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# **Kinematic analysis of the trot in CCI\*\*\* 3-day-event horses.**

A thesis presented in partial fulfilment of the requirements for  
the Degree of Doctor of Philosophy at Massey University

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1999

## ***Acknowledgements***

My sincere thanks go to my supervisors Associate Professor A.S. Davies and Associate Professor P. S.Davie for their constant support and guidance throughout this study and for their careful scrutiny during the preparation of this thesis

A special thank you must be extended to Professor Dirk Pfeiffer who has been a friend, mentor and unofficial supervisor throughout this project

Sincere thanks must also go to Professor Elwyn Firth for his support and encouragement during the final stages of this project.

A very special thank you must be extended to my wife for her unselfish support and encouragement.

For funding I would like to thank The New Zealand Equine Research Foundation, and particularly Professor Des Fielden and Dr Brain Gouldan for there support of this project. Funding was also provided from the Graham Chalmers Allen Memorial Scholarship for which I am very grateful.

I would also like to thank The New Zealand Equestrian Federation and the Officials at the 1995 Taupo three-day event for providing me with the permission to film the horse inspections.

And last but not least I would like to extend a very special thanks to my family for their untiring support and encouragement.

## **Abstract**

Three day eventing is an equestrian sport originally designed to test the capabilities of cavalry horses and riders. An integral component of the sport are the horse inspections to ensure the horse is fit and sound to continue from one phase to the next. This study examined the "in-hand" trot of horses presented at the first and third horses inspections during the CCI\*\*\* class at the 1995 New Zealand Horse Trials Championships, Taupo, New Zealand. This study involved five stages.

1. Quantification of the three day event inspection process by use of time motion analysis.
2. Examination of the linear and temporal characteristics of the trot event horses during the first inspection process.
3. Comparison of the temporal gait characteristics between the first and third inspections.
4. Examination of the kinematics of a subset of horses during the first horse inspection and,
5. Comparison of the kinematics of this subset of horses between the first and third horse inspections.

The optimal strategy for both the inspection panel and competitors is to present a horse in a relaxed manner. The time motion analysis revealed that two different approaches to the inspection were used. One third of the class opted to walk their horses rather than trot their horses past the judge's panel on the final section of the return run. Two thirds spent a significantly longer time at the initial walk ( $4.36 \pm 0.94$ s vs  $3.53 \pm 0.91$ s,  $P < 0.01$ ), but spent less time during the stationary inspection ( $8.77 \pm 2.2.16$ s vs  $10.43 \pm 2.90$ s,  $P < 0.05$ ) and for the total time ( $42.04 \pm 2.50$ s vs  $45.34 \pm 3.38$ ,  $P < 0.01$ ). A correlation was found between initial walk and the time spent at the stationary inspection ( $r^2 = 0.249$ ,  $P < 0.01$ ). It is concluded that the initial impression gained as the horse is walked toward the inspection panel significantly influences the subsequent inspection.

The trot of 3-day event horses during the preliminary horse inspection of a CCI\*\*\* 3-day event was quantified and temporal characteristics defined. A

cross sectional study was made of the kinematics of 24 three day event horses during the first horse inspection. The horses were filmed using a panning lateral S-VHS video camera (50Hz). Video footage was digitised and linear and temporal measurements were made. The horses trotted for an average of  $10.44 \pm 1.55$  strides. Spatial measurements were made on an average of  $5.66 \pm 0.92$  consecutive strides when the horses were within the calibration zone. The horses increased and then maintained a constant velocity within the calibration zone. The relationships between stride length, stride duration and velocity when compared with previously published values. Horse specific differences in stance and retraction time as a percentage of stride were identified that may contribute to each horses unique gait or “kinematic fingerprint”. It is proposed that the initiation of, and completion of, stance by the hind limb first may represent “engagement of the hind quarters” and be a response to dressage training.

Temporal stride parameters between of the trot at the first and third horse inspections were quantified. This provided a repeat sample on 16 horses. Spatial measurements were taken for an average of  $5.66 \pm 0.92$  strides for the first inspection and  $5.05 \pm 1.27$  for the third inspection

The horses trotted with a significantly higher mean velocity during the third inspection ( $0.26 \pm 0.05 \text{ms}^{-1}$   $p < 0.001$ ). During the third inspection the horses trotted with a shorter stride length ( $0.193 \pm 0.03 \text{m}$   $p < 0.001$ ) and stride duration ( $31 \pm 42 \text{ms}$   $p < 0.001$ ). The third inspection was characterised by a significant decrease in retraction percentage for both the forelimbs ( $3.69 \pm 2.39\%$   $p < 0.001$ ) and the hindlimbs ( $2.48 \pm 2.16\%$   $p < 0.001$ ). However, no significant difference was found between the 2 inspections for other temporal parameters when measured as a percentage of stride. It is proposed that the event horses trot with a decreased stride length and duration during the third horse inspection but maintain a consistent temporal relationship.

The kinematics six 3 day event horses presented during the preliminary horse inspection at a CCI\*\*\* 3 day event were examined. The six horses trotted with a mean velocity of  $3.94 \pm 0.22 \text{ms}^{-1}$ . Displacement, velocity and acceleration data

are presented for X,Y and Z axis. Larger than expected vertical displacement values for the central body marker and fore and hind limbs are presented as evidence that during the preliminary horse inspection three day event horses trot with a more animated action. This more animated gait is believed to be due to a combination of the atmosphere of the competition environment and the high level of horse fitness. The significantly greater horizontal ( $1.129 \pm 0.103\text{m}$  vs  $1.108 \pm 0.05\text{m}$ ) and vertical displacement of the forelimbs ( $0.221 \pm 0.027\text{m}$  vs  $0.159 \pm 0.05\text{m}$ ) to the hind limbs are interpreted as evidence of dressage training.

Comparison of the kinematics of the trot a group of six horses ( $12.3 \pm 2.4$  years) during the first and third horse inspections at a CCI\*\*\* 3 day event competition was undertaken. The horses trotted with a mean velocity of  $3.94 \pm 0.22\text{ms}^{-1}$  during the first inspection and  $4.14 \pm 0.15\text{ms}^{-1}$  for the third inspection. During the third inspection a greater range of motion was observed in the hoof trajectories. The horses carried there heads higher during the third inspection ( $1.752 \pm 0.090\text{m}$  vs  $1.796 \pm 0.091\text{m}$ ,  $P < 0.05$ ) in an attempt to reduce the minimum vertical acceleration on the forelimbs ( $-9.83 \pm 5.28\text{ms}^{-2}$  vs  $-9.09 \pm 3.17\text{ms}^{-2}$ ,  $P < 0.05$ ). Significant differences were found between inspections for most variables. However, the differences were not large, indicating that effect of the exertion of speed and endurance day on the kinematics of this group of event horses was subtle.

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## Chapter 1 Introduction

The horse has played an integral role in New Zealand culture since its arrival in 1794. Historically the main focus of equestrian sport in New Zealand has been hunting and thoroughbred racing. This love of galloping and jumping across open country meant the New Zealand horse and rider were ideally suited to the sport of three day eventing.

New Zealand event horses and riders have dominated the Federation Equestre Internationale / Best Communications and Management (FEI/BCM) global rankings for three day eventing since their inception. In terms of world championships and Olympic medals won three day eventing is New Zealand's most successful equestrian sport (Tunnah 1998).

The sport of three day eventing evolved from the riding tests for cavalry officers. The competition was designed as a test of the cavalry officers all round horsemanship. The first day's dressage was to test the officer's ability to train the horse. The second day's speed and endurance was to test the officer's bravery and ability to ride his charger across country. The third day's show jumping was to demonstrate the conditioning and obedience of the officer's charger. Because of the demanding nature of the sport the three horse inspections are an integral part of the three day event format. These inspections are performed to ensure that throughout the competition that the horse is fit and free of lameness.

Concerns with the humidity and associated animal welfare risk of holding an Olympic three-day event in Atlanta during mid-summer led to a great expansion of our present knowledge as to the effects of high humidity climate on the exercise capacity of the event horse (Jeffcott and Clarke 1995; 1996). However, the kinematics of the event horse has not received much attention (Deuel and Park 1993; Moore *et al.* 1995; Clayton 1997). To date no studies have been performed on the kinematics of the horse inspections. This is surprising since the horse inspections can prevent a horse from proceeding in the competition, and

because standardisation of the trot-up surfaces used for horse inspections at the major three day events is considered necessary (Wilford 1997).

The examination of the changes in the kinematics between the first and third horse inspections at a three day event not only addresses issues of interest to the three day eventing fraternity but also examines the way horses respond and recover from strenuous exercise. Epidemiological studies have identified that lameness is a major cause of wastage in thoroughbred racehorses, and that this predominantly occurs during training (Rossdale *et al.* 1985; Olivier *et al.* 1997). A better understanding of the kinematic changes that occur the day after a strenuous work out may permit greater refinement in racehorse training programmes and minimise musculoskeletal injury.

The exercise physiology study performed for the 1996 Atlanta Olympics focused on immediate recovery from strenuous exercise. Only one study examined the recovery period through to 16 hours after the completion of the cross country phase (Marlin *et al.* 1995). Many of the biochemical parameters monitored had returned to basal level by 16 hours after the cross country phase. However, creatine phosphokinase was still elevated at around twice basal level. In humans elevated creatine phosphokinase levels have been associated with delayed onset muscle soreness (MacIntyre *et al.* 1995) and McMiken (1983) does refer to the possibility of muscle soreness in horses a day or two after exercise. These factors raise the question as to what changes would be observed in the gait of three day event horses during the third horse inspection and what impact these changes would have on subsequent performance in the show jumping phase?.

The purpose of this study was to investigate the horse inspection procedure and the changes in gait between the first (preliminary) and the third horse inspections at a CCI\*\*\* three day event.

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## **Chapter 2 Literature Review**

## Definition of locomotion

Locomotion can be described as the translation of the centre of gravity through space along a pathway requiring the least expenditure of energy (Saunders *et al.* 1953).

The locomotor system consists of muscles, bones, joints, tendons, ligaments - subjected to an input, the force of gravity, and producing an output, movement (or the special case of movement: standing still) under the control of a regulating system: the central and peripheral nervous systems (Rooney 1974).

Locomotion depends on two important interactive components:

- 1) The central pattern generator within the brain and spinal cord that produces the neural activity responsible for movement of the limbs and,
- 2) A peripheral mechanism capable of providing sensory inputs to the central pattern generator for making necessary adjustments during each cycle of the limb movement.

The central pattern generator is organised hierarchically with several brainstem areas being responsible for the actual 'generation' of the neural activity. The spinal cord centres receive this input from the brain in order to control the patterns of the muscular contractions between the flexor and extensor groups of each limb, as well as the co-ordination between the limbs (Loeb 1985; Rossignol and Drew 1985).

Peripheral inputs during cursorial locomotion over uneven ground surfaces are required if the centrally generated patterns of limb movements are to remain smooth and co-ordinated. This important input will originate from different sources, including receptors in muscles, tendons and ligaments, within the distal limb and the hoof and enables the spinal cord generators to make the appropriate muscle and limb adjustments (Bowker *et al.* 1995).

## Gait analysis

The science of motion in animals, including man, is referred to as kinesiology.

The subject may be subdivided into kinematics, the field of kinesiology dealing



with the temporal and displacement characteristics of motion without regard to the forces associated with it, and kinetics, which deals with the forces that produce, arrest, or modify motion (Dalin and Jeffcott 1985).

## **Kinematics**

The earliest known study of the kinematics of animals, and horses in particular, was performed by Eadweard Muybridge in 1887 using a series of still cameras (Muybridge 1957). Currently a number of different techniques exist for kinematic study. Video based systems are the most common (Clayton *et al.* 1995; Holmstrom *et al.* 1994; Drevemo *et al.* 1993).

The use of alternative systems, such as the opto-electronic CODA-3, (Cartesian Optoelectronic Dynamic Anthropometer) (Back 1994) and accelerometer (Barrey *et al.* 1994) based systems is restricted to specific labs. An opto-electronic system with horses is currently only used by the team at University of Utrecht, the Netherlands (Back *et al.* 1995b) and the accelerometer based system appears restricted to the French group from the Institut Nationale de la Recherche Agronomique (INRA) (Barrey *et al.* 1994). However, accelerometers can be used in conjunction with opto-electronic and videography methods to quantify the period of hoof contact (Back *et al.* 1993; Clayton 1996a).

The analysis of three dimensional (3D) kinematics of the horse has been limited. The first documented 3D analysis of equine locomotion was performed by Fredricson *et al.* (1972) using Swedish standardbred horses. Because of the greater computational effort required for 3D analysis, most studies examine equine gait in two dimensions (2D) (Drevemo *et al.* 1980b; Deuel and Lawrence 1987; Balch *et al.* 1996). Recent advances in computer processing power and availability have made 3D analysis a more viable option for equine biomechanic researchers (Peloso *et al.* 1993; Galloux *et al.* 1994; Deguerce *et al.* 1996).

## **Kinetics**

The use of a force plate for the analysis of ground reaction forces in horses was pioneered by Pratt and O'Connor (1976). The subsequent application of the force

plate in either clinical or research situations was slow partially due to the large number of attempts required to obtain suitable data (Seeherman *et al.* 1987). The team at University of Utrecht has been responsible for much of the work on equine kinetics (Schamhardt and Merkens 1987; Merkens *et al.* 1993) while a valuable contribution has also been made by the Swedish group at Uppsala (Hjerten and Drevemo 1994).

## **The three day event**

### **History**

Three-day eventing is a multidiscipline sport that includes dressage, speed and endurance and show jumping tests. Originally developed as a test for cavalry horses, three-day eventing has been an Olympic sport since the 1912 Stockholm Olympics. This sport has experienced phenomenal growth since the 1960s, during which the cross-country courses have become increasingly demanding both technically in the demands placed on the horse and rider relationship, and physiologically (Clayton 1991).

Three-day eventing has four levels of difficulty recognised internationally by the Federation Equestre Internationale (FEI). At the top level, only 5 competitions are recognised as (Concours Complets Internationaux Four star) CCI\*\*\*\*, these are the Olympics, the World Championships, Badminton, Burghley and Kentucky three day events. The next levels down are the CCI\*\*\*, CCI\*\*, and then CCI\*. The CCI\*\*\* level is the highest FEI recognised level in which a horse can compete in unless it is competing in one of the five elite competitions.

Currently the three tests of the three-day event have the following relative influence on the final result; Dressage 3: Endurance (Road and Tracks (phase A and C), Steeplechase (phase B) and Cross country (phase D)) 12: Showjumping 1 (Anon 1993). The heavy weighting of the endurance test places a large emphasis on soundness and athletic ability.

### **Physiology**

With the announcement that Atlanta had been awarded the 1996 Olympic games, much attention was focused on the physiological response of event horses to competition in hot humid environments (Jeffcott and Hodgson 1995; Jeffcott 1995). The bulk of this work was subsequently published as two supplementary issues of the *Equine Veterinary Journal* (Jeffcott and Clarke 1995; Jeffcott and Clarke 1996). It contributed to our understanding of the physiological stress an event horse is subjected to during the speed and endurance test. It focused on the immediate recovery from strenuous exercise, while only Marlin *et al.* (1995) continued measurements after cross country through to 16 h after completion of phase D of speed and endurance day. Under standard format for three-day event competitions, the third horse inspection is held approximately 16 hours after completion of phase D. Within this period, the majority of measured parameters were within the pre-competition reference range. At 16 hours after phase D levels of both creatine phosphokinase (CK) were approximately twice pre-competition levels, and aspartate aminotransferase (AST) was approximately one and half times pre-competition-level. Rectal temperature was also slightly decreased at 16 hours.

### **Time motion analysis**

Time motion analysis can be used for the assessment of the physiological requirements of different sports and also the different roles and positions within the same sport. It quantifies the time periods spent on various activities. Performance is analysed according to the time spent on an activity and the type or intensity of the activity. From this activity intensity and time budget information, competition specific conditioning and preparation regimes can be developed to maximise performance (Clayton 1993a). In equestrian sport, time motion analysis has been performed on Grand Prix dressage and show jumping (Clayton 1989b; Clayton 1993a; Clayton 1996b). From the results of time motion analysis, recommendations have been made to refine the training protocol with emphasis placed on the aerobic or anaerobic requirements of different sports. The application of time motion analysis to equestrian sport has been reviewed by Clayton (1991).

### **The horse inspection**

An integral part of the three day event competition are the horse inspections.

Three horse inspections are performed. The first inspection is on day one prior to the dressage. The second inspection takes place at the end of phase C just prior to the cross country and a third inspection is performed on the morning of the show jumping (Anon 1997). Both the first and third horse inspections are performed with the horses trotted up on a hard level surface (Anon 1998) and in New Zealand on an asphalt surface (Wilford 1997).

Examination of the kinematics of three day event horses has focused on the cross country test (Deuel and Park 1993; Moore *et al.* 1995; Clayton 1997), but the kinematics of the horse inspection has not previously been examined.

### **Lameness**

Lameness examinations are performed at either the walk or trot. Lameness is suspected if asymmetric motion is observed or asymmetric sounds of the feet contacting the tread surface are heard (Seeherman 1991). Lameness is an indication of a structural or functional disorder in one or more limbs that is manifested during progression or in the standing position.

In a horse lame in a forelimb at the walk or trot, the lowest height of the head occurs during the stance phase of the sound limb and the maximum height of the head occurs during the stance phase of the lame limb. In severe lameness only one sinusoidal curve can be observed for the head trajectory. Lameness is usually graded using a five point subjective scale according to the guidelines established by the American Association of Equine Practitioners in 1991 (Peloso *et al.* 1993). According to Stashak (1987), lameness can be classified into the following four categories

1. Supporting limb lameness. This is evident when the horse is supporting weight on the foot or when the horse lands on it.
2. Swinging limb lameness. This lameness is evident when the limb is in motion.

3. **Mixed lameness.** This is evident when the limb is moving and when it is weight bearing.
4. **Complementary lameness.** Pain in a limb will cause uneven distribution of weight on another limb or limbs, which can produce lameness in a previously sound limb. Muscle and upper limb problems are considered to cause a swinging limb lameness, while bone and lower limb problems could cause a supporting limb lameness (Stashak 1987)

### **Asymmetry**

Traditionally, asymmetry has been believed to result in increased biological strain with ensuing pathological changes in the locomotor system (Rooney 1969), and asymmetry has also been associated with poor performance in standardbred trotters (Dalin *et al.* 1985). However, within certain bounds, gait asymmetry may be normal and not indicative of some underlying pathological condition.

Contrary to the consistent sinusoidal wave of the head at the trot, Buchner *et al.* (1993) found that in sound horses there is a physiological asymmetry in the course of one hip. Asymmetry of linear and temporal gait patterns has also been identified in the trot of elite level dressage horses (Deuel and Park 1989; Clayton 1994). In standardbred trotters, asymmetries of the trot have been found in healthy horses (Drevemo *et al.* 1980c), and were most pronounced in a group of intensively trained 18 month old horses (Drevemo *et al.* 1987), and were believed to be manifestations of already existing asymmetries or laterality. A number of theories exist in lay literature as to the reason for asymmetry or “handedness” in horses. Meij and Meij (1980) found functional asymmetry in all 30 horses examined and proposed that this sidedness was due to asymmetrical neural control of motor function.

### **Epidemiology**

From a survey of six racehorse stables over a two year period, the greatest loss of training days was due to lameness (67.6%), well ahead of the next category, respiratory problems (20.5%) (Rossdale *et al.* 1985). This value is remarkably similar to an analysis of wastage of thoroughbred racehorses in Gauteng, South

Africa, where training days were lost due to lameness (66.9%) and then respiratory problems (Olivier *et al.* 1997). Recently the epidemiology of lameness in performance horses and racehorses in particular has received increasing attention (Peloso *et al.* 1990; Wilson *et al.* 1993; Wilson *et al.* 1996). Unfortunately many risk factors have been identified including sex, age, age at first race, horseshoe characteristics, racing frequency, duration of racing career, number of starts per year, intensity of racing and training schedules, weather, season and pre-existing osseous lesions. It has been proposed that the conflicting results from these studies may result from variability of the definition of injury and the population studied (Cohen *et al.* 1997).

### **Economic loss**

“Locomotion disorders constitute the major veterinary problem in thoroughbred racing and result in tremendous losses to horse owners” (Fredricson *et al.* 1980). Some researchers have estimated that lameness consumes at least half the maintenance expense of a racehorse (MacKay-Smith M P 1977). Recently estimates were made that 1 of 600 to 700 Thoroughbred entrants sustains a catastrophic racing injury (Estberg *et al.* 1998). This loss of horses not only has a direct financial affect on the owners but also provides a negative public perception of the horse racing industry, the direct costs of which are difficult to calculate (Estberg *et al.* 1996).

### **Definition of the trot**

The trot is a running gait performed by the majority of quadrupeds and is characterised by the more or less synchronous movements of the diagonal limb pairs (Muybridge 1957). The Federation Equestre Internationale (FEI) states that the trot is a pace of “two time” on alternate diagonal legs (left fore and right hind leg and vice versa) separated by a moment of suspension (Anon 1991).

### **Types of trot**

According to the FEI rule-book the trot can be divided into four categories, the collected, working, medium and extended trot (Anon 1991). Clayton (1995)

examined these classifications and showed that there was a steady increase in velocity and stride length progressing from the collected through to extended trot. Stride frequency remained relatively constant across categories supporting the FEI rules that changes between gait type should be characterised by an increase in stride length and maintenance of a consistent rhythm. Historically the boundaries between, and within gaits have been often based on factors of breed or style rather than on general differences in the manner of the movement of the legs (Hildebrand 1965). At racing speeds the trot is distinctively different from the observations of the collected through to extended trot. At racing speeds ( $\geq 12 \text{ m.s}^{-1}$ ) there is greater disassociation of the limb pairs and negative advanced placement (Drevemo *et al.* 1980a; Drevemo *et al.* 1980b; Drevemo *et al.* 1980c). These differences may be an artefact of the velocity ranges observed or may represent different strategies employed to achieve the different objectives. From comparison of the observations made by Clayton (1995) for riding or dressage horses and the observations of Drevemo *et al.* (1980a; 1980b; 1980c) for racing standardbreds there is justification for inclusion of a fifth common type of trot; the racing trot.

### **Velocity, stride length and, stride frequency**

As a general rule, stride length increases linearly with velocity in the normal horse (Back *et al.* 1993). Individual horses may have a preferred stride frequency at a given velocity and gait (Ratzlaff *et al.* 1995). Most human distance runners have a preferred stride frequency. Cavanagh and Williams (1982) proposed that this preferred combination of stride frequency and stride length was chosen to minimise the metabolic cost during level running.

Increases in velocity at moderate speed is achieved by increases in stride frequency, while at the faster gaits increases in velocity is mostly by an increase in stride length (Deuel and Lawrence 1986). Clayton (1994) found that at the trot, increases in velocity at the moderate speeds used in equestrian sport were achieved primarily by increases in stride length. However above this velocity range at the racing trot (approximately  $12 \text{ m.s}^{-1}$ ), increases in velocity are

achieved by increases in stride frequency (Drevemo *et al.* 1980a; Drevemo *et al.* 1980b).

Training can alter the relationship between stride length, frequency and velocity. The effect of training on this relationship may be influenced by the training objective and the breed of horse. It has been demonstrated that in racing standardbreds with a period of training there is an associated decrease in stride length and an increase in stride frequency (Drevemo *et al.* 1987). This has been attributed to an improvement in neuromuscular co-ordination. However, more recently, conflicting results have been presented. In response to training, a group of treadmill interval trained standardbred trotters had an increased stride length and a decrease in stride duration when examined at  $8\text{ms}^{-1}$  (Gottlieb-Vedi *et al.* 1995). Differences in results may be due to the lower velocity ( $8\text{ms}^{-1}$  vs  $12\text{m.s}^{-1}$ ) and that they were treadmill trained. Different training objectives may influence the relationship of velocity with stride length and duration. If comparison is made between the stride lengths and frequencies of horses not trained for dressage (Clayton 1989a) and dressage trained horses (Clayton 1994) at the same velocity, the dressage trained horses had a longer stride and stride duration than the other horses. This is similar to the response to show jumping training by Spanish Anglo-Arab horses (Munoz *et al.* 1998). In contrast to this, with a 70 day training period in young (2.5 year old) Dutch warmblood horses there was no significant change in the relationship of velocity with either stride duration or stride length (Back 1994).

Breed may also interact with the training objective to modify the responses observed. Andalusian horses demonstrated a decrease in stride length in response to dressage training (Munoz *et al.* 1997). However, at the extended canter ( $6-7\text{ms}^{-1}$ ), breed does not appear to contribute significantly in the relationship between velocity and stride length and duration between thoroughbred racehorses and warmblood dressage horses (Clayton 1993b).

Caution should be used when comparing studies. The velocity at which the horses were examined may influence the changes in the inter-relationship observed between velocity and stride length and duration. The different



responses to training in the stride length, frequency and velocity relationship observed between the Standardbred trotters (Drevemo *et al.* 1987) and the other studies (Clayton 1994; Gottlieb-Vedi *et al.* 1995; Munoz *et al.* 1998) may be an artefact of the velocity range at which the horses were examined.

## **Temporal & Kinematic patterns**

### **Kinematic fingerprint.**

The consistency of the stride length and frequency relationship with velocity observed within horses by Ratzlaff *et al.* (1995) implies that a horse's temporal pattern may also be consistent. The horse's gait pattern has been shown to be stable and is regularly repeatable from one stride to the next (Drevemo *et al.* 1980a). Only a few longitudinal studies comparing horses during periods of growth have been performed on equine locomotion, possibly due to the expense of such trials. Back *et al.* (1994) found strong resemblance both visually and graphically during a period of growth and development. Even with experimentally induced low level lameness (lameness score 2/5), horses maintained their temporal pattern (Buchner *et al.* 1995). This consistency of the equine gait pattern has led to the term "kinematic fingerprint" to describe this consistency of an individual's gait pattern which is already fully developed at 4 months (Back 1994).

### **Swing Phase**

The swing phase in gait analysis refers to the non weight bearing phase of the stride. At the trot it comprises about 75% of the stride cycle. Swing phase duration is believed to be the main contributor to stride time variations in different horses trotting at the same velocity (Drevemo *et al.* 1980b). The term swing phase has been accepted as the preferred term for the non-weight bearing phase of the stride cycle as it implies both functional and timing elements (Leach *et al.* 1984). Subsequently (Holmstrom *et al.* 1993) has subdivided the swing phase into protraction and retraction elements.

### ***Protraction***

Protraction is the time from the end of the start of swing phase until the limb is at maximum extension.

#### *Retraction*

Retraction during the swing phase is the time period from the end of protraction (limb at maximum extension) until the beginning of the stance phase with contact of the hoof with the ground surface. For Swedish warmblood horses this has been quantified as being 22% of the stride duration in the forelimbs and 5% in the hind limbs (Holmstrom *et al.* 1993).

#### *Stance Phase*

According to the terminology recommended by (Leach 1993) the stance phase begins when the hoof contacts the ground. This can be either heel-first, flat footed or toe first placement. At the end of the stance phase, heel off usually occurs before the limb is lifted from the ground (Dalin and Jeffcott 1985).

#### *Mid Stance*

Mid stance is when the metacarpus is in the vertical position of the forelimb stance phase and, in the hind limb when the hip joint is vertical to the hoof (Drevemo *et al.* 1980b). Because of this description, mid stance is a descriptive of limb position rather than representing the temporal mid point of the stance phase (Leach *et al.* 1984). It has been suggested that mid stance represents the period of change from deceleration of the limb to a propulsive phase (Drevemo *et al.* 1980b).

#### *Advanced Placement and Advanced Completion*

At slow speeds, the hooves of the diagonal limb pair tend to contact the ground together. However, with increasing velocity there is a tendency for dissociation of the limb pair with the forelimb landing and taking off first (Drevemo *et al.* 1980c). Impact of the forehoof precedes that of the hindhoof consistently at racing speed with the magnitude of the disassociation at landing being greater than that at lift off (Drevemo *et al.* 1980a). This disassociation has been termed advanced placement for the period between limb contact time and advanced completion for the time period between lift-off of the legs of the diagonal (Leach *et al.* 1984). Positive advanced placement has been observed in riding horses and

it has been proposed that this may be an effect of training (Deuel and Park 1989; Clayton 1994).

### *Overlap*

*Overlap* is the period when both limbs of the diagonal pair are in stance phase concurrently (Leach *et al.* 1984). With the progression from the slower collected trot through to the faster extended trot in dressage horses there is a decrease in the period of overlap ( $346 \pm 9$  to  $253 \pm 6$  ms) (Clayton 1994). Associated with this decrease in overlap is a decrease in stance time and an increase in diagonal advanced placement and completion.

### *Trajectories*

#### *Head trajectory*

Anecdotal evidence for a role of head and neck position on stride length can be found in the FEI rules for dressage. (Clayton 1994) identified that one of the primary demarcations between the FEI classifications for the trot was the difference in velocity with the horses maintaining their stride frequency. The FEI rules describing the differences between the types of trot refer to the elevated head and neck position found in the slower shorter striding collected trot and the lengthening on the “frame” or lowering of the head and neck position with the faster longer striding extended trot (Anon 1991).

According to Girtler (1988), at the normal trot the head stays in almost the same position. In contrast, Peloso *et al.* (1993) found that during the trot the head moved in a sinusoidal pattern. The head was lowered and raised during the support phase of each forelimb, producing a down and up head movement for the support phase of each forelimb. The symmetry of this pattern was only altered when the subjective lameness grade reached 3/5.

#### *Hoof Trajectory*

Before the advent of kinematic studies, the flight of the hoof was often described as being a unimodal parabolic curve with the shape and often the length of the curve determined by hoof angle (Stashak 1987). Subsequently, hoof angle has been demonstrated to influence break-over time and not hoof trajectory.

However it is the weight of the shoe that appears to be the predominant cause for alterations in the hoof trajectory in trotting horses (Balch *et al.* 1996).

Kinematic analysis has identified that hoof trajectory in both the fore- and hindlimbs has a characteristic bimodal pattern (Balch *et al.* 1996). The first peak that occurs soon after lift-off is always greater than the second peak. Different hoof trajectories are observed between the fore- and the hindlimbs. Overall there is a greater range of movement in the forelimb than the hind limb (Back 1994; Holmstrom 1994). Not only are there differences between the fore- and hindlimb for range of motion but there are also differences in the temporal pattern of the trajectories. In the forelimb of the Swedish warmblood the first peak of hoof flight occurs at approximately 50% of the stride cycle (with stride cycle beginning from initial ground contact of the hoof). The second peak occurs at approximately 80% of the stride cycle when the forelimb is at maximum extension (Holmstrom *et al.* 1993). In the hindlimb the first peak occurs earlier at approximately 40% of the stride cycle. The second peak is not as pronounced and occurs at approximately 80-90% of the stride.

#### *Hoof Velocity and Acceleration*

Differences in the trajectories between fore- and hindlimbs are also reflected as differences in the pattern of the velocities and accelerations. The kinematics of the distal forelimb during the stance phase and at loading have been examined by Johnston *et al.* (1995) and Johnston *et al.* (1996). Back *et al.* (1995b) compared the kinematics of the forelimb with the hind limb. In the forelimb of standardbred trotters, vertical and horizontal velocity did not reach zero until 19% and 25% of stance time (Johnston *et al.* 1995). In 26 month old Dutch warmblood horses, a significantly larger negative peak for vertical velocity at impact is observed in the forelimb than in the hindlimb. Horizontal velocity also has a different pattern between the fore- and hindlimbs. The forelimbs had a slightly larger peak horizontal velocity that occurred later in the swing phase (Back *et al.* 1995b). Differences in the acceleration plots were also observed between the fore- and hindlimbs. Peak horizontal and vertical acceleration was larger in the forelimbs at the completion of the stance phase. The differences in the velocity and acceleration data between the fore- and hindlimbs have been

used as an argument for the greater observation of lameness in the fore- rather than hindlimbs of horses (Back *et al.* 1995a). This argument is based on the assumption that the higher level of loading and oscillations in the forelimb will predispose the forelimb to an increased chance of trauma and injury.

#### *Limb trajectories*

When analysing equine gait, one of the difficulties is the volume of information and the best method to present the data. Joint angle-time diagrams and stick diagrams have previously been used (Fredricson and Drevemo 1972; Marteniz-del Campo *et al.* 1991; Back *et al.* 1995c; Back *et al.* 1995d). The more distal the position measured on the limb the greater the trajectory or displacement (Back *et al.* 1995c; Back *et al.* 1995d). Within each limb there is a tight relationship between the trajectories of the different segments.

Similar to the temporal patterns, the joint angle curves have a high degree of individual horse specificity and repeatability across strides (Back *et al.* 1995c) and even across gaits, between the walk and the trot (Back *et al.* 1996). The inter-relationship between segments for both the forelimb and hindlimb have been documented by Back *et al.* (1995c) and Back *et al.* (1995d).

To understand the pattern of the equine limb it can be considered to be analogous to a pendulum (Back *et al.* 1995c). In human gait analysis a modified pendulum model (compass gait) has been proposed as an aid in the understanding of the walk (Saunders *et al.* 1953). This theorem attributes 6 primary methods to minimise the displacement of the centre of mass. These 6 determinants being;

The first determinant: Pelvic rotation,

The second determinant: Pelvic tilt,

The third determinant: Knee flexion in the stance phase,

The fourth and fifth determinants: Foot and knee mechanisms and,

The sixth determinant: Lateral displacement of the pelvis.

One of the six determinants of gait proposed involves the placement of the foot under the median plane by alteration of tibiofemoral angle and by adduction of the hip joint. At the racing trot, horses have been observed to place their hooves

under the centre line (Dalin *et al.* 1973). Further similarity between the six determinants of human gait proposed by Saunders *et al.* (1953) and equine locomotion can be found in the observation of Back (1994) that the body height at the trot is always lower than that when standing still. This implies that the conservation of energy by minimising the displacement of the centre of mass is also a fundamental concept in equine gait.

At the trot, the movements of the legs are too fast to be explained solely by a pendulum theory but rather that the trot frequency is best explained by the elastic resonance of the diagonal pair of limbs (Witte *et al.* 1995). This theory is similar to the damped spring mass system (Rooney 1969). From observations of the trot of Dutch Warmbloods, a combination of the resonance and pendulum theories has been proposed (Back 1994). During the stance phase, fore and hind limbs act as passive struts, whereas during the swing phase they move like a pendulum with pivots in the scapula and hip joint, respectively.

### **Kinetics**

Obtaining data from a force plate can be a frustrating exercise. Quddus *et al.* (1978) mentioned that only 1 run in 20 was successful in obtaining ground reaction force (GRF) data. However, by standardised and carefully controlled measurement conditions Seeherman *et al.* (1987) were able to demonstrate that the force plate was a feasible tool for equine gait analysis. In order to compare ground reaction forces between horses it is necessary to standardise the values. Standardisation is normally done with respect to the body mass of the animal and the stance phase duration (Merkens *et al.* 1993).

### **Kinetics of the stance phase**

Mid stance is commonly used as a descriptive term for the division of the stance phase. As previously discussed, mid stance does not necessarily represent the equal division of the stance phase into temporal halves but rather provides a point for the transition of the limb during stance from deceleration to propulsion (Pratt and O'Connor 1976). Peak loading of the forelimb occurs close to this mid point at 45-50% of the stance phase (Quddus *et al.* 1978) but is slightly earlier in the hindlimb 40-45%.

### *Ground Reaction Forces - GRF*

Ground reaction forces measure the forces exerted in 3 dimensions:  $F_x$  is the transverse (latero-medial) force,  $F_y$  is the longitudinal (forward-backward) force and,  $F_z$  being the vertical force (Merkens and Schamhardt 1988). Similar to kinematic results, kinetic data as measured by GRFs are highly repeatable. The differences between individuals are greater than between recordings of the same animal, even after a three year interval (Merkens *et al.* 1985). By standardisation of GRFs to body mass and stance phase time it is possible to compare GRFs between horses. Merkens *et al.* (1993) produced representative GRF patterns for the Dutch warmblood. Peak vertical forces increase as the progression is made from walk to trot to the canter. At the walk peak forces are approximately equivalent to 0.5 to 0.7 times body weight, at the trot these forces are 0.9 to 1.3 times body weight and are up to 1.75 times body weight at  $14\text{m.s}^{-1}$  (Dalin and Jeffcott 1985). The load on the forelimbs is higher than that on the hindlimbs because the centre of gravity is situated closer to the forelimbs (Merkens *et al.* 1993).

At the walk, two small peaks can be observed in the vertical GRF ( $F_z$ ) curve but at the trot only one peak is observed (Merkens *et al.* 1993). Between the walk and trot differences exist between the retarding ( $F_y$ ) and propulsive forces ( $P_y$ ). At the trot, the retarding forces have a longer and larger peak in the forelimbs than the hind limbs. The opposite is true for the propulsive forces implying that the forelimbs act as passive struts with the hindlimbs providing the propulsive force (Merkens *et al.* 1993). In contrast, at the walk the propulsive force of the forelimbs is larger than that of the hindlimbs (Merkens *et al.* 1985).

### *Inverse Dynamics*

Inverse dynamics calculates the time histories of joint torques (or moments) by combining kinematic and kinetic data. Joint torques are calculated by considering the limb to be a series of linked segments (van den Bogert 1998). Inverse dynamics provides a solution to the problem of not being able to identify the forces in kinematic analysis and the difficulty of not being able to identify the source of the change in forces measured using kinetic (force plate) analysis. Joint torques are related directly to the combination of forces generating

antagonistic muscle activity across a joint. Even more so than man, the horse with its 4 multijointed limbs, frequently acting as closed-chain mechanisms, may redistribute its joint torques without visual change in the gait. Evidence for this can be observed from the stability of the temporal pattern under induced lameness (Buchner *et al.* 1995). Inverse dynamic analysis permits us to 'see' these differences in muscle co-ordination.

In the human studies, inverse dynamics has been applied to 2 and 3 dimensions (Winter 1990; van den Bogert 1994). Recently, inverse dynamics has been successfully applied to the horse using a 2 dimensional linked segment model of the forelimb for the stance and swing phase of the trot (Clayton *et al.* 1998; Lanovaz *et al.* 1998).

### **Tendon strain / action**

Because of the difficulties inherent with *in vivo* work on tendon strain, much attention has been focused on work *in vitro*. However differences in results between *in vitro* and *in vivo* work has been demonstrated (Riemersma and Lammertink 1988; Riemersma *et al.* 1996b).

As expected, the loading on the tendon structures and the pattern of deformation is dependent on the gait and the velocity within the gait (Riemersma *et al.* 1988; Riemersma and Lammertink 1988). Ground surface has also been shown to change the pattern of loading (Riemersma *et al.* 1996b) with the maximal strain on the inferior check ligament and suspensory ligament significantly higher on pavement than on sand.

At the walk, the loading of the inferior check ligament is similar to that at the trot (5.36% to 4.88%) and so may not play as significant a role in the retention of elastic strain energy as the superficial digital flexor tendon, deep digital flexor tendon and suspensory ligament which all increased in loading significantly from the walk to the trot (Riemersma and Lammertink 1988). At the trot, the strain patterns for the superficial digital flexor tendon, deep digital flexor tendon and suspensory ligament showed a rapid increase at the beginning of stance phase,



followed by a plateau with a small incline or decline and then a rapid decrease at the end of stance phase indicating some storage of elastic strain energy (Riemersma *et al.* 1996a).

## **Effect of ground surface**

The importance of a “good” ground surface on which to train horses on has long been recognised (Drevemo *et al.* 1994). However, it is only recently that we have been able to quantify the effects that different ground surfaces have on the kinematics and kinetics of the equine gait. With a hard resistant surface there is a decrease in the stride length and duration (Riemersma *et al.* 1996b) and a reduced vertical displacement of the withers (Buchner *et al.* 1994).

When the hoof contacts the ground at the beginning of the stance phase, there are high frequency components of the horizontal and vertical force traces or impact oscillations (Pratt and O'Connor 1976; Hjerten and Drevemo 1987). The frequency components of the impact accelerations differ according to the ground surface and the horse shoe construction (Barrey *et al.* 1991; Benoit *et al.* 1993). On more compliant surfaces the frequency of these impacts are as low as 41Hz and increase to 592 Hz on stiff surfaces (Barrey *et al.* 1991). Force plate studies have indicated that impact frequencies above 70Hz reflect the properties of the limb during loading at the initiation of the stance phase (Merkens and Schamhardt 1994). It may be that these high frequency impact oscillations are the signals for the horse to alter its gait pattern to minimise concussion and yet have sufficient elastic energy recovery to maintain an efficient gait.

The pliability of the surface appears to affect the angle of the hoof sole and the ground. With a more compliant surface, like sand, a small positive caudal angle has been observed in association with the hoof sole angle (Riemersma *et al.* 1996b). This forward rotation of the hoof is so that the sole is perpendicular to the vector of the GRF, which may prevent the hoof slipping.

## Overground vs treadmill trot

The high speed treadmill is commonly used in equine research (Sloet van Oldruitenborgh-Oosterbaan and Barneveld 1995). Current opinion is that normal overground exercise is more demanding than treadmill exercise (Persson 1983; Barrey *et al.* 1993a). Daniels *et al.* (1953 cited by Sloet van Oldruitenborgh-Oosterbaan and Barneveld 1995) reported that energy expenditures of young adult men were consistently about 10% lower on a treadmill than on an asphalt road or cinder path.

The reasons proposed in the literature to explain the difference between the workload of a mounted horse on a normal track and that of an un-mounted horse on a treadmill are the riders action, a lower air resistance on the treadmill, the changes in kinematic variables and a psychological adaptation (Barrey *et al.* 1993b).

It has been shown that when they are walking on a treadmill, people tend to use a faster and shorter stride than when they are walking normally (Murray *et al.* 1985). However, at a walk, horses had slower, longer strides on a treadmill than on a track, even when the treadmill was inclined (Barrey *et al.* 1993a). In un-mounted horses, the relative stance duration at the trot increased significantly on a treadmill compared with trotting on a track (Buchner *et al.* 1994). It has been suggested that the moving treadmill belt brings the supporting limb back under the body during the support phase of running and thus reduces the energy requirements of a runner (Frishberg 1983).

Exercise on a horizontal treadmill proved to be significantly less demanding than exercise on a firm shell track (Barrey *et al.* 1993b). The difference in workload between the exercise on the track and the treadmill appeared to be better balanced by a 10 per cent increase in speed than by a 1 to 2 per cent inclination in the treadmill, particularly if the higher lactate concentrations were related to the use of different muscles. Because of the physiological and kinematic differences observed between over ground and treadmill exercise, caution should be used when extrapolating results from the treadmill studies to the overground / field environment.

## Effect of fatigue

It has been proposed that "the proper functioning of the locomotor system depends on precise synchronisation of the movement of each part on every other part and in relation to the body as a whole. Pathological changes may occur when improper synchronisation occurs" (Rooney 1969). This indicates the danger to the body when fatigued.

A characteristic of fatigue in human middle-distance runners is the use of a shorter and higher frequency stride to achieve the same relative velocity. Associated with the change in the relationship of stride length and frequency with velocity, there is an associated increase in stance as a relative percentage of stride time (Elliott and Roberts 1980). It is likely that the kinematic responses to fatigue in bipeds (humans) and quadrupeds (horses) will be similar. The trot is analogous to running in humans (Alexander *et al.* 1977). The role fatigue plays with respect to changes in kinematic parameters in the horse is not well understood. Wilson *et al.* (1993) found a decrease in velocity and an increase in the stance component of the stride in endurance horses near the completion of a 120km endurance race. Leach and Sprigings (1979) found that stride duration increased with an associated increase in stance as a percentage of stride at the end of a flat race, and was considered to be due to fatigue. Pratt and O'Connor (1978) proposed that fatigue caused a reduction in the swing phase of the stride and that this provided a reduced opportunity for retraction of the limb. This reduction in time available for retraction was believed to lead to poor placement of the hoof and subsequent breakdown.

Fatigue has also been implemented as a contributing factor to tendon damage when associated with muddy or slippery track conditions (MacIlwraith 1987).

## Delayed onset muscle soreness (DOMS)

Muscle soreness usually develops within the first 24 hours following exercise (Ebbeling and Clarkson 1989). This phenomenon has been referred to as delayed onset muscle soreness (DOMS). In humans the soreness is a dull aching pain combined with tenderness and stiffness (MacIntyre *et al.* 1995). DOMS does not

appear to have been described in horses but McMiken (1983) does refer to the possibility that there may be sub-clinical structural damage in muscle which is reflected in the “soreness” a day or two after exercise. This may be the cause of the stiffness on the morning following speed and endurance day reported in 3-day event handbooks (Leng and Murphy 1990; Holderness-Roddam 1991). Elevated creatine phosphokinase levels have been associated with DOMS and Marlin *et al.* (1995) have found elevated creatine phosphokinase at twice basal level 16 hours post completion of phase D of speed and endurance day.

With DOMS, a decreased range of motion could be expected (MacIntyre *et al.* 1995). Therefore horses may find it more efficient or comfortable to use a lower stride length and duration to achieve the same velocity. From studies in human running it has been proposed that long strides require considerable power during propulsion and result in excessive vertical oscillation of the centre of mass, produce a foot-strike position which creates large braking forces, and require joint ranges of motion which invoke increased internal friction and stiffness (Anderson 1996). After strenuous exercise, the expectation would be that the horse would attempt to minimise the effect of these factors. Because of this there should be measurable changes in the temporal and kinematic pattern of three day event horses between the first and third horse inspections.

### **Effect of breed**

It has been proposed that each horse has a distinctive gait pattern (Ratzlaff *et al.* 1995; Drevemo *et al.* 1980a; Back *et al.* 1994). If so, it is expected that distinctive patterns will be clustered within breed. Schamhardt *et al.* (1991) found that the stance phase of the forelimbs in Dutch warmblood horses was longer than the stance phase of the hindlimbs. This was in contrast to the observations of Drevemo *et al.* (1980b) who found trotting standardbreds had a slightly longer stance phase for the hindlimbs. Differences in gait pattern have been measured between such diverse breeds as the Shetland pony and the Dutch warmblood (Back *et al.* 1998).

A breed effect on ground reaction forces (GRF) has been proposed from comparison of standardised GRFs between studies using different breeds (Merkens *et al.* 1993). Because of the differences in GRF pattern, Merkens *et al.* (1988) proposed that the H(or)se index developed to evaluate gait symmetry based on force plate data could only be used for the Dutch warmblood and could not be applied across other breeds.

Even the predominance of certain tendon injuries within a breed implies that there may exist a breed difference in gait pattern (Fackelman 1973). However it is possible that the differences in tendon injury and types of lameness observed between breeds may be predominantly a reflection of the specific tasks asked of each breed or type.

### **Gait analysis of field or competition data**

The choice of gait analysis procedure becomes very restrictive when the horse is to be examined in the field or competition environment. The protocol has to be non-invasive. It is the need for flexibility and a non-invasive protocol that may explain why many field studies have been kinematic, using cinematographic or videographic based systems (Fredricson *et al.* 1980; Deuel and Park 1990; Wilson *et al.* 1993; Drevemo and Johnston 1995; Clayton *et al.* 1996). A number of different types of competition have been subjected to kinematic analysis including endurance competitions (Wilson *et al.* 1993), showjumping (Clayton *et al.* 1995), and three-day eventing (Moore *et al.* 1995; Clayton 1997). However to date there has been no kinematic analysis of the horse inspections at three-day events.

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## **Chapter 3 General Materials and Methods**



## Introduction

Videography is currently the most common method of kinematic analysis in the horse (Clayton 1996). For this form of analysis the sequence of events usually is;

*Video recording,*

The obtaining of the video footage of the event of interest.

*Digitisation,*

The process of obtaining the raw co ordinate points from the video images.

*Transformation,*

The process of converting the raw coordinate points into measurements of known dimension (i.e metres or angles)

*Smoothing,*

The process of removing measurement noise from the trajectory data. This is usually performed with a low pass digital filter or with the use of splines.

*Normalisation,*

The conversion of the trajectory data to a standard scale (usually 100 points) so that comparisons can be made between trajectories of different time scales. And,

*Statistical analysis.*

The statistical testing of the differences or similarities between the different measurements.

### The event of interest and selection of horses

The horses were filmed when they were presented for the first and the third veterinary inspections at the 1995 New Zealand three Day Horse Trials Championship, Taupo, New Zealand. At the first or preliminary horse inspection twenty four horses were presented (23 geldings and 1 mare  $10.7 \pm 2.2$  years old). This data set was used in chapter five to examine the linear and temporal characteristics of the horse inspection. At the third horse inspection four horses were not presented, providing a sample of 20 horses presented at both

inspections. From the third inspection 4 horses were excluded from analysis due to incomplete footage or poor resolution. This provided a data set of 16 horses with repeat measurements between the first and third inspections. The changes in gait between inspections were examined in chapter six. For the kinematic analysis in chapters seven and eight a sample of six horses ( $12.3 \pm 2.4$  years) with consistent velocities across inspections ( $3.94 \pm 0.22 \text{ m.s}^{-1}$  and  $4.14 \pm 0.15 \text{ m.s}^{-1}$ ) were chosen.

## **Video Recording.**

### **Camera set up:**

A minimum of two cameras must be used to capture data simultaneously for three dimensional analysis. For a converging set-up with two cameras, the optimal angle of intersection is theoretically 90 degrees (Gosh 1979 cited by Wood and Marshall 1986). The two cameras were a Panasonic MS-4 S-VHS and a Panasonic NV-MS1EA<sup>1</sup> at 25 frames per second with a 1/1000 second exposure rate. The cameras were loaded with Panasonic XD S-VHS 180 videotape<sup>1</sup>. The cameras were positioned to provide a simultaneous lateral and anterior view of the horse. The panning lateral camera was set 17.5m perpendicular to the path of the horses. The anterior camera was positioned to record the trot at a focal distance of 30m. Camera lens height was set at 1.2m, approximately at the height of the 'average' horse's elbow in accordance to the recommendations of Clayton (1990).

This experimental set-up was designed to fulfil the following criteria proposed by Drevemo and Johnston (1995)

1. The horse fills approximately 75% of the image,
2. Strides recorded simultaneously from a lateral and anterior view,
3. At least two reference markers appear in each film frame and,
4. Later calculations and compensations for camera angle and perspective errors.

### **Reference markers**

The reference markers were 15 fluorescent yellow sports cones (142 mm x 230 mm). The cones were placed at 1 m intervals on the edge of the trot up track closest

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<sup>1</sup> Panasonic, Matsushita Electrical Industrial Company Ltd, Osaka, Japan

to the lateral camera. A black line (4mm diameter) was marked to bisect the cone and to improve the accuracy of cone placement and subsequent calibration. For the lateral video footage a calibration template was developed from the cone video footage. This was subsequently overlaid over the horse footage to provide spatial reference markers from which displacement measurements could be made. Correction factors were derived to solve the problem of the calibration template not representing the same sagittal plane as the horse's path of progression. The horses trotted within a sagittal plane  $1.10 \pm 0.17$  m from the edge of the asphalt track closest to the camera. Therefore the lateral camera had an effective focal distance of  $17.10 \pm 0.17$  m ( $n=25$ ). From the anterior camera only medio-lateral or transverse angle measurements were made from the central body reference point to the hoof and head reference points. The consistency of this technique was verified by a trial obtaining angle measurements made on a calibration board of known dimensions at 7 sequential sites within the calibration zone. The measurements were made every 2m as identified by the calibration cones in a view progressing from left to right. The mean error was  $0.36 \pm 0.29$  degrees (0.01 to 1.08 degrees) and indicated that a parallax effect would not provide a significant source of error in the angle measurements.

## Digitising

### Video capture

Analogue video footage was converted to digital images (PICT files) using a IIVx Apple Macintosh<sup>TM2</sup> computer with a RasterOps Mediagrabber<sup>TM3</sup> digitising card. For the pilot study, a complete stride was downloaded as a QuickTime<sup>1</sup> movie and from these movies individual frames were obtained. Subsequently, individual fields were grabbed one at a time as PICT files because of the opportunity for greater control in image quality.

The faster the video board the faster the video frames can be drawn on the screen. To capture full frame video at 30 FPS most boards capture only one of two fields

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<sup>1</sup> Panasonic, Matsushita Electrical Industrial Company Ltd, Osaka, Japan

<sup>2</sup> Apple Computers, Inc. 1 Infinite Loop, Cupertino, California

<sup>3</sup> RasterOps Corporation. 890 west 410 North Lindon Utah. USA

(odd or even screen lines) in each frame and replicate the data to complete the frame. This compromises image quality. However, for capturing images at less than full screen size this compromise is not always necessary. In general, hardware compression on the capture board greatly increases movie capture performance. Video boards that have JPEG compression can usually capture full screen motion video very effectively.

The faster the hard drive access the faster the computer can read and write to the hard disk. It is generally recommended that the hard disk has an access time of 10ms or less and a data transfer rate of 3MB per second or more (this data transfer rate is currently available with 5400rpm drives).

The faster the CPU the faster the computer will be able to process the data necessary to capture and play back digital video. The IIvx Macintosh computer used was believed to provide an acceptable level of CPU speed for video capture at 25 fps. To maximise the CPU devoted to the video capture all unnecessary extensions and control panels should be turned off.

On many computers, the best method is to capture the video directly to RAM. Capturing to RAM is faster than capturing to a hard disk drive. However, the movie's size is limited to the amount of free memory. Because only one stride of interest was captured for analysis, capturing to RAM (30MB of available RAM) did not impose a direct limitation on the movie size captured. The digitising software can provide a bottle-neck and therefore a limitation on the captured video image frames per second. Each second of analogue video contains a large volume of information. Therefore, in order to record video, some compromise must be made to bring data volume within range. There are three methods of compromise:

- reducing the video speed (frame rate),
- reducing the image size (resolution), and
- reducing data volume through compression.

Reduction in video speed was not a viable option, as it would cause a limitation to the variables able to be analysed. The reduction in film speed or the frames per

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<sup>1</sup> Apple Computers, Inc. 1 Infinite Loop, Cupertino, California

second digitised would eliminate the possibility of calculating any temporal measurements and greatly limit the already small number of data points available for analysis within the strides of interest.

Decreasing the image size greatly reduces the analogue data to be processed. There exists an inverse relationship between film speed and image size. The reduction in data to be processed is proportional to the squared sum of the reduction in image size, i.e 1/4 reduction in image size results in only 1/16 of the normal data needing to be processed.

Compression reduces the amount of data with little compromise to quality and none to size. But the process of compressing each video frame takes time, and this can contribute to frame dropping. The RasterOps MoviePak2™ compression accelerator can alleviate this problem. The compression accelerator enables full size video capture at up to 30 fps.

#### *Testing the sampling rate.*

For kinematic analysis using cine film it is important to know the actual sampling rate. Actual sampling rate or film speed can vary depending on a number of variables from tape tension to individual variation in camera mechanisms. With the protocol used for the pilot study, actual frame rate of the QuickTime movie could be influenced by individual computer variables ranging from the processor speed and hard drive access rate to the available RAM on the digitising card. To test the actual frame rate captured, a calibration trial was performed. The video was believed to be captured at the PAL industry standard rate of 25 frames per second.

Ten random sample clips of 3 second duration were captured from throughout the field data video using the software provided with the video digitising card (RasterOps MediaGrabber™). This was performed on one tape initially to examine the limitations, if any, imposed on the film capture rate using different frame sizes and picture quality (Table 3-1). A second trial was performed on each of the four field data video tapes (Table 3-2). The number of frames per second was calculated for each clip using the software's inbuilt calibration system. The frames per second

displayed represents the actual frames per second that were captured by the software. This film speed therefore represents a combination of actual film speed from the field data video and the film speed able to be captured within the limitations of the computer's processing power.

To examine the effect of different frame sizes and quality on film capture speed, four different settings were used to sample the same segment of video tape (Table 3-1).

Initial inspection of the results indicated that the full screen options were slightly slower than the half screen. These differences were not significant when tested with a one way analysis of variance (ns,  $p < 0.123$ ).

**Table 3-1 QuickTime movie capture trial comparing frames per second using four different protocols for video capture.**

Process		Mean	Standard Deviation
Full screen & standard quality	10	24.29	0.277
Full screen & maximum quality	10	24.24	0.481
Half screen & standard quality	10	24.60	0.365
Half screen & maximum quality	10	24.46	0.291

Although the differences were not significant, there was nevertheless a difference between the trial groups. To optimise the ability to digitise video at a film speed equal to that used in capturing the field data, a combination of approaches was used. Image size was reduced to ½ a screen and compression was aided by the use of the compression accelerator. This reduction of image was found to not adversely affect resolution of image and subsequent image measurement.

This combination of options was believed to reduce the possibility of the software and hardware providing a restriction on the frames per second downloaded and the quality of the image.

*Camera Performance.*

Using this protocol of a ½ screen image size and use of the onboard video compression card a comparison was made between the four tapes used to capture the field data. This trial was performed to quantify any difference in the observed frame rate between tapes due to differences in tape tension and video camera mechanisms. However, the greatest contribution to variation in frame rate was likely to be due to the capacity of the frame grabber.

**Table 3-2 Descriptive statistics of captured frame rate (frames per second) for the four tapes used to capture field data.**

<b>Tape Number</b>	<b>1</b>	<b>2</b>	<b>3</b>	<b>4</b>
<b>Camera Type</b>	<b>MS-4</b>	<b>MS-1</b>	<b>MS-4</b>	<b>MS-1</b>
<b>Mean ±</b>	24.29±0.28	24.75±0.24	24.38±0.34	24.62±0.26
<b>Standard deviation (n=10)</b>				
<b>Median</b>	24.40	24.75	24.45	24.6
<b>Minimum</b>	23.500	24.400	23.900	24.200
<b>Maximum</b>	25.500	25.000	25.000	25.000
<b>Start of tape (n=3)</b>	24.00±0.44	24.86±0.23	24.50±0.20	24.4±0.20
<b>End of tape (n=3)</b>	24.40±0.00	24.77±0.21	24.30±0.26	24.77±0.25

Across all four tapes the difference in frames per second observed between the start and finish of filming of the field data did not change significantly (paired t-test  $p<0.27$ ). There was also no significant difference between film speed between the two cameras used in capturing the field data using a Students t-test ( $24.45\pm0.317$  fps vs  $24.56\pm0.347$  fps,  $n=20$ ,  $p<0.30$ ).

The specified and actual film speed are rarely identical in film. The average captured video speed was  $24.51\pm0.33$  frames per second representing a 1.95% difference between the captured and the original video speed. This level of variation in video frames speed would be due to variation in the efficiency of the framegrabber digitising card, but did not provide a variation in frame rate dissimilar to that found by Clayton (1990), however it was a higher level of variation than that

found by Fredricson *et al.* (1972) using cine film [1%] and Fredricson *et al.* (1980) [0.2%] also using cine film.

Camera and intra tape variation was not a significant source of experimental error in this study and offered a acceptable level of error within the bounds reported by other authors examining equine locomotion.

#### *Division of frames into fields*

Each video frame is consists of odd and even fields. If the odd and even fields can be separated it is possible to increase the sampling rate from 25 frames per second (25hz) to 50 fields per second (50hz). Each video frame was split into its two composite (odd and even) fields using the single frame advance feature on the video cassette recorder.

### **Measurement and Template Development.**

The digitising process was performed using Claris Draw™<sup>1</sup>. This software permitted the development of image templates for calibration and the marking of anatomical reference points. For each field three separate measurements were made of the co-ordinates, which provided the best trade off between improved opportunity of measuring the correct variable and the time required to achieve this. A worst case test of a poor quality image with pixelation validated this choice. There were no significant differences of the co-ordinate standard deviations between 3, 4 or 5 repeat measurements (ns,  $p < 0.972$ ). Reliability of template placement was tested by comparison of 3 repeat measurements for each template. The average variation in marker placement as measured by standard deviation was  $1.1 \pm 0.8$  cm. Measurements were made of points and absolute angles between markers were recorded and subsequently entered in to a Microsoft Access database<sup>2</sup>.

#### **Calibration Templates**

From the video of the calibration markers (sport cones), templates were developed to overlay on to the individual horse images. Fifteen different calibration templates were developed to cover the 15m field of interest when the

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<sup>1</sup> ClarisDraw, Claris Corporation, 5201 Patrick Henry Drive, Santa Clara California

<sup>2</sup> Microsoft Access 97, Microsoft Corporation, Chicago, USA



horses were within the calibration zone approximately perpendicular to the panning lateral camera. Thirteen templates were developed to satisfy the criteria of having one background reference point visible and contain at least two cones. Two calibration templates were developed for either end of the reference zone which only contained one calibration marker. Background reference points were used to cross-reference the calibration templates with the horse field of interest. The background reference points provided a method of validation for the overlay process.

#### Horse specific templates.

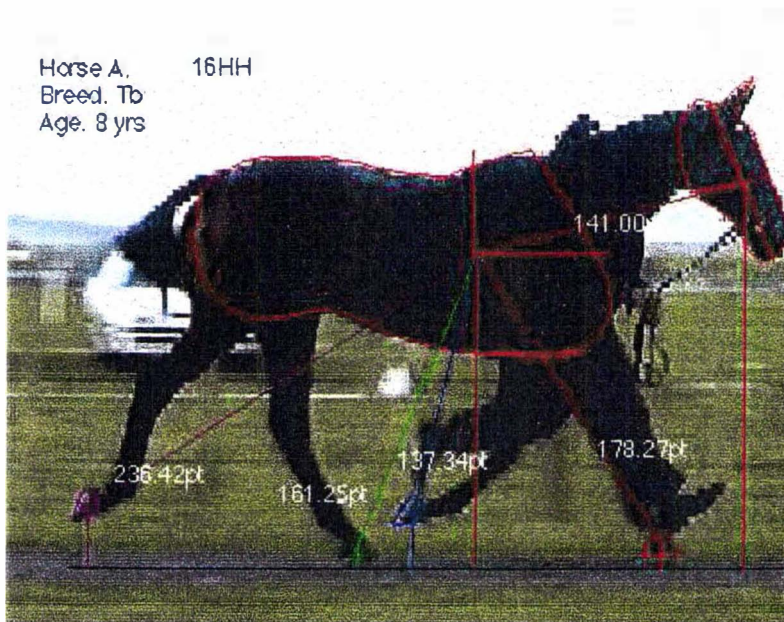
The placement of markers on anatomical reference points of the actual horse was not possible due to filming in a competition environment. The use of templates to locate reference points for the head, body and each hoof enabled identification of a feature of interest for digitising without using markers on each horse.

#### *Lateral view templates*

For the lateral view, templates were made to define a central head reference point, a body marker representative of the stationary centre of mass of the torso and a marker defining the centre of each hoof. All of the reference points identified by the lateral template also had to satisfy the criteria of being a point that could be referenced from the anterior view. All lateral templates were created from the field when the horse was at mid stance of the stride, when the left forelimb was perpendicular to the ground reference plane. Figure 3.1 shows the application of the lateral body markers.

**Lateral head marker template:** To measure the excursions of the head, limbs and trunk, reference points were defined. The head marker template was designed to identify a site representative of the mid point of a straight line drawn from the poll (summit of nuchal or occipital crest) to the tip of the upper lip along the check strap of the bridle. The check strap was used as a reference point because it was a consistent line irrespective of head orientation. An outline of the head was combined with the reference marker to improve the repeatability of template placement.

**Lateral body template:** The lateral body template was developed to be representative of the site of the stationary centre of mass of the horse torso (Sprigings and Leach 1986; van den Bogert 1989). In this study, the point used was a location that bisected a line drawn from the point of the withers to the base of the sternum. The X axis location was the point 1/3 the distance from the point of shoulder (cranial part of greater tuberosity of humerus) to the point of buttock (tuber ischii). An outline of the torso was combined with the reference grid to enable consistent placement. The outline was aligned with the withers (spinous processes of 3<sup>rd</sup> to 8<sup>th</sup> thoracic vertebrae) as this rigid structure consistently maintained its shape throughout the stride cycle.



**Figure 3-1** Diagram of horse with overlaying of body, head, hoof reference templates

**Lateral hoof template:** An outline was drawn of the perimeter of each hoof. The purpose of the outline was to improve the accuracy of the template placement and define the sites to be used in locating the hoof. The lateral hoof template defined the node as the mid point of a proximal to distal line from the top of the coronet band to the ground surface of the hoof, at a site that bisected a line from the point of toe to the bulb of the heel.

*Anterior templates.*

The anterior view templates were developed to provide reference points for the measurement of the angles from the central body reference point to the head and hoof reference points. The subsequently derived angle measurements provided information of the transverse displacement during a stride cycle.

**Anterior view head template:** The head reference point for the anterior view was obtained by equal bisection of a proximal-distal line running through a plane equidistant between the horse's eyes. An outline of the head was combined with the reference grid to improve placement in a similar manner as was used with the lateral templates.

**Anterior view body template:** The anterior view body template was obtained by first defining the width of the horse at the level of the sternum. The most dorsal part of the withers were then identified and a transverse line equal in length to the width of the horse as defined earlier was drawn. The mid point of the trunk was then identified by drawing two lines that joined the opposite ends of each line to form a cross identifying the mid point between the withers and the sternum.

**Anterior view hoof template:** This was constructed in a method similar to the lateral template. Initially an outline was drawn of the hoof and then the hoof was bisected vertically from the highest point of the coronary band to the ground surface of the hoof at a point defined as the bisection of the width of the ground surface.

## **Transformation**

The use of cinematographic or videographic data for analysis and interpretation of equine locomotion suffers from a number of limitations. The inability for the ground reference markers to be within the same sagittal plane as the horse reference plane requires the use of a calibration factor to correct for the associated error. Typically, calculation of spatial measurements have been derived from the limb movement and the ground reference markers. This result is then corrected for perspective error utilising a previously calculated calibration factor (Fredricson *et al.* 1972, Drevemo and Johnston 1995).

The data points and angles obtained by digitising within ClarisDraw™ were entered into a MS Access™ database. Queries were then run to extract the data into MS Excel™ for transformation. Transformation of the data as defined below was performed using a customised macro within Excel. Data integrity was checked by plotting the raw digitising co-ordinates within Excel. Data points on the plot that appeared unusual in comparison to their neighbours were then checked against the original input values.

### **Correction factor derivation**

Perspective errors were estimated by the use of a specially prepared 1m x 1m free standing square of plywood. The outer 15cm of the perimeter was painted black to provide a sharp contrast. The calibration board was passed through the field of view mimicking the previous path of the horses. This was performed for the lateral and anterior view cameras.

The horses and the calibration board passed through a medial plane  $1.10 \pm 0.17$ m from the ground reference marker medial plane. This variability in the distance between the horse reference plane from the ground reference plane was similar to that of other field trials (Moore *et al.* 1995).

The effect of parallax error on measurements was quantified by a test using five images containing a view of three sport cones and the 1m x 1m calibration board. The calibration board was positioned 1.10m behind the cones to mimic the plane of progression of the horses. The use of five images ensured the trial examined the effect of parallax error across the full calibration zone. Measurements were taken on the height of the sports cones and the width of the calibration board. Transformation was only performed using correction factors calculated from the known height of the sport cones. The results of this trial can be seen in Table 3.3 (refer appendix).

The effect of perspective error can be observed from the results in Table 3.3. In both the X and Y axes the calibration factor calculated from the height of the ground reference markers (yellow sport cones) were underestimating values for the calibration board dimensions with an error of  $11.04 \pm 2.20\%$  in the X axis and

10.99±1.87% in the Y axis. These large error values were obtained even though there was only a small coefficient of variation associated with the measurement of the height of the sport cones. The large percentage error observed was believed to be due to the cones and the calibration board being in different medial planes and the extrapolating from a small measurement on which the correction factor was based. The trial also identified that the effect of the parallax error increased with the increasing focal distance between the camera and the calibration board when the board was at either end of the calibration zone. Because of these sources of error, correction factors were subsequently derived by calibrating the 1m distance between the sport cones and the calibration board. For each 1m distance between cones three measurements were taken. These measurements were then averaged and the mean measurement was used for the calculation of the correction factors for both the X and Y axis. A low pass Butterworth digital filter (15Hz) (Winter 1990) in the numerical differentiation software QuickSAND ver006 (Walker 1997) was used to smooth the correction factors. Smoothing was performed to reduce the random error bias in the correction factors. Smoothing was not performed on the raw measurements because of the low variance observed in the measurements between cones (Table 3.4).

The inability to accurately determine the focal distance for the anterior camera limited the spatial information that this view could provide. Length measurements could not be made from this view. However an acceptable level of precision was possibly with the angle measurements. Parallax error was not found to contribute to distortion of the angle measurements in the anterior view

## Smoothing

As part of the digitising process, small errors have the effect of creating “noise” in the signal. Noise has little effect on trajectory data but becomes increasingly important with time derivatives such as velocity and acceleration. An example from (Bartlett 1997) demonstrated that a 1% level of noise as measured as an amplitude of the signal in the raw data ( $r=2\sin 2t + 0.02\sin 20t$ ) became a noise amplitude of 10% in the velocity ( $v = 4 \cos 2t + 0.4\cos 20t$ ).

For equine kinematic data a low pass digital filter is generally recommended with a cut-off frequency of 10 to 15Hz (Clayton 1996). In this study, raw data was initially subjected to a Fourier series analysis. This was performed to provide an understanding of the underlying frequency spectrum of the raw data. As with human kinematic data, the signal of interest was low frequency with the noise being found at the higher frequencies. A generalised cross-validated quintic spline (Woltring 1986) was used to smooth the raw trajectory data. This was performed within the QuickSAND numerical differentiation software (Walker 1997). A quintic rather than cubic spline was used because of the ability to achieve better endpoint with first and second derivatives (Wood and Jennings 1979).

### **Normalisation**

Normalisation enables comparison between strides of different durations and permits the construction of mean curves for a number of strides. Normalisation was achieved by the use of interpolation routine within QuickSAND after smoothing the data using the generalised cross-validation quintic spline routine. All trajectory data were normalised to 100 data points from the initiation of stance phase. After normalisation, average trajectory curves were produced for the three separate measurements on the segment trajectories. From this normalised data, velocity and acceleration were derived using QuickSAND.

### **Reconstruction of the lateral and cranio-caudal view trajectories.**

Trajectories from the two views were combined to provide multiplanar displacement, velocity and acceleration data in the x, y and z axis after normalisation. Because of the nature of the filming set up, the two cameras were not synchronised. This may provide a potential source of temporal error in combining trajectories from the two cameras. This absolute difference in timing could be as large as 6.8%. It is believed that this potential error is primarily a product of the low sampling rate (50Hz) and that a camera synchronising mechanism would not contribute significantly to any reduction in the maximum

potential temporal error associated with combining trajectory data from the two camera sources.

### **Time motion analysis**

Time motion analysis examines the time spent on an activity and the type or intensity of the activity. The panning lateral camera recorded the complete preliminary horse inspection procedure. This provided the opportunity to perform a time motion analysis by quantifying the time spent on each of the activities that are components of the horse inspection. Temporal data was obtained by recording the time spent on each activity from the timing display on the video cassette recorder.

### **Statistical analysis**

Statistical analysis was performed using the statistical software SPSS™<sup>1</sup>. For comparisons of paired data a paired t-test was performed. For multiple comparison of related data, a repeated measures general linear model was used with a *post hoc* comparison.

To compare the regression equations between inspection days for the relationship between stride length and velocity, a mixed model regression procedure was used. This model used the SPSS based macro of Hedeker *et al.* (1994).

With any kinematic study caution should be used when interpreting the statistical significance of differences in temporal measurements. In this study the sampling rate was 50Hz. This provided an effective window for sampling of 0.02 second. Differences between categories that are less than this value should then be treated with caution as this involves interpreting differences in measurements that occur at a higher resolution than achieved with direct measurement.

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<sup>1</sup> SPSS Inc., Chicago, Illinois

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	Cone (pt)	height	Board (pt) (x axis)	width	Board (pt) (y Axis)	height	Calibration factor width	Error measurement	(%) of actual	board
									Board width	Board height
Left cone	23.9		94.50		92.50		9.62	9.06		10.98
Middle cone	23.9		93.56		92.49		9.62	9.96		10.99
Right cone	23.9		92.30		92.3		9.62	8.99		11.17
Mean	23.9±0.00		93.45±1.10		92.43±0.11		9.62±0.00	9.33±0.54		11.05±0.10
Frame 5										
	Cone (pt)	height	Board (pt) (x axis)	width	Board (pt) (y Axis)	height	Calibration factor Width	Error measurement	(%) of actual	board
									Board width	Board height
Left cone	24.1		90.50		90.44		9.54	13.63		13.68
Middle cone	23.9		90.57		91.46		9.62	12.84		11.98
Right cone	23.9		91.46		92.46		9.62	11.98		11.02
Mean	23.98±0.11		90.84±0.53		91.45±1.01		9.59±0.04	12.82±0.82		12.23±1.35

**Table 3-4: Correction factor calculation by measurement of the distance between cones and the use of the calibration board.**

Initial cone of pair	X axis distance between cones (pt)	Calibn board X axis (pt)	Calibn board Y axis (pt)	X axis correction factor	Y axis correction factor	Mean ± Std.Dev X axis correction factor	Mean ± Std.Dev Y axis correction factor
A	169.68	161.73	171.7	1.049	0.988		
A	169.68	161.65	171.69	1.049	0.988		
A	169.68	161.73	172.69	1.049	0.982	1.049±0.003	0.986±0.003
B	174.89	158.64	177.71	1.102	0.984		
B	175.84	159.64	177.85	1.101	0.988		
B	174.85	159.64	177.85	1.095	0.983	1.099±0.004	0.985±0.003
C	181.73	174.69	176.78	1.040	1.028		
C	181.91	173.92	178.79	1.045	1.017		
C	181.73	174.78	177.8	1.039	1.022	1.042±0.003	1.022±0.005
D	186.92	173.69	178.72	1.076	1.045		
D	186.92	173.69	179.92	1.076	1.038		
D	186.75	173.67	179.74	1.075	1.039	1.075±0.001	1.041±0.004
E	190.9	182.76	182.83	1.044	1.044		
E	190.77	182.74	182.73	1.043	1.043		
E	190.77	183.81	183.73	1.037	1.038	1.042±0.004	1.042±0.003
F	194.78	180.85	183.74	1.077	1.060		
F	194.87	181.85	183.84	1.071	1.059		
F	194.87	181.85	183.81	1.071	1.060	1.073±0.003	1.060±0.000
G	193.86	180.73	183.84	1.072	1.054		
G	193.77	180.73	183.74	1.072	1.054		
G	193.86	181.73	183.84	1.066	1.054	1.070±0.003	1.054±0.000
H	192.78	187.76	185.74	1.026	1.037		
H	192.84	186.76	185.74	1.032	1.038		
H	193.86	186.76	185.74	1.038	1.043	1.032±0.005	1.039±0.003
I	195.79	185.01	185.01	1.058	1.058		
I	195.86	185.04	185.01	1.058	1.058		
I	195.53	185.01	185.01	1.056	1.056	1.057±0.001	1.057±0.001
J	193.79	185.74	186.76	1.043	1.037		
J	192.77	185.74	185.75	1.037	1.037		
J	193.78	185.69	185.75	1.043	1.043	1.041	1.039

K	189.77	185.2	186.35	1.024	1.018		
K	189.76	185.74	185.27	1.021	1.024		
K	190.77	185.01	186.27	1.031	1.024	1.025	1.022
L	185.75	181.72	181.8	1.022	1.021		
L	186.75	181.78	181.73	1.027	1.027		
L	186.75	181.78	181.78	1.027	1.027	1.025	1.025
M	180.73	176.72	178.73	1.022	1.011		
M	180.72	176.7	176.74	1.022	1.022		
M	180.72	176.7	176.74	1.022	1.022	1.022	1.018
N	173.71	169.73	175.72	1.023	0.988		
N	173.7	169.68	172.71	1.023	1.005		
N	174.7	169.73	172.71	1.029	1.011	1.025	1.001

**Chapter 4 Time Motion Analysis of the preliminary horse inspection at a CCI\*\*\* three day horse trials event**

## **Abstract**

The aim was to identify factors that influence the examination procedure of the preliminary horse inspection at a CCI\*\*\* three-day event. Time motion analysis was performed on the preliminary horse inspection of the 26 horses entered in the CCI\*\*\* class at the 1995 National Three Day Horse Trials Championships, Taupo, New Zealand. Performance was analysed according to the time spent on an activity and the type or intensity of the activity. Two distinct approaches were used for the inspection. One third of the class (group B) opted to walk rather than trot their horses past the judge's panel on the final section of the return run. Group A spent a longer time at the initial walk ( $4.36 \pm 0.94$ s vs.  $3.53 \pm 0.91$ s,  $p < 0.01$ ), but spent less time during the stationary inspection ( $8.77 \pm 2.16$ s vs.  $10.43 \pm 2.90$ s,  $p < 0.05$ ) and, for the total time ( $42.04 \pm 2.50$ s vs.  $45.34 \pm 3.38$ s,  $p < 0.01$ ). For group B a relationship was found between initial walk and the time spent at the stationary inspection ( $r^2 = 0.249$ ,  $p < 0.01$ ). The results demonstrate that the initial impression gained as the horse is walked toward the veterinary panel significantly influences the subsequent inspection. The optimal strategy for both the inspection panel and competitors is to present the horse in a relaxed manner.

## **Introduction**

Three-day eventing is a multidiscipline sport that includes dressage, speed and endurance, and show jumping tests. Integral parts of the competition are the horse inspections. Three horse inspections are performed. The first inspection is on day one prior to the dressage. The second inspection takes place on day two

at the end of phase C just prior to the cross country and a third inspection is performed on the morning of the show jumping. Both the first and third horse inspections are performed with the horses trotted up on an asphalt surface. Equine exercise physiologists have studied on the event horse's ability to perform in a high humidity climate (Jones and Carlson 1995; Jeffcott 1995; White 1996), but little has been documented about the horse inspection procedure (Wilford 1997). This is surprising, as the result of the horse inspection determines whether the horse may proceed in the competition.

Time-motion analysis is used to analyse the integral activity components and energetic requirements of an activity. It has been successfully applied to a variety of sports, including more recently to equestrian sport (Clayton 1989; Clayton 1993; Clayton 1996). Performance is analyzed according to the time spent on an activity and the type or intensity of the activity. From this activity intensity and time budget information, competition specific conditioning and preparation regimes can be developed to maximize performance. Time motion analysis of the horse inspection has the potential to provide improved understanding of the inspection procedure in three day eventing. It may help riders better present their horses and improve the public's understanding of this integral component of the three day event.

This chapter performs a time motion analysis of the preliminary (first) horse inspection at a national level (CCI\*\*\*) three day event.



## Materials and Methods

All 26 horses entered in the CCI\*\*\* class of the 1995 National Three Day Horse Trials Championships, Taupo, New Zealand were filmed at the initial horse inspection. The horses were led 'in-hand' at the trot by their regular riders on a specially prepared asphalt surface.

The horses were Thoroughbreds or Thoroughbred somatotype (Thoroughbred cross) with a mean age of  $10.7 \pm 2.2$  years of Advanced grade having previously gained the qualification as defined by the Federation Equestre Internationale (FEI) for CCI\*\*\* level competitions (Anon 1993). A panning video camera (50 Hz)<sup>1</sup> was used to film the horses from a lateral view (Drevemo and Johnston 1995). The camera was placed 17.5m perpendicular to the horse's line of progression with a lens height of 1.2 m, in accordance with previous recommendations (Clayton 1990). Each video frame was split into its 2 composite (odd and even) fields. This increased the sampling rate from 25 frames per second to 50 fields per second. Time measurements were made by counting the fields from the video footage with the aid of a video cassette recorder<sup>2</sup> and a Macintosh™ computer<sup>3</sup> equipped with a video digitizing card<sup>4</sup>. Stride lengths were calculated by copying across selected images for each horse in to Claris Draw™<sup>1</sup> and measuring the distance between successive footfalls using the previously derived calibration templates. Velocity was calculated from known stride length measurements. Reference markers consisted of 15 fluorescent yellow sports cones (142mm x 230mm), placed 1m equidistant within the previous path of the horses. From this footage ground

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<sup>1</sup> Panasonic MS-4, Matsushita Electrical Industrial Company Ltd, Osaka, Japan

<sup>2</sup> Panasonic NV-FS88 HQ, Matsushita Electrical Industrial Company Ltd, Osaka, Japan

<sup>3</sup> Apple Computer, Inc. 1 Infinite Loop, Cupertino, California

<sup>4</sup> RasterOps Corporation. 890 west 410 North Lindon Utah. USA

reference templates were developed which were overlaid on the horse footage to provide reference points for length measurements. A 1 m x 1 m calibration board was used to derive equations to correct for differences in focal distance. Data were analysed using student's t-test and least squares regression analysis with the statistical software SPSS™ 7.5<sup>2</sup>.

## Results

The inspection consisted of 6 or 7 separate stages depending on the strategy taken. These stages consisted of 3 separate activities, halt; walking and trotting. The horses walked to a stationary halt where the veterinary panel inspected the horse. The horse was then lead first at the walk and then at the trot, away from the panel. The horses were brought back to a walk and turned around in a clockwise direction to walk and then trot back towards the panel. Two strategies were used by the riders for presentation of their horses. Once parallel to the judges, some of the horses (Group A, Figure 1) continued trotting to the end of the track and were led away, while others were brought back to a walk to the end of the inspection track (Group B, Figure 4-1).

High coefficients of variation were found for all individual activities during the horse inspection. Coefficients of variation averaged across activities around 20%, the exception being the final walk with a coefficient of 193%. However, in spite of the high variation for individual phases of the presentation, the coefficient of variation for the total duration taken for presentation was only 7.6%.

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<sup>1</sup> Claris Corporation, 5201 Patrick Henry Drive, Santa Clara, California

<sup>2</sup> SPSS Inc., Chicago, Illinois

**Table 4-1 Descriptive statistics of time horses spent in the different phases of activity at the CCI\*\*\* Veterinary inspection (n=26).**

Activity	Mean Time (s)	Standard deviation	Coefficient of variation
Walk	4.11	0.99	24.18
Halt	9.26	2.47	26.69
Walk	5.45	1.31	24.04
Trot	7.31	1.12	15.39
Walk & turn around	6.44	1.31	20.36
Trot	9.40	1.39	14.79
Walk (Group B,n=8)	1.14	2.21	193.55
Total Time	43 14	3.30	7.65

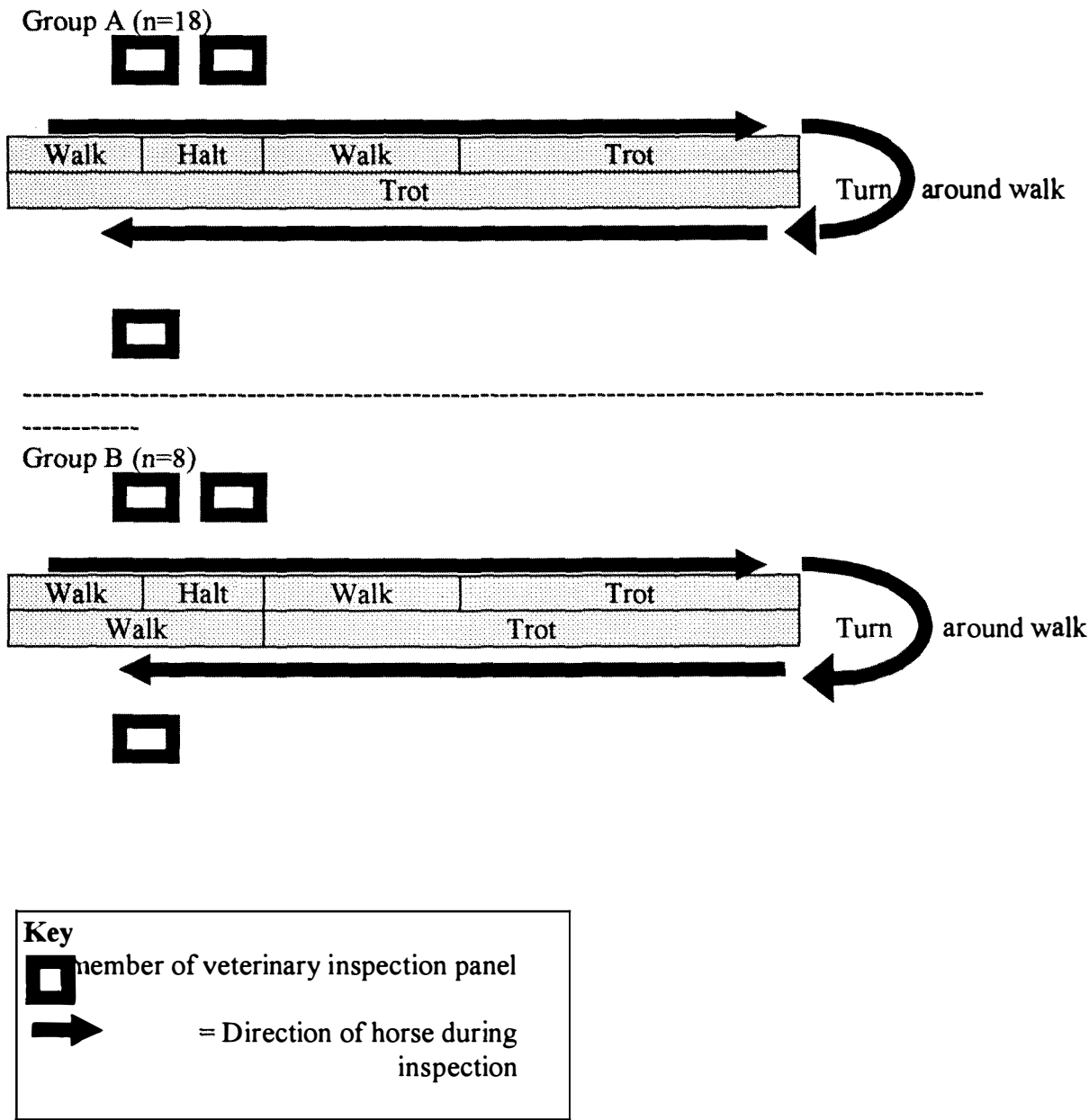
Significant differences were found between the two groups. Group A took longer for the initial walk segment but took less total time for the inspection ( $p<0.01$ ). Group B took longer for the stationary inspection ( $p<0.05$ ). No significant difference was found between groups for the other activities. Least squares regression analysis revealed a significant but weak relationship between time taken for the initial walk and the time for the stationary halt ( $R^2=0.249$ ,  $p<0.01$ ).

**Table 4-2 Time differences between the various activities, compared by t-test between 2 groups differing in gait during the final part of the inspection**

Activity	Group A (s) n=(18)	Group B (s) n=(8)	significance level
pre walk	4.36 ± 0.94	3.53 ± 0.91	p<0.01
halt	8.77 ± 2.16	10.43 ± 2.90	p<0.05
walk	5.17 ± 1.41	5.39 ± 1.22	n.s
trot	7.16 ± 1.11	7.66 ± 1.23	n.s
turn around	6.61 ± 1.29	6.03 ± 1.34	n.s
trot	9.64 ± 1.26	8.81 ± 1.59	n.s
Total	42.04 ± 2.50	45.34 ± 3.38	p<0.01

Values are mean and standard deviation

**Figure 4-1 Representation of the two procedures used by competitors for the preliminary horse inspection.**



## Discussion

The New Zealand Equestrian Federation rule book states that “The horse must be inspected in hand, at rest and in movement on a firm level and clean surface (Anon 1993). This definition of the horse inspection at the three-day event is open to different interpretations. The lack of constraints provided in the requirement was reflected in the highly variable times seen for all activities.

The two distinct strategies used did not differ in format until the return trot period when some competitors brought their horses to a walk when parallel to the panel (Group B) rather than continue trotting to the end of the inspection track (Group A). The lowest coefficient of variation (7.65%) was for the total time taken for the inspection ( $43.14 \pm 3.30$ s). That this variation was lower than variation in any of the internal components implies that irrespective of the strategy, total time appeared to converge towards a constant.

Significant differences ( $p < 0.05$ ) were found in the time taken for the activities of pre-walk, halt and total time between the groups. Horses that walked at the end of the horse inspection (Group B) took less time to arrive at the halt but were stationary at the halt for a longer period of time than horses that continued trotting at the end of the inspection. The longer time period at the halt contributed to the horses in Group B taking a longer time overall for the horse inspection. During the halt, it is the horse inspection panel that dictates the length of time a horse is stationary. That the panel inspected these horses for a longer period when stationary may have created doubt in a handler's mind as to the horse's ability to pass the inspection. This may have lead to handlers walking their horses past the panel in case a second trot-up was requested. During the preliminary inspection this only occurred with one horse. Regression analysis identified a weak but significant relationship ( $R^2 = -0.25$ ,  $p < 0.01$ ) between the time for the initial walk and the time at the stationary inspection. Horses that were hurried forward to the judge's panel had an increased chance of a longer stationary inspection. Such horses perhaps appear rushed and not

relaxed. A tense and uneven horse may require the judge's panel to spend more time at the stationary inspection to thoroughly assess the horse.

The activities during the horse inspection are low intensity (maximum velocity  $4.9\text{m}\cdot\text{s}^{-1}$ ;  $3.81\pm0.40\text{m}\cdot\text{s}^{-1}$ ) and as such they would not require a specific focus in the conditioning program of a three day event horses. From within the CCI\*\*\* class examined it appeared that the more experienced horses trotted up in a more relaxed fashion. Tension in the horse can make the gait appear uneven. It is therefore concluded that consistent dressage training to improve the suppleness of a horse should be combined with specific training to have a horse trot freely in-hand.

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**Chapter 5 Linear and temporal stride characteristics of  
three day event horses at a CCI\*\*\* three day event  
preliminary horse inspection.**



## Abstract

The aim was to quantify the linear and temporal characteristics of the trot of three day event horses during the preliminary horse inspection of a CCI\*\*\* three day event. A cross sectional study was made of the kinematics of 24 three day event horses during the first horse inspection at a CCI\*\*\* three day event. Video footage was digitised and linear and temporal measurements were made. The horses trotted for an average of  $10.44 \pm 1.55$  strides. Spatial measurements were made on an average of  $5.66 \pm 0.92$  consecutive strides when the horses were within the calibration zone. The horses increased and then maintained a constant velocity within the calibration zone. Trotting on the asphalt track did not alter the relationships between stride length, stride duration and velocity when compared with previously published values. Horse specific differences in stance and retraction percentages were identified. Horse specific differences were identified that may contribute to each horses unique gait or “kinematic fingerprint”. It is proposed that the initiation of, and completion of, stance by the hind limb first may represent “engagement of the hind quarters” and be a response to dressage training.

## Introduction

Three day eventing is a multidiscipline sport that includes dressage, speed and endurance and show jumping tests. Of the three main equestrian sports, the three day event is the most physically demanding. A three day event horse must have stamina, speed and soundness to cope with the rigours of speed and endurance day but also the tractability to perform in the dressage and show jumping phases. The horse inspection is an integral part of the competition. Three horse inspections are performed, the first is prior to the first day’s dressage, the second prior to the steeplechase phase on speed and endurance day, and the third on the morning of day three before the show jumping phase. A number of studies have focused on the three day event horses ability to perform in a high humidity climate (Jones and Carlson 1995; Jeffcott 1995; White 1996). Less has been documented about the kinematic characteristics of three day event horses (Deuel and Park 1993) (Schroter *et al.* 1996), and nothing about the horse inspection.

This paper examines the linear and temporal characteristics of the trot of a group of national level (CCI\*\*\*) three day event horses during a preliminary horse inspection.

## **Materials and Methods**

Twenty-four horses (23 geldings, 1 mare) were filmed during the initial horse inspection at the 1995 National Three Day Horse Trials Championships, Taupo, New Zealand. The horses were led 'in-hand' at the trot by their regular riders on a specially prepared asphalt surface. The horses were Thoroughbred or Thoroughbred somatotype (Thoroughbred cross) with a mean age of  $10.7 \pm 2.2$  years, having previously qualified to a standard set by the international equestrian governing body the Federation Equestre Internationale (FEI) for CCI\*\*\* level competitions (Anon 1993).

The filming technique was based on that of Drevemo and Johnston (1995). A panning lateral camera<sup>1</sup> at 50hz (50 fields per second) with a 1/1000 second exposure rate was used to first film the horses and then the ground reference markers. The camera was positioned 17.5m from the ground reference plane with the horses passing in a medial plane  $1.10 \pm 0.17$ m from the ground reference plane. Camera lens height was set at 1.2m, as recommended by Clayton (1990). The calibration zone consisted of 15 sports cones (142mm x 230mm) placed at 1m intervals at the edge of the trot-up track after the horse inspection. A vertical black line (4mm thick) was marked on the cone to bisect it, to improve the accuracy of cone placement and subsequent calibration. A 1m x 1m calibration board was used to derive equations to correct for systematic differences in focal distance. Calibration templates were developed from the ground reference marker footage. The calibration templates were then over-laid on to the frames of horses containing the strides of interest.

## **Analysis**

Analogue video footage was converted to digital images using video digitising software<sup>2</sup>. Graphics software<sup>1</sup> was used for the superimposition of the reference

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<sup>1</sup> Panasonic MS-4, Matsushita Electrical Industrial Company Ltd, Osaka, Japan

<sup>2</sup> RasterOps Corporation. 890 west 410 North Lindon Utah. USA

marker derived calibration template on to the horse trajectory frames. This software was used to define points on the horse by superimposition of marker templates and permitted the calculation of spatial measurements.

The temporal parameters of the trot that were measured are similar to those previously described (Clayton 1994), and are defined as follows.

Initial ground contact of a limb was the frame in which loading of the limb first took place. This was when a change in fetlock angle was observed. Stance was the time from initial contact of the hoof with the asphalt surface until contact was lost. The swing phase began when the limb was no longer seen to be in contact with the asphalt surface and ended at ground contact. Retraction was the time from maximum protraction of the limb until ground contact. Advanced placement was deemed to be the time interval between ground contacts of the two limbs of the diagonal pair. Advanced completion was the time between lift-off of the two limbs of the diagonal limb pair. Positive values represent the hindlimb first and negative values the forelimb first for both the advanced placement and completion measurements. Overlap was the period when both limbs of the diagonal limb pair were in stance phase, that is in contact with the asphalt surface.

Because data was collected in a competition environment, no control could be placed on the specific location at which the handlers initiated the trot. This meant that horses were at differing stages of the trot before they entered the calibration zone. To account for this, stride number in this study refers to the sequence of trot strides from the initiation of the trot by the horse.

### **Statistical Analysis.**

Statistical analysis of the relationship between velocity, stride length and, stride duration was performed using least squares regression. Polynomial regression models were used to identify non-linear relationships. A repeated measures general linear model with the horse as a co-variant was used to identify differences between strides. To identify individual differences Tamhane's post-hoc test was used. This

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<sup>1</sup> ClarisDraw, Claris Corporation, 5201 Patrick Henry Drive, Santa Clara, California

test was used as it could be applied to data sets with unequal variances. All statistical analysis was performed using the statistical software SPSS <sup>TM</sup>7.5<sup>1</sup>.

## Results

The horses trotted for  $10.44 \pm 1.56$  strides. Spatial measurements were taken for an average of  $5.66 \pm 0.92$  strides when the horses were within the calibration zone. Velocity was correlated with stride length ( $r^2 = 0.871$ ,  $p < 0.001$ ) and negatively correlated to stride duration was ( $r^2 = -0.655$ ,  $p < 0.001$ ). A negative relationship between stride length and stride duration was identified ( $r^2 = -0.204$ ,  $p < 0.05$ ).

In this analysis, stride number is the number of the stride from the initiation of the trot and not from when the horse first entered the calibration zone (Table 5.1). Regression analysis of the relationship of velocity and stride number indicated that the horses increased and obtained a constant velocity (3<sup>rd</sup> order polynomial,  $r^2 = 0.243$ ,  $p < 0.001$ ). A cubic regression model was found to best describe the relationship between stride duration ( $r^2 = 0.180$ ,  $p < 0.001$ ), and stride length ( $r^2 = 0.164$ ,  $p < 0.001$ ) and stride number. Significant differences were found for velocity and stride duration relative to stride number ( $p < 0.05$ ). Differences in stride length were not as significant ( $p < 0.10$ ). Post-hoc tests (Tamhane) revealed in both the velocity and stride duration data that the initial two strides differed significantly from the later strides when the horse had reached a constant velocity.

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<sup>1</sup> SPSS Inc., Chicago, Illinois

**Table 5-1 Temporal and spatial parameters for the trot strides analysed for the preliminary horse inspection.**

Stride	1	2	3	4	5	6	7	8
Sample size (n)	12	17	21	25	25	24	15	8
Stride Duration (ms)	738±51 <sup>a</sup>	709±33 <sup>c</sup>	693±35	676±31 <sup>bc</sup>	677±27 <sup>bc</sup>	675±23 <sup>a</sup>	680±55	667±26 <sup>bc</sup>
Stride length (m)	2.40±0.15	2.48±0.22	2.57±0.23	2.64±0.21	2.67±0.21	2.65±0.18	2.65±0.15	2.66±0.24
Velocity (m.s <sup>-1</sup> )	3.27±0.34 <sup>a</sup>	3.51±0.51 <sup>c</sup>	3.72±0.41	3.91±0.31 <sup>b</sup>	3.95±0.34 <sup>b</sup>	3.94±0.28 <sup>b</sup>	3.92±0.34 <sup>bc</sup>	4.00±0.15 <sup>bc</sup>

Values are means ± standard deviations

Different superscripts indicate values that are significantly different (p<0.05)

Post-Hoc Tamhane p<0.05

**Table 5-2 Descriptive statistics for the temporal variables of each stride measured for the preliminary horse inspection.**

Stride	1	2	3	4	5	6	7	8
Sample size (n)	12	17	21	25	25	24	15	8
Stance %	34.74±4.26 <sup>a</sup>	33.30±3.34	33.41±3.23	32.58±3.04 <sup>b</sup>	32.22±2.85 <sup>b</sup>	32.31±2.72 <sup>b</sup>	32.15±3.32 <sup>b</sup>	33.24±3.67
Retraction %	8.31±1.61 <sup>abc</sup>	9.21±1.67 <sup>b</sup>	9.31±1.73 <sup>c</sup>	9.61±1.79 <sup>a</sup>	9.76±1.54 <sup>a</sup>	10.23±1.76 <sup>ab</sup>	10.21±1.71 <sup>abc</sup>	10.66±1.66 <sup>abc</sup>
Advanced placement (ms)	16±12.2	17.1±12.1	12.8±13.8	15±12.7	12.4±13.3	13.6±10.2	10.4±13.1	7.5±14.1
Advanced completion (ms)	31.3±10.0 <sup>acd</sup>	29.5±16.0 <sup>cd</sup>	28.8±14.0 <sup>d</sup>	24.1±13.0	16.8±16.3 <sup>bc</sup>	24.0±10.6	23.0±11.1 <sup>bd</sup>	20.6±12.9
Diagonal overlap (m.s)	238±37 <sup>a</sup>	216±27	211±24 <sup>b</sup>	202±22 <sup>b</sup>	203±21 <sup>b</sup>	201±21 <sup>b</sup>	203±24 <sup>b</sup>	212±25 <sup>b</sup>

Values are means ± standard deviations

Different superscripts indicate values that are significantly different (p<0.05).

Post-hoc (Tamhane) p<0.05.

**Table 5-3 Descriptive statistics for limb pairs (n=24).**

<b>Variable</b>	<b>Forelimb pair</b>	<b>Hindlimb pair</b>	<b>Significance</b>
Stance duration (ms)	236±30	218± 30.4	p<0.001
Retraction %	10.48±1.85	8.97±1.50	P<0.001
Suspension Duration (ms)	454±56	472±55	p<0.001
	<b>Left-fore diagonal pair</b>	<b>Right-fore diagonal pair</b>	
Retraction %	9.66±1.86	9.79±1.82	n/s
Diagonal advance placement (ms)	14.3±10.8	11.4±14.6	p<0.05
Diagonal advanced completion (ms)	22.8±12.2	26.3±15.2	p<0.05
Diagonal overlap (ms)	213±26.6	206±28.7	p<0.05

Values are means ± standard deviations

Stride number had a significant effect on a number of temporal variables. Stance percentage, retraction percentage, advanced completion, diagonal overlap ( $p<0.01$ ), and advanced placement ( $p<0.05$ ) all differed significantly with stride number. Post-hoc tests revealed significant differences between the preliminary strides and the middle or constant velocity strides for all variables, except for the variable advanced placement. This was similar to the velocity and stride length data with differences between the preliminary strides and the middle or constant velocity strides. A weak 3<sup>rd</sup> order polynomial relationship was found between overlap and velocity ( $r^2=0.356$   $p<0.001$ ) and overlap and stride number ( $r^2=0.137$ ,  $p<0.001$ ).

Differences in temporal parameters were observed between the fore and hindlimbs and the diagonal limb pairs. Stance duration, suspension and retraction as a percentage of stride differed significantly. Stance duration and retraction was longer in the forelimb ( $p<0.001$ ). When comparing diagonal limb pairs, advanced placement was significantly greater in the right diagonal limb

pair ( $p < 0.05$ ). In the diagonal limb pairs the hindlimb was the first to start and complete stance phase ( $p < 0.05$ ).

## Discussion

### **Stride frequency and ground surface.**

According to the FEI, the trot can be classified into 4 groups. From the slowest trot to the fastest trot the categories are collected, working, medium and, the extended trot (Clayton 1994). The velocity of the horses presented at the horse inspection in this study became constant at a velocity range equivalent to the boundary between the working and medium trot (Clayton 1994). At this constant velocity the stride length was best described by the working trot. However, the stride frequency started at the upper limit for the extended trot and continued to increase. This high stride frequency could be due to the horses trotting on an asphalt surface. Horses trotting on a hard non-yielding surface maintain the same velocity by increasing stride frequency and decreasing stride length (Barrey *et al.* 1993; Buchner *et al.* 1994). This mechanism makes it difficult to compare parameters measured from horses presented on different ground surfaces. Recently the FEI veterinary committee has focused attention on standardisation of trot-up surfaces. At the major competitions the trotting surfaces are usually level firm surfaces and in New Zealand are specially prepared asphalt surfaces (Wilford 1997). As the horse inspection provides a potential limitation to a horse's ability to proceed in the three day event competition, it is surprising that there are no reports on the kinematics of this pivotal activity.

From the data in Table 5-1 the horses accelerated to and obtained a constant velocity within the measurement field. This provides an opportunity to examine the interaction of changes in velocity on kinematic parameters within the trot. In the measured strides the horses increased velocity initially by decreasing stride duration and increasing stride length. Within the first two strides a constant stride duration was attained and subsequently further increases in velocity were primarily due to increased stride length. This agrees with the results from dressage horses that increased velocity between the different trot types is achieved by increasing stride length (Clayton 1994). Trotting on the asphalt

surface, the event horses in this study had shorter stride durations at a given velocity than the horses examined by Clayton (1994). However the relationship between velocity, stride length and stride duration was constant.

The rules of the FEI emphasise that increases in velocity from the collected through to extended trot should be obtained with the horse maintaining the same rhythm (Anon 1993). At moderate trot velocities it has been proposed that increases in velocity are primarily due to increases in stride length, while at racing trot speeds ( $12 \text{ m.s}^{-1}$ ) increases in velocity are due to decreases in stride duration (Leach 1987). For the event horses, stride duration was constant as velocity increased in agreement with the FEI rules and previous observations (Clayton 1994; Leach 1987).

### **Horse Specific Characteristics.**

Neither stance or retraction percentage had a significant relationship with velocity or stride number. The general linear model demonstrated a significant horse and horse by stride effect ( $p < 0.01$ ) for both stance and retraction percentage. Thus each horse may have a distinctive or pre-programmed preferred stance and retraction percentage within the velocity range examined. Horse specific differences were also identified for advanced completion, advanced placement and, diagonal overlap ( $p < 0.001$ ). Horse specific characteristic patterns for the fetlock and tarsal joints have been observed (Sloet van Oldruitenborgh-Oosterbaan *et al.* 1996), and in pro/retraction angles in Dutch warmblood horses (Back *et al.* 1994). It appears that within this velocity range for the trot, the variables in Table 5-2 may be horse specific, contributing to a unique kinematic fingerprint. This parameter specificity may be a reflection of a horse's specific gait modifications to the asphalt surface, each horse adopting a slightly different strategy. However as only minor kinematic differences have been found between Dutch warmblood horses trotted on asphalt and a rubber surfaces (Buchner *et al.* 1994), consistent individuality should also be apparent on more compliant surfaces.

### **Training.**



The trot is described as a two beat gait consisting of two alternate diagonal limb pairs separated by a moment of suspension (Anon 1993). Motion analysis has identified that there is a slight disassociation of the diagonal limb pairs and that the characteristics of the disassociation may be velocity dependent. At the racing trot ( $12\text{m.s}^{-1}$ ) the forelimb lands first (Clayton 1989), while at the moderate trot velocities observed in equestrian sport, the hindlimb precedes the forelimb of the diagonal pair (Clayton 1994; Deuel and Park 1990; Drevemo *et al.* 1980a). The magnitude of advanced placement is greater than that of advanced completion (Drevemo *et al.* 1980a).

In the present study, stance duration as a percentage of stride was greater in forelimbs than the hindlimbs. No velocity dependent relationship could be identified. This is similar to parameters reported for the collected and working trot (Clayton 1994). The hindlimb consistently preceded the forelimb of the diagonal limb pair at both the initiation and completion of stance phase. The hind limb appears to precede the forelimb of the contra-lateral limb pair at lower trot velocities (Clayton 1994; Drevemo *et al.* 1980b) and the forelimb precedes at racing trot velocities (Drevemo *et al.* 1980a). In the present study the forelimb was observed to proceed the hindlimb only when a horse was rapidly decelerating.

One of the primary goals of training the young horse is “engagement of the hind quarters” (Crossley. 1993). It is conceivable that the hind limb proceeding the forelimb of its limb pair at both the initiation and completion of stance phase may be a reflection of the training goal for these horses. By the time a horse reaches advanced grade (CCI\*\*\*) it has a high level of dressage training. With advanced national representative level dressage horses, the hind limb initiated stance before the forelimb and consistently completed the stance phase before the forelimb, irrespective of the speed or type of trot (Clayton 1994). Earlier maximal protraction of the hind limb with respect to the retracting ipsilateral forelimb was observed for Dutch warmblood horses after 70 days intensive training (Back *et al.* 1994). This supports the theory that dressage training encourages the hind limbs to “engage” (Crossley1993), as observed by the hind limb initiating stance phase before the forelimb of the limb pair.

### **Track surface and breed effect on gait.**

In Swedish Warmblood stallions the forelimb retraction (22%) was found to be greater than hind limb retraction (5%) (Holmstrom *et al.* 1993). In the present study retraction percentage was significantly greater in the forelimbs but the difference was not as large as that observed by Holmstrom *et al.* (1993). The difference may be due to the horses being presented on asphalt rather than a sand arena. Horses trotting on asphalt had reduced vertical displacement of the withers compared to horses trotting on rubber (Buchner *et al.* 1994). Therefore retraction time may have been reduced as a consequence of horses attempting to minimise the concussion forces. It is also possible that breed differences, predominantly thoroughbreds in this study and the training objective three day event versus dressage in the elite Swedish stallions, may also be contributing factors to these differences. Thoroughbreds are recognised as having a long low gait pattern as opposed to the rounder knee action of the warmblood. Differences in gait parameters have been found between thoroughbred racehorses and warmblood dressage horses (Clayton 1993). While the breed and training effect in that study provided confounding variables the indication was that there could be breed associated differences in gait parameters. This breed and asphalt surface effect may explain some of the disparity with the retraction percentages between this study and that of Holmstrom *et al.* (1993).

### **Asymmetry.**

Laterality or “leggedness” in horses has been previously described (Clayton 1994; Deuel and Park 1990). Significant differences between diagonal limb pairs were found for diagonal advanced placement and completion. A number of theories have been advanced as to the reason for observed laterality in horses (Meij and Meij 1980). For the three day event horses the level of dressage training required should minimise any laterality, as one of the goals of dressage is to “make the horse straight” to correct any natural laterality (Crossley. 1993). However; motion analysis tends not to support this, at least within the context of the variables examined. Previous studies have found evidence of laterality in elite and national level dressage horses (Clayton 1994; Deuel and Park 1990). In the present study the horses were led in-hand from the near side and this may have contributed the appearance of laterality. It is possible that increased

dressage training may not remove laterality but super-impose the rider or trainers laterality on to the horse. This may manifest itself either as a minimisation of laterality or superimposition of the existing bias.

### **Conclusion**

In conclusion this study indicates that the asphalt track used for horse inspections at major three day event competitions decreases the stride duration of the trot at this velocity range when compared to other studies. However the relationship between stride duration, stride length and velocity appeared constant. Velocity dependent changes in a number of temporal variables could not be identified or had weak relationships. Horse specific differences were identified. It was proposed that these differences could contribute to the horses unique gait or “kinematic fingerprint”. It is proposed that initiation of and completion of stance by the hind limb first may be a response to dressage training.

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**Chapter 6 Temporal changes in the trot between the first and third horse inspections at a CCI\*\*\* three day event.**

## **Abstract**

Kinematic parameters were measured from horses competing in a CCI\*\*\* three day event. The horses were filmed during the first and third horse inspection. This provided a repeat sample on 16 horses. The horses were filmed using a panning lateral S-VHS video camera (50Hz). Spatial measurements were taken for an average of  $5.66 \pm 0.92$  strides for the first inspection and  $5.05 \pm 1.27$  for the third inspection

Within the calibration zone, data of the horses accelerating and obtaining a constant velocity were collected. The horses trotted with a higher mean velocity during the third inspection ( $0.26 \pm 0.05 \text{ms}^{-1}$   $p < 0.001$ ). During the third inspection the horses trotted with a shorter stride length ( $0.193 \pm 0.03 \text{m}$   $p < 0.001$ ) and stride duration ( $31 \pm 42 \text{ms}$   $p < 0.001$ ). The third inspection was characterised by a decrease in retraction percentage for both the forelimbs ( $3.69 \pm 2.39\%$   $p < 0.001$ ) and the hindlimbs ( $2.48 \pm 2.16\%$   $p < 0.001$ ). However, no significant difference was found between the 2 inspections for other temporal parameters when measured as a percentage of stride. It is proposed that the event horses trot with a decreased stride length and duration during the third horse inspection but maintain a consistent temporal relationship.

## **Introduction**

The three day event competition places a high physiological demand on the equine participants (Jones *et al.* 1995, Schroter *et al.* 1996). The horse inspections are an integral part of the three day event. The first inspection is on day one prior to the dressage. The second inspection takes place on day 2 (speed and endurance day) at the end of phase C. A third inspection is performed on the morning of day 3 prior to the show jumping. Both the first and third veterinary inspections are performed using a standardised format with the horses trotted up on a firm, level surface (Anon 1998).



Previously the examination of the kinematics of three day event horses has focused on the cross country test (Deuel and Park 1993, Moore *et al.* 1995, Clayton 1997). But to date the kinematics of the horse inspection does not appear to have been examined. This is surprising considering that the inspections can prevent a horse from continuing in the competition, and the debate that is often created as a result of the decision by the judge's panel, particularly with the third inspection.

A characteristic of fatigue in human middle distance runners is the use of a shorter and higher frequency stride to achieve the same relative velocity. Associated with the change in the relationship of stride length and frequency with velocity there is an associated increase in stance as a relative percentage of stride time (Elliot and Roberts 1980). It is likely that the kinematic responses to fatigue in bipeds (humans) and quadrupeds (horses) will be similar. In examining fatigue in horses Leach and Sprigings (1979) and Wilson *et al.* (1993) found an increase in stance time as a result of fatigue. The horse inspection provides a model of the effects of high physiological loading and subsequent partial recovery on gait. Since there does not appear to have been such a study previously, this chapter examines changes in temporal parameters in a sample of CCI\*\*\* event horses between the first and third horse inspections.

## **Materials & Methods**

Twenty-four horses were filmed at the initial veterinary inspection at the 1995 National Three Day Horse Trials Championships, Taupo, New Zealand. At the third horse inspection 4 horses were not presented, providing a sample of 20 horses presented at both inspections. From the third inspection 4 horses were excluded from analysis due to incomplete footage or poor resolution. The remaining sample of 16 horses with repeat measurements from both inspections provided the data set for this study. For the horse inspections the horses were led 'in-hand' at the trot by their regular riders on a specially prepared asphalt surface.

The horses were Thoroughbreds or Thoroughbred cross of advanced grade, having previously qualified to a standard set by the international equestrian governing body the Federation Equestrian Internationale (FEI) for CCI\*\*\* level competitions (Anon 1995).

The filming technique was based on that of Drevemo and Johnston (1994). A panning lateral camera<sup>1,2</sup> at 50hz (50 fields per second) with a 1/1000 second exposure time was used to film first the horses and then the ground reference markers. The calibration zone consisted of 15 prefabricated sports cones placed at 1m intervals. A 1m x 1m calibration board was used to derive equations to correct for differences in focal distance. The camera was positioned 17.5m from the ground reference plane with the horses passing  $1.10 \pm 0.17$ m from the ground reference plane. Calibration templates were developed from the ground reference marker footage. The calibration templates were then over-laid on to the frames containing the strides of interest.

### **Data Acquisition:**

Analogue video footage was converted to digital images using video digitising software<sup>3</sup>. This provided individual images representing the odd and even fields of the video footage. Graphics software<sup>1</sup> was used for the development, and overlaying of, the reference marker calibration template on to the horse trajectory frames. This software also permitted the calculation of spatial and temporal measurements.

The temporal parameters measured are similar to those previously described by Clayton (1994). Initial ground contact was the frame when loading of the limb first took place. This was when a change in fetlock angle was observed. The swing phase began when the limb was observed to be no longer in contact with the asphalt surface. Retraction was the period from maximal protraction until initial ground contact. Advanced placement was deemed to be the time between ground contacts

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<sup>1</sup> Panasonic MS-4, Matsushita Electrical Industrial Company Ltd, Osaka, Japan

<sup>2</sup> Panasonic XD S-VHS 180 video tape, Matsushita Electrical Industrial Company Ltd, Osaka, Japan

<sup>3</sup> MediaGrabber RasterOps Corporation. 890 west 410 North Lindon Utah. USA.

of the two limbs of the diagonal pair. Advanced completion was the time between lift-off of the two limbs of the diagonal limb pair. Positive values represent the initiation of the movement by the hind limb first, and negative values the forelimb first, for both the advanced placement and completion measurements. Overlap was the period when both limbs of the diagonal limb pair were in contact with the asphalt surface.

### **Statistical Analysis:**

A mixed effects regression model for clustered data was used to provide a maximum marginal likelihood solution for the relationship of velocity with stride length and stride duration. Horses were treated as random effects to reflect the dependence of successive measurements of individual horses. Inspection days were treated as nominal variables in the regression equation permitting the comparison of inter-relationships across inspection days. This technique was performed using the mixreg macro developed for SPSS™ by Hedeker *et al.* (1994). A repeated measures general linear model was used to identify differences in temporal patterns between the two inspections. These statistical techniques were performed using the statistical software package SPSS™7.5<sup>1</sup>.

## **Results**

Spatial measurements were taken for an average of  $5.66 \pm 0.92$  strides for the first inspection and  $5.05 \pm 1.27$  for the third inspection (Group B) when the horses were within the calibration zone. Within the calibration zone, data of the horses accelerating to and maintaining a constant velocity were collected. The horses trotted at a higher average velocity during the third inspection (paired t-test  $0.26 \pm 0.05 \text{ m} \cdot \text{s}^{-1}$ ,  $p < 0.001$ ) maintaining a similar standard deviation. Stride length had a linear relationship with velocity (first inspection  $r^2 = 0.86$ , third inspection  $r^2 = 0.73$ ). Regression analysis revealed different strategies between the first and third inspections to obtain the same velocity (Fig 6-1). The regression lines were not parallel, because there was a significant interaction between inspection and

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<sup>1</sup> ClarisDraw, Claris Corporation, 5201 Patrick Henry Drive, Santa Clara, California

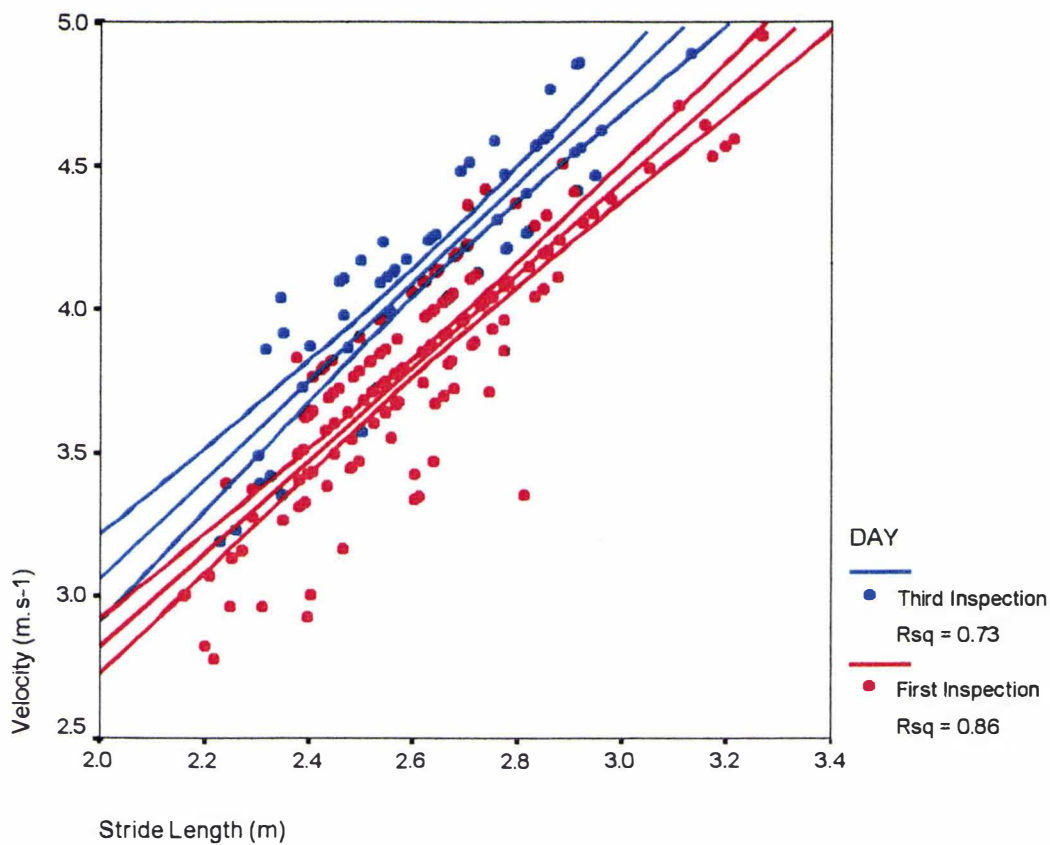
stride length ( $\beta$  coefficient  $0.293 \pm 0.154$ ,  $p < 0.057$ ). A paired t-test indicated that at the same velocity, the third inspection had shorter strides ( $0.193 \pm 0.03$  m,  $p < 0.001$ ). A low correlation was found for the stride duration between inspections ( $r^2 = 0.247$ ,  $p < 0.001$ ). This low correlation between days possibly contributed to the non-significant difference in stride duration identified by analysis of the regression slopes. However, a paired students t-test did identify a significant difference between inspection for stride duration ( $0.031 \pm 0.042$  s,  $p < 0.001$ ). Both stride length and stride duration had a similar reduction in the deviation about the mean from the first to third inspections with the range reduced by 18.9% and 20% respectively.

The results of the paired t-tests are presented in Table 6-1. Retraction as a percentage of stride was significantly greater during the first horse inspection for all limb pairs (Table 6-1). Retraction was greater in the forelimbs when compared to the hindlimbs. No laterality effect was observed in retraction between diagonal limb pairs.

Diagonal advanced placement (ms) was significantly greater in the left diagonal for the first horse inspection. However, when measured as a percentage, of stride time no significant differences were found between inspections. Laterality was observed in differences between the left and right diagonals. For both inspections the diagonal advanced placement for the right diagonal pair was nearly twice that of the left diagonal pair.

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<sup>1</sup> Spss Inc., Chicago, Illinois



**Figure 6-1** Regression lines (including 95% confidence intervals) of the relationships between velocity and stride length for the first and third horse inspection.

**Table 6-1 Temporal measurements (mean  $\pm$  standard deviation) for limb pairs between the 1<sup>st</sup> and 3<sup>rd</sup> horse inspections.**

Variable	Forelimbs		Hindlimbs		Significance
	1 <sup>st</sup> Inspection	3 <sup>rd</sup> Inspection	1 <sup>st</sup> Inspection	3 <sup>rd</sup> inspection	
Stance %	34.46 $\pm$ 3.36	34.00 $\pm$ 2.58	31.83 $\pm$ 3.59	31.51 $\pm$ 3.59	n/s
Retraction%	10.70 $\pm$ 1.89 <sup>a</sup>	7.00 $\pm$ 1.79 <sup>b</sup>	9.11 $\pm$ 1.48 <sup>a</sup>	6.63 $\pm$ 1.64 <sup>b</sup>	P<0.001
Variable	Right diagonal		Left diagonal		Significance
	1 <sup>st</sup> Inspection	3 <sup>rd</sup> Inspection	1 <sup>st</sup> Inspection	3 <sup>rd</sup> inspection	
Stance %	33.40 $\pm$ 3.94	32.82 $\pm$ 2.91	32.88 $\pm$ 3.45	32.69 $\pm$ 3.32	n/s
Retraction %	9.82 $\pm$ 1.91	7.00 $\pm$ 1.58	9.99 $\pm$ 1.83 <sup>a</sup>	6.63 $\pm$ 1.54 <sup>b</sup>	P<0.001
Diag.Adv.Plmt (ms)	14.59 $\pm$ 10.43	15.49 $\pm$ 14.06	9.32 $\pm$ 16.43 <sup>a</sup>	7.36 $\pm$ 14.66 <sup>b</sup>	P<0.001
Diag.Adv.Plmt %	2.15 $\pm$ 1.55 <sup>a</sup>	2.34 $\pm$ 2.15 <sup>a</sup>	1.37 $\pm$ 2.50 <sup>b</sup>	1.11 $\pm$ 2.24 <sup>b</sup>	P<0.01
Diag.Adv.Cmpt (ms)	21.64 $\pm$ 12.99 <sup>a</sup>	23.43 $\pm$ 12.15 <sup>b</sup>	23.38 $\pm$ 15.55	24.48 $\pm$ 12.89	P<0.05
Diag.Adv.Cmpt (%)	3.21 $\pm$ 1.93	3.58 $\pm$ 1.83	3.44 $\pm$ 2.30	3.75 $\pm$ 1.94	n/s
Overlap (ms)	210.60 $\pm$ 24.29 <sup>a</sup>	195.50 $\pm$ 19.87 <sup>b</sup>	201.50 $\pm$ 25.09 <sup>c</sup>	192.80 $\pm$ 19.37 <sup>d</sup>	P<0.01
Overlap %	31.14 $\pm$ 2.96 <sup>a</sup>	30.13 $\pm$ 2.58 <sup>b</sup>	29.81 $\pm$ 3.05 <sup>b</sup>	29.73 $\pm$ 2.65 <sup>b</sup>	P<0.001

Note:

Values are a percentage of total stride (%) or raw values in milliseconds (ms)

Analysis is repeated measures general linear model

Different superscripts are values significantly different at p<0.05.

Stance as a percentage of stride did not differ significantly between inspections for any of the limb pairs. At both inspections, stance percentage was greater in the forelimbs than the hindlimbs. No significant difference could be found between diagonal limb pairs. As with advanced placement, laterality was also observed with stance time. When diagonal limb pairs were combined across days the right diagonal had a longer stance time.

Overlap measured as time and as a percentage of stride was greatest during the first inspection, but only overlap time was significantly different between days. Differences in overlap between diagonals may indicate some underlying laterality in these horses.

The only significant difference found in advanced completion was between diagonal pairs. Advanced completion was significantly different between the first and third inspections for the right diagonal only. In the left diagonal pair advanced completion always occurred at an earlier stage than the right diagonal. This pattern was consistent across days.

## **Discussion**

Leach and Crawford (1983) proposed that one of the first steps to understanding equine locomotion should be a descriptive or qualitative phase. To understand the changes in gait pattern due to strenuous exertion it is preferable to initially examine changes in the relationship of stride length and duration with velocity.

It was observed that after the high physical demands of speed and endurance day, event horses trotted with a lower stride length and duration to achieve the same velocity. Leach and Sprigings (1979) proposed that with the onset of fatigue stride duration increased significantly. Differences between this study and the one reported by Leach and Sprigings could be expected as a result of the different models used. In the present study comparisons were based on a re-sampling 16-18hrs after strenuous exercise with trotting event horses, whereas Leach and Sprigings (1979) compared galloping Thoroughbred racehorses at

different stages of a race. Through the use of different time periods in the two studies it is possible that the horses could have had different physiological and biomechanical needs at the time of sampling and therefore required differing strategies to address the relevant priorities. As a consequence of the shorter time period between repeated samples it is possible that Leach and Sprigings (1979) measured the changes in gait pattern caused by fatigue. In our study changes in gait pattern would be due to muscle soreness rather than fatigue. Muscle soreness usually develops within the first 24 hours following exercise (Ebbeling and Clarkson 1989). This phenomenon has been referred to as delayed onset muscle soreness (DOMS). In humans the soreness is described as a dull aching pain combined with tenderness and stiffness (MacIntyre *et al.* 1995). DOMS does not appear to have been described in horses but McMiken (1983) does refer to the possibility that there may be sub-clinical structural damage in muscle which is reflected in the “soreness” a day or two after exercise. This may be the cause of the stiffness on the morning following speed and endurance day reported in three day event handbooks (Leng 1990, Holderness-Roddam 1991). Elevated creatine phosphokinase levels have been associated with DOMS and Marlin *et al.* (1995) have found elevated creatine phosphokinase at twice basal level 16 h post-completion of phase D of speed and endurance day.

The DOMS model fits the observed changes in gait pattern. With DOMS, a decreased range of motion could be expected (MacIntyre *et al.* 1995). Therefore the horses may have found it more efficient or comfortable to use a lower stride length and duration to achieve the same velocity on the third inspection. From studies in human running it has been proposed that long strides require considerable power during propulsion, result in excessive vertical oscillation of the centre of mass, produce a foot-strike position which creates large braking forces, and require joint ranges of motion which invoke increased internal friction and stiffness (Anderson 1996). After strenuous exercise the expectation would be that the horse would attempt to minimise the effect of these factors.

The relatively long time period for recovery in this study (16-18h post-exercise) may explain the limited changes in the temporal patterns observed between the inspections. The temporal patterns for individual horses were consistent between



inspections even to the level of maintaining a similar degree of measured laterality between diagonal limb pairs. This consistency tends to add weight to the observation of previous authors that temporal patterns appear to be resistant to change.

At both examinations the horses demonstrated a lower than expected retraction percentage. Overall values were less than the parameters previously published for warmblood horses on a sand surface (Holmstrom *et al.*, 1994). Retraction time as a percentage of stride may have been altered due to the asphalt surface. However, the findings of Buchner *et al.*, (1994) tends to discount this theory. A more likely possibility may be related to a breed effect. The horses in this study were predominantly Thoroughbreds or of Thoroughbred type whereas Holmstrom *et al.*, (1993) was using Swedish Warmblood horses. Thoroughbreds have been described as having a long low gait, this type of gait pattern could account for the decreased retraction time. A long low gait may have a reduced retraction component when compared to the rounder and higher knee action of the warmblood.

A reduction in retraction time was observed between the first and the third inspection. Pratt and O'Connor (1978) proposed that with fatigue in racing thoroughbreds there is a reduced amount of time available for retraction. In our study there was a reduction in both retraction time and as a percentage of stride. The reduction in time would be a direct effect of the reduced stride duration observed during the third inspection. However, the reduction in retraction percentage may be related to the shorter stride length due to DOMS. With a decreased range of motion the limb would not be protracted to the same extent and so retraction as a percentage of the stride duration would be reduced due to the shorter distance to cover.

The third veterinary inspection was characterised by lower stride length and duration to obtain the same velocity. Temporal patterns of most variables measured remained consistent between inspections. Only retraction and overlap percentage decreased between the first and third inspection. The consistency of

most temporal variables implies that these variables are resistant to the effect of external influences even after strenuous exercise.

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**Chapter 7 Kinematic examination of the trot in t hree day  
event horses during the preliminary horse inspection at a  
CCI\*\*\* three day event.**

## Abstract

The kinematics of six horses presented during the preliminary horse inspection at a CCI\*\*\* three day event are examined. The six horses trotted with a mean velocity of  $3.94 \pm 0.22 \text{ m.s}^{-1}$ . Displacement, velocity and acceleration data are presented for the X, Y and Z axes. Larger than expected vertical displacement values for the central body marker and fore and hindlimbs are presented as evidence that during the preliminary horse inspection, three day event horses trot with a more animated action. This finding could be due to a combination of the atmosphere of the competition environment and the high level of fitness. The greater horizontal ( $1.129 \pm 0.103 \text{ m}$  vs  $1.108 \pm 0.05 \text{ m}$ ) and vertical displacement of the forelimbs ( $0.221 \pm 0.027 \text{ m}$  vs  $0.159 \pm 0.05 \text{ m}$ ) to the hind limbs are presented as evidence of dressage training.

## Introduction.

The in-hand trot is commonly used for lameness inspections and is used for the first and third horse inspections at three day event competitions. The objective of the horse inspections at a three day event is to ensure that the horse is fit and sound, and therefore able to progress on to the next stage of the competition. To date the 3 dimensional kinematics of the trot of event horses during the horse inspection has not been examined.

In Dutch warmblood horses, the differences between the kinematics of the forelimbs and hindlimbs have been proposed as a contributing factor for the greater incidence of lameness seen in the forelimbs rather than the hindlimbs (Back *et al.* 1995).

Previous studies of three day event horses during the horse inspection had identified horse specific temporal patterns (Chapter five) and have shown that these temporal patterns were consistent between the first and third horse inspections after the horses had completed the speed and endurance day (chapter six). Between the first and third inspection the horses had a decrease in stride

length and stride duration. Of the temporal measurements only retraction time measured as a percentage of stride decreased between inspections. The decrease in retraction time was greatest in the forelimbs. These changes in gait pattern between the first and third inspections may have been as a result of soreness from concussion received by the forelimbs during speed and endurance day. However, before one tests such an hypothesis it is important to quantify the normal kinematics of event horses during the horse inspection. This chapter examines the difference between the distal kinematics of the fore and hind limbs of six event horses performing an 'in-hand' trot during the first horse inspection at a CCI\*\*\* three day event.

## Materials and Methods

Twenty-four horses (23 geldings, 1 mare) were filmed during the initial horse inspection at the 1995 CCI\*\*\* National Three-Day Horse Trials Championships, Taupo, New Zealand. The horses were presented 'in-hand' by their regular riders on a specially prepared asphalt surface. Linear and temporal measurements were made of the 'in-hand' trot of this group (chapter five). Based on these measurements six horses were selected for kinematic analysis. To identify the horses and the strides for analysis, initial screening was based on consistency of velocity. A subset of horses was identified. Within this subset, strides of interest were identified based on the criteria that there were no changes in locomotor pattern two strides before or one stride after the stride of interest. This resulted in the selection of six CCI\*\*\* event horses ( $12.3 \pm 2.4$  years) trotting with a mean velocity of  $3.94 \pm 0.22 \text{ m.s}^{-1}$ .

The filming technique consisted of two 50 Hz S-VHS video cameras<sup>1,2</sup> with a 1/1000 second exposure rate. The cameras were positioned to bisect at 90 degrees. A panning lateral view camera was positioned 17.5m from the ground reference plane with the horses passing in a medial plane  $1.10 \pm 0.17 \text{ m}$  from the ground reference plane. A stationary anterior view camera was positioned at a focal

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<sup>1</sup> Panasonic MS-4, Matsushita Electrical Industrial Company Ltd, Osaka, Japan

<sup>2</sup> Panasonic XD S-VHS 180 video tape, Matsushita Electrical Industrial Company Ltd, Osaka, Japan



distance of 30m from the centre of the calibration zone. Both cameras were set to have a lens height of 1.2m (Clayton 1990).

In this competition environment it was not possible to film both the horses and the reference points simultaneously. To solve this problem the reference markers for the calibration zone were subsequently filmed after the horses were presented at the initial horse inspection. From this reference marker footage, calibration templates were developed and were then subsequently over-laid on to the horse footage.

The calibration zone consisted of 15 prefabricated sports cones (142mm x 230mm) placed at 1m intervals at the edge of the trot-up track after the horse inspection. A black line (4 mm thick) was marked on the cone to bisect it, to improve the accuracy of cone placement and subsequent calibration.

Analogue video footage was converted to digital images using a Apple MacIntosh<sup>TM1</sup> computer with a RasterOps Mediagrabber<sup>TM2</sup> digitising card connected to a S-VHS video recorder<sup>3</sup>. Initiation of the stride of interest was when the left forelimb initiated stance phase. This was when there was an observed change of fetlock angle in the lateral view and, as a decrease in the observed distance of the fetlock to the ground in the anterior view.

Template development and measurement were performed within Claris Draw<sup>TM1</sup>. Horse specific body templates were developed to define reference points from images when the left foreleg was at mid stance and perpendicular to the ground reference plane. Templates were developed for the head, body and the hooves. Trajectories were measured in relation to the ground reference plane and to the central body marker. The head and hoof templates identified a central reference site in each template. This was obtained by finding the point of intersection of lines bisecting the X and Y axis. The use of a central reference point for each template permitted combination of trajectory information from the lateral view with transverse angular deviation data (Z axes) from the anterior view. The torso

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<sup>1</sup> Apple Computer Inc, 1 Infinite loop, Cupertino California, USA

<sup>2</sup> RasterOps Corporation, 890 west 410 North Lindon Utah, USA

<sup>3</sup> Panasonic NV-FS88 HQ, Matsushita Electrical Industrial Company Ltd, Osaka, Japan

template reference point was designed to represent the stationary horses centre of mass (Sprigings and Leach 1986; van den Bogert A J 1989). The torso Y co-ordinate was a location that bisected a line drawn from the point of the withers to the sternum. The X axis location was the point  $\frac{1}{3}$  the distance from the point of shoulder (cranial part of greater tuberosity of humerus) to the point of buttock (tuber ischii). An outline of the torso was combined with the reference grid to provide a mechanism for consistent placement.

A 1m x 1m calibration board was used to derive equations to correct for differences in focal distance. For the lateral view, calibration templates were developed from the ground reference marker footage. The calibration templates were then over-laid on to the frames containing the strides of interest.

To minimise the possibility of measurement bias for each field three separate measurements were made of the co-ordinates in both the fields of view.

The absolute difference in timing between the lateral and anterior cameras could be as large as 6.8%. It is believed that this potential error is primarily a product of the low sampling rate (50Hz) a camera synchronising mechanism may have contributed in reducing the maximum potential temporal error associated with combining trajectory data from the two camera sources.

The inability to accurately determine the focal distance for the anterior camera limited the spatial information that this view could provide. Length measurements could not be made from this view. However an acceptable level of precision was possibly with the angle measurements. Parallax error was not found to contribute to distortion of the angle measurements in the anterior view. Maximum error in angle measurement was estimated to be 1.07 degrees. Perspective errors were estimated by use of a 1m x 1m calibration board. Correction factors were derived to solve for differences in focal distance between the horse's path of progression and the sagittal plane of the reference markers.

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<sup>1</sup> ClarisDraw, Claris Corporation, 5201 Patrick Henry Drive, Santa Clara, Claifornia, USA

Raw data points were transformed using a customised macro within MS Excel. These data points were then smoothed with a generalised cross-validated quintic spline (Woltring H J 1986) and normalised using the numerical differentiation software QuickSAND (Walker J A 1997).

#### Statistical analysis

A general factorial linear model was used to test for differences between variables. In the models, leg pair code (forelimb or hindlimb) was included as a fixed effect and horse identification was included as a random effect. Statistical tests were performed using SPSS™ version 8.01<sup>1</sup>.

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<sup>1</sup> SPSS Inc, Chicago, Illinois, USA

## Results.

**Table 7-1 Temporal descriptive stride statistics of the preliminary inspection for the fore- and hindlimb pairs (mean±standard deviation, n=6).**

	Forelimbs	Hind limbs	Significance
Stride duration (ms)	646±26	666±23	n/s
Stance duration (ms)	215±19	205±19	n/s
Stance duration (%) <sup>*</sup>	33.24±2.58	30.97±2.93	n/s
Swing duration (ms)	431±23	461±18	P<0.01
Swing duration (%)	67.02±2.35	69.28±2.34	n/s
Retraction (ms)	70±10	58±5	P<0.001
Retraction (%) <sup>*</sup>	10.50±1.48	8.74±1.63	P<0.001

Note these variables are measured as a percentage of total stride duration.

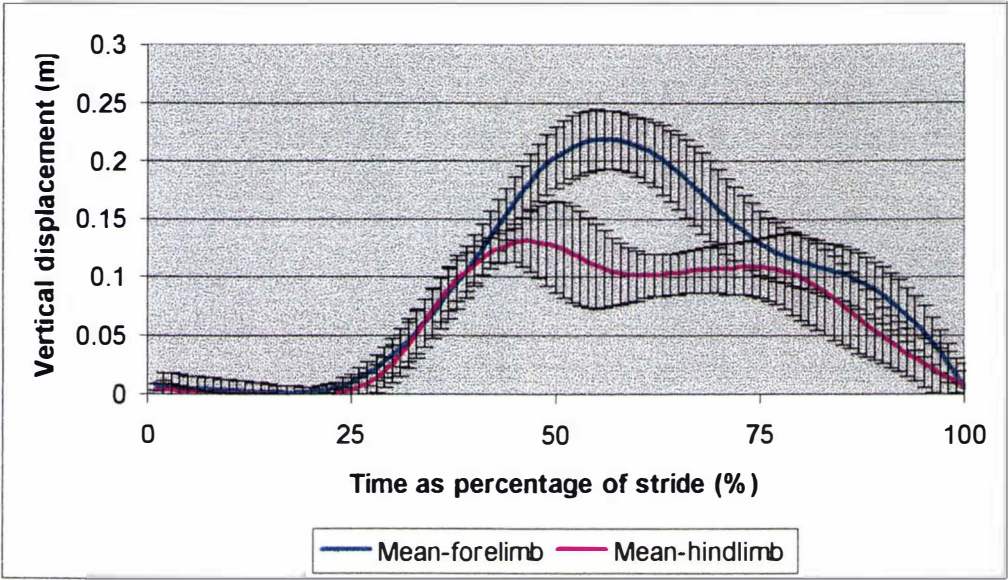
Differences were observed between the temporal values of the fore- and hindlimb pairs (Table 7-1). Significant differences were only found for the swing phase measurements. These included swing duration (ms) and for retraction when measured as either milliseconds or as a percentage of total stride duration.

**Table 7-2 Maximum displacement variables in the preliminary inspection for range of movement for the fore and hind limb pairs (mean±standard deviation, n=6)**

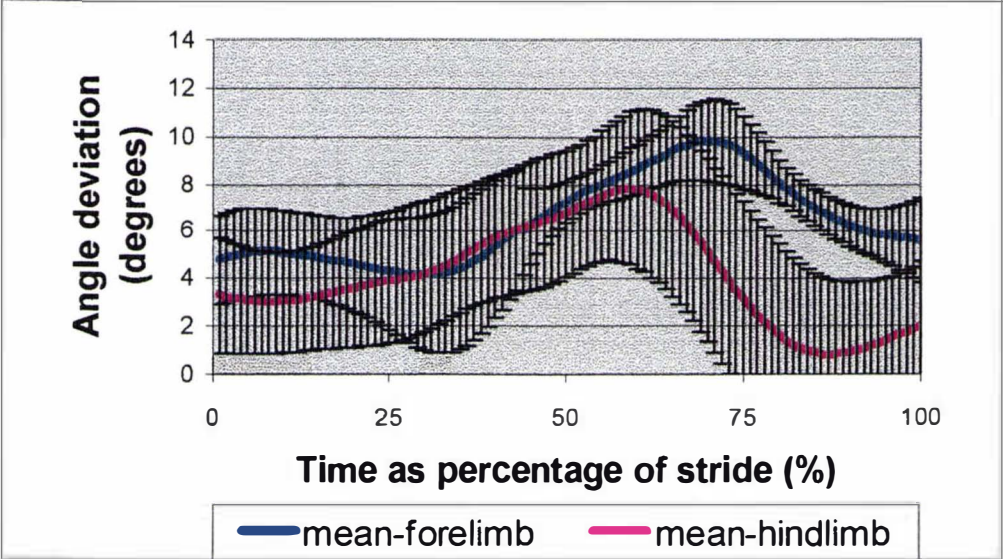
	Forelimbs	Hind limbs	Significance level
X: Horizontal (m)	1.129±0.103	1.108±0.05	P<0.091
Y: Vertical(m)	0.217±0.027	0.156±0.018	P<0.001
Z: Angle (degrees)	7.4±2.4	8.1±3.5	n/s

Significant differences were found between the fore-and the hindlimb pairs for the range of movement in the horizontal and vertical axis. The forelimbs had a larger range of movement in the vertical and horizontal plane but it was the hind limbs that had the greatest degree of medial to lateral movement in the anterior view.

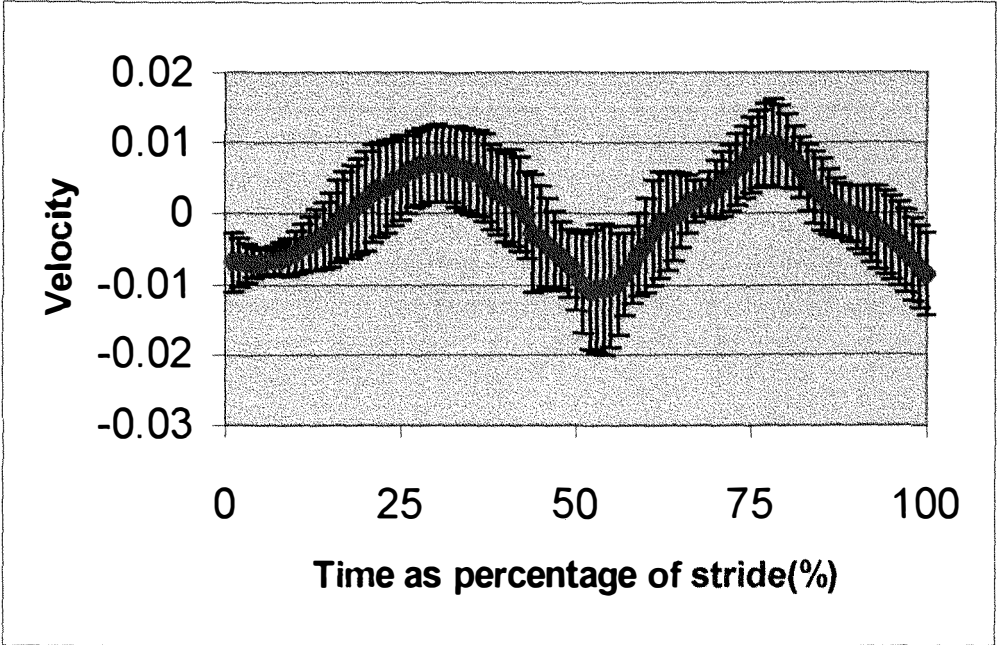
**Figure 7-1** Plot of fore- and hindlimb vertical trajectories for the preliminary horse inspection (mean±standard deviation, n=6)



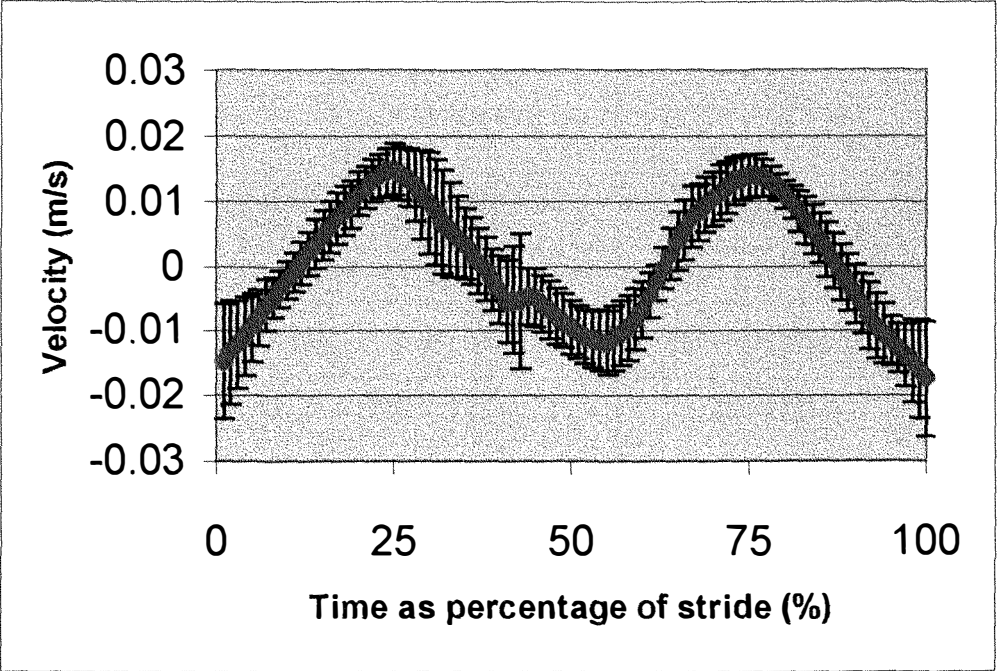
**Figure 7-2** Plot of fore- and hindlimb transverse trajectories for the preliminary horse inspection (mean±standard deviation, n=6).



**Figure 7-3** Plot of head vertical velocity for the preliminary horse inspection (mean±standard deviation, n=6).



**Figure 7-4** Plot of body vertical velocity for the preliminary horse inspection (mean±standard deviation, n=6).



**Table 7-3 Mean displacement variables for the head (mean±standard deviation, n=6)**

	Length <sup>a</sup> (m)	Vertical (m)	Transverse Angle (degrees) <sup>b</sup>
Maximum	1.231±0.0604	1.752±0.090	96.97±19.33
Minimum	1.177±0.076	1.670±0.087	85.365±17.5806
Range of motion	0.053±0.018	0.082±0.013	11.606±3.47

**Note**<sup>a</sup>. This measurement is the distance from torso body marker to the head body marker.

<sup>b</sup> This measurement is the anterior view angle from the torso marker to the head marker. 90 degrees represents the head held directly in the same plane as the centre of the torso.

Head position was relatively constant throughout the stride for the length and vertical measurements (Table 7-3). However, there was greater than expected transverse movement of the head throughout the stride cycle.

**Table 7-4 Mean displacement variables for the central torso marker (mean±standard deviation, n=6)**

	Vertical (m)
Maximum vertical displacement	1.339±0.039
Minimum vertical displacement	1.243±0.037
Vertical range of movement	0.096±0.018

Vertical deviation of the central torso marker (Table 7.4) was similar to the vertical deviation of the head (Table 7-3) as anticipated. The velocity curves of the body and head were also similar (Figure 7-3, 7-4).

The forelimbs exhibited a greater vertical displacement than the hindlimbs ( $0.061\pm0.004$ ,  $p<0.001$ ) and achieved their peak vertical displacement later than the hindlimbs ( $7\pm0.691\%$ ) (Figure 7-2, Table 7-2). In contrast to the timing of the vertical maximum, there is large variation in the timing of the maximum deviation from the median line (Figure 7-2). There was no significant difference between forelimbs and hindlimbs for maximum deviation from the median line or time of maximum deviation from the median line.

Differences in the timing of the hoof maximum values for the Y (vertical) and Z (transverse) axes was examined with a paired students t-test. Significant

differences were found between the time of the two maxima ( $-5.3472 \pm 10.1581$ ,  $p < 0.001$ ).

**Table 7-5 Standardised displacement and timing measurements. All temporal values have been standardised for onset of stance phase as the initiation of the stride (mean  $\pm$  standard deviation,  $n=6$ ).**

Limb	Variable	Vertical displacement (m)	Z max (degrees from median line)
Left	Maximum value	$0.219 \pm 0.025$	$9.12 \pm 1.62$
forelimb	% of stride time at maximum	$55.38 \pm 2.72$	$62.22 \pm 8.43$
Right	Maximum value	$0.223 \pm 0.029$	$5.763 \pm 2.048$
forelimb	% of stride time at maximum	$52.88 \pm 5.46$	$54.83 \pm 15.30$
Left	Maximum value	$0.169 \pm 0.010$	$7.89 \pm 3.67$
hindlimb	% of stride time at maximum	$49.38 \pm 1.88$	$55.33 \pm 5.83$
Right	Maximum value	$0.154 \pm 0.024$	$8.40 \pm 3.11$
hindlimb	% of stride time at maximum	$44.88 \pm 1.99$	$53.27 \pm 9.20$

Minimum horizontal velocity occurred during the stance phase and was not significantly different between the fore- and hindlimbs but did differ in the time of minimum velocity occurrence ( $p < 0.05$ ). This could be a real difference but also may be a reflection of the system's background measurement error.

Maximum longitudinal velocity was also similar between fore -and hindlimbs but did differ in the timing of the maximum. Maximum longitudinal velocity occurred earlier in the hindlimbs but again there was variation in the timing.

Vertical velocity differed between the fore- and hindlimbs for all variables measured. Forelimbs reached both the minimum and maximum values earlier in the stride than the hind limbs. For both the fore- and hindlimbs maximum vertical velocity occurred prior to maximum longitudinal velocity.

Relatively large standard deviations were again observed for the transverse axis. Minimum velocity (maximum adduction) was observed in the later stages of the stride. This minimum occurred later in the stride for the forelimb than the hindlimb. In the forelimbs maximum transverse velocity was observed as the limb was being abducted prior to the maximum vertical velocity.



**Table 7-6 Standardised velocity and timing measurements. All temporal values standardised for onset of stance phase as the initiation of the stride (mean±standard deviation, n=6).**

Horizontal velocity	Forelimbs	Hindlimbs	Significance
Minimum Value (m.s <sup>-1</sup> )	-0.42±0.67	-0.40±0.37	n/s
Min value timing	16.72±10.90	7.77±12.49	P<0.05
Maximum Value (m.s <sup>-1</sup> )	6.55±0.66	6.58±0.96	n/s
Max Value timing*	63.50±11.51	56.61±7.81	P<0.05
Vertical velocity			
Minimum Value (m.s <sup>-1</sup> )	-1.06±0.34	-0.85±0.26	P<0.001
Min value timing*	93.05±11.20	92.94±5.49	n/s
Maximum Value (m.s <sup>-1</sup> )	1.14±0.19	1.20±0.18	P<0.05
Max Value timing*	40.19±2.68	36.44±3.87	P<0.001
Transverse velocity			
Minimum Value (°.s <sup>-1</sup> )	-21.46±13.22	-45.93±17.31	P<0.001
Min value timing*	86.16±12.38	77.63±10.63	P<0.001
Maximum Value (°.s <sup>-1</sup> )	24.03±12.88	27.53±8.20	n/s
Max Value timing*	41.55±10.78	38.13±12.93	n/s

Note. \*Timing values are measured as a percentage of standardised stride time with stride starting at onset of stance phase.

Minimum and maximum acceleration for both the fore and hindlimbs occurred at similar times during the stride. Minimum horizontal acceleration was in the last quarter of the stride whereas maximum acceleration occurred at approximately 40% of stride time before the maximum for horizontal velocity.

Maximum vertical acceleration occurred before the horizontal maximum but timing between fore- and hindlimbs was not significantly different. Vertical acceleration was significantly larger in the hindlimbs in contrast to acceleration in the other two axis where there was not a significant difference in maximum acceleration.

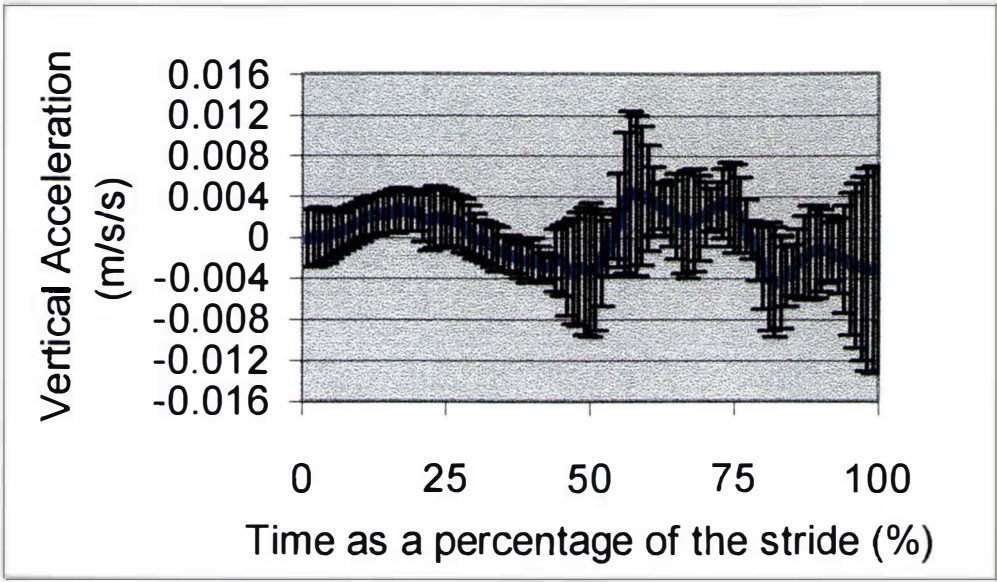
Similar to the velocity measurements the acceleration for the medial lateral deviation had the minimum value in the later part of the stride during abduction

and the maximum acceleration during the initiation of swing phase during adduction.

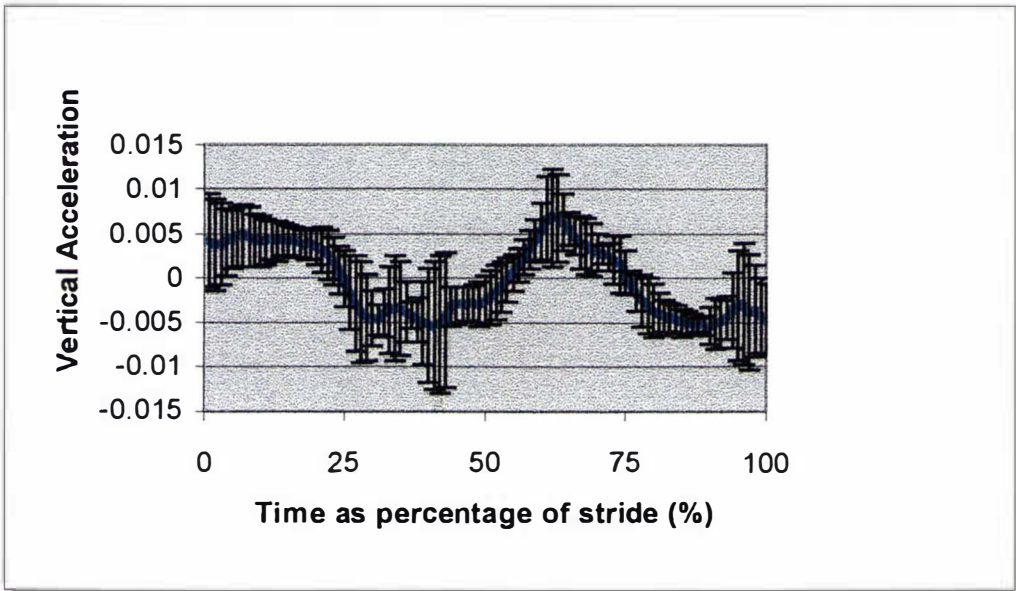
**Table 7-7 Standardised acceleration and timing measurements. All temporal values standardised for onset of stance phase as the initiation of the stride (mean±standard deviation, n=6).**

<b>Horizontal acceleration (<math>\text{ms}^{-2}</math>)</b>	<b>Forelimbs</b>	<b>Hindlimbs</b>	<b>Significance</b>
Minimum value ( $\text{m.s}^{-2}$ )	-41.62±26.08	-37.91±15.68	n/s
Min value timing (% stride)	87.66±6.43	87.50±11.01	n/s
Maximum value ( $\text{m.s}^{-2}$ )	37.32±15.02	43.34±19.70	n/s
Max Value timing (% stride)	40.33±3.41	39.66±6.95	n/s
<b>Vertical acceleration (<math>\text{ms}^{-2}</math>)</b>			
Minimum value ( $\text{m.s}^{-2}$ )	-9.83±5.28	-11.49±1.99	P<0.05
Min value timing (% stride)	74.97±17.38	79.97±6.58	P<0.069
Maximum value ( $\text{m.s}^{-2}$ )	9.16±3.58	14.75±6.12	P<0.001
Max Value timing (% stride)	29.30±4.92	31.86±14.67	n/s
<b>Transverse acceleration (<math>^{\circ}.\text{s}^{-2}</math>)</b>			
Minimum value ( $^{\circ}.\text{s}^{-2}$ )	-351.06±233.28	-563.98±306.93	P<0.01
Min value timing (% stride)	75.69±11.73	76.88±14.65	n/s
Maximum value ( $^{\circ}.\text{s}^{-2}$ )	378.86±185.24	423.80±218.24	n/s
Max value timing (% stride)	38.66±10.03	38.11±10.21	n/s

The vertical acceleration for the body and head were similar displaying the same bimodal shape as the displacement and velocity plots (Figure 7-5, 7-6)..



**Figure 7-5** Plot of head vertical acceleration for the preliminary horse inspection (mean±standard deviation, n=6).



**Figure 7-6** Plot of mean body vertical acceleration for the preliminary horse inspection (mean±standard deviation, n=6).

## Discussion

The vertical and horizontal range of motion in this study were consistent with previous findings in warmblood horses (Back 1994; Holmstrom *et al.* 1994). The horizontal and vertical displacements were greater than those found for Dutch warmblood horses on a treadmill and were in close agreement with the trajectories reported for Swedish warmbloods. This result was unexpected. The expectation was that the horses would have had a longer lower trajectory as the thoroughbred has often being described as has a long low gait or “daisy cutter style” and that the event horses in this study were presented on an asphalt surface. Temporal analysis of the preliminary inspection had identified the event horses were taking longer than expected stride lengths considering presentation was on an asphalt surface (Chapter Five). A breed effect was proposed as a contributing factor to this as the event horses tend to be thoroughbred or of thoroughbred somatotype. However, as previously mentioned if it were solely due to a breed effect then the vertical displacement value would be expected to be less than that observed for the warmblood type horse which is believed to have a rounder and higher knee action.

A possible explanation for the greater displacement may be found in the presentation of the horses for the horse inspection. Many riders make a conscious effort to present the horses at the inspection trotting “freely” in-hand. Before the inspection many riders work-in their horses to ensure they are thoroughly warmed up. At the preliminary inspection the horses are also very fit and fresh in preparation for the demands of speed and endurance day and this may be translated into a trot that is more exuberant than normal. Evidence for this can be found by comparison of the vertical displacement of the body marker and the vertical displacement of the withers measured in Dutch warmblood horses on a treadmill, rubber surface and asphalt (Buchner *et al.* 1994). The event horses had a vertical displacement of  $0.096 \pm 0.018\text{m}$ , whereas in the Dutch study the vertical displacement ranged from  $0.061 \pm 0.017$  to  $0.079 \pm 0.008\text{m}$ . In a less tense environment and when not at the peak of fitness these horses would probably display a trot with reduced displacement.

One of the objectives of training the horse for dressage is to teach the horse to work in a balanced fashion with engagement of the hind limbs (Crossley, A. 1993). Previous temporal analysis of the preliminary horse inspection had identified that the hindlimb initiated stance first of the diagonal limb pairs. This was believed to represent the engagement of the hind legs (Chapter Five). Another pattern used to recognise this is that the forelegs should describe a larger trajectory than the hind legs (Paalman 1988) and has been observed in elite Swedish warmblood stallions (Holmstrom *et al.* 1993). This was observed in this sample of three day event horses and may represent the level of dressage training attained by these horses. The larger displacements of the forelimbs may also indicate that the horse used for CCI\*\*\* eventing do not have the long low gait so often used to describe the thoroughbred action. It is often said that when selecting a jumping horse it is preferable to have a horse that has “a bit of knee action” (Steinkraus 1987). Because of this riders may have selected for horses that had a larger forelimb hoof trajectory.

In contrast to the larger displacement of the forelimbs in the horizontal and vertical axes there was larger displacement in the transverse plane of the hindlimbs which may have been a necessity to avoid brushing of the hind limbs. Trotting wide behind (excessive lateral movement of the distal hind limb during progression) is commonly thought of as a fault of movement and / or training (Klimke 1985). Horses that normally move well will trot “wide behind” when in an excited state. Similar to the larger than expected vertical displacement the larger than expected transverse displacement may also be due to the horses becoming tense with the competition environment and exuberance from being very fit.

The issue of how much transverse swing is normal and what constitutes poor movement has not been defined with gait analysis. Certainly sport horses and dressage horses in particular are generally selected to have “straight movement”. In this study during protraction of the limb, adduction and then abduction of the limb were observed. Perspective error while small may have contributed to this observation due to the protracting limb having a reduced distance between the central body marker and hoof marker. The reduced distance can have a

distorting effect on the true angular displacement and provide a positive bias in the abduction measurements. In human gait abduction and adduction of the limb are one of the mechanisms used to minimise the amount of displacement of the centre of mass (Saunders *et al.* 1953). In horses it has been observed that the height of the withers during the trot is lower than the height of the withers when the horse is stationary (Back 1994). The use of adduction and abduction during protraction and placement of the limb under the median line of the horse is one of the mechanisms to achieve this. While tension of the horses in this study and measurement technique may account for some of the observed adduction and abduction, a limited amount of transverse movement during limb progression may be required. Limited transverse deviation in equine gait must be an inevitability of the initial forces that act on the distal limb during progression.

### **Conclusion:**

The larger than expected trajectories for the fore and hindlimbs in this sample of event horses may have been due to tension due to the fitness level of the horses and the competition atmosphere. It is also possible that the horses used for eventing in New Zealand even though are thoroughbred or of thoroughbred somatotype do not display the long low gait often used to describe the thoroughbred action. These factors must be taken into consideration by the inspection panel when assessing the horses.

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**Chapter 8 Comparison of the Kinematics of the trot in  
three day event horses between the first and third horse  
inspections at a CCI\*\*\* three day event.**

## Abstract

The kinematics of the trot of a group of six event horses ( $12.3 \pm 2.4$  years) during the first and third horse inspections at a CCI\*\*\* three day event competition were compared. The horses trotted with a mean velocity of  $3.94 \pm 0.22 \text{ m.s}^{-1}$  during the first inspection and  $4.14 \pm 0.15 \text{ m.s}^{-1}$  during the third inspection. During the third inspection a greater range of motion was observed in the hoof trajectories. The horses carried their heads higher during the third inspection ( $1.752 \pm 0.090 \text{ m}$  vs  $1.796 \pm 0.091 \text{ m}$ ,  $P < 0.05$ ) possibly to reduce the minimum vertical acceleration on the forelimbs ( $-9.83 \pm 5.28 \text{ m.s}^{-2}$  vs  $-9.09 \pm 3.17 \text{ m.s}^{-2}$ ,  $P < 0.05$ ).

Significant differences were found for most variables between inspections. However, the differences were not large, indicating that the effect of the exertion of speed and endurance day on the kinematics of this group of horses was subtle.

## Introduction.

Horse inspections are an integral part of any three-day event competition. Three inspections are performed during the competition. The first inspection is on day one prior to the dressage. The second inspection takes place on day 2 (speed and endurance day) at the end of phase C. A third inspection is performed on the morning of day 3 prior to the show jumping. Both the first and third veterinary inspections are performed using a standardised format with the horses trotted up on a firm, level surface (Anon 1998). Examination of the linear and temporal patterns of three day event horses during the first (Chapter Five) and first and third horse inspections (Chapter Six) has been performed. However, to date examination of the changes in the kinematics of the trot of event horses between the first and third horse inspections has not been performed.

In Dutch warmblood horses the differences between the kinematics of the forelimbs and hindlimbs have been proposed as a contributing factor for the

greater incidence of lameness seen in the forelimbs rather than the hindlimbs (Back *et al.* 1995).

In previous studies of three day event horses at the horse inspection, horse specific temporal patterns were identified (Chapter Five). These temporal patterns were consistent between the first and third horse inspections after the horses had completed speed and endurance day (Chapter Six). Between the first and third inspection the horses had a decrease in stride length and stride duration. Of the temporal measurements only retraction time measured as a percentage of stride decreased between inspections. The decrease in retraction time was greatest in the forelimbs. This may have been as a result of the increased concussion received by the forelimbs during speed and endurance day. This paper examines the changes in the kinematics of the fore- and hind limbs of six event horses performing an 'in-hand' trot during the first and third horse inspections at a CCI\*\*\* three day event.

## Materials and Methods

Twenty-four horses (23 geldings, 1 mare) were filmed during the initial horse inspection at the 1995 CCI\*\*\* National Three Day Horse Trials Championships, Taupo, New Zealand. The horses were presented 'in-hand' by their regular riders on a specially prepared asphalt surface. Linear and temporal measurements were made of the 'in-hand' trot of this group (Chapter six). Based on these measurements, 6 horses were selected for kinematic analysis. To identify the horses and the strides for analysis, initial screening was based on the consistency of velocity during each inspection and between the inspections. A subset of horses was identified. Within this subset, strides of interest were identified based on the criteria of that were no changes in locomotor pattern two strides before or one stride after the stride of interest. This resulted in the selection of six CCI\*\*\* event horses ( $12.3 \pm 2.4$  years) trotting with a mean velocity of  $3.94 \pm 0.22 \text{ m.s}^{-1}$  for the first inspection and  $4.14 \pm 0.15 \text{ m.s}^{-1}$  for the third inspection.

The method used to obtain the data and transform the data points into displacement, velocity and acceleration values is the same as has been previously described in Chapter Seven.

### Statistical analysis

A paired t-test was used to compare values between the two inspections. When examining for an interaction of the variable and inspection effect a repeated measures general linear model was used. Inspection day and leg code were treated as main effects and, horse identification was included as a random effect in the model. Statistical tests were performed using SPSS™ version 8.01<sup>1</sup>.

## Results.

**Table 8-1 Temporal descriptive stride statistics for the fore- and hindlimbs pairs (mean±standard deviation, n=6).**

	Forelimbs		Hind limbs		Significance
	1 <sup>st</sup> Inspection	3 <sup>rd</sup> Inspection	1 <sup>st</sup> Inspection	3 <sup>rd</sup> Inspection	
Stride duration (ms)	666±23 <sup>a</sup>	640±0.20 <sup>b</sup>	666±23 <sup>a</sup>	644±0.20 <sup>b</sup>	P<0.05
Stance duration (ms)	220±19 <sup>a</sup>	213±19	205±19 <sup>b</sup>	200±28	P0.05
Stance duration (%) <sup>*</sup>	32.98±2.35 <sup>a</sup>	33.31±2.58 <sup>a</sup>	30.97±2.93 <sup>b</sup>	31.00±3.88 <sup>b</sup>	P<0.05
Swing duration (ms)	446±19 <sup>a</sup>	436±20 <sup>d</sup>	461±18 <sup>b</sup>	453±20 <sup>d</sup>	P<0.05
Swing duration (%)	67.02±2.35	66.85±2.42	69.28±2.34	69.00±3.88	n/s
Retraction (ms)	70±10 <sup>a</sup>	46±13 <sup>c</sup>	58±5 <sup>b</sup>	44±8 <sup>d</sup>	P<0.001
Retraction (%) <sup>*</sup>	10.50±1.48 <sup>a</sup>	7.30±2.07 <sup>c</sup>	8.74±1.63 <sup>b</sup>	6.85±1.42 <sup>d</sup>	P<0.001

<sup>\*</sup>Note These values are measured as a percentage of stride time.

Different superscripts represent values that are significantly different

Stride duration decreased for the strides examined during the third inspection (Table 8-1). Stance time also decreased between inspection days, but increased when measured as a percentage of total stride time. Differences in stance as a

<sup>1</sup> SPSS Inc, Chicago, Illinois, USA

percentage of stride were only found between the fore and hindlimb pairs.

Retraction when measured as time and as a percentage of stride duration decreased on the third inspection. Consistently across inspections, retraction time and its percentage of stride was greater in the forelimbs than the hindlimbs.

**Table 8-2 Mean displacement of hooves for range of movement for the fore- and hindlimb pairs (mean±standard deviation, n=6)**

	Forelimbs		Hind limbs		Significance level
	1 <sup>st</sup> Inspection	3 <sup>rd</sup> Inspection	1 <sup>st</sup> Inspection	3 <sup>rd</sup> Inspection	
Longitudinal (m)	1.129±0.103 <sup>a</sup>	1.190±0.104 <sup>c</sup>	1.108±0.05 <sup>b</sup>	1.130±0.08 <sup>d</sup>	P<0.05
Vertical(m)	0.217±0.027 <sup>a</sup>	0.235±0.023 <sup>c</sup>	0.156±.0018 <sup>b</sup>	0.187±0.038 <sup>d</sup>	P<0.001
Transverse Angle (degrees)	7.4±2.4 <sup>a</sup>	5.6±1.4 <sup>b</sup>	8.1±3.5 <sup>c</sup>	8.0±2.3 <sup>c</sup>	P<0.05

Different superscripts represent values that are significantly different.

In the longitudinal and vertical axes, a greater range of motion was observed during the third inspection than during the first inspection. In contrast, the transverse range of motion decreased from the first to the third inspection.

Range of motion was consistently greater across days in the forelimbs than the hindlimbs for the longitudinal and vertical measurements. In contrast, the transverse deviation of the range of motion was greater in the hindlimbs.

**Table 8-3 Mean displacement variables for the head (mean±standard deviation, n=6)**

	Length <sup>a</sup> (m)		Vertical (m)		Transverse Angle (degrees)	
	1 <sup>st</sup> Inspection	3 <sup>rd</sup> Inspection	1 <sup>st</sup> Inspection	3 <sup>rd</sup> Inspection	1 <sup>st</sup> Inspection	3 <sup>rd</sup> Inspection
Maximum	1.231±0.060	1.250±0.09	1.752±0.09 <sup>a</sup>	1.796±0.091 <sup>b</sup>	96.97±19.33 <sup>a</sup>	84.00±12.32 <sup>b</sup>
Minimum	1.177±0.076	1.209±0.0825	1.670±0.087 <sup>a</sup>	1.6965±0.09 <sup>b</sup>	85.36±17.58 <sup>a</sup>	76.59±10.12 <sup>b</sup>
Range of motion	0.053±0.018	0.05±0.015	0.082±0.013 <sup>a</sup>	0.099±0.013 <sup>b</sup>	11.60±3.47	9.44±4.21

<sup>a</sup> Note. This measurement is the distance from torso body marker to the head body marker.

Different superscripts represent values that are significantly different (P<0.05).

During the third inspection, the horses had a larger minimum and maximum X displacement of the head. During the third inspection, the head had a greater maximum and minimum value for displacement from the ground reference plane. The head was also held in a different lateral position in relation to the sagittal plane. During the first inspection, the horses tended to have their heads positioned centrally or positioned away from the handler, whereas the third inspection was characterised by the horses having their heads inclined towards the same side as the handler.

**Table 8-4 Mean displacement variables for the central body marker (mean±standard deviation, n=6)**

	1 <sup>st</sup> Inspection	3 <sup>rd</sup> Inspection	Significance level
	Y vertical	Y vertical	
Maximum vertical displacement	1.339±0.039	1.350±0.033	n/s
Minimum vertical displacement	1.243±0.037	1.249±0.040	n/s
Vertical range of movement	0.096±0.017	0.101±0.026	n/s

**Table 8-5 Standardised displacement and timing measurements for hooves. All temporal values standardised for onset of stance phase as the initiation of the stride.**

Leg	Variable	Vertical displacement			Z max (degree from median line)		
		(m)		Significance			Significance
		1 <sup>st</sup>	3 <sup>rd</sup>		1 <sup>st</sup>	3 <sup>rd</sup>	
Left Fore	Maximum value (m)	0.219±0.025	0.238±0.029	P<0.002	9.12±1.62	5.76±1.24	P<0.004
	% of stride time at maximum	55.38±2.72	55.00±4.45	n/s	62.22±8.43	61.38±7.35	n/s
Right Fore	Maximum value (m)	0.223±0.029	0.231±0.023	P<0.192	5.76±2.048	5.56±1.50	P<0.03
	% of stride time at maximum	52.88±5.46	56.22±3.02	P<0.042	54.38±16.26	71.72±14.95	P<0.023
Left Hind	Maximum value (m)	0.169±0.010	0.171±0.013	n/s	7.89±3.67	8.67±1.96	n/s
	% of stride time at maximum	49.38±1.88	51.77±8.50	n/s	55.33±5.83	58.50±14.82	n/s
Right Hind	Maximum value (m)	0.154±0.02	0.156±0.01	n/s	8.40±3.11	7.35±2.53	n/s
	% of stride time at maximum	44.88±1.99	48.33±8.66	n/s	53.27±9.20	53.88±5.87	P<0.07

Consistent with observations from the first inspection, the forelimbs exhibited greater vertical displacement than the hindlimbs (Table 8-5). Vertical displacement was greater during the third inspection and there was a trend for the maximum vertical displacement to occur later in the stride cycle than during the 1<sup>st</sup> inspection.

**Table 8-6 Standardised velocity and timing measurements for hooves. All temporal values standardised for onset of stance phase as the initiation of the stride**

	Forelegs		Hind legs		Significance
X m.s <sup>-1</sup>	1 <sup>st</sup> Inspection	3 <sup>rd</sup> Inspection	1 <sup>st</sup> Inspection	3 <sup>rd</sup> Inspection	
Minimum Value	-0.42±0.67	-0.40±0.67	-0.40±0.37	-0.35±0.54	n/s
Min value timing	16.72±10.90 <sup>a</sup>	13.44±8.37 <sup>a</sup>	7.77±12.49 <sup>b</sup>	11.80±8.70 <sup>b</sup>	P<0.05
Maximum Value	6.55±0.66 <sup>a</sup>	6.23±0.72 <sup>b</sup>	6.58±0.96 <sup>a</sup>	5.95±1.63 <sup>b</sup>	P<0.05
Max Value timing*	63.50±11.51 <sup>a</sup>	55.88±10.36 <sup>b</sup>	56.61±7.81 <sup>a</sup>	58.88±11.23 <sup>b</sup>	P<0.01
Y m.s <sup>-1</sup>					
Minimum Value	-1.066±0.342 <sup>a</sup>	-0.032±0.047 <sup>b</sup>	-0.859±0.261 <sup>c</sup>	-0.022±0.055 <sup>d</sup>	P<0.01
Min value timing*	93.05±11.20 <sup>a</sup>	77.08±11.46 <sup>b</sup>	92.94±5.49 <sup>a</sup>	84.13±7.64 <sup>b</sup>	P<0.05
Maximum Value	1.146±0.194 <sup>a</sup>	1.641±0.231 <sup>b</sup>	1.2048±0.1887 <sup>c</sup>	1.373±0.144 <sup>d</sup>	P<0.01
Max Value timing*	40.19±2.68 <sup>a</sup>	40.05±3.71 <sup>a</sup>	36.44±3.87 <sup>b</sup>	34.61±5.29 <sup>b</sup>	P<0.001
Z degrees s <sup>-1</sup>					
Minimum Value	-21.4±13.2 <sup>a</sup>	-19.8±6.9 <sup>a</sup>	-45.9±17.3 <sup>b</sup>	-28.4±14.5 <sup>c</sup>	P<0.01
Min value timing*	86.16±12.38 <sup>a</sup>	64.05±20.61 <sup>bc</sup>	77.63±10.63 <sup>b</sup>	67.0±21.0 <sup>c</sup>	P<0.05
Maximum Value	24.03±12.88 <sup>a</sup>	26.77±8.23 <sup>b</sup>	27.53±8.20 <sup>a</sup>	32.867±9.31 <sup>b</sup>	P<0.01
Max Value timing*	41.55±10.78	44.97±8.85	38.13±12.93	42.44±15.96	n/s

Note. \*Timing values are measured as a percentage of standardised stride time with stride starting at onset of stance phase.

Different superscripts represent values that are significantly different.



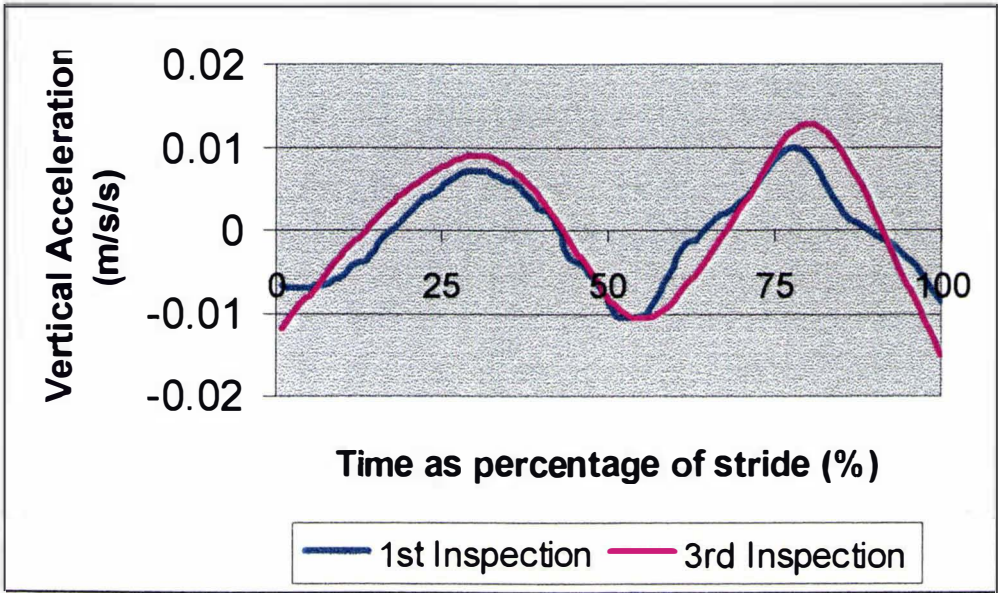


Figure 8-1 Plot of the mean head vertical velocity for the 1<sup>st</sup> and 3<sup>rd</sup> inspection.

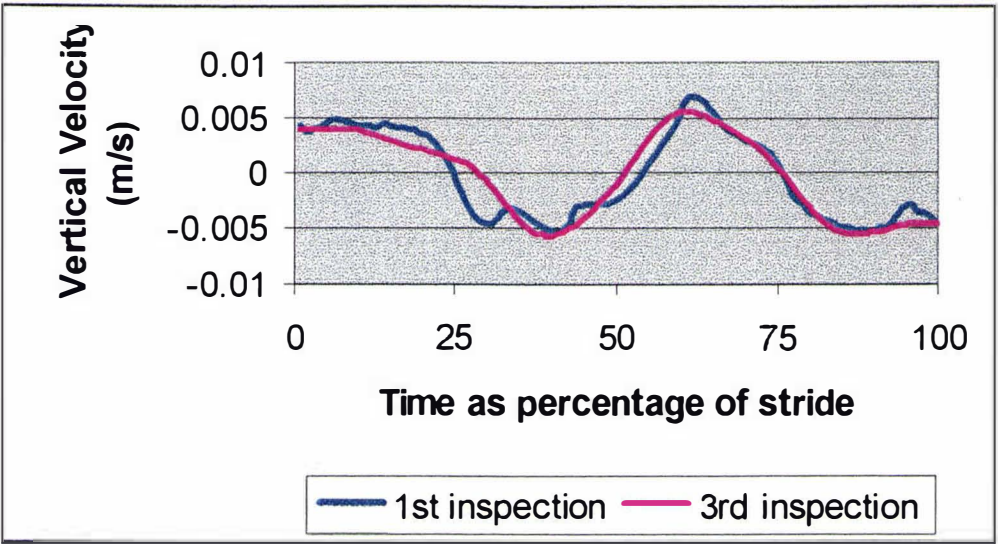


Figure 8-2 Plot of the mean body vertical velocity for the 1<sup>st</sup> and 3<sup>rd</sup> inspection.

**Table 8-7 Standardised acceleration and timing measurements for hooves.**  
**All temporal values standardised for onset of stance phase as the initiation**  
**of the stride**

	Forelimbs		Hind limbs		
Horizontal acceleration (m.s <sup>-2</sup> )	1 <sup>st</sup> Inspection	3 <sup>rd</sup> Inspection	1 <sup>st</sup> Inspection	3 <sup>rd</sup> Inspection	Significance
Minimum Value (m.s <sup>-2</sup> )	-41.628±26.085	-39.786±20.881	-37.913±15.687	-40.632±10.946	n/s
Min value timing (% stride)	87.66±6.43 <sup>a</sup>	83.38±10.36 <sup>b</sup>	87.50±11.01	89.02±11.00	P<0.01
Maximum Value (m.s <sup>-2</sup> )	37.326±15.024	36.194±6.639 <sup>a</sup>	43.348±19.703	42.494±12.959 <sup>b</sup>	P<0.01
Max Value timing (% stride)	40.333±3.414	39.722±5.300	39.666±6.957	39.305±6.497	n/s
Vertical acceleration (ms <sup>-2</sup> )					
Minimum Value (m.s <sup>-2</sup> )	-9.83±5.28 <sup>a</sup>	-9.09±3.17 <sup>b</sup>	-11.49±6.52 <sup>a</sup>	-7.64±1.99 <sup>b</sup>	P<0.05
Min value timing (% stride)	74.97±17.38 <sup>a</sup>	70.30±11.30 <sup>b</sup>	79.97±6.58 <sup>a</sup>	73.44±5.58 <sup>b</sup>	P<0.069
Maximum Value (m.s <sup>-2</sup> )	9.168±3.59 <sup>a</sup>	12.58±3.15 <sup>b</sup>	14.76±6.12 <sup>c</sup>	11.69±2.48 <sup>d</sup>	P<0.05
Max Value timing (% stride)	29.30±4.93	31.42±4.62	31.86±14.68	28.75±9.15	n/s
Transverse acceleration (°s <sup>-2</sup> )					
Minimum Value (°s <sup>-2</sup> )	-351.06±233.28 <sup>a</sup>	-386.21±170.61	-563.98±306.93 <sup>b</sup>	-427.21±191.65	P<0.01
Min value timing (% stride)	75.69±11.73	72.52±11.30 <sup>a</sup>	76.88±14.65	80.75±13.42 <sup>b</sup>	P<0.05
Maximum Value (°s <sup>-2</sup> )	378.86±185.24	400.56±136.39 <sup>a</sup>	423.80±218.24	318.31±183.13 <sup>b</sup>	P<0.05
Max Value timing (% stride)	38.66±10.03	45.08±11.61 <sup>a</sup>	38.11±10.21	36.77±10.52 <sup>b</sup>	P<0.01

Maximum horizontal velocity was lower in both the fore and hindlimbs during the third inspection. In contrast, differences between the fore and hindlimb pairs was consistent across inspections with the hindlimbs during the third inspection showing a reduction in velocity. For transverse velocity the minimum values were lowest for the 1<sup>st</sup> inspection and also occurred later during the stride. Whereas the maximum values for transverse velocity were greater for the third inspection but this was not significantly different across inspections. Consistently across inspections, transverse velocity was greater in the hindlimbs.

Minimum horizontal acceleration occurred in the later part of the stride cycle and was greater in the forelimb pair during the first inspection. Both the timing and the minimum acceleration values were significantly different between the fore- and hindlimb pairs for both inspections, but were not significantly different across days. Maximum acceleration was also significantly different between the fore and hindlimbs pairs for both value and timing of the maximum but were only significantly different across days for the maximum value and not the timing of the maximum vertical acceleration. Minimum transverse acceleration (adduction) and the timing of minimum acceleration was significantly different between the fore- and hindlimb pairs only for the 1<sup>st</sup> inspection and was not significantly different across days. However the trend was for lower minimum acceleration values in the hindlimbs for both inspections. In contrast to the minimum values for acceleration the maximum values for transverse acceleration were significantly different between the fore- and hind limbs only for the third inspection and there was a day effect. There was no day effect for the timing of the maximum acceleration.

## Discussion

Between the first and third inspections, horse specific differences in the change of gait pattern were found for a number of the variables. Horse specific differences have been identified with the temporal patterns during the preliminary horse inspection (Chapter Five) and these horse specific temporal patterns were also found to be consistent across inspections (Chapter Six). Therefore it was not unexpected that horse specific differences would be found in

the kinematic analysis and that these horses would respond differently to the exertion of the speed and endurance day. The horse specific components of the gait or kinematic fingerprint may only be a partial explanation of the differences in response, which could also be due to each horse having different experiences during the speed and endurance day, including such factors as the number of time faults, and the level of fitness. The pre-selection of the horses should have minimised this possibility, but nevertheless it may be a contributing factor. Even though subtle horse specific differences in the kinematics between the first and third horse inspection were found there was a consistent pattern of change observed.

A hypothesis was proposed in the previous chapter that the gait exhibited during the first inspection was influenced by tension due to the atmosphere of the inspection process and the fitness level of the horses. It was predicted from this hypothesis and results from the linear and temporal analysis (Chapter Six) that there would be an observed decrease in the range of motion of both the fore- and the hindlimbs at the third inspection. It was also predicted that there would be a greater reduction in the range of motion in the forelimbs than the hindlimbs. However, the results from this analysis demonstrated a small but significant increase in the range of motion in the limbs in the horizontal and vertical axis and a decrease in the angular deviation measured in the anterior view.

Certainly the greater vertical and horizontal range of motion implies that tension is not providing a limitation to the movement of the distal limb during the third inspection. Decreased tension should also provide a reduction in the abduction level and this was observed during the third inspection. With a decrease in tension the distal limb may not be as tightly controlled during the third inspection and this less constrained regulation of the distal limb may be a reason for the greater longitudinal and vertical displacement seen.

Because of the structure of the horse's leg the action of the limb can be considered analogous to the action of a pendulum (Back 1994). The proximal muscle mass (extrinsic shoulder and elbow muscles) generates the movement with the distal limb largely acting passively. Net joint moment studies on the

swing at the trot in the Dutch warmblood has identified that the elbow initially generates acceleration and then at 50% of the swing works to decelerate the limb (Lanovaz *et al.* 1998). In a tense horse (first inspection) the muscle action may not be as smooth or fluid. This lack of fluidity may be translated into the distal limb displaying greater abduction than expected. Certainly in dressage horses tension is often manifested in this way. If the horses were not as tense at the third inspection then the distal limb would display reduced transverse deviation as was observed in this study.

The increases in the vertical and longitudinal hoof trajectories during the third inspection could also be due to the horses not being as tense. Head position may also contribute to the greater longitudinal and vertical ranges of motion seen during the third inspection. During the first inspection the horse's head tended to be positioned towards the handler, but, during the third inspection the head was orientated away from the handler and towards the crowd. The neck also appeared to be held higher and in a more extended position during the third inspection. The head and neck represent a significant portion of the horse's mass. By raising the head during the third inspection a horse may be attempting to shift the load off the forelimbs. As the forelimb's are closest to the horses centre of mass and have been shown to have higher vertical velocity and accelerations at impact (Back *et al.* 1995) it would be in the forelimbs than any concussion would be first felt. Therefore after the rigours of speed endurance day there would be the expectation of an attempt to minimise forelimb concussion. Decreased minimum vertical acceleration at the third inspection and its occurrence earlier in the stride supports this proposal.

While significant differences were found in the kinematics between the first and third veterinary inspection biologically these differences were not large, and certainly would be hard to identify with the naked eye. To the most observers these horses would appear to trot with a consistent gait. Previous studies have identified that horses do have a consistent gait pattern (Drevemo *et al.* 1980) and this pattern does appear to be resistant to change even with low grade lameness (Buchner *et al.* 1995). The small magnitude of the differences identified implies there is no drastic change in the horses underlying physiological status. The pre-

selection of this group for study based on the consistency of the trot velocity may have meant that indirectly, selection had been on horses that were the least affected by the rigours of speed and endurance day. Certainly the group of horses selected were all experienced event horses, ridden by experienced riders and would have been well prepared from their conditioning programme cope with the physiological demands of speed and endurance day. Elite event horses appear to cope very well with the demand of speed and endurance day. Support for this view can be found in the consistency of physiological parameters between basal (pre-competition) and 16 hours after speed and endurance day in elite level event horses (CCI\*\*\*\*) ridden by experienced riders (Marlin *et al.* 1995). It is possible that the magnitude of the kinematic differences may be greater in the horses that did not cope as well to the challenges of speed and endurance day. Therefore the differences found in this sample should be regarded as indicators for study as to the kinematic variables that are the most likely candidates to change in response to the physiological demands of speed and endurance day.

It could be concluded from this study that this group of CCI\*\*\* event horses did not demonstrate changes to the kinematics of the in hand trot that would indicate that they were unduly fatigued by the exertion of speed and endurance day. It is possible that the atmosphere of the inspection process and then the horses not being as fresh or tense during the third inspection may have been the reason for the observed differences between inspection days. If tension is the cause then it is important for the inspection panel to consider these variables when inspecting the horses at either the first or third inspection.

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## **Chapter 9 Conclusion**

### **Introduction.**

Limited information is available about the kinematics of the event horses, and no studies have previously been undertaken examining the kinematics of horses performing the horse inspection. The FEI is currently attempting to promote the standardisation of the surfaces on which the horse inspections are performed at major three day event competitions (Wilford 1997). Often at three day events the horse inspection process and the results arising from it can be the topic of much discussion. In recent years this has resulted in modification of the process to permit a holding pen for horses that on initial inspection did not appear even so that they could be represented for a second inspection (Anon 1998). However, the fundamental question as to what are the kinematics of the event horse during the inspection process and how do they change between the first and third inspection remained unanswered. This thesis has attempted to address this point.

### **The horse inspection process.**

Even though guidelines are provided by the FEI for the horse inspection process they are worded imprecisely. Two different approaches to the inspection process were observed. The approaches taken appeared to be influenced by the initial impression the judge's panel received when the horses were walked toward the panel. If rushed, horses appear tense and uneven and therefore would be placed under greater scrutiny than horses that walked in a relaxed manner toward the panel. Based on this observation it is recommended that the competitors make every effort to present the horse in a relaxed manner. It would be interesting to perform a follow study to this to examine if there have been any changes in the process as the FEI continues to standardise procedures at the CCI level three day event competitions.



## **Temporal characteristics.**

In agreement with studies on different populations of horses, temporal stride characteristics were found to be repeatable across a number of sequential strides. The study concludes that the asphalt surface used for the horse inspections at major three day event competitions alters the trot stride frequency when compared to studies on different surfaces. However the relationship between stride frequency, stride length and velocity appear constant. Stance and retraction times, when measured as a percentage of stride time were identified as being horse specific. The consistent advanced placement observed of the hindlimb of the diagonal limb pair is interpreted as a result of dressage training.

## **Comparison of temporal stride characteristics between the first and third horse inspection.**

The relatively long time period between the first and third horse inspection (16-18 hours) may explain why many of the variables examined were remarkably consistent across inspections. The temporal patterns for individual horses were consistent between inspections even to the level of maintaining a similar degree of measured laterality between diagonal limb pairs.

Changes in gait pattern were however observed for the velocity, stride length and stride duration relationship. During the third inspections at the same velocity the horses took shorter quicker strides. It was proposed that this change could be due to delayed onset of muscle soreness (DOMS).

## **Kinematic examination of the trot during the preliminary horse inspection.**

The vertical and longitudinal ranges of motion in this study were consistent with observations in warmblood horses by other authors (Back 1994; Holmstrom 1994). It was proposed that the tension of the inspection process, the horses being very fit and a thorough working in by the riders, contributed to the horses displaying a gait with a range of motion larger than that expected from a

thoroughbred or thoroughbred type horse trotting on an asphalt surface at the first inspection. The larger longitudinal and vertical displacement of the forelimbs than the hindlimbs could be an effect of dressage training.

Larger than expected transverse swing was observed. It was proposed that this may have been due to tension as excessive abduction and adduction of the limb as it progresses is generally considered to be a fault in movement and also a fault in training methods (Klimke 1985). However the question was raised as to what is the normal level of transverse deviation and, in a manner similar to human gait adduction and abduction of the limb could be a mechanisms employed to help minimise the amount of displacement of the centre of mass during locomotion.

### **Comparison of the kinematics between the first and third horse inspection.**

In a manner similar to the temporal measurements there was remarkable similarity between the measurements of the first and third horse inspection even though significant differences were found between most measurements between the two inspections. However, biologically these may not constitute a change in gait pattern that would be easily distinguishable to the naked human eye. To the observer the gait would have appeared repeatable between inspections.

Contrary to expectation, the hoof had a greater horizontal and vertical but a reduced transverse range of motion during the third inspection. Reduction in the transverse deviation may be an indicator that there was less tension in the horses during the third inspection. The larger longitudinal and vertical ranges of motion supports this concept that the horses analysed were more relaxed during the third inspection and not fatigued.

Examination of a larger data set including horses that incurred a large number of time and jumping penalties on speed and endurance day may demonstrate a different result.

### **General conclusion.**

The results of this study support the work of other authors that the horse has a highly repeatable gait that contains elements that are unique to each horse. This gait pattern appears to be resistant to perturbation caused by external stimulus including the exertion of speed and endurance day.

This study does however suffer from the limitation of only examining the kinematics of six horses in detail and only one stride from each inspection. Horses also are able to redistribute joint torques without any visual change in gait and this can limit the quantity of information available to the researcher when only examining the kinematics of the distal limb. Caution should therefore be used in interpreting these results.

It is important that this work be followed up with a study examining another data set of CCI\*\*\* event horses and examining in detail a larger group of animals. This is particularly important with the increasing pressure that the animal welfare lobby is placing on horse sports and eventing in particular. The results from this study have demonstrated that the kinematics reflect that speed and endurance day does not unduly fatigue event horses.

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