

# A Quantitative Force Plate Assessment of Equine Locomotor Performance

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## Summary

*Force plate data from trotting ponies were used to evaluate methods of treatment for a standard induced tendon injury. The dynamic force plate patterns from normal, injured and treated ponies were characterized using thirteen digital co-ordinates from constant features on the waveforms. Canonical variates analysis of these data provides a statistical technique for the discrimination of different functional states of locomotor performance. Using this technique, line firing, tendon splitting and conservative treatments for tendon injury were compared. Animals in which rest alone was allowed after injury showed a progressive return to the normal pre-injured state. Line firing produced a varied response but no clear indication of a return towards normality, whilst tendon splitting resulted in a progressive departure from the pre-injured condition. These results demonstrate that canonical variates analysis of force plate data can be used to evaluate changes in equine locomotor performance.*

## Introduction

Partial rupture of the flexor tendons in the racehorse constitutes a major source of financial loss to the racing industry. Assessment and consequent treatment of such injuries is currently based on subjective opinion. In recent years, studies on human gait have shown that measurement of the distribution of forces between the foot and the ground can provide objective clinical data without the need for surgically implanted

transducers (Jacobs *et al.*, 1972). This technique has now been widely used in human investigations and extended to the study of locomotion in animals (Alexander and Jayes, 1978; Pratt and O'Connor, 1976). The aim of this study was to use force plate data in the evaluation of tendon injury and its treatment in the horse (Goodship *et al.*, 1977) to provide the basis for a technique which would facilitate objective clinical assessment in locomotor disorders.

### *Material and Methods*

#### *Force platform*

A 900 × 600 × 110 mm Kistler piezoelectric platform which measured the three orthogonal forces, Vertical ( $F_z$ ), Fore and Aft ( $F_y$ ) and Lateral ( $F_x$ ) was installed outdoors in a concrete walkway covered with non-slip rubber matting. It was capable of measuring forces up to 5 kN and had a minimum resonance frequency of 1000 Hz.

#### *Recording equipment*

The force platform output was amplified by three Kistler charge amplifiers and monitored on a 4-channel Tektronix storage oscilloscope before being recorded on FM tape using a Bell & Howell FM cassette recorder. The analogue force patterns were digitized at a sample rate of 1000 Hz and stored on the hard disks of a DEC PDP 11/34 computer running under RSX-11m operating system using FORTRAN IV software. The co-ordinates illustrated in Fig. 1 were extracted from the individual force patterns, using a manually controlled cursor, and filed for subsequent analysis.

#### *Data collection*

A group of 12 ponies with a weight of  $243 \pm 29$  kg (mean  $\pm$  SD) was divided into three treatment sub-groups each containing four animals. A standard injury was inflicted on all animals by an intratendinous injection of collagenase into the superficial digital flexor tendon of the left forelimb (Silver *et al.*, 1982). At one month post injury each sub-group was treated differently: one was line fired and one tendon-split, while the remaining sub-group acted as an untreated control (Silver *et al.*, 1982).

Force platform recordings were obtained according to the following protocol:

Pre-Injury Control.....	Recording Session 1
Standard Acute Injury	
1 Month Post Injury .....	Recording Session 2
Treatment – Tendon-Split, Line Fired or Control	
2 Months Post Injury	
1 Month Post Treatment .....	Recording Session 3
5 Months Post Injury	
4 Months Post Treatment .....	Recording Session 4
9 Months Post Injury	
8 Months Post Treatment .....	Recording Session 5
12 Months Post Injury	
11 Months Post Treatment .....	Recording Session 6

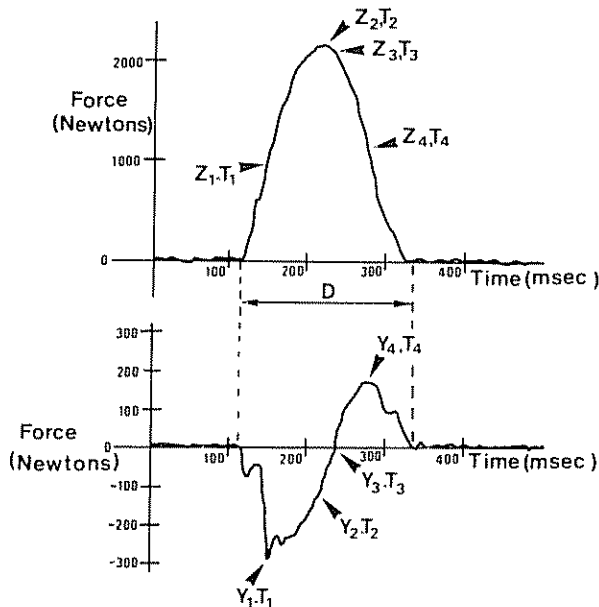
Half the animals in each group were sacrificed after recording session 5.

Each recording session consisted of ten force patterns taken at the trot ( $3 \pm 1.5$  m/s) from each leg on three successive days, giving a total of 30 patterns from each leg. This number of samples was required because of the high level of variation between individual force patterns. A concurrent independent locomotor assessment was carried out by an experienced clinician at various stages of the experiment.

#### Statistical analysis

Only the  $F_z$  and  $F_y$  force/time curves were subject to analysis, since the large inherent variation evident in the lateral force made it unsuitable for inclusion. The maximum vertical force ( $Z_2$ ), maximum negative fore and aft force ( $Y_1$ ), cross-over point from negative to positive fore and aft force ( $Y_3$ ) and maximum positive fore and aft force ( $Y_4$ ) were used as pre-defined waveform markers to produce a series of characterizing co-ordinates (Fig. 1). The synchronous force values from the other channel, together with their time values, were obtained for each predefined marker, producing three co-ordinates (Z, Y and T) for each of the four selected markers, giving a total of 12. The force values were normalized to an idealized pony weight of 250 kg in an attempt to compensate for weight differences in individual group members. In addition, the time values (T) were expressed as a percentage of the total period of force application 'D' to allow direct comparison between consecutive force patterns (Fig. 1).

FIGURE 1. Positions of the pre-defined waveform markers taken from the force patterns and used as a data base in the canonical variates analysis.



The 12 extracted values, plus the time 'D', gave the 13 co-ordinates (Fig. 1) which were used as a data base to perform a canonical variates analysis. MacFie *et al.* (1978) and Gutteridge *et al.* (1979) used multivariate statistical techniques to identify bacteria by studying their pyrograms. Canonical variates analysis was found to be well suited to characterizing a series of complex waveforms, and successfully discriminated between different bacterial species on the basis of their pyrograms. The technique of canonical variates analysis was applied to force plate data from trotting ponies in an attempt to discriminate between different states of locomotor performance. Using the 13 variables previously described, the mean characterization of the waveform at each recording session was represented by a point in thirteen dimensional space. Maximum variations between the session means are obtained from successive directions in the multidimensional space; these directions are termed canonical variate axes. Plotting the means relative to the first two canonical variate axes allows a two-dimensional approximation of the multidimensional plot. A 95% confidence region can be drawn around each mean, and any points that lie within this region originate from the same statistical population and are consequently not statistically significantly different. The degree of spatial association between the mean points and their 95% confidence regions is directly related to their level of statistical similarity. Further details of this technique may be found in Marriott (1974) and Blackith and Reyment (1971).

## *Results*

### *Clinical assessment*

All animals were found to be lame immediately after the induced injury, but no locomotor defect was evident at any recording session by independent clinical assessors.

### *Objective assessment*

The results of this assessment are expressed by canonical variate mean plots. An example of one plot from each sub-group is shown in Figs. 2, 3 and 4. All the plots were derived from force patterns taken from the left forelimb, and the overall results are summarized in Table 1. The numbered points on the plots refer to the recording session numbers described in the experimental protocol. The circular or elliptical areas indicate the 95% confidence regions for the day to day variation within a recording session.

### *The control sub-group*

Pony 13 (Fig. 2) shows a highly significant injury effect indicated by the marked migration of point 2, and a gradual return with time to the original pre-injury condition at point 1. The results from the remainder of the sub-group (ponies 21, 23 and 25) are summarized in Table 1.

### *The line fired sub-group*

Pony 9 (Fig. 3) shows a statistically significant injury with a slight tendency to return to the pre-injured condition at session 1. The very large confidence regions indicate a high degree of variation within recording sessions. Ponies 22 and 24 (Table 1) show a marked injury effect with a further severe line firing effect resulting in no tendency to return to the original pre-injury condition at session 1.

TABLE 1. Summary of canonical variates analysis of force plate data from three groups of ponies treated by different methods for an induced injury of the superficial digital flexor tendon.

Sub-group	Pony no.	Induced injury effective?	Tendency to return to pre-injured condition following treatment	Special comments
Control	13	Yes – marked	Yes	—
	21	Yes – marked	Yes	—
	23	Yes – slight	Yes – except at session 6	—
	25	No	Yes – except at session 5	—
Line fired	4	No	Yes	Large confidence regions, confused spread with no trends
	9	Yes	Slight	Very large confidence regions
	22	Yes	No	Smaller confidence regions
	24	Yes	No	As pony 22
Tendon-split	2	Yes	No	Progressive drift away following treatment
	17	Yes	No	Slight return at sessions 3 and 4, followed by marked separation at sessions 5 and 6 – possible delayed effect
	19	Yes	No	As pony 2
	20	Yes	No	As pony 2

#### *The tendon-split sub-group*

The canonical variate plot of pony 2 (Fig. 4) is representative of the results obtained from all members of the sub-group (Table 1). Each tendon-split pony showed a statistically significant injury effect and a marked migration *away* from the normal pattern as a result of the treatment.

#### *Discussion*

The efficacy of each of the three different types of treatment régime for a standard induced injury has been studied using an objective form of locomotor assessment. The conservatively treated control sub-group showed signs of recovery by returning to the original pre-injury condition. The response to line firing was diverse, and the large confidence regions indicate a high level of statistical variation between replicate force

FIGURE 2. A canonical variate mean plot from one member of the control sub-group.

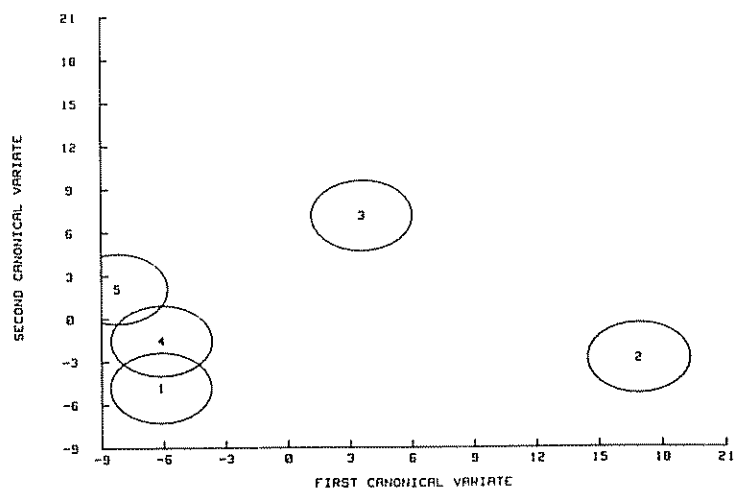
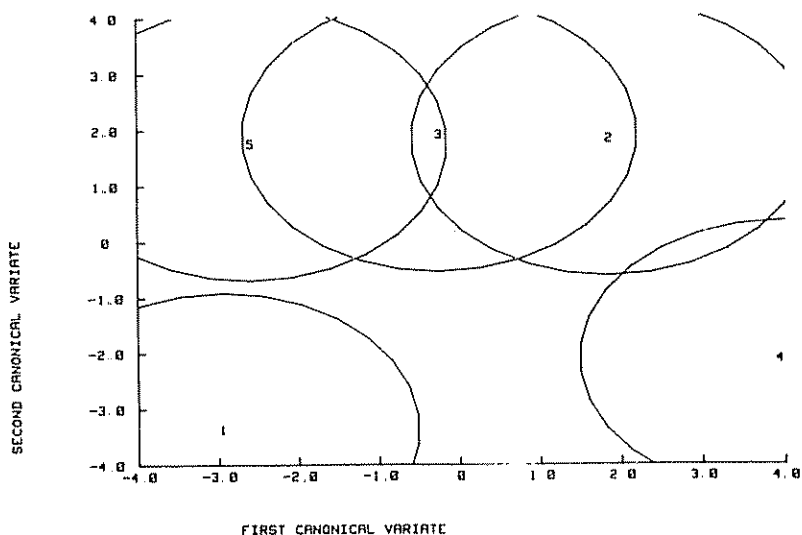
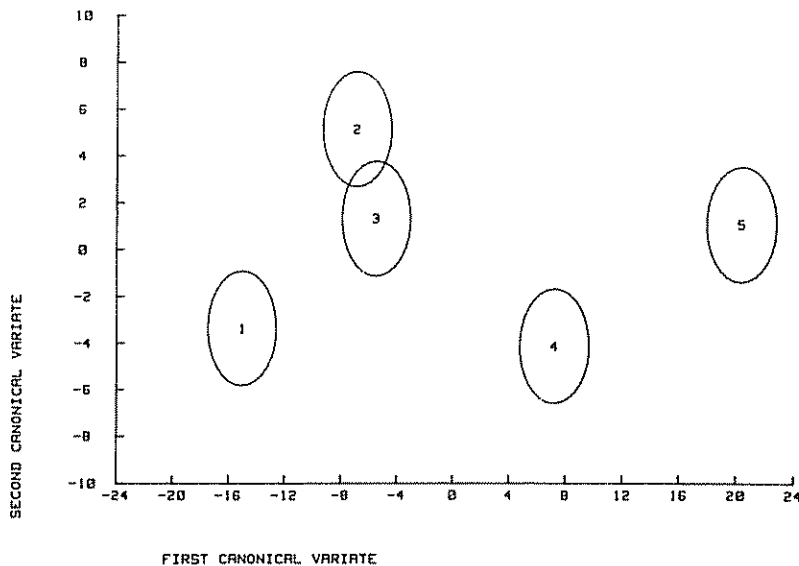


FIGURE 3. A canonical variate mean plot from one member of the line fired sub-group.



patterns. However, no member of this sub-group exhibited an improved recovery response compared to the control animals. The use of tendon splitting as a treatment régime appeared to cause a progressive, pathological change, indicated by the increasing statistical divergence from the original pre-injury condition shown in their canonical variate mean plots.

FIGURE 4. A canonical variate mean plot from one member of the tendon-split sub-group



The concurrent clinical evaluation of the induced injury and subsequent treatment régimes indicated no apparent effect upon locomotor performance, in contrast to the objective assessment technique which displayed a statistically significant standard injury effect in 10 out of the 12 experimental ponies and a very marked statistically significant divergence from the norm caused by tendon splitting.

Canonical variates analysis has the advantage over other statistical techniques that it accounts for the intercorrelations that occur between a number of variables chosen to describe a complex waveform. Its use for assessing equine locomotor performance objectively has provided a more discriminating means of detecting low-grade (subclinical) locomotor abnormalities than can be provided by subjective clinical observation. This ability has been utilized to provide an effective method for evaluating the efficacy of different régimes currently used in treating partial rupture of the flexor tendon in the horse.

### Acknowledgement

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