– Index of TRot (ITR) is an annual official index of performance published by French National Stud-book (Langlois, 1989). This criterion is computed annually for each French trotter on the basis of the natural logarithm of the average earnings per start every year. The mean of the population is 100 and S.D. is 20. This index has a normal distribution and it supplies a linear scale to compare the race performances of all the French trotters.
– Earnings: all earnings calculations (in euros) were cumulative and ended on the 31st of December of the year of the test. For example, the earnings for a 4-year-old horse are the total sum of the earnings reached at the very end of its fourth year, i.e., at 2, 3 and 4 years of age.
– Best recorded time (BT): it is the best time officially recorded during a race (most often a 2,100-m race) during or before the year of the test.

Table 1
Description of the population

Performance groups	Age (years)	n	Mean ITR±S.D.	Mean of height at withers±S.D. (m)
Elite performers	3	20	125±8	1.64±0.02
	4	15	129±10	1.63±0.04
	5 and over	17	135±10	1.63±0.04
	Total	52	130±10	1.63±0.04
Medium performers	3	22	100±12	1.60±0.04
	4	14	100±14	1.62±0.02
	5 and over	16	98±15	1.64±0.04
	Total	52	99±14	1.64±0.04

2.3. Exercise test

The horses performed a locomotor test at increasing speed. All the tests were carried out on similar race tracks. The absence of track effect on biomechanical variables has been checked (Leleu et al., 2004a). For all horses, the locomotor test was performed after 10 min warming-up and consisted of a 400-m straight line at the three increasing submaximal velocities : 8.5, 10 and 11.7 m/s, and then at maximal speed. The velocity was controlled by an experienced driver with a tachometer (1) composed of a magnet and an electromagnetic wave detector fixed on a wheel of the sulky and connected to a display screen to maintain the speed as constant as possible during each step.

2.4. Accelerometric gait analysis system

The three-dimensional accelerometric device used for the experiment was an Equimetrix 3D accelerometric transducer, connected to a small data logger (2). The transducer consisted of three orthogonal accelerometers measuring accelerations at the sternum, along the dorsoventral, longitudinal, and lateral axes of the horse. Positive values were obtained when accelerations were in dorsal, cranial and left directions. The accelerometers were glued together to form a small block (4×2.2×1.7 cm) inserted into a small case on a specific harness girth. It was positioned over the horse sternum, which provided good stability and was close to the animal center of gravity at rest. The range of acceleration was ±10 g. The data logger was inserted into a leather pocket fixed on the left shaft of the sulky. This recorder collected data continuously for up to 38 min, at a sampling rate of 100 Hz. The data were transferred to a laptop computer at the end of the test.

2.5. Accelerometric data analysis

The trajectory and speed of the horses running on the race track were recorded as function of time, by a GPS Garmin 12™ (3) placed on the left shaft of the sulky. This system also measured the instantaneous speed every 2.5 s. A custom-designed program was used to synchronise the acceleration and GPS signals. Samples of 20.48 s, at constant speed, in straight line of the race track were analysed. The analysis was carried out by signal analysis procedures, developed under a scientific software environment (Matlab 5) (4), to obtain both dynamic and temporal stride variables.

2.6. Variables measured

Stride is defined as a full cycle of limb motion and, at a constant speed, trot can be considered as a sum of stationary periodic motions.

- Velocity (m/min): measured by two independent systems: an electromagnetic tachymeter (Speed Puls Equus™) and a GPS system (Garmin 12).
- Stride frequency (SF; stride/s) : number of strides per second and is also equal to the inverse of stride duration. It was measured by finding the frequency of the main peak of the power spectrum calculated by a fast Fourier Transform (FFT) of the dorsoventral acceleration signal.
- Stride length (SL; m): deduced from the relationship SL=Velocity/SF.
- Stride temporal variables: these variables were calculated by plotting specific points on the dorsoventral acceleration curve (Leleu et al., 2002) under specific software. They were all expressed as a percentage of the stride duration.
- Right stance duration (RS): time between the right diagonal hoof landing and the same diagonal toe-off.
- Right propulsion duration (RP): time between the right forelimb midstance position and the same diagonal toe-off.
- Stride regularity (REG; /200): regularity is a sum of correlation coefficients corresponding to the peaks of the autocorrelation function of the dorsoventral acceleration, measured at a time equal to the half stride and stride duration. It measures the acceleration pattern similarity of successive strides.
- Stride symmetry (SYM; %): symmetry is a correlation coefficient, corresponding to the peak of the autocorrelation function of the dorsoventral acceleration measured at a time equal to half stride duration. It measures the acceleration pattern similarity of the right and left diagonals.
- Dorsoventral activity (DVA; g^2/Hz): this is the integral (cumulative sum of the energy modules between 0 and 25 Hz) of the power spectrum obtained by FFT from the dorsoventral acceleration signal. This variable measured the limb suspension and loading activity.
- Longitudinal activity (LONA; g^2/Hz): this is the integral of the power spectrum obtained by FFT from the longitudinal acceleration signal. This variable measured the amount of deceleration and acceleration along the longitudinal axis.
- Lateral activity (LATA; g^2/Hz): this is the integral of the power spectrum obtained by FFT from the lateral acceleration signal. This variable measured the amount of deceleration and acceleration along the lateral axis.

2.7. Statistical analysis

The stride variables calculated from the accelerometric measurements, carried out with Equimetrix 3D, were studied using Statistical Software (5). A two-factor analysis of variance (ANOVA) tested the influence of the step and the performance groups for all the stride variables. For variables influenced by the performance group, four other analyses of variance (ANOVAs) tested this influence at the four different steps, completed with Duncan's post hoc test if differences appeared.

A correlation matrix was calculated to quantify the relationship between locomotor variables and performance indices.

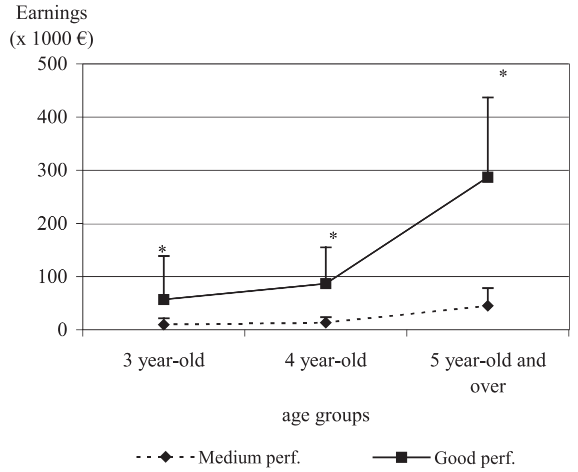

Fig. 1. Earnings in the two performance groups. *Significant difference at $p<0.05$ between performance groups.

A significance level of $p<0.05$ was used throughout this study for all the tests.

3. Results

In the two performance groups, mean age and height at withers were similar. As expected, the ITR was significantly higher in the elite performers group ($p<0.05$). Their mean earnings and best recorded times were also significantly better in that group compared to the medium performers group (Figs. 1 and 2).

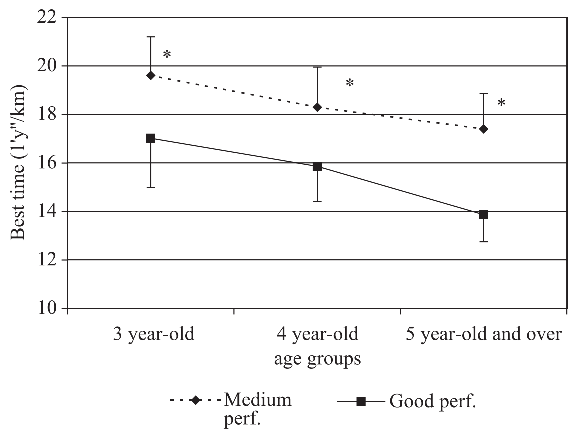

Fig. 2. Best recorded times in the two performance groups. *Significant difference at $p<0.05$ between performance groups.

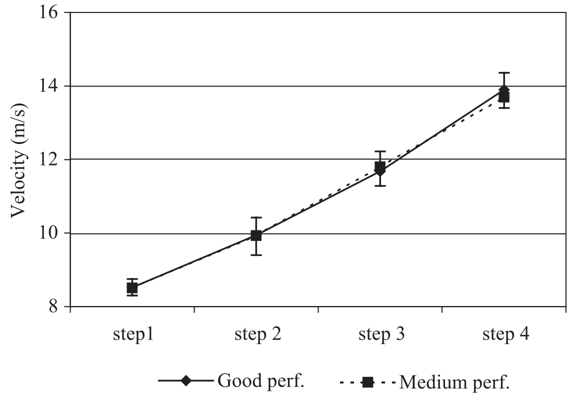

Fig. 3. Velocity in the two performance groups. *Significant difference at $p<0.05$ between performance groups.

Locomotor variables, such as stride length and frequency, and the three activities significantly increased at the four steps of speed. Symmetry was constant at increasing speed whereas regularity and temporal stride variables significantly decreased with speed.

At each step, the speed was similar in the two performance groups, even at maximal speed (Fig. 3). Symmetry, regularity, dorsoventral, longitudinal and lateral activities were also similar in the two performance groups (Table 2). However, three locomotor variables were significantly different between the two performance groups: stride fre-

Table 2
Results of the two-factor analysis of variance testing the influence of the performance group and the step of velocity

	Influence of the step	Influence of the performance group	Interaction
Velocity	0.0001	ns	ns
Stride frequency	0.0001	0.0001	ns
Stride length	0.0001	0.01	ns
Stance duration	0.0001	0.0001	ns
Propulsion duration	0.0001	0.001	ns
Braking duration	0.05	ns	ns
Symmetry	ns	ns	ns
Regularity	0.0001	ns	ns
Dorsoventral activity	0.0001	ns	ns
Longitudinal activity	0.0001	ns	ns
Lateral activity	0.0001	ns	ns

quency, stance and propulsion durations. Elite performers showed significant higher stride frequency at steps 1, 2 and 4 (Fig. 4). Stance duration was significantly longer in elite performers at steps 1, 2 and 3 (Fig. 5). Propulsion duration was also found significantly higher in this group at steps 2 and 3 (Fig. 6). All these findings were confirmed by the correlation matrix (Table 3). Positive and significant correlations were found between ITR and stride frequency (r=0.15), ITR and both stance and propulsion durations (r=0.22).

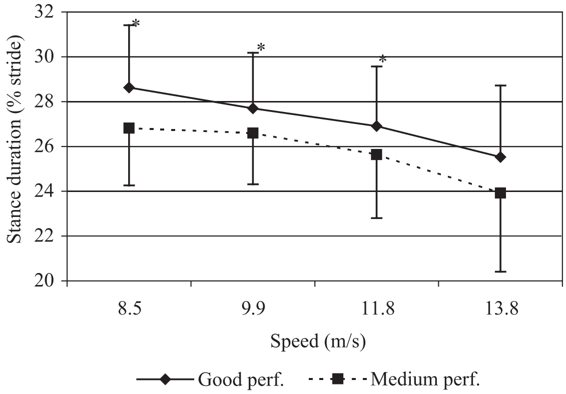

Fig. 5. Stance duration in the two performance groups. *Difference significant at p<0.05 between performance groups.

4. Discussion

4.1. Control of variability

Validation and reproducibility of the accelerometric measurements with Equimetrix have been previously described in trotter racehorses (Barrey et al., 1995; Leleu et al., 2002, 2004a). This method allows the quantification of some stride characteristics. However, these variables are influenced by defined factors, such as speed, age or height at wither (Leleu et al., 2004b).

Thus, we took particular care in selecting and comparing two groups of performers:

- with the same mean age,
- with the same mean height at wither,
- running at the same submaximal speed.

All horses were submitted to the same standardized locomotor test, on similar tracks. Another important point was the great variability of performance between the two groups. At maximal speed, we were expecting that the best horses would reach the highest speeds. In fact, the mean "maximal speed" was similar in both groups. This can be explained by a lack of motivation when the horses are not under competition conditions.

4.2. Factors of performance

Our main result was that performance is correlated to two stride characteristics in trotter racehorses:

4.2.1. Stride frequency

At the same submaximal and maximal speeds, stride frequency was found higher in elite performers

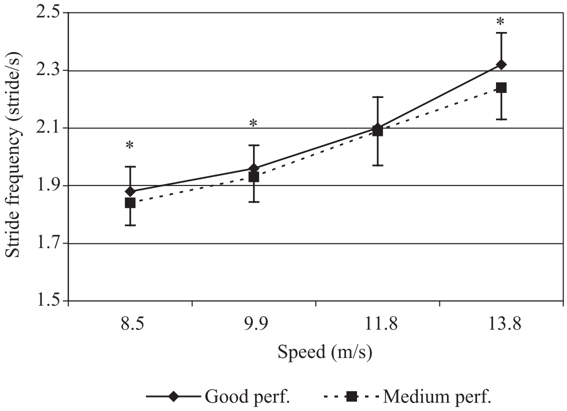

Fig. 4. Stride frequency in the two performance groups. *Difference significant at p<0.05 between performance groups.

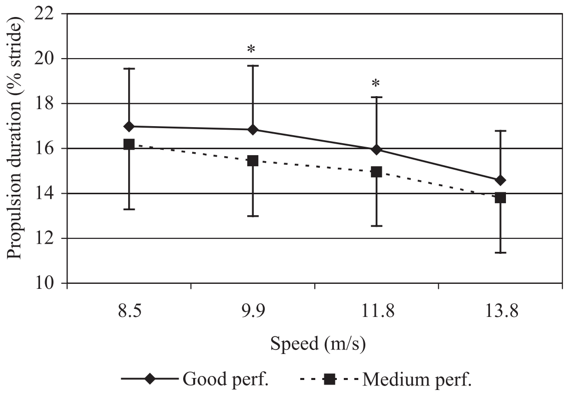

Fig. 6. Propulsion duration in the two performance groups. *Significant difference at p<0.05 between performance groups.

Table 3
Correlation matrix (r significant at $p<0.05$)

	ITR	Earnings	Best time
Earnings	0.70	–	–
Best time	−0.66	−0.90	
Stride frequency	0.15	ns	−0.10
Stride length	ns	0.11	−0.13
Stance duration	0.22	ns	−0.08
Propulsion duration	0.22	0.15	−0.12
Symmetry	ns	0.12	−0.14
Regularity	ns	ns	ns
Dorsoventral activity	ns	ns	ns
Longitudinal activity	ns	ns	ns
Lateral activity	ns	ns	ns

than in medium performers. This finding has been previously described in both trotters and Thoroughbreds (Bayer, 1973; Gunn, 1982; Barrey et al., 1995, 2001). Because of the pendulum mechanics, stride frequency depends on the height of the horse (length of the limbs), the weight distribution of the limbs (moment of inertia), the elasticity of the limbs (modulus of elasticity) and the percentage of fast muscle fibers in the limb muscles. Gunn (1982) compared Thoroughbreds with other breeds to identify adaptations which would favour their superior athletic capacities. He found that Thoroughbreds did not have longer legs relative to their liveweight than nonathletic horses. However, Thoroughbreds had a greater mass of their hindlimb nearer the hip joint than other breeds. This feature favours a high natural frequency of hindlimb movement and facilitates a higher stride frequency and consequently a faster running speed in Thoroughbreds as compared to other breeds of horses. Bayer (1973) measured different stride characteristics in 15 trotters: stride frequency and length, duration of ground contact. He also noticed that the best performers of the group had higher stride frequency. Finally, Barrey et al. (1995, 2001) have the same conclusions for both trotters and thoroughbreds. In a population of 24 trotters divided into three groups of performance, the authors found that stride frequency was higher in the high-performance group compared to the other group. A negative and significant correlation was found between stride frequency and best recorded time ($r=-0.459$). In a group of 30 thoroughbreds, they found a positive and significant correlation between stride frequency and an equivalent of ITR (log earnings/starts): $r=0.42$. In contrast, a negative correlation was found between stride length and equivalent of ITR: $r=-0.32$.

However, it is important to notice that, in all these previous studies, the horses were measured at maximal speed. In the current study, the relationship between stride frequency and performance is, for the first time, also described at submaximal speed.

In human, a high stride frequency is reported to be a discrimant factor of performance (Coh et al., 2001; Kunz and Kaufmann, 1981). However, for other authors, faster top running speeds are achieved with greater ground forces and not by more rapid leg movements (Weyand et al., 2000).

4.2.2. Stance and propulsion relative durations

We also found that stance and propulsion relative durations are longer in elite trotters compared to medium performers. Barrey et al. (2001) observed the same finding in the group of 30 Thoroughbreds at maximal speed. They also found a positive correlation between stance relative duration and the equivalent of ITR (log earnings/starts): $r=0.41$. On contrast, Bayer (1973) reported shorter stance duration in best trotters. An explanation is that he considered the absolute stance duration and not the relative stance duration.

Interestingly, in human athletes, the shortness of the stance period is a criterion of performance (Novacheck, 1998). Indeed, sprinters have to increase both stride length and frequency to produce important propulsive forces in a very short time. One biomechanical characteristic of best sprinters is short stance duration which can be reduced to 22% of stride duration at the speed of 9 m/s (for running speeds of 3.2 and 3.9 m/s, stance relative duration is, respectively, 39% and 36%). In human, a decrease in stance duration is made possible by an incomplete contact of the foot surface. Runners can be classified as rearfoot, midfoot or forefoot strikers according to the part of the foot that first contacts the ground during the step. Some observations by coaches and trainers seem to indicate that rearfoot strikers are predominant among long-distance runners, while middle-distance runners and sprinters tend to land with the anterior part of the foot. Each running style affects shape, amplitude and timing of the ground reaction force. Ardigo et al. (1995) undertook a study to assess the metabolic and mechanical aspects of two different foot strike patterns in running, i.e., forefoot and rearfoot striking.

Their conclusions were that the time the foot is on the ground is shorter for forefoot strikers and this pattern is "an obligatory choice to increase one's speed" even if it is energy consuming. For the same speed, the relative stance duration is 12% shorter in forefoot strike compared to rearfoot strike. The authors also mentioned that the fastest living mammals, like the cheetah and the pronghorn antelope, run with the posterior part of the foot raised from the ground, i.e., they are, respectively, a digitigrade and an unguligrade, while man is a plantigrade. The same observation can be made in the present study. Anatomically, a horse foot already presents a reduced ground contact surface and this characteristic predisposes horses to speed. Thus, the strategy for human sprinters is to reduce stance and braking durations by forefoot striking in order to gain running efficiency, whereas in horses, the strategy would be to increase stance and propulsion relative durations. Hence, relatively longer and more frequent phases of propulsion activity could be an explanation for a more efficient trotting gait in racehorses.

In addition to biomechanical variables, other physiological variables are highly related to racing performance in trotters. Using submaximal exercise tests, relationships between V_4 values (velocity for a blood lactate concentration of 4 mmol/l) and some performance indices have been reported. Leleu et al. (in press (c)) reported correlation between ITR and V_4 with an r=0.72 (p<0.05) in a population of 223 Trotters aged from 3 to 8 performing a standardized exercise test. Casini and Greppi (1996), studying 20 Trotters during a field exercise test, compared 10 good performers and 10 poor performers, the qualifications being based on best time. These authors found significantly higher V_4 values in the first group and a negative correlation between V_4 values and best time (−0.61).

5. Conclusion

The aim of that work was to point out the existence of gait differences between trotter racehorses of different levels of performance at submaximal and maximal speeds. This cross-sectional study, carried out with 104 trotters, was based on the comparison of two performance groups, observed at our increasing speeds. We found that some locomotor variables are significantly different between the two groups. Thus, the most remarkable features of this study were that best performers have significantly higher stride frequency, longer stance and propulsion durations at submaximal speed. On the contrary, symmetry, regularity, dorsoventral and longitudinal activities were not discriminant criteria of performance. Stride frequency, stride and propulsion duration at submaximal speed could be considered as markers of a more efficient gait. In practice, this locomotor test might be used for estimating the racing ability of trotters in combination with physiological evaluation.

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