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1 Abstract

Previously published studies observing trotting horses concluded that a significant percentage (50-94%), had measurements for at least one variable in excess of the accepted values for movement symmetry. Three possible explanations existed; 1) the variables were innate in healthy animals due to body asymmetry, individual sensory or locomotory preference or influenced by training methods; 2) they were due to mechanical non-painful abnormality or 3) some horses were clinically lame. There is currently no objective measurement system designed specifically to assist the veterinary physiotherapist in distinguishing asymmetry from lameness and facilitates data sharing and interprofessional communication. The central aim of this pilot study was to test the ability of smart phone video technology to capture meaningful and reliable data of sound horses in trot when analysed using software applications Kinovea v9.5 and HoofmApp. The variables considered were the dorsal wall hoof angle, laterality choice and suspension phase kinematics. Pain was assessed using the horse grimace scale at rest, during gait assessment and the exercise.

The owners of seven (n=7) ridden horses aged six to twenty-three years, gave written permission for inclusion. A questionnaire for history taking and protocols were developed for initial examination, gait assessment, hoof photography and the exercise. Horses were filmed at their own locations using standardised equipment at trot over seven poles at heights from 5-35cms.

This aim was achieved as a smartphone was able to capture the suspension phase and high-quality hoof and facial images for analysis. Asymmetry was demonstrated in 21% of suspension phases, with 67% of these in three horses who averaged just 12mins pole work per week each. They also accumulated 100% of the pole faults and reached the published threshold (5/12) for grimace score significance. The greatest variability occurred when the leading leg or rein changed or faults were recorded, with 67% of asymmetric suspensions associated with one of these events and 33% with two of them. Horses were using the visuomotor system to adapt to the exercise with the four horses previously trained over poles regularly (one hour per week each) being more successful. Tarsal flexion exceeded carpal flexion for all horses by 20% on average. Carpal flexion increased by up to 25% and tarsal by 50% over the poles at 35cms compared to 5cms. There were 42 entrances to the exercise with 50% left and 50% right forelimbs leading. Only one horse mirrored this result, emphasising that laterality was expressed at an individual rather than population level. Maximum flexion occurred in contralateral limb pairs of 5/7 (71%) of horses and 3/7 (43%) also correlated flexion pairs with dominant laterality. All horses had a steeper left fore although only two, displayed asymmetry of 3° or more. A trend emerged that as the left fore became steeper the horses tended to right fore/left hind or right sided maximum flexion laterality and right fore exercise laterality. Larger studies are required to provide statistical evidence and clinical significance thresholds which could be integrated with software to analyse videos recorded in the field.
[500 words]

Abbreviations

AS	asymmetric suspension
BL	baseline
CPG	central pattern generator
DG	digital goniometer
DWHA	dorsal wall hoof angle
EQL	equine-librium scale of lameness
FAU	facial action unit
FL	forelimb
HGS	horse grimace scale
HL	hindlimb
HLF	high left forefoot
HoR	horse record
HRF	high right forefoot
IMU	inertial measurement unit
LCH	left cerebral hemisphere
LFL	left forelimb
LHL	left hindlimb
LL	left limb
LLSP	left lead stride pattern
LR	left rein
MSK	musculoskeletal therapists
RCH	right cerebral hemisphere
RFL	right forelimb
RHL	right hindlimb
RL	right limb
RLSP	right lead stride pattern
RR	right rein
UG	universal goniometer
VP	veterinary physiotherapist

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2. Introduction:

2.1: Relevance to Veterinary Physiotherapy

In 2020, the Royal College of Veterinary Surgeons clarified guidance regarding the existing Exemption Order to the Veterinary Surgeons Act 1966, which allows musculoskeletal therapists (MSK), to treat an animal under supervision where that animal has been previously examined by the veterinarian (Royal College of Veterinary Surgeons, 2020). The clarification confirmed that the maintenance of a healthy animal does not require prior veterinary referral. Veterinary physiotherapists (VP) treating horses in full work under an owner self-referral system regularly saw sub-optimal gait patterns (Rhodin et al., 2015). In that 2015 study, 72% of the horses trotting in a straight line (n=220) had measurements for at least one variable in excess of the accepted values for movement symmetry. There were three possible explanations provided by the authors for these observations; 1) they were innate in healthy animals with variations in the population, 2) they were due to mechanical or non-painful abnormality, or 3) some of these horses were clinically lame.

2.2 Recognising clinical lameness.

Lameness was defined as a diagnosis of abnormal and (usually) asymmetric gait indicating musculoskeletal pathology and frequently pain (Ross, 2011). Lameness requires a veterinary diagnosis which in turn relies heavily on a visual subjective gait assessment and flexion tests. A study of fifty seven sport horses, all actively being ridden, trained and/or competed without any comment from trainers or judges, concluded that 65% were lame rising to 75% after fourteen days (Dyson & Greve, 2016). These authors also concluded that horses with sound movement in a straight line may not be sound on a circle or when ridden. A further complicating factor regarding lameness assessment is that inter-rater subjective gait assessment by veterinarians, and by extrapolation veterinary physiotherapists, becomes unreliable in cases of mild lameness and generally is lower for hind/multi limb lameness compared to forelimb lameness (Keegan et al., 2010). Keegan et al. concluded that the development of a method of evaluating lameness in the field that is objective and reliable was justified and should be encouraged.

The distinction between clinical lameness and asymmetry becomes further complicated by compensatory patterns. Where there is a true clinical lameness in a forelimb (FL) there is a shift in weight bearing to the contralateral hindlimb (HL) and a decrease in push off causing a compensatory asymmetry which was improved by diagnostic anaesthesia to the FL and so was not in itself a true lameness (Maliye & Marshall, 2016; Maliye et al., 2015). A kinetic study using a force measuring treadmill and horses diagnosed with mild to moderate induced FL lameness recorded that stride duration decreased and frequency increased (Weishaupt et al., 2006). Stance duration increased in both forelimbs reducing the rate of loading and peak forces but remained the same in the HL, meaning the speed of protraction of the FL increased. The period of trot suspension decreased by 20% in mild and 46% in moderate lameness on the lame diagonal and only 7-17% on the sound diagonal, giving earlier support of the body to the sound limbs (Weishaupt et al., 2006). The term *lame* should be confined to horses deemed unfit to compete following a comprehensive assessment (van Weeren et al., 2017). Horses with gait asymmetry may include sound horses and so any association with poor welfare resulting in potentially both public and professional misunderstanding needs to be avoided (van Weeren et al., 2017). This concept, has now been underlined using research into the wider social licence required to continue using horses for sport, where 40% of respondents supported their continued use only if welfare was improved, 20% did not support the use of horses in sport under any circumstances (World Horse Welfare, 2022).

2.3 The role of laterality and asymmetry

The results from large research projects have also supported caution when using the term "lame". A population of warmblood type riding horses (n=222), with a median age of ten years were assessed as 72.5% asymmetric for at least one parameter (Rhodin et al., 2017). Up to 67% of polo ponies in training (n=60), demonstrated asymmetries that were not population wide, were not predominantly left or right and the degree of head and pelvic movement did not increase with age (Pfau et al., 2016). Yearling standardbred trotting horses (n=103), at the start of training were classified as 93% asymmetric in-hand and 94% when driven (Kallerud et al., 2021). As observed previously, there was no population bias and on an individual basis 20% changed their asymmetric side for at least one parameter when the exercise changed from in-hand to driven. Although the young age of these horses limited the role that prior injury and training has on asymmetry, it also increased the variability of the results within and between the tests. Musculoskeletal immaturity may also have been a factor. A study looked at 200 horses and divided them into disciplines (show jumping, eventing, dressage, military), elite and non-elite groups (Mackechnie-Guire & Pfau, 2021). In total, 100 horses (50%) had asymmetries in the head and withers of more than the threshold of 6mm, and 120 horses (60%) had a greater than 4mm pelvic asymmetry. There were no significant differences between the groups except that elite dressage horses (n=12) showed increased hind limb push off asymmetry. This exception could have been a training bias for the specific biomechanical effort required in high level dressage, and required further research to confirm (Mackechnie-Guire & Pfau, 2021).

Taken together these studies indicated that asymmetry can be present as an individual trait in sound horses across many breeds, ages and types of training and these levels often exceeded the parameters built into the inertial measurement unit (IMU) systems for lameness detection. What cannot be inferred from these studies is where asymmetry originates from and whether the age that training begins, or the type and intensity of training is significant. The question of the suitability of the asymmetry thresholds, which are generally consistent due to the same manufacturer's systems being used, could also be raised in terms of their physiological significance to the horse.

Normally occurring asymmetries may arise within the central pattern generators (CPG) of the spinal cord (Goulding, 2009). These groups of neurons, one for each limb, are connected front to hind via interneurons and left to right by decussating neurons (Golubitsky et al., 1999). They control the automatic rhythmic protraction and retraction of the limbs, flexion and extension of the joints to produce the gait patterns (Balaban et al., 2014). Feed forward and feedback information from the peripheral and central nervous systems allow the CPG to adapt to prevailing conditions (Goulding, 2009). A pole exercise at trot, for example, for which visual feed forward information and proprioceptive (knocking a pole) feedback allowed the horse to negotiate and learn the exercise which then became automatic (Haussler et al., 2021). If the timing and/or size of the CPG outputs vary very slightly from left to right, functional asymmetries may arise which are non-pathological and non-blockable (Clayton et al., 2019).

In addition to clinical lameness and non-pathological abnormalities, there are also innate, morphological asymmetries which can be broadly divided into body asymmetry, locomotor and sensory laterality.

Body asymmetry may arise as a consequence of the uneven arrangement of the organs in the body, such that the centre of gravity is 1.0cm to the left of the midline and due to the size of the head and neck, 58% of the weight of the horse is borne by the FL and 42% by the HL (Clayton & Hobbs, 2019). The HL are attached to the body via the pelvis, a bony girdle providing stability whereas the FL are wholly attached to the trunk by the muscular thoracic sling. In locomotion ground reaction forces from the FL, head and neck are transmitted to the cranial thoracic spine (T1-T14/16) and those from the HL to the caudal thoracic and lumbosacral spine (Clayton & Sha, 2006).

Lateralisation occurred when an organ or function is largely under the control of either one side of the brain or the other (McGreevy & Rogers, 2005). Locomotor laterality was evident from soon after birth in some horses which over time led to asymmetric forces being transmitted from the distal limbs through the musculoskeletal system to the spine, causing uneven muscle development, gait compensation and ultimately pathology (Mackechnie-Guire, 2022). The observation of 79 foals concluded that one third of the foals studied expressed a strong motor lateralization for suckling on one side or the other which increased with age from 4-7 months, with no population or gender bias and no side influence recorded in the mares (Komarkova & Bartosova, 2012). Longitudinal studies of grazing foals found that around 50% of foals protracted one fore limb consistently by seven months of age and this resulted in uneven foot development (Van Heel et al., 2006). The protracted limb was heel low with additional strain on the deep digital flexor tendon and the retracted hoof more upright, with higher bone density and less fracture risk, but less agility and dexterity (Moleman et al., 2006). Foals with particularly short heads and long limbs were most affected which should have implications for future breeding programmes (Van Heel et al., 2006). At three years old, 24% of these horses remained strongly lateral with foot unevenness up to four times greater and a canter strike off preference. These horses were untrained and there was no population bias (Van Heel et al., 2010). Force vectors have been mapped in the sagittal and frontal planes in horses with foot asymmetry (differential FL dorsal wall hoof angles, (DWHA), of between 1.5° and 12.3°) suggesting that unbalanced sagittal plane and increased frontal plane forces in these horses presented greater locomotory challenges than horses with even hooves to the extent that high right fore horses had difficulty turning in a clockwise direction. The high limb on either side was regarded as the “affected” limb with postural and locomotory compensations similar to those seen in induced lameness (Hobbs et al., 2018).

Whilst the evidence so far pointed to laterality at the individual, but not population level, a large USA study of racehorses (n=9362) indicated a population effect in that 90% preferred a right lead stride pattern (RLSP) where the LH pushes off, followed by RH/LF and then the RF. The findings were not sex, age or breed dependant and considered horses running clockwise and anticlockwise (Williams & Norris, 2007). The horse has laterally placed eyes with visual input to the right eye processed by the left cerebral hemisphere (LCH) and vice versa with interocular transfer of information through the corpus callosum. The right cerebral hemisphere (RCH) controls predator recognition and escape, heightened emotion and proprioception with the LCH controlling considered responses such as vocalisation, foraging, approach and the inhibition of strong emotion (Larose et al., 2006). The start gate at a racecourse is a high emotion environment with predominantly RCH processing which may dictate LH strike off into a RLSP maintained throughout the race through herd synchronicity and collision avoidance. Another interpretation related to body asymmetry in that RLSP may allow for optimal lung expansion on the right side where there are three lobes and confer a biochemical advantage in respiration. A UK study (Cully et al., 2018), of over two thousand racehorses found that there was no overall population laterality and it was suggested that in the USA study, assistant starters in the stall positioned to the left of the horse used a variety of (sometimes harsh) control techniques which influenced the initiation of RLSP. The UK study confirmed individual laterality in 44 horses, 21 left, 22 right, and one ambidextrous with left lateralization being stronger. A horse racing in a direction contra to its preferred leading leg is more at risk of fracture in the "forced" leading leg due to decreased agility. Identification of sidedness and training programmes to encourage balanced development would prevent racing losses (Cully et al., 2018).

2.4 Objective measuring systems and interprofessional communication.

An on line survey of (mainly US) veterinarians found that physiotherapy was the complementary therapy most often chosen by horse owners and yet respondents were less familiar with this profession and referred and communicated less often with physiotherapists than with chiropractors or acupuncture practitioners (Bergenstrahle & Nielsen, 2016). A Swedish study of horse owners (n=204) found that some owners referred to a complementary therapist before a veterinary surgeon, 15% for lameness and 52% for back pain with only 10-15% of owners not using complementary therapy at all for prevention and/or rehabilitation. Of the veterinarians who responded (n=100), 55% referred to therapists and of the 124 therapists who responded 50% received referrals but 25% worked without any collaboration with a veterinary surgeon (Gilberg et al., 2021). An Irish study (Doyle & Horgan, 2006) of 97 veterinarians that included general and equine practices found that although the majority of respondents were aware of physiotherapy only 20% had referred cases, which were mainly competitive horses. This study concluded that close collaboration between veterinary practices and physiotherapists promoted referrals where the clinical need and cost were justified. Veterinary physiotherapy is a developing profession and whilst detailed extrapolation from these studies, which occurred over a fifteen year period and on different continents, is not justified it is clear that equine VPs are in a front line position regarding the recognition of lameness and the development of clear lines of interprofessional communication, including methods of objective measurement which can be shared between practitioners would be an advantage in promoting the welfare of the horse.

Although the most accurate assessment of pain and therefore true clinical lameness is by kinetics rather than kinematics, measuring ground reaction forces has not been possible in a therapeutic setting (van Weeren et al., 2017). This pilot study suggested that a protocol combining kinematics combined with other measurable variables indicated by previous research studies may assist the practitioner. Kinematic gait analysis systems, utilising inertial measurement units (IMU) have been developed for ease of use in a therapeutic setting. One such system, Equinosis Q, detected lower levels of induced lameness in fifteen mature horses than the three experienced veterinarians who each undertook subjective gait assessments (McCracken et al., 2012) and was successfully used in large field studies into asymmetry mentioned above (Kallerud et al., 2021; Rhodin et al., 2017). Whilst it is an important advance, this system costs circa £17k (Personal communication with manufacturers, Dec 2021) and is mainly used in pre and post diagnostic anaesthesia evaluations by veterinary practices, (Personal communication with manufacturers and Dr C Frigast, Equinosis Certified Practitioner, Dec 2021). It is currently sold only to registered veterinarians and therefore not available to VPs.

A thorough evaluation of all currently available IMU systems in terms of cost and availability to VPs was outside of the scope of this pilot study, however, modern smart phones also contain IMUs and their ownership and use is becoming universal. In the UK 99% of 16-34 year olds and 96% of 35-54 year olds own a smart phone (S. O'Dea, 2021). A pilot study demonstrated that when positioned correctly on the sacrum an iphone measured pelvic asymmetry comparably to two specific IMU gait analysis sensors, (Pfau & Weller, 2017). A larger study (n=301) comparing visual lameness assessment with smartphone pelvic symmetry measurements confirmed the usefulness of the upward pelvic excursion measurement in field based initial diagnostics (Marunova et al., 2021). Video film has also been used for gait analysis (Hewetson et al., 2006) with good to high correlations recorded for intra-rater reliability, albeit the inability to request change of speed, direction or viewing angle was a limitation and the placing of camera(s) and quality of images was paramount (Hammarberg et al., 2016).

To ascertain the presence or absence of pain is vital in any objective assessment of gait and key in distinguishing non painful asymmetry from lameness. Pain has also been assessed using stills from a video. The Horse Grimace Scale (HGS) researchers scored pain reactions in six facial action units and developed a clear scoring method (Dalla Costa et al., 2014). The scores appeared largely unaffected by the animal's emotional state (Dalla Costa et al., 2017).

2.5: Hypotheses for the pilot study

The aim of this pilot study was to test the ability of modern smart phone video technology to capture meaningful kinematic data in a therapeutic setting, which was then analysed by a single qualified VP using freely available software applications. The variables considered were laterality choices (supporting and dextrous limb pairs), angular kinematics for the carpus and tarsus over two cavaletti and the length of the right compared to the left suspension phase of (owner declared) sound horses in trot. In developing the protocols for this project care was taken to familiarise the horses to a new exercise minimising a RCH "fright" or "flight" response as discussed in the publications relating to USA and UK studies of racehorses and to allow a true choice of preferred limb diagonals on entering the exercise. The results of this analysis were considered in conjunction with the VP's subjective gait assessment; HGS scoring and the dorsal wall hoof angle (DWHA) of the fore feet. The equipment and software used was all small, lightweight, portable and relatively inexpensive and therefore accessible to the mobile equine VP.

> Hypothesis 1 was that video analysis would be able to quantify asymmetry in terms of milliseconds of gait suspension and carpal and tarsal flexion angles, to provide a more accurate assessment of soundness that would otherwise score all asymmetric individuals as level "1" on the equine-librium scale (EQL).
>
> Hypothesis 2 was that there would be a positive correlation between gait asymmetry and a) Foot asymmetry, dorsal wall hoof angle (DWHA) comparisons of the fore feet, b) Rider scoring of "sidedness", and c) Presence of facial pain or stress ethogram markers.

3. Materials and Methods:

Overview

Ethical permission was granted by CARE, School of Veterinary Medicine and Science, University of Nottingham (3546 220201). Horses were recruited from a pool of current maintenance clients and riding club colleagues who gave written permission for their horses to participate. Initial data collection covering signalment, training, husbandry and veterinary history was gathered remotely using a questionnaire in excel which then formed the horse record (HoR). Initial screening took place at this stage and horses under six years of age, those requiring a veterinary surgeon consultation for lameness in any limb within the previous six months, or that were outside of a height band of 15.0hh to 17.0hhh, were excluded.

The remaining eight horses were assessed and filmed in their own settings. The same equipment, including the poles and cavaletti, were used throughout the study to ensure consistency. The filming days were chosen to be not less than two days or more than 21 days after shoeing or trimming. The horses were examined by a veterinary physiotherapist using Protocol 1. Conformation and trot up examinations were recorded and stored. One horse was deemed to be at least point 2/5 in one or more limbs on the adapted equine-librium scale of lameness (table 3.1), and was therefore withdrawn from the study at this stage. Photographs of the distal forelimbs and hooves of all horses, were taken per Protocol 2, using the equipment shown in figure 3.1.

The HoR was provided to and signed by the owner as being accurate with reasons for exclusion from the project and veterinary referral given where appropriate.

The seven horses approved for the study were videoed trotting over a simple cavaletti grid of seven poles after warm up and familiarisation, Protocol 3. The photographs of the distal limbs were imported to the HoofmApp iphone application and the dorsal wall hoof angles (DWHA) measured in both fore feet. This was repeated three times and the data recorded (figure 3.2).

The cavaletti exercise was filmed using a red iphone 13 in video mode HD 60fps and 1x zoom, mounted on a pivo and tripod. The Pivo App supported tracking only at 30fps (37ms per frame in Kinovea) rather than 60fps (18ms per frame in Kinovea) required. Consequently, the iphone Camera App was used with manual start, track and finish. A marker card was held up at the start of filming (01,02,03 for left and 91,92,93 for right rein approaches). The videos were analysed using Kinovea 9.5 software, per Protocol 4. Laterality, right and left suspension times (figure 3.3), alongside carpal and tarsal flexion angles (figure 3.4) were recorded.

Conformation photographs and still frames from the trot up and cavaletti exercise were used to provide three measurements of tension/pain for each horse, at rest, during movement on the flat and over cavaletti. These were analysed using the HGS. Facial action unit (FAU) scores, 0/12 -2/12 were non-significant, 3/12-4/12 indicated mild tension and 5/12 was significant for moderate tension discomfort or fatigue. Scores of 6 or more indicated pain (Costa et al., 2016; Dalla Costa et al., 2017; Dalla Costa et al., 2014).

GRADE		SL Walk FL/HL	SL Trot FL/HL	Circle (Walk) LEFT/RIGHT	Consistent Y.N	Comment
0	Sound	0/0	0/	0/	Y	
1	Movement Asymmetry		/1	/1	N	Very slight RHL stiffness, improving
2	Mild					
3	Moderate					
4	Severe					
5	Non weight bearing					

Table 3.1: Lameness scale record example (Adapted from equine-librium 2019)
Example HERB11 slight asymmetry in the right hind. SL=Straight Line, FL=forelimb, HL=hindlimb

Figure 3.1: Equipment for hoof photography.

Green/white board, Gopro, stand, chalk markers, grey mat and tape measure.

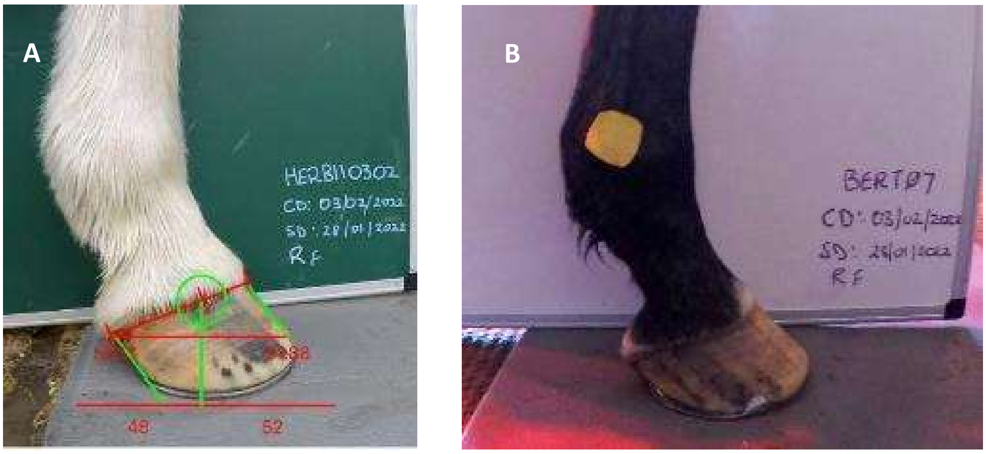

Figure 3.2: A) HoofmApp image with angles and green board **B) Original image** of a dark foot using white board**.**

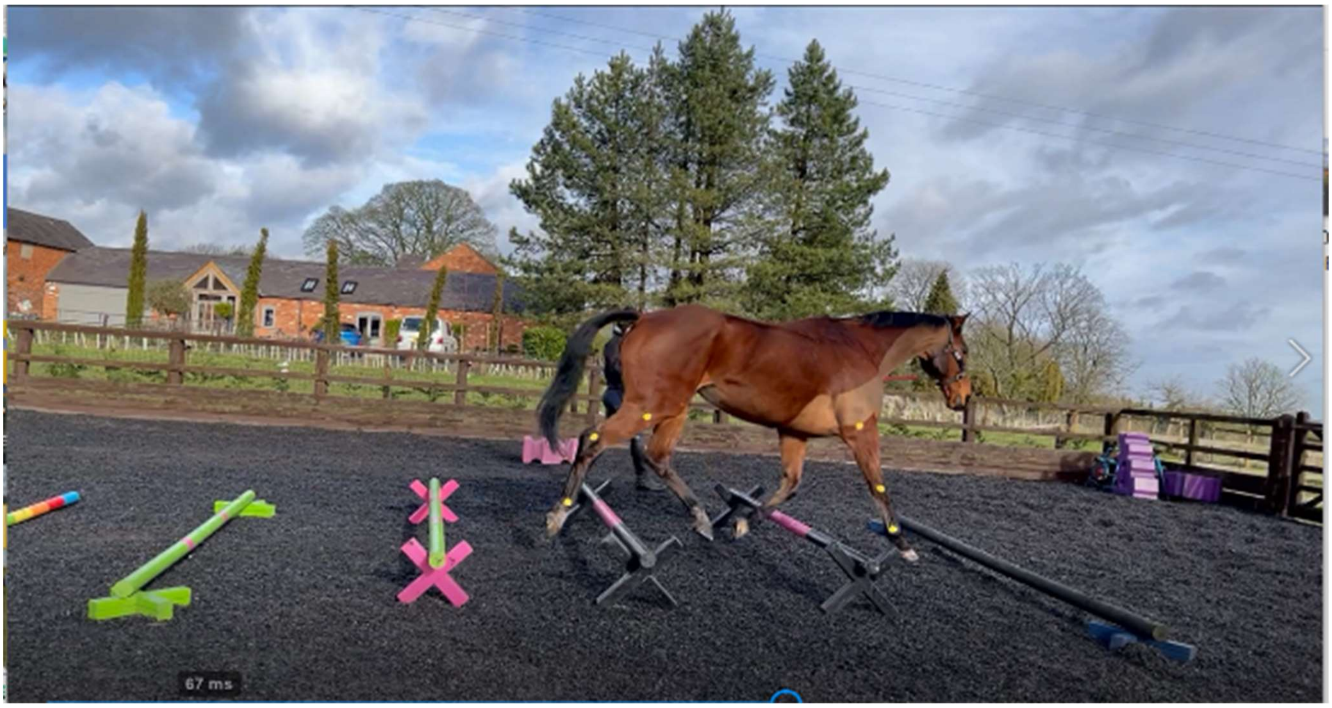

Figure 3.3: Kinovea Analysis, suspension phase. Still frame at 67ms of 117ms total left suspension phase, filmed from the right. Stopwatch bottom left of frame and yellow limb markers

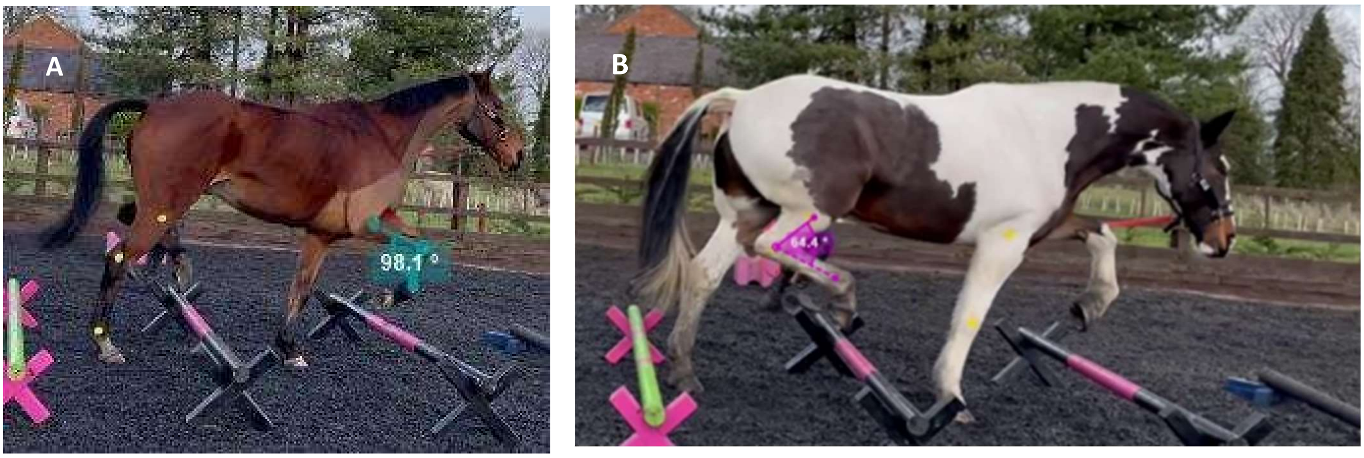

Figure 3.4: Kinovea analysis: carpal and tarsal flexion. A) Carpal flexion, leading forelimb fence 6, 98.1°, B) Tarsal flexion, leading hind limb fence 5, 64.4°.

3.1: Protocol 1: Initial examination.

a) The horse was stood up square on a hard flat surface. Standard conformation photographs were taken and recorded.
b) Each limb was palpated and checked for heat and swelling, abrasions, punctures or cuts.
c) The digital pulse and temperature of each hoof was compared with the contra lateral limb.
d) Records were made regarding whether the horse was shod, type of shoes, excessive wear etc.
e) The flexor tendons and check ligament were palpated and any pain reaction noted.
f) A gait assessment was undertaken in walk and trot, repeated and videoed, forming part of the HoR.

A decision was made and recorded regarding inclusion of the horse in the project based on the equine-librium scale of lameness (table 3.1).

3.2: Protocol 2: Foot photography.

a) The horse was allowed to familiarise itself with the equipment (figure 3.1).
b) The horse was led on to the mat, wearing a safe headcollar and lead rope, in easy reach of a hay net and held on a loose line/tied up with a safety knot.
c) The appropriate board was chosen (white or green) and the horse project code, shoeing date (SD) and current date (CD) added.
d) The mini tripod and GoPro 5, were positioned 52cms and 90° from the lateral bulb of the heel and a test picture taken.
   The board was added between the forefeet and two photographs taken.
e) This was repeated for the other foot.
f) The board and mat were cleaned.
g) The clearest image for each foot was uploaded to HoofmApp –
   a. Templates were applied in the following order; "cor green circle", (marks the coronet and outer edges of hoof wall cranially and caudally), "base %", (bisects the hoof wall and establishes a perpendicular ground line), "t2heel", (triangulates heel and DWHA). The "lock to ground parallel" feature was used on base and t2heel templates.
   b. The templates were placed on the same hoof picture three times to gain average and median DWHA and then repeated on the other foot. All images and DWHA were stored.

Two levels of symmetry and two of asymmetry were established. Symmetrical horses, SYMM1 up to 1.5° difference between FL hooves; SYMM2, 1.6° to 2.9°; ASYMM1, 3.0° to 5.0° and ASYMM2, 5.1° or more (Curtis, 2012; Van Heel et al., 2010; Wiggers et al., 2015).

3.3: Protocol 3: Cavaletti exercise.

Set up: Seven poles were placed 1m 10cms to 1m 20cms* apart, poles one and two on the ground (= 5cms), pole three at height 10cms, pole four at 30cms and five and six at 35cms. Pole seven, at 10cms height helped maintain the horse's focus forward and straight over the measurement poles, five and six. The camera was placed between poles five and six, 5.2m away and at 90°. Height, 1m 25cms (ground to lower edge of iphone).

Guide poles were 4.5m long and at 45° angle from pole one, being three or four trot strides. The poles were paired according to colour. Poles one and two stripey, poles three and four pink/green, poles five and six black/pink and pole seven natural. The guide poles were blue/green and natural (figure 3.5). This pairing of poles and colour order was maintained for each horse in the study.

* adjusted for stride length.

There were three parts to the exercise; warm up, familiarisation and test.

Warm up. The horses wore a Dually head collar and single 20m long line, ensuring the mouth and teeth were not affected by test equipment. Pink/purple circular markers (kinesioequine.com or rocktape.co.uk) were placed on the left side of the horse and yellow/red on the right side at the following bony landmarks:

Hindlimb
- Lateral epicondyle of the femur
- Calcaneal tuberosity
- Collateral tuberosity of fetlock.

Forelimb
- Epicondyle of the humerus
- Carpus lateral to accessory carpal bone
- Collateral tuberosity of fetlock

The horses were warmed up to work with maximum muscular efficiency and guard against injury: ten minutes of walk, trot and canter on each rein around the arena, using the guide poles as single practice poles on a circle. Handlers, photographers and owners wore a hard hat, gloves and safety boots.

Familiarisation. The seven poles were walked over on the ground approaching several times on alternate reins. The exercise was then built, starting with pole six at 35cms and poles one to five and seven on the ground, then pole five was raised for the second run and so on until all the poles were at the height required for the test. The horses worked at trot with changes of rein for up to fifteen minutes.

Test. Six runs were completed, three from the left rein (filmed by a camera on the right of the horse) and then three from the right approach (filmed by a camera on the left of the horse), in trot with all poles at the set heights.

Figure 3.5: Cavaletti exercise set up. A) Pole distances and heights in metres, B) Camera position relative to cavaletti five.

3.4: Protocol 4: Using Kinovea 9.5 software.

a) The video of each run was uploaded to Kinovea with a unique code – first four letters of horse name, year of birth, date of test, run identifier. E.g. HERB07271091. Herbie Rides Again, DOB 2007, test date 27th October, run one from the right rein.
b) The “working zone” feature was used to identify and mark the positions of

   i. Forelimb toe lift off at the start of suspension and hindlimb point of full foot contact, (non-weight bearing) at the end of suspension (poles five and six). Stance was not included.

      The stopwatch and frame markers were added to the working zone. The time difference in milliseconds between the first and last frame represented the duration of the suspension.

   ii. The “slide show from key images” method was used to record each suspension phase.

   iii. A still frame of the leading FL for each run was taken over pole one (figure 3.6).

      A pole count method was used. One point for a knocked over pole at position one, two, three and seven and two points for poles four, five, and six, without deviation. Ten points for each deviation which ends the pass and/or knocks over a cavaletti, such as a spook/refusal/canter/trip. Horses with scores of five or more in either or both of the first two passes, 01 and 02 were excluded.

   iv. A still of the frame showing carpal and tarsal flexion at the point the ipsilateral limb is instance at poles five and six was taken. Trailing and leading limbs were measured separately. The Kinovea “angle utility” and markers placed on the horse were used to calculate the degree of flexion. These measurements were compared with a kinematic graph for each horse.

Figure 3.6: Leading limb photographs. A) Left lead, pass 1 right rein. B) Left lead pass 1 left rein. BERT07 maintains left lead consistently on left and right reins. C) Right lead for all passes on the left rein and the first two on the right rein. HERB11 showed one change of leg on the last pass of the exercise, D).

4. RESULTS:

4.1 Suspension Measurements, Laterality and the use of Grimace Scoring.

The moment of trot suspension was measurable over cavaletti at 35cms height, using the iphone 13 set at 60fps, or 16.67ms per frame. There were 42 passes over the poles, 21 on each rein, completed by seven horses. Laterality was recorded as 21/42 passes, (50%), with LFL lead and 21/42, (50%) with RFL lead. Population laterality was not therefore demonstrated but for the individual it was important, with only one horse recorded as 50% LFL lead and 50% RFL. Three horses were 4/6 (67%) lateralised, two LFL lead and one RFL lead. Two horses were 5/6 (83%) lateralised, both RFL lead. One horse was 100% lateralised LFL lead (table 4.1). To investigate any emerging gait patterns the suspension time measurements were plotted alongside the laterality choice of the horse (figure 4.1).

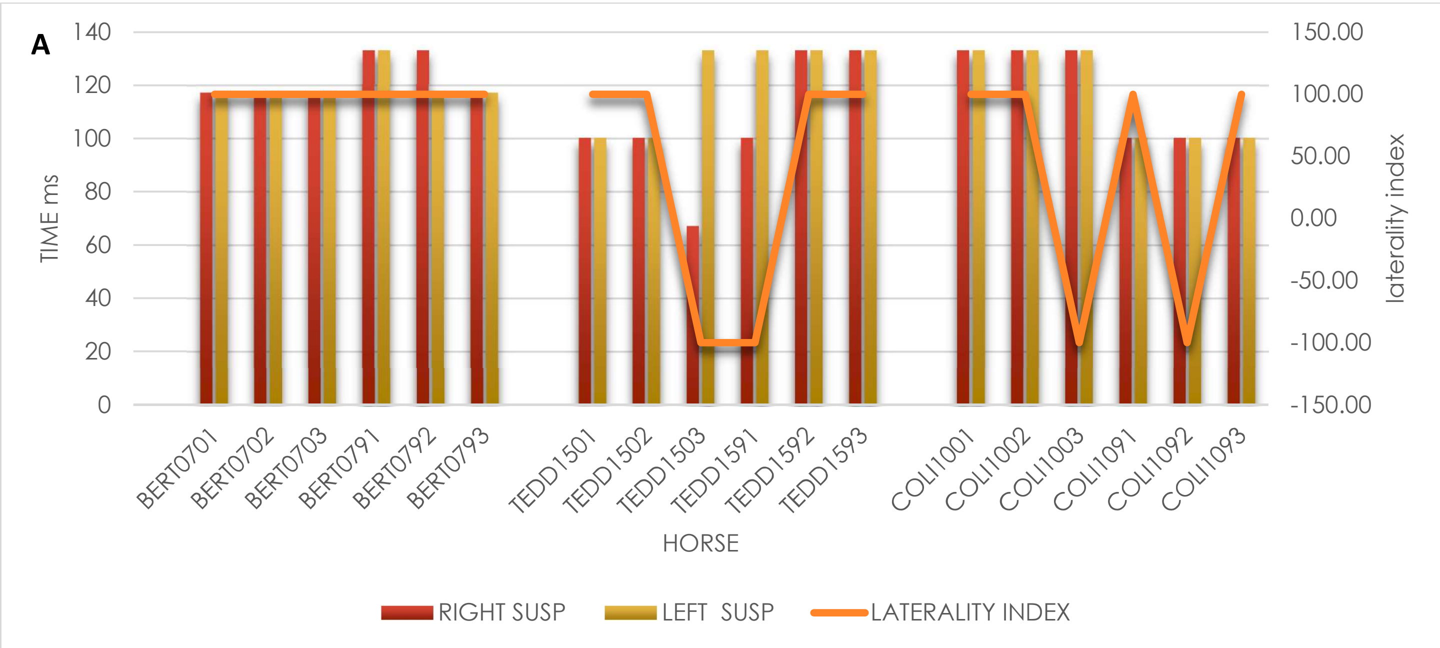

Figure 4.1: Comparison of right and left suspension times with horse laterality choice. A) LFL lateral horses. A Laterality index of -100 equates to RFL lead and +100 LFL lead.

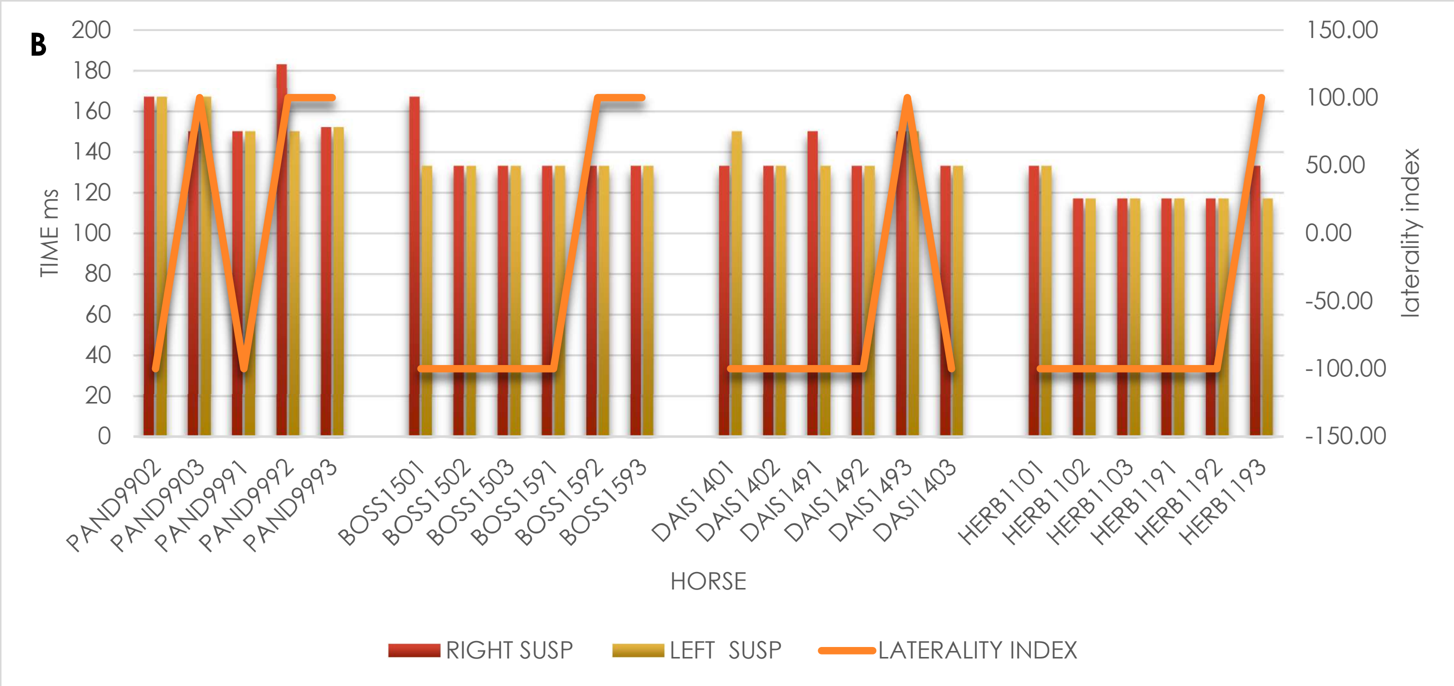

Figure 4.1: Comparison of right and left suspension times with horse laterality choice. B) No laterality (PAND99) and RFL lateral horses. A Laterality index of -100 equates to RFL lead and +100 LFL lead.

In total, 33 of the 42 passes measured the right and left suspension as being symmetrical, defined as taking the same length of time in milliseconds (ms). Nine of the 42 passes (21%) were asymmetrical, five demonstrating slower right and four slower left suspension. In order to investigate this further, the nine asymmetric passes were tabled against exercise variables (table 4.2). Where an AS was associated with one or more variables, they were given equal weight although this was an assumption that requires further research. On this basis, 39% of the AS recorded at cavaletti 4/5 and six were associated with a change of leading leg at cavaletti one.

AS ASSOCIATIONS	DAIS14	PAND99	TEDD15	BOSS15	BERT07	HERB11	TOTAL	%
First Pass (01)	1.0			1.0			2.0	22
Change of rein	0.5		0.5				1.0	11
Change of leading leg		1.5	1.0			1.0	3.5	**39**
Fault	0.5	0.5	0.5				1.5	17
Other (Not known)					1.0		1.0	11
TOTAL AS PER HORSE	**2.0**	**2.0**	**2.0**	**1.0**	**1.0**	**1.0**	**9.0**	100

Table 4.2: Asymmetric Suspensions (AS) per horse and associations with exercise variables.

HORSE PASS NUMBER	RST (ms)	LST (ms)	STdiff (ms)	Pole Count	Laterality: LFL	RFL
HERB1101	133	133	0	0		
HERB1102	117	117	0	0		
HERB1103	117	117	0	0		
HERB1191	117	117	0	0		
HERB1192	117	117	0	0		
HERB1193	133	117	16	0		
BERT0701	117	117	0	0		
BERT0702	117	117	0	0		
BERT0703	117	117	0	0		
BERT0791	133	133	0	0		
BERT0792	133	117	16	0		
BERT0793	117	117	0	0		
TEDD1501	100	100	0	2		
TEDD1502	100	100	0	0		
TEDD1503	67	133	66	0		
TEDD1591	100	133	33	1		
TEDD1592	133	133	0	1		
TEDD1593	133	133	0	1		
DAIS1401	133	150	17	0		
DAIS1402	133	133	0	0		
DASI1403	133	133	0	0		
DAIS1491	150	133	17	10		
DAIS1492	133	133	0	0		
DAIS1493	150	150	0	0		
COLI1001	133	133	0	0		
COLI1002	133	133	0	0		
COLI1003	133	133	0	0		
COLI1091	100	100	0	0		
COLI1092	100	100	0	0		
COLI1093	100	100	0	0		
PAND9901	150	150	0	0		
PAND9902	167	167	0	0		
PAND9903	150	167	17	10		
PAND9991	150	150	0	0		
PAND9992	183	150	33	0		
PAND9993	150	150	0	2		
BOSS1501	167	133	34	0		
BOSS1502	133	133	0	0		
BOSS1503	133	133	0	0		
BOSS1591	133	133	0	0		
BOSS1592	133	133	0	0		
BOSS1593	133	133	0	0		
NUMBER ASYMMETRIC SUSPENSIONS (AS)			9			
PERCENTAGE OF TOTAL RUNS			21			
LATERALITY: RIGHT ENTRY						21
LATERALITY: LEFT ENTRY					21	
TOTAL RUNS					42	

Table 4.1 **Individual right and suspension times, time differences in ms, pole count and laterality**

RST right suspension time, LST left suspension time and STdiff suspension time difference.

Table 4.2 included data for 6/7 horses, one horse (COLI10), recorded six symmetrical suspensions, the first two at a slower rate (133ms) and the remaining four at the fastest rate in the pilot, (100ms), without asymmetry or fault. Although AS were associated with a change of leading FL, at a population level, COLI10 recorded the highest number of leading FL changes (4), whilst retaining 6/6 (100%) symmetry, and showed 4/6 left laterality. A rapid completion of the exercise without faults and with four leading leg changes was therefore potentially due to other factors such as age/experience and the amount of training completed over poles. This horse also had the lowest HGS, reported below. The results (table 4.1) were further analysed against the questionnaire answers (table 4.3).

HORSE	AGE (Years)	Regularly trained over Poles (Years)	Exercise Pole Faults	Changes of lead fore	Asymmetric Suspension	Current total work (hours per week)	Current pole work (hours per week)
DAIS14	8.0	0.0	10.0	1.0	2.0	7.0	0.0
PAND99	23.0	1.0	12.0	3.0	2.0	5.0	0.0
TEDD15	7.0	0.3	5.0	2.0	2.0	1.5	0.5
TOTAL Group A	**38.0**	**1.3**	**27.0**	**6.0**	**6.0**	**13.5**	**0.5**
Average	**12.7**	**0.4**	**9.0**	**2.0**	**2.0**	**4.5**	**0.2**
BOSS15	7.0	1.0	0.0	1.0	1.0	5.0	1.0
BERT07	15.0	2.0	0.0	0.0	1.0	9.0	1.0
COLI10	12.0	6.0	0.0	4.0	0.0	5.0	1.0
HERB11	11.0	8.0	0.0	1.0	1.0	8.5	1.0
Total Group B	**45.0**	**17.0**	**0.0**	**6.0**	**3.0**	**27.5**	**4.0**
Average	**11.3**	**4.3**	**0.0**	**1.5**	**0.8**	**6.9**	**1.0**
TOTAL A plus B	**83.0**	**18.3**	**27.0**	**12.0**	**9.0**	**41.0**	**4.5**
Average	**11.9**	**2.6**	**3.9**	**1.7**	**1.3**	**5.9**	**0.6**

Table 4.3: **Comparison of trot exercise variables with age and current work levels**.

The population results indicated that the seven horses, with an average age of almost 12 years, had received an average of 2.6 years of pole training of 38mins per week per horse. The total number of faults possible by knocking poles down (excluding jumping, stopping or running out) was 10 points (pts) per run or 60 points in total per horse as set out in Protocol 4. For horse welfare reasons scores of five or more in the first two passes would have excluded the horse from further participation, but no horse breached this rule. Average faults for the exercise were low at 3.9pts per horse over the six runs with 1.7 changes of lead fore and 1.3 AS. The population were divided into two groups, A) three horses completing less than one hour of ridden and/or in hand work over poles each week and B) four horses completing at least one hour. Group A) completed only 12mins pole work on average per week per horse and accumulated 100% of the pole faults, nine per horse over the six runs. They worked on average 35% less per week than group B horses, and had less than five months regular pole work training compared to group B who had trained regularly over poles for over four years. Group A had two asymmetric suspensions and two changes of lead FL compared to 0.8

AS and 1.5 FL lead changes in group B. In summary horses with more pole work experience were more successful in the pilot study cavaletti exercise.

Horse	Trot Up	Pole Exercise
COLI10	1	3
HERB11*	2	3
BERT07 *	2	4
DAIS14	2	5
BOSS15*	3	4
TEDD15	3	5
PAND99	5	3
Total	18	27
Average	**3**	**4**

Table 4.4: A table of total grimace scores per horse. Non-significant scores shown in green, mild tension in orange and moderate tension in red. The maximum score was 12 per horse per situation. All horses scored zero at rest.

Population results indicated an increase in tension levels from zero at the outset during conformation photographs, to three at trot up and four during the pole exercise. Trot up and pole exercise scores on average indicated mild tension. However, 6/7 horses demonstrated increasing FAU scores during the total observed time (approximately 1.5 hours) and two horses had reached the threshold, 5/12, for discomfort or fatigue by run 6/6 of the exercise. A decrease in HGS was shown by 1/7 horses following the trot up, on seeing the exercise. Light conditions precluded the use of video stills of the head for analysis in runs 4-6 for three horses (marked with an asterisk in table 4.4), therefore run three was used. This may have affected the results potentially lowering the scores. Photographs and FAU scores presented in Appendix 2.

4.2 Flexion Angles and Angular Kinematics

Flexion angles were measured using stills from the videos at the point the dorsal wall of the hoof passed over cavaletti five and six to provide four reproducible points of comparison between horses. A comparison of average measurements (table 4.5) showed that tarsal flexion exceeded carpal flexion for all horses and on both reins and leading legs by 20.2% average for the population (range 15.9% to 25.8%). In addition, tarsal flexion over cavaletti at 35cms height was on average 40.2% more for the leading compared to the trailing limb, (range 15.6% to 50%). In contrast trailing carpal flexions exceeded leading carpal flexions by an average of 10% (range 0.9% to 23.8%).

HORSE	AVERAGE FLEXION CARPUS	TARSUS	% Diff	TRAILING CARPUS	LEADING CARPUS	% Diff	TRAILING TARSUS	LEADING TARSUS	% Diff
HERB11	87.6	73.7	15.9	78.6	96.6	18.6	81.2	66.1	18.6
BERT07	96.7	77.2	20.1	101.1	92.3	8.7	102.6	51.8	49.5
TEDD15	90.5	73.0	19.4	90.9	90.1	0.9	95.3	50.6	46.9
DAIS14	90.4	73.0	19.2	86.3	94.5	8.7	97.4	48.7	50.0
COLI10	89.3	72.7	18.6	81.1	97.6	16.9	94.8	50.5	46.7
BOSS15	93.6	73.5	21.4	88.4	98.8	10.6	94.7	52.4	44.7
PAND99	99.9	74.1	25.8	86.5	113.4	23.8	74.7	63.0	15.6
Population	**92.6**	**73.9**	**20.2**	**87.5**	**97.6**	**10.3**	**91.5**	**54.7**	**40.2**

Table 4.5: Flexion angles in degrees measured over cavaletti five and six.

Analysis of the right and left limbs, produced lower average differences within the population at 1.0% between right and left carpal and 9.1% between right and left tarsal flexions. Further reliable interpretation of these results was not possible due to sample size and that the measurement error and levels of insignificance are not known. Similarly physiological significance levels in ipsilateral limb flexion differences were not known and these may vary with age, sex, breed and differ between lame and sound populations. In these results the aged mare PAND99, who had minor age-related arthritic changes, exhibited differences between her limb flexions of 7.8% and 12.2%, both greater than the population average. However, this was also true of COLI10 at 7.7% carpal and 16.8% tarsal flexion differences and yet this horse, 10 years younger and presented in competition fit condition demonstrated dexterity and ease of movement throughout the observations.

HORSE	RIGHT CARPUS	LEFT CARPUS	% Diff	RIGHT TARSUS	LEFT TARSUS	% Diff
HERB11	92.3	82.9	10.3	73.2	74.2	-1.4
BERT07	97.5	95.8	1.7	80.5	73.9	8.2
TEDD15	89.7	91.3	-1.8	66.6	79.4	-16.1
DAIS14	88.5	92.2	-4.1	70.8	75.3	-6.0
COLI10	85.8	92.9	-7.7	66.0	79.4	-16.8
BOSS15	95.2	92.0	3.6	66.4	80.7	-17.7
PAND99	95.9	104.0	-7.8	69.3	79.0	-12.2
Population	**92.1**	**93.0**	**-1.0**	**70.4**	**77.4**	**-9.1**

Table 4.6: Flexion angles in degrees differentiating left from right limbs at cavaletti five and six

The population results for trailing and leading limbs – where 100% (n=7) horses demonstrated increased flexion for the leading tarsus prompted further analysis. The videos were further analysed using paired passes, (01 and 91 or 92) for each horse, to produce kinematic graphs for right (RL) and left limbs (LL). The pairings were chosen to ensure an approach from each rein with individually consistent leading fore limb (n=7), four left and three right, (figure 4.2 TEDD15 and Appendix 3).

HORSE	DOMINANT	%		CARPUS			TARSUS	
	LATERALITY	Dominance		RIGHT	LEFT		RIGHT	LEFT
HERB11	RIGHT	83.3	*	**64.7**	72.5		46.8	**42.2**
DAIS14	RIGHT	83.3	*	40.7	58.5		33.4	41.3
BOSS15	RIGHT	66.7		66.1	62.0		28.0	29.9
PAND99	**NONE**	N/A		66.0	84.2		45.0	39.1
COLI10	LEFT	66.7	*	67.9	**65.4**		**45.3**	53.3
TEDD15	LEFT	66.7	*	76.4	**71.8**		**36.4**	49.1
BERT07	LEFT	100.0	*	78.6	74.7		45.9	41.3

Table 4.7: Maximum carpal and tarsal flexion angles and correlation to laterality. * indicates 5/6 horses with maximum carpal flexion corresponding to laterality and bold type those also with max flexion in the contralateral hind limb.

Maximum carpal and tarsal flexions taken from the kinematic graphs (table 4.7) showed that in 5/6 horses (83%) the laterality of entry into the exercise correlated with increased flexion in the dominant carpus and of these 3/5 showed maximum flexion in the contralateral limb, two dominant left fore/right hind and one right fore/left hind. The remaining 2/5, BERT07 and DAIS14, who were strongly lateralised appeared to flex the ipsilateral limbs on the dominant side of the body, BERT07 left and DAIS14 right.

In summary, 5/7 horses (71%) including the non-lateral horse, demonstrated maximum flexion in contralateral pairs of which 3/5 horses (60%) correlated with recorded laterality. On a population level this is 3/7 horses (43%) where contralateral maximum flexion also correlated with laterality. The 2 horses that recorded ipsilateral maximum flexion both correlated to dominant laterality.

A base line measurement of flexion on entry to the exercise over cavaletti one/two for each horse using Pass 01, right limbs, was conducted (figure 4.2. TEDD15, Appendix 3 shows all horses). Carpal (up to 25% more) and tarsal flexion (up to 50% more) increased over the raised poles (at 35cms) compared to the ground poles, (5 cms; table 4.8).

HORSE	DOMINANT	%	BL	CARPUS	ANGLE	BL	TARSUS	ANGLE
	LATERALITY	Dominance		RIGHT	% INC.		RIGHT	% INC.
HERB11	RIGHT	83.3	89.0	64.7	27.3	70.0	46.8	33.1
DAIS14	RIGHT	83.3	61.8	40.7	34.1	98.0	33.4	65.9
BOSS15	RIGHT	66.7	90.5	66.1	27.0	101.2	28.0	72.4
PAND99	**NONE**	N/A	97.6	66.0	32.4	59.9	45.0	25.0
COLI10	LEFT	66.7	98.2	67.9	30.8	93.1	45.3	51.4
TEDD15	LEFT	66.7	76.5	76.4	0.1	70.2	36.4	48.1
BERT07	LEFT	100.0	102.6	78.6	23.4	70.0	45.9	34.5
POPULATION	**NONE**	**N/A**	**88.0**	**65.8**	**25.3**	**80.3**	**40.1**	**50.1**

Table 4.8: Baseline (BL) flexion angles (ground poles) compared to maximum flexion angles (cavaletti exercise)

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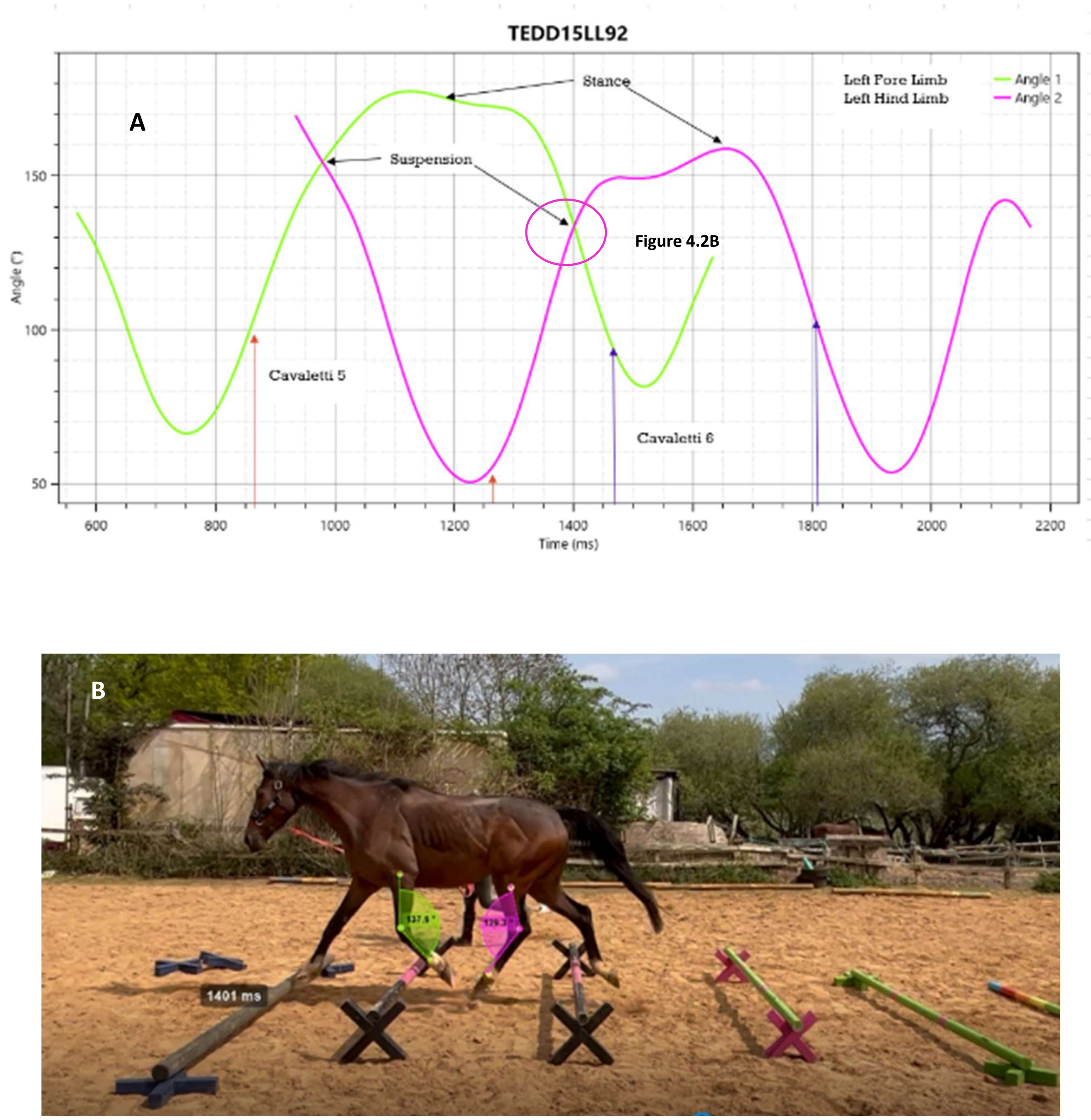


Figure 4.2 Angular Kinematics TEDD15: A) LL RR approach, left lead, LFL entry, cavaletti five leading FL/HL. B) The point of suspension, left limbs between cavaletti five and six.

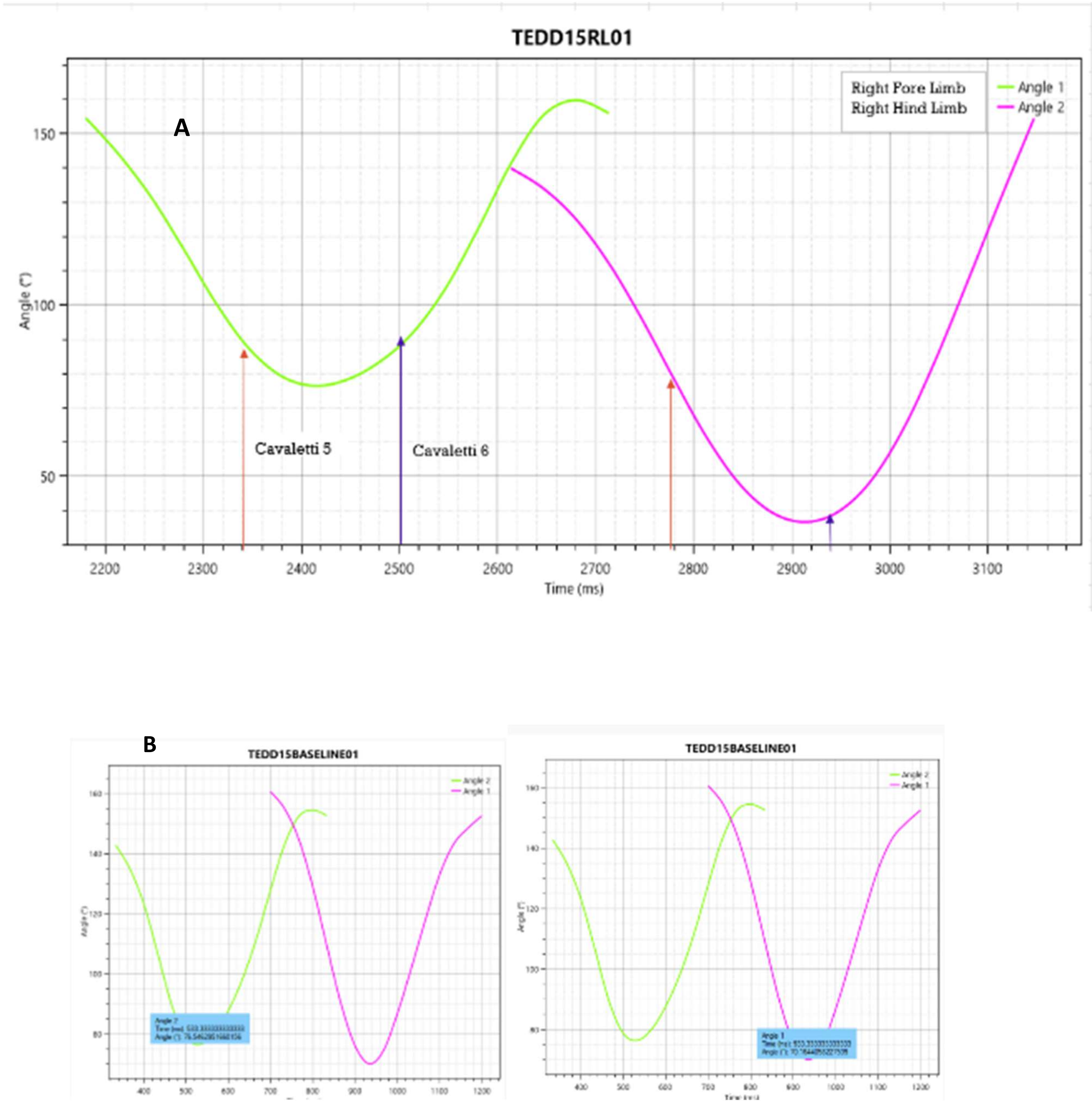


Figure 4.3 Angular Kinematics TEDD15: A) RL LR approach, left lead, LFL entry, cavaletti five trailing FL/HL. B) Baseline fore (Green) and hind (purple) flexion measurements, cavaletti at ground level.

4.3 Dorsal Wall Hoof Angle measurements

The average and median DWHA measurements placed 6/7 horses in the same symmetry classification, indicating high intra-rater reliability. As a group they fell into the second symmetrical group SYMM2.

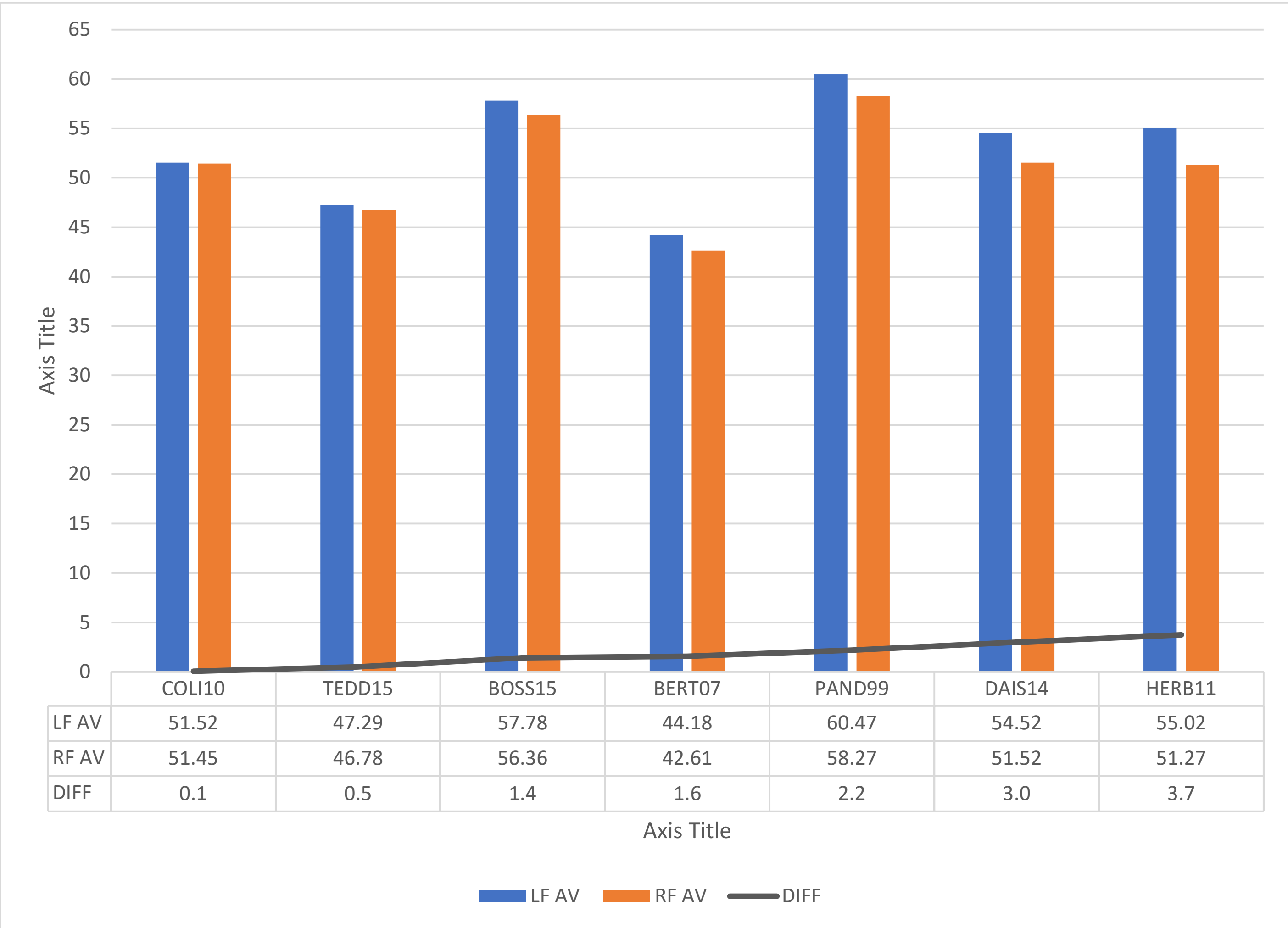
Name	LF AV	RF AV	DIFF	RESULT	LF MED	RF MED	DIFF2	RESULT2
COLI10	51.52	51.45	0.1	SYMM1	51.71	51.46	0.3	SYMM1
TEDD15	47.29	46.78	0.5	SYMM1	47.56	46.2	1.4	SYMM1
BOSS15	57.78	56.36	1.4	SYMM1	58.16	56.77	1.4	SYMM1
BERT07	44.18	42.61	1.6	SYMM2	44.38	42.49	1.9	SYMM2
PAND99	60.47	58.27	2.2	SYMM2	60.68	58.72	2.0	SYMM2
DAIS14	54.52	51.52	3.0	ASYMM1	54.33	51.5	2.8	SYMM2
HERB11	55.02	51.27	3.7	ASYMM1	55.3	51.29	4.0	ASYMM1
Population Average	**52.97**	**51.18**	**1.79**	**SYMM2**	**53.16**	**51.20**	**1.96**	**SYMM2**

Table 4.9: Left (LF) and right fore (RF) average and median DWHA calculated from three measurements of each hoof.

Classification code	Meaning	Number
SYMM1	up to 1.5 deg.	3
SYMM2	1.6-2.9 deg.	2
ASYMM1	3.0-5.0 deg.	2
ASYMM2	5.1 deg. or more	0
Total horses		**7**

Table 4.10. Total horses per dorsal wall hoof angle classification

All horses (100%, n=7) had a steeper LF DWHA although only two horses, (28.5%, n=2) displayed asymmetry as defined in table 4.10. Average DWHA measurements were then used for comparison between horses (figure 4.4). Two horses, (28.5%) had DWHA less than 50° in the range 42.61° to 47.29° and 3 horses (43%) were in the range 51.27° to 55.02°. Two horses (28.5%) had higher hooves in the range 56.36° to 60.47°. Both low hoof and high hoof horses were classified as symmetrical (n=2 SYMM1, n=2 SYMM2). The low hoof horses were of known breeding being predominantly thoroughbreds; one having a Weatherby's passport and had been purchased from racing (TEDD15) and the other (BERT07) had an Irish sport horse passport with racing sire and grandsires. One of the high hoof horses was a small Connemara cross (PAND99) and the other predominantly of Irish sport horse breeding, (BOSS15). The middle group of three horses contained both ASYMM1 horses and another SYMM2 horse.



	COLI10	TEDD15	BOSS15	BERT07	PAND99	DAIS14	HERB11
LF AV	51.52	47.29	57.78	44.18	60.47	54.52	55.02
RF AV	51.45	46.78	56.36	42.61	58.27	51.52	51.27
DIFF	0.1	0.5	1.4	1.6	2.2	3.0	3.7

Figure 4.4: A comparison of average dorsal wall hoof angle measurements and angle differences in degrees.

Summary of Results

The pilot study was summarised in table 4.11. The horses were placed in the order of increasing LF DWHA. The three horses with symmetrical hooves varying by less than 1.5° demonstrated maximum flexion laterality as LF RH and of these 2/3 horses correlated with LF lead exercise laterality. As the LF DWHA became steeper the horses tended to either RF/LH or right sided maximum flexion laterality and RF exercise laterality. There had been no attempt to recruit LF steeper horses into the study, it is possible that this is a result of the small sample size. There does not appear to be any obvious pattern or association between age and working hours in this group with DWHA and rider assessed sidedness was not strongly represented. The results were considered both on a population (n=7) an individual basis and compared and contrasted to published studies (Section 5) which added to the scientific evidence in the field through the statistical analysis of results. This pilot study did not generate a large enough body of evidence for this type of analysis and so does not directly contribute to the body of evidence but was able to demonstrate where measurements were possible, areas of research difficulty and signposted areas where more in depth studies could take place and directions in which video based objective measurement methods might develop in the future.

HORSE/ (hh)	AGE	WORK, HPW	RIDER ASSESSED SIDEDNESS	EQUINE-LIBRIUM SCORE	CATEGORY DWHA	DWHA DIFF IN DEG.	Exercise laterality	Max Flexion laterality
COLI10 15.2 hh	12	5	NONE	LF/RF 0 RH/LH 0	SYMM1	**0.1**	Left Fore Lead	**LF-RH**
TEDD15 16.2 hh	7	1.5	LEFT	LF/RF 0 RH/LH 1	SYMM1	**0.5**	Left Fore Lead	**LF-RH**
BOSS15 16.0 hh	7	5	NONE	LF/RF 0 RH/LH 0	SYMM1	**1.4**	Right Fore Lead	**LF-RH**
BERT07 16.0 hh	15	9	LEFT	LF/RF 0 RH/LH 0	SYMM2	**1.6**	Left Fore Lead	**LF-LH**
PAND99 15.0 hh	23	5	NONE	LF/RF 0 RH/LH 1	SYMM2	**2.2**	None	**RF-LH**
DAIS14 17.0 hh	8	7	NONE	LF 1.0 RF 0, RH/LH 0	ASYMM1	**3.0**	Right Fore Lead	**RF-RH**
HERB11 16.2 hh	11	8.5	NONE	LF/RF 0 RH 1 LH 0	ASYMM1	**3.7**	Right Fore Lead	**RF-LH**

Table 4.11: **Comparison of DWHA score with rider assessment, equine-librium score and laterality**. The height of each horse is given in hands (hh)

5: Discussion

Hypothesis 1 proposed that the video analysis quantifying gait asymmetry with tarsal and carpal flexion angles would be a more accurate assessment of soundness than traditional gait analysis. This hypothesis was supported in part by this pilot study. Gait asymmetry and flexion angles were measured effectively over the trot exercise, raised and ground poles. However, these results do not replace the EQL score, which can be tabulated for each limb separately, over different surfaces and on straight and bending lines which would not be appropriate for the cavaletti exercise. As the videos were reduced to a series of static moments, (suspension and flexion angles) the essence of movement was lost. However, by recording the gait assessments and the exercise and adding them to the HoR, gains were made in terms of the VP's ability to review the gait repeatedly and in slow motion, where appropriate, ensuring more accurate EQL records. Furthermore, the tracking of gait by kinematic analysis, which resulted in objective outputs such as graphs (Appendix 3), has potential for protocol development. The cavaletti exercise added variables for laterality, experience/ training which correlated with the clinical and veterinary history, thus providing quantitative data for these elements whether the EQL score was 0 (sound) or 1 (asymmetric). The horses were all in work and sound from their owner/rider's perspective and not receiving veterinary treatment for lameness. Therefore, large right/left differences in the trot suspension phase were not expected within this population, and where it was observed it correlated with changes in rein or leading leg through the exercise.

Hypothesis two proposed that there would be positive correlations between gait asymmetry, DWHA sidedness and HGS. This proposal was supported by this study. Numbers were small but (table 4.11), increasing left FL DWHA were associated with flexion and exercise laterality. Rider assessed sidedness was only positively reported in 2/7 horses, but they were LF lead and with flexion angles greater on the left side or LF/RH diagonal. Stress/pain facial markers (table 4.4), reached reported levels of significance in three horses that were naive to pole exercises and who also scored faults and changes of leading leg during the exercise with changes of speed (Group A table 4.3). One horse (PAND99), an aged hunter/jumper mare, improved HGS on starting the exercise. She had been stabled prior to running the exercise and moved progressively more fluently as familiarisation occurred. This underlines the significance of monitoring facial expression over time when training or rehabilitating horses.

5.1 Suspension Measurements, Laterality and the use of Grimace Scoring

The results showed no population laterality with exactly 50% LF and 50% RF entry to the exercise. However, laterality was important to the individual horse with only 1/7 (14%) mirroring the population result, 3/7 had LFL entry and 3/7 RFL. It is not known whether these results are caused by locomotor preference, sub clinical pathology or sensory laterality induced by tension or situational stress. LFL sensory laterality has been demonstrated in tasks described as being stressful and involving additional spatial awareness, such as stepping down and loading and also in the exploration of a new static novel object with the left eye (Larose et al., 2006; Siniscalchi et al., 2014). However, in this study a careful familiarisation session per Protocol 3 was designed to eliminate a purely sensory response and allow time in the approach for the horse to select a FL lead based on a sustained locomotor preference or no preference if ambidextrous. Of the horses naïve to pole work (Group A, table 4.3), only 1/3 (TEDD15) demonstrated LFL laterality. Strong lateralisation, defined as 5/6 or 6/6 exercise runs using the same FL, was seen in 3/7 (43%) horses and moderate lateralisation in 3/7 (43%) with 4/6 runs using the same FL (table 4.7). These results are similar to a larger study (n=482) of reining horses in competition that demonstrated strong individual laterality with only 20% performing equally to the left and right (Whishaw, 2015).

The results for TEDD15 and DAIS14 suggested that sensory laterality played a role, even after familiarisation, with high pole counts of 15/27, 3/6 lead changes and 4/6 asymmetric suspension phases together with high HGS for the pole exercise (Group A tables 4.3 and 4.4). DAIS14 was RFL lateral for the exercise, contrary to sensory laterality studies, but high LF DWHA may be the overriding factor in this individual's choice of leading leg. It is interesting that of the seven horses, DAIS14 at eight years of age was theoretically the most advanced in her training, regularly competing at BE Intermediate and qualified for Advanced Level. However, she completed the cavaletti exercise as her first introduction to pole work. Her reactions and results were true to this naivety rather than her competition record. COLI10 is a very experienced BE Grass Roots championship (2022) horse at 90cms. His training regime has been comprehensive, ranging from forest rides to classical dressage, pole work to hunting, in addition to his competitive experience. This appeared to positively affect his results which were fast with no fault runs. Inexperience, negative associations due to knocking poles and fatigue may have played a role in the response of at least 2/7 horses. Further research is required into developing protocols for young/naive horses through which the benefits and challenges of "cross training" for horses could be explored.

Asymmetry was demonstrated in 9/42 (21%) of suspension phases, 6/9 (67%) of these were seen in the Group A horses. The greatest variability, in both speed and differences between the right and left sides in suspension, occurred when the leading leg changed, faults occurred or there was a change of rein (table 4.2). The analysis showed that 6/9 (67%) of asymmetric suspensions were associated with one of these three events and 3/9 (33%) with two of them. These results were consistent with the adaptation of CPG gait patterns in sound horses in response to the pole exercise, the visuomotor system, which involves feed forward, (sight of an obstacle) and feedback (contact with a pole) mechanisms between the motor cortex of the brain and the spinal cord (Clayton et al., 2015; Drew et al., 1996). In a cat study, researchers concluded that motor cortex control can vary from subtle modifications that do not affect the gait rhythm to complete control of locomotion (Drew et al., 1996).

In designing this pilot study, a key research assumption was made.

- That in order to be measured with an iphone it would be necessary to lengthen the suspension phase using cavaletti. Slowing the trot phase down as an output of the exercise was evidenced in a study of eight horses where the trotting speed decreased by 0.16 m/s over poles at 20 cm height due to a lengthening of the swing phase of all limbs (Brown et al., 2015).

Analysis of video taken during familiarisation (where poles were laid on the ground) demonstrated that the duration of suspension can also be measured by the iphone 13 in these circumstances. The exercise familiarisation phase was fine-tuned for each horse individually, per Protocol 3 and so was not standardised for this measurement. Therefore figure 5.1 represents an indicator for future study development. Although not tested in this pilot, it may also be measurable when no induced elevation is present, for example during the trot phase of the gait assessment carried out by a VP (Personal communication Dr Ilse Daly, Blackdog Biomechanics, June 2022).

Figure 5.1: TEDD15 The suspension phase of trot measured between two poles on the ground – 67ms.

The HGS parameters described in the "Methods and Materials: Overview" were extrapolated from published research. Dalla Costa and colleagues established a clear link with sound non painful subjects scoring two or less and post-surgical horses five or more from a possible total of twelve (Costa et al., 2016; Dalla Costa et al., 2014). A low positive score is expected in photographic analysis due to "shutter accident" where an isolated non-painful response is scored; such as a partial blink mistaken for orbital tightening. There is less information concerning scores of three or four, but a negative emotional stimulus, (sudden umbrella opening) resulted in a mean score of three (Dalla Costa et al., 2017). The present pilot study indicated that scores of three or four equated to some tension, and a score of five the onset of fatigue and/or moderate tension due to due to hitting a pole.

Whilst clear photographs during conformation and gait assessments were obtained, light conditions and the distance of the camera from the subject during the cavaletti exercise diminished the quality of the results particularly in the case of the darker bay horses. The very low position of the sun in the sky for the February horses and the extreme contrast between sun and shadow for the June and July horses was challenging for the iphone operating in automatic video mode (figure 3.6 A and B). These shots were only a few minutes apart and the changing light was wholly due to a change of rein and the relative position of the camera to a low sun. If multiple stills had been taken at each stage and analysed the volume and reliability of the data produced would have increased. However, the problems of picture quality for the cavaletti exercise would still have remained and the task of analysing multiple photographs was beyond the scope of this project. It is certainly something to consider for the future as equine assessment happens throughout the year under differing conditions. Nevertheless, a trend of increasing HGS was established (table 4.4), and this correlated with the findings drawn from the trot exercise and questionnaire (table 4.3). The full results and photographs are included (Appendix 2).

In providing evidence that the suspension phase of trot is measurable by smart phone, the pilot study has demonstrated that poles placed to match the natural striding of each horse were likely to invoke motor cortex control leading to symmetry and introduce variability caused by age (experience and training) and athletic fitness which is reflected in the varying HGS response of the horses. Further studies into using the HGS by therapists could assist in the clinical reasoning of sets and repetitions in exercise prescription.

5.2 Flexion Angles and Angular Kinematics

Measurement of carpus and tarsus passive range of motion in horses has been previously validated using digital (DG), universal goniometers (UG), and radiographic methods as having excellent intra-rater reliability (measurement error 2-3°), (Bergh et al., 2020; Liljebrink & Bergh, 2010). Stifle flexion in canine cadavers compared UG, DG and smartphone based apps (real time and photographic) and concluded that UG, followed by the real time smartphone application provided the closest approximation to a gold standard (radiograph) measurement (Freund et al., 2016). There do not appear to be similar studies using smart phone applications in horses.

Two studies using multi camera and force plate technology provided evidence that can be used to explain the results of this pilot. Brown et al. 2015 found that carpal and tarsal flexion increased with pole height. The difference between lift off angle and minimum angle (= maximum flexion) was greater in the tarsal than carpal joints which correlated with the results (table 4.5). They concluded that as there was insignificant change in wither and croup height in the swing phase, the horses cleared the obstacles by engaging the musculature of the limbs and not by elevating the trunk. The HL contributed approximately 2/3 of elastic energy storage/release and the FL, 1/3. This explained the increased vertical excursion of the croup in the stance phase and the more acute maximum flexion of the tarsal joint compared to the FL and carpal joints (Clayton et al., 2015) correlating with the results of the pilot (tables 4.6, 4.7 and 4.8). The pole height that can be cleared comfortably in this way has a natural maximum but was not tested by Brown et al. (2015). In the current pilot study the poles were all cleared at a greater height, (35cms) than used by either the Brown or Clayton studies (20cms). All study horses approached the exercise with enthusiasm, albeit some had faults which was expected. In terms of running the study only 1/7 horses responded in a way that made analysis more difficult and that was the smallest at 15.00hh (PAND99). The show jumping mare was inclined to jump the poles during familiarisation, when they were at perfect stride distance for her (defined as being that distance in metres that meant the limbs naturally landed equidistant between the poles, 0.9m to 1.10m) and put in an extra stride changing leg, when the distance was “long”. This might be a horse height/pole height parameter that needs to be considered in the future. A study combining variable cavaletti height and HGS would provide further evidence as to the height that can be cleared comfortably and whether this changed significantly with the size and age of the horse assisting the VP in clinically reasoning a pole exercise prescription.

Measuring flexion angles at four specific points, two forelimb and two hindlimb, provided comparative data, but was not measuring the point of maximum flexion for either FL or HL. The point of maximum flexion occurred shortly before each leading limb crossed the pole and after each trailing limb crossed. This had less impact in the measurement of forelimb flexion where leading and trailing limbs were at similar points in the swing phase. Hind limb flexion was closer to maximum flexion for all horses when the limb was leading at the point of data capture (figures 4.2,4.3 and Appendix 3).

5.3 DWHA Measurements.

It is the difference between the measurements of the two front feet that has an important biomechanical effect and not whether the two feet are symmetrically at a lower or higher DWHA (Hobbs et al., 2018). One horse, BOSS15 had symmetrical feet that were in the range 56.4°-57.8° and another BERT07 was in the range 42.6°-44.2° (figure 4.4). However, quantifying a physiologically significant degree of difference varied between studies. The asymmetry threshold has been set as low as 1.5 degrees, although researchers cautioned re-using this parameter where measurement of DWHA was less accurate (Wiggers et al., 2015). As a population, the seven study horses were above 1.5° but below 2.0° with a population median of 1.96° and mean of 1.79° (table 4.9). In this pilot study a measurement difference of 1.5 degrees or less was assigned SYMM1 (table 4.10) and accounted for 3/7 horses (43%). A linear study of young warmbloods identified a mean of 2.8 degrees above which horses were regarded as asymmetric, which was in the range 2.4° to 2.9° identified previously (Van Heel et al., 2006; Van Heel et al., 2010). The range 1.5° to 2.9° degrees was assigned category SYMM2 and included 2/7 (28.5%) of horses. A foal study categorised two types of club feet, 3°-5° degrees and 5°-8° degrees steeper than the contralateral foot (Curtis, 2012). These thresholds were represented by ASYMM1 (2/7, 28.5%) and ASYMM2 (no horses). The two horses with asymmetric fore feet, category ASYMM1, had a high left foot which studies suggested was a supporting foot with the more dextrous being the RF (Hobbs et al., 2018; Moleman et al., 2006). The laterality of choice on entering the cavaletti exercise for the ASYMM2 horses was the RFL with increased right side or RF/LH diagonal flexion angles (table 4.11) and so individually agree with the previously published studies.

Studies have established that the mean DHWA of the FL is between 51.8° and 53.7, but can vary from 45° to 58° (Clayton, 1990). The mean results for this study were similar 51.2° RFL and 53.0° LFL, with a range of 42.6° to 60.5° (table 4.9), which indicated that the use of HoofmApp should produce reliable and reproducible results if confirmed in a larger study. The length of the hoof wall directly influenced the length of time between mid-stance and break-over, defined as the point of heel lift off and rotation over the toe as the whole hoof left the ground and swing phase began. A longer toe, or hoof wall had a more acute angle and the effect on gait was that the foot stays on the ground for longer. This conformation increased the energy stored in the superficial digital flexor tendon but consequently injury to the deep digital flexor tendon was more likely. A more upright foot with a larger DWHA angle had shorter ground contact time and a quicker transition into the swing phase (Leśniak et al., 2019). These researchers found that larger horses (being those over 16.0hh and also heavier breed types), required larger feet being a bigger surface area to spread the load and this occurred as a longer hoof wall and wider base but with a larger DWHA, protecting the digital flexor tendons. Lesniak and colleagues measured the forefeet of riding school horses (n=63) and showed statistically that as the DWHA increased so did asymmetry with the right foot becoming more upright than the left. More load is placed through the vertically placed bones of the upright foot, whereas the acutely angled foot loads the soft tissues. The researchers concluded that it was difficult to decide which hoof type was more at risk of injury or importantly which shape is more appropriate and so correction through farriery should be step wise and cautious. Hoof asymmetry has been associated with pathology and the early retirement of warmblood dressage horses and showjumpers (Ducro et al., 2009). This pilot study found that all seven horses had higher left rather than right DWHA. Lesniak recognised that individual horses differed from the overall results and so it is entirely possible that the small sample size explains this difference. Additionally, the riding school horses being attended by the same farriers may have been influential in the upright RF, whereas the study horses other than BERT07 and HERB11, who had the same farrier, had individual unrelated professionals involved. The two asymmetric horses, DAIS14 and HERB11 were also both tall, 16.2hh and 17.0hh and heavy (table 4.11). DAIS14 had a visibly obvious gait asymmetry at trot in the swing phase of the LF and HERB11 had a serious RH fetlock injury some years earlier which may have influenced a locomotory preference for the RF/LH contralateral pair. The HoR (conformation photographs) showed that HERB11 appeared visibly short in the neck in relation to his height to wither which may have predisposed him to a RFL forward grazing stance as a foal.

6. Future Developments

The results obtained in this pilot indicated that 60fps is sufficient to capture gait without elevation by raised poles. Initially, a new pilot study filming a standard physiotherapy gait assessment would be necessary. The new study could capture video at 60fps using two cameras activated remotely to allow simultaneous left and right side analysis and enhanced HGS by taking multiple stills of the horse at rest, during walk and trot. After the development of methods and protocols a larger study would be needed to test them.

The aim would be to gather enough data to develop a physiotherapy gait assessment application for smart phone/notepad could then be developed as a useful adjunct to visual scoring. A laterality function could be standardised over a simple ground pole exercise to record preferences and dominant limb pairs.

Other modules that could be added to a video gait application:

a) **Inertial Sensor data**. Either using the smart phone at the pelvis to record a single parameter, pelvic excursion, or potentially using several external IMUs which capture data from the withers forelimb and pelvis to send to the smart phone application for processing.
b) **Conformation**: Still frames/ video of the front back and both sides of the horse could use maps of known posture adaptations (such as valgus and varus limb deviations, kyphosis and lordosis), to provide an external assessment of the horse. It is not thought that this is available yet as commercial software.
c) **Hoof Asymmetry mapping** which is already commercially available. HoofmApp, (The Equine Documentalist, 2022), used in this pilot, is inexpensive (under £100 pa Dec 2021), and operates through a smart phone but requires manual application of digital templates to measure angles. Alternatively, EponaCam (EponaTech, 2022), which initiates through a smart phone but sends images for automatic calibration of hoof angles by software algorithms on a computer. This is a more sophisticated and expensive solution that eliminates human error in applying templates to an image and standardises the quality of the image required, but it needs a networked computer running Metron software and so is not easily used in a therapeutic setting at the time of writing.

These functions together in one application would be a useful tool for the VP to aid clinical reasoning of treatment plans and exercise prescription; communicating with the client to demonstrate a base line and improvements or conversely a drop in performance and to liaise with veterinarians and farriers to improve interprofessional communication and contribute to the welfare of the horse population.

A glimpse into the future for this type of application is given by Blackdog Equestrian Biomechanics (www.blackdogequestrian.com). This software analyses the position of the upper body of the rider in a live or uploaded video. The rider's position is colour coded for ease of interpretation (figure 6.1), and the software then matches the metrics produced to exercises to assist with the rider's core strength and balance.

Figure 6.1: Blackdog Equestrian Biomechanics: BERT15 analysis of rider and horse at trot. A) Green lines represent ideal position, the position of the horse's head is yellow being sub optimal, above the vertical B) yellow line for the lower leg which is swinging back with the upper body in red tipping forward. White spots are machine generated markers on the horse.

However, the software also identifies key points on the horse's body (figure 6.1), calculating stride length, flexion and extension angles (figure 6.2). It is an equitation not a therapeutic application and only registers the horse with a rider present. It seeks to monitor the effect of the rider on the horse as the rider improves their riding position. It also has a library of schooling exercises for the horse.

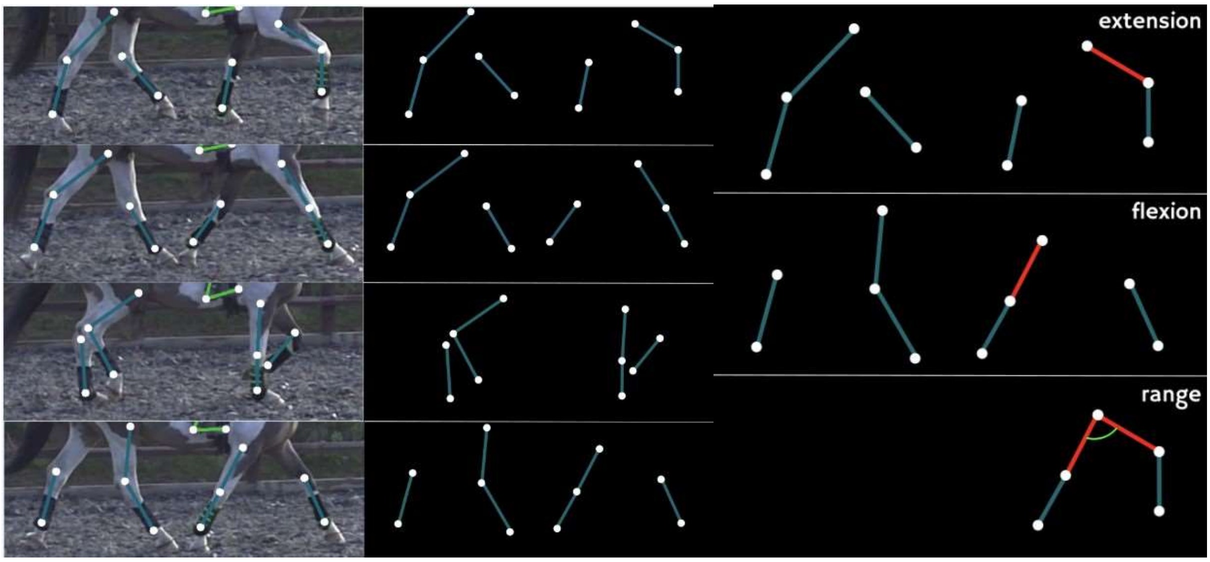


Figure 6.2: Blackdog Equestrian Biomechanics: Horse measurement points. A) Machine generated limb positions generated from the video and B) limb range of motion.

Data based output reports provide a summary for the rider, the left side can be compared to the right and also comparisons can be made over time and between horses (figure 6.3).

A

Stride Time

In video 1 (SarahWalkR), each stride took an average of 2.8175 seconds and in video 2 (SarahWalkL), each stride took an average of 2.5125 seconds.

All Metrics

If you're feeling analytical, the table below shows all of the angles for the horse's gait in videos 1 and 2.

Limb	Metric	Video 1	Video 2
Upper Front	extension	44°	45°
	flexion	-30°	-30°
	range	74°	75°
Lower Front	extension	22°	24°
	flexion	-42°	-42°
	range	64°	66°
Upper Hind	extension	-7°	-16°
	flexion	-60°	-60°
	range	53°	44°
Lower Hind	extension	37°	39°
	flexion	-25°	-26°
	range	47° **62**	50° **65**
Stride Time	seconds	2.8175	2.5125
Head Carriage	average	9°	2°

B

Stride Time

In video 1 (SarahTrotR), each stride took an average of 2.0675 seconds and in video 2 (SarahTrotL), each stride took an average of 2.57 seconds.

All Metrics

If you're feeling analytical, the table below shows all of the angles for the horse's gait in videos 1 and 2.

Limb	Metric	Video 1	Video 2
Upper Front	extension	49°	47°
	flexion	-24°	-31°
	range	73°	78°
Lower Front	extension	14°	21°
	flexion	-30°	-46°
	range	44°	67°
Upper Hind	extension	-13°	-16°
	flexion	-59°	-62°
	range	46°	46°
Lower Hind	extension	38°	40°
	flexion	-15°	-17°
	range	29° **53**	38° **57**
Stride Time	seconds	2.0675	2.57
Head Carriage	average	12°	12°

C

Stride Time

In video 1 (SarahCanterR), each stride took an average of 1.6675 seconds and in video 2 (SarahCanterL), each stride took an average of 1.5825 seconds.

All Metrics

If you're feeling analytical, the table below shows all of the angles for the horse's gait in videos 1 and 2.

Limb	Metric	Video 1	Video 2
Upper Front	extension	48°	62°
	flexion	-15°	-18°
	range	63°	80°
Lower Front	extension	21°	30°
	flexion	-43°	-42°
	range	64°	72°
Upper Hind	extension	9°	0°
	flexion	-55°	-59°
	range	64°	59°
Lower Hind	extension	49°	50°
	flexion	-12°	-15°
	range	33° **61**	45° **65**
Stride Time	seconds	1.6675	1.5825
Head Carriage	average	9°	0°

Figure 6.3: Comparative range of motion data for BERT07 A) walk B) trot and C) canter. Video 1 in each are the right limbs, video 2 the left limbs. Head carriage is between 0° and 12° above the vertical. Erratum: Lower hind range calculation, only, a software error is being corrected. Actual figures stated in bold.

The 12 measurements, four for each pace, predominantly recorded a greater range of motion in the left than the right limbs, 9/12 with 2/12 right rather than left limbs and 1/12 were the same value. Anecdotally this correlated with the findings of this pilot study (table 4.7), which concluded that BERT07 was left fore and left hind flexion dominant. The Blackdog analysis shared a limitation with the pilot study in that the right and left limbs were videoed consecutively rather than simultaneously, the rider changed direction on a 20m circle so that the videographer could record the alternate limbs from the centre.

All pictures and data in figures 6.1-6.3 are the copyright of Blackdog Equestrian Biomechanics and reproduced with kind written permission from Dr I Daly.

A therapeutic application for the horse using machine learning would have many advantages in the ease and speed of use. Machine learning is a sub-category of artificial intelligence where software develops pattern recognition or the ability to continuously learn from and make predictions from data without being specifically programmed to do this. This pilot study utilised a complex data set which in addition to movement (kinematics), recorded behavioural (sensory laterality) and emotional (grimace scale) responses which could potentially be modelled using machine learning rather than a hypothesis/statistical approach in the future (Valletta et al., 2017). Such an application could be linked to other modules as described above, provide an exercise prescription library, referral report templates and supplementary clinical notes pages.

CONCLUSION

If the results of this study are confirmed in larger studies, lateralisation would be established as an important parameter in the evaluation of the biomechanical health of each individual horse during maintenance and rehabilitation by VPs. Laterality was shown by 6/7 (86%) of horses with 3/7 (43%) demonstrating strong laterality with more than 80% use of a preferred forelimb. These results indicated that almost one in two horses on a VP client list may have levels of asymmetry that affect optimal performance. The widely held practice of changing the rein during trot exercise to work the horse's musculoskeletal system equally on both sides was challenged by this study as the horse used visuomotor skills to adapt stride patterns and continue using the preferential limb pairs, where present. There was a strong correlation between a high (3°-3.7°difference) hoof and laterality to the opposite side, in this study 2/2 (100%) of horses with a high left hoof correlated 100% with right limb preference. The hoof difference observed was visible to the eye but only on careful observation, whilst taking photographs from the side and at ground level. This study found that carpal and tarsal flexion increased with the use of poles in a range of 25%-50% but more work is required to establish the optimum height(s) for use in rehabilitation programmes and the introduction of horses to this type of exercise. The integration of behaviour parameters such as the horse grimace scale can be done with the use of video but not where the output is purely kinetic, where IMU's are used alone, for example. In this study group A (naïve) horses, reached the significance threshold for discomfort (scores of 5/12), whereas the trained horses did not. The smart phone carried by 99% of those under 35 years, is currently underutilised as a powerful observational tool in veterinary physiotherapy. The establishment of straight forward protocols together with field-based videography provides a basis for software analysis and objective measurement. A reference library of video clips and photographs for each horse could be compiled and re-analysed as software improves over time or indeed as the horses ages or has differing training regimes.

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[16,437 words incl. Bibliography 1,856]

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APPENDIX 1

METHODS AND MATERIALS APPENDIX: PROTOCOL DEVELOPMENT

WHAT	ORIGINAL	UPDATE	WHY
DWHA measurement software	Bosch tool box (£free) 	HoofmApp £60 pa or can purchase weekly from £2.49	A change from a simplistic construction industry to a bespoke application with more precise templates and algorithms designed for the horse.
DWHA measurement camera	As used in this project, pre-owned Gopro 5 and tripod, replacement cost £430. 	For future projects: Eponacam iphone cradle and app, circa $250 	The Gopro produced good pictures but it adds complexity to image handling – they need to be uploaded via the Gopro app. Expensive and more vulnerable to breakage. The cradle is robust and holds the smart phone at the correct angle. Photos are stored on the App ready for analysis via HoofmApp. Changing to the cradle would allow all recording to be done with one camera. Epona has AI software available purchased separately for circa $1,000 which adds angle measures to the picture automatically. Cost and supply issues (sold to Vet practices only, from the US) and the fact it only operates on a computer are the main drawbacks.
Dynamic camera	Iphone 11 captures 30 fps or 37ms between frames	Iphone 13, 60fps, 18ms between frames and HDD quality	Upgrading the smart phone greatly increased clarity of the recordings and the accuracy of the time measurements. But see below.
Camera automation	Pivo silver and tall tripod.	From remote (using hand held control) to manual tracking.	Using the remote control means operating the camera through the Pivo App which only supports 30fps, confirmed with Pivo corporation. This means two researchers are essential rather than desired. It is likely that Pivo will update soon. (60fps available only since 2021 on "high end" smart phones such as iphone 13.)

Identification of rein approach Two methods originally	• Mark head collar with Velcro “0” for left and “9” for right side • Define colours for limb marking in the protocols	• Maintained for handling and head shots but not visible in filming, so of limited use, see below. • Some colours are blanched by sunlight. • **Added** rein and pass code banner as filming starts. “01” means left rein first pass. “91” is right rein first pass.	A very important factor as films and stills can be “flipped” within the software accidentally. Laterality is a feature being recorded and must be clearly defined. Colour protocols developed separately for dark and light coated animals. The addition of a filmed code ensures security of data. 
Cavaletti Set Up	Various configurations of five and six poles.	Seven poles with “ladder” configuration per protocol 3 was the least confusing to two horses in pre pilot testing. To maintain consistency poles were paired in a set pattern.	The aim of the cavaletti exercise is to slow down suspension to allow filming due to the gait elevation achieved over 35 cm poles (five and six). Pole seven on the ground helps to maintain straightness. The aim is not to over challenge or confuse horses resulting in uneven gait patterns loss of confidence or even injury.
Handling Equipment 	Various configurations tried: Bridle and either single or two long reins Dually head collar and either single or two long reins.	Prefer Dually head collar and single line kept loose with minimal guiding. As the horses have familiarisation time they learned to take themselves over the exercise.	Most horses are familiar with single line lunging from a headcollar in the UK. A bridle can be used if necessary for safety but this potentially allows more interference by the handler which can alter the gait. The Dually, pictured, allows for an intermediate level of control - more than a Newmarket head collar if pressure is applied but less than a bridle and has no effect on the mouth. Two long reins kept the horses straighter in pre pilot testing and can be operated with little pressure by a skilled handler but not all horses are accustomed to the use of two reins and so it was not taken forward into the pilot.

APPENDIX 2

Detailed results and still frames taken from video for HGS scoring at 3 distinct points

A (Conformation assessment) B (Trot up/familiarisation) and C (Cavaletti exercise).

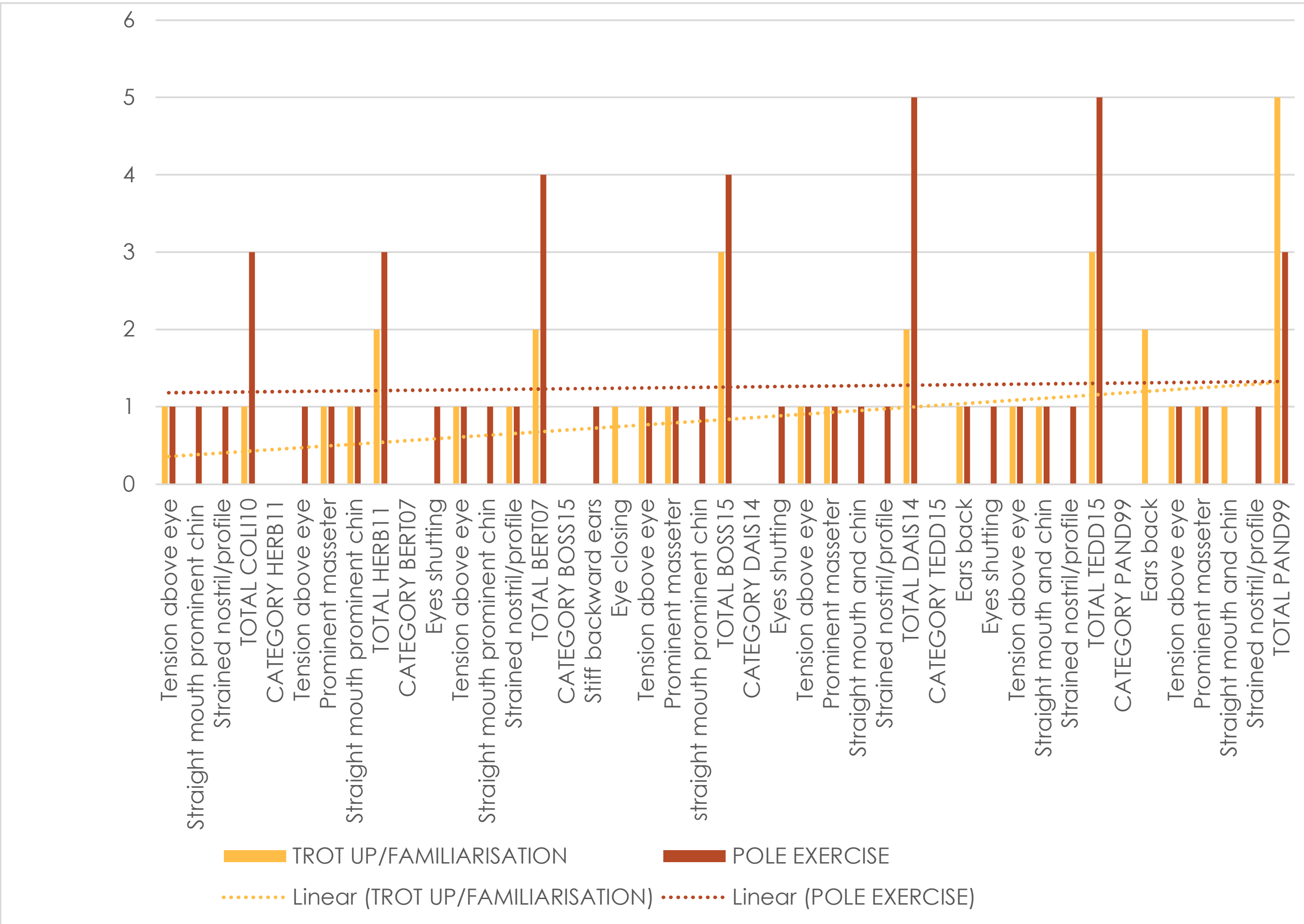


Figure 1 Appendix 2 Individual HGS where each FAU is scored 0 1 or 2 points, maximum 12 points per horse.

HERB11	A	B	C
Stiffly backward ears	0	0	0
Orbital tightening	0	0	0
Tension above the eye	0	0	1
Prominent chewing muscle	0	1	1
Straight mouth and pronounced chin	0	1	1
Strained nostril flattened profile	0	0	0
TOTAL	**0**	**2**	**3**

A (conformation) B (trot up / familarisation) C (Cavaletti exercise, pass 3 of 6*)

* In February light conditions on the right rein precluded any head shots for passes 4-6 for both horses.

BERT07	A	B	C
Stiffly backward ears	0	0	0
Orbital tightening	0	0	1
Tension above the eye	0	1	1
Prominent chewing muscle	0	0	0
Straight mouth and pronounced chin	0	0	1
Strained nostril flattened profile	0	1	1
TOTAL	**0**	**2**	**4**

A (Conformation) B (Trot Up) C (Cavaletti pass 3 of 6*

TEDD15	A	B	C
Stiffly backward ears	0	1	0
Orbital tightening	0	0	1
Tension above the eye	0	1	1
Prominent chewing muscle	0	0	0
Straight mouth and pronounced chin	0	1	2
Strained nostril flattened profile	0	0	1
TOTAL	0	3	5

A (Conformation) B (Trot Up) C (Cavaletti pass 6 of 6)

PAND990706	A	B	C
Stiffly backward ears	0	2	0
Orbital tightening	0	0	0
Tension above the eye	0	1	1
Prominent chewing muscle	0	1	1
Straight mouth and pronounced chin	0	1	0
Strained nostril flattened profile	0	0	1
TOTAL	**0**	**5**	**3**



A (Conformation) B (Trot Up) C (cavaletti pass 6 of 6)

BOSS152206	**A**	**B**	**C**
Stiffly backward ears	0	0	1
Orbital tightening	0	1	0
Tension above the eye	0	1	1
Prominent chewing muscle	0	1	1
Straight mouth and pronounced chin	0	0	1
Strained nostril flattened profile	0	0	0
TOTAL	**0**	**3**	**4**



A (Conformation) B (Familiarisation) C (Cavaletti pass 3 of 6)

COLI10	**A**	**B**	**C**
Stiffly backward ears	0	0	0
Orbital tightening	0	0	0
Tension above the eye	0	1	1
Prominent chewing muscle	0	0	0
Straight mouth and pronounced chin	0	0	1
Strained nostril flattened profile	0	0	1
TOTAL	**0**	**1**	**3**

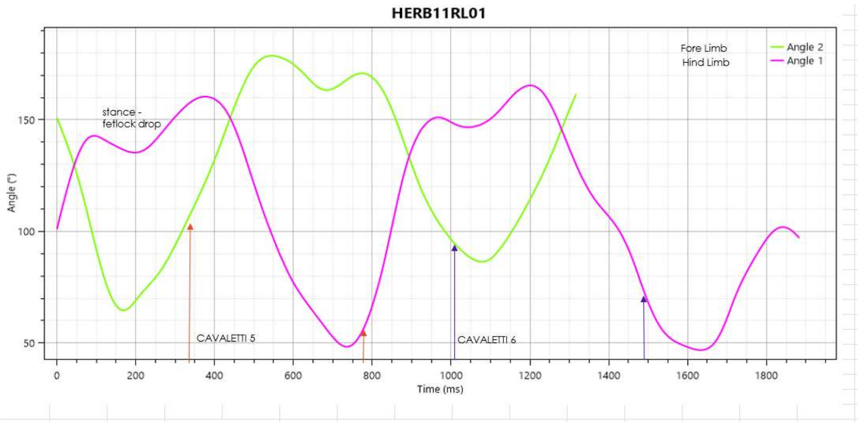


A (Conformation) B (Familiarisation) C (cavaletti pass 6 of 6)

DAIS142907	A	B	C
Stiffly backward ears	0	0	0
Orbital tightening	0	0	1
Tension above the eye	0	1	1
Prominent chewing muscle	0	1	1
Straight mouth and pronounced chin	0	0	1
Strained nostril flattened profile	0	0	1
TOTAL	**0**	**2**	**5**

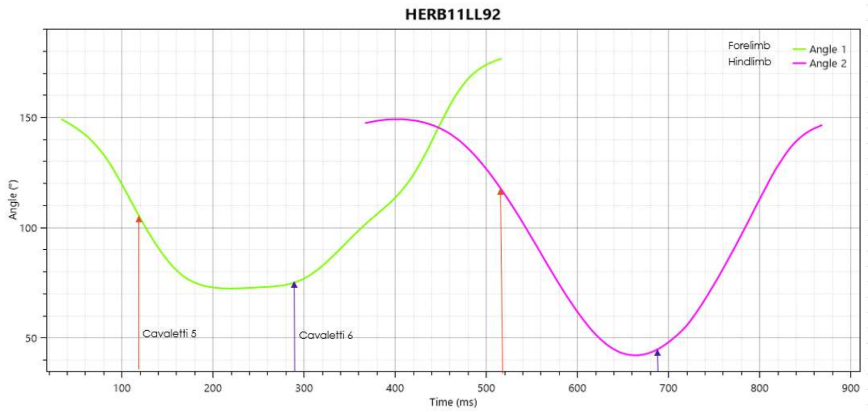
A (Conformation) B (Familiarisation) C (cavaletti pass 6 pf 6)

Appendix 3 Angular kinematics – Calculation of maximum and minimum flexions.



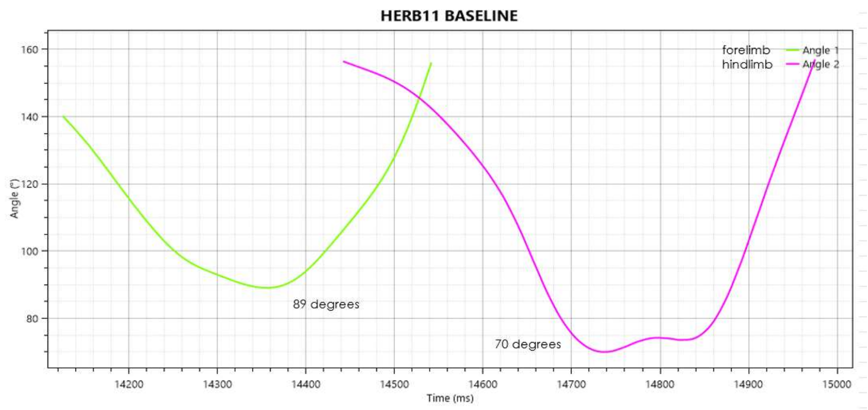
HERB11

RIGHT LIMBS



HERB11

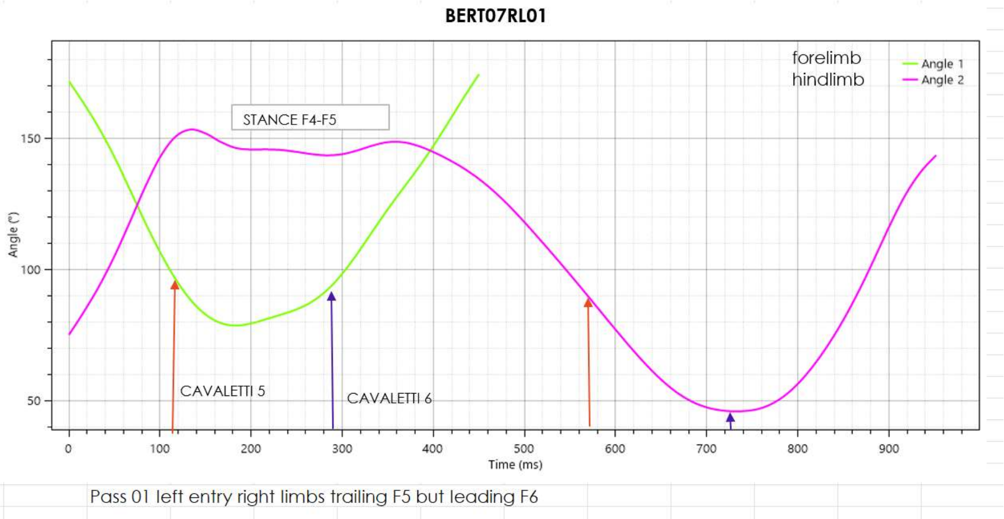
LEFT LIMBS



HERB11

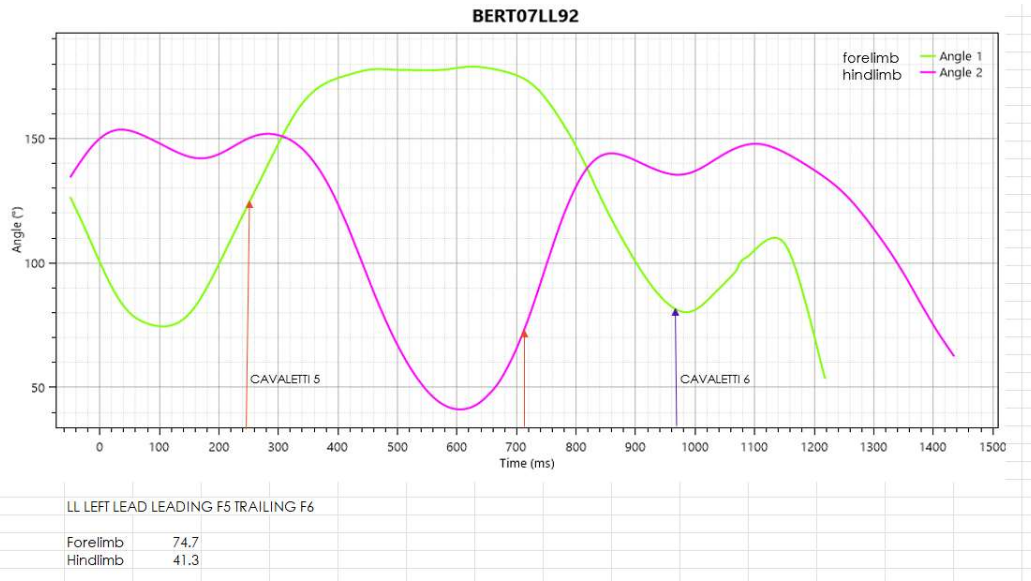
Baseline

Right limbs



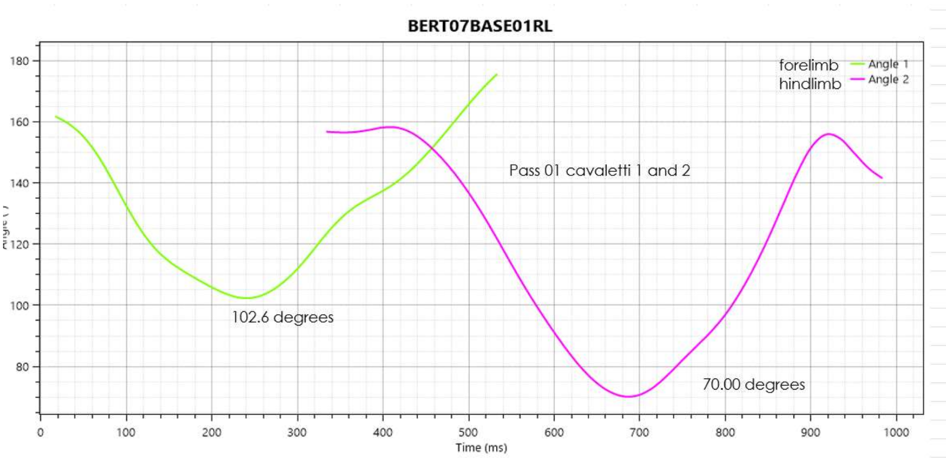
BERT07

Right Limbs



BERT07

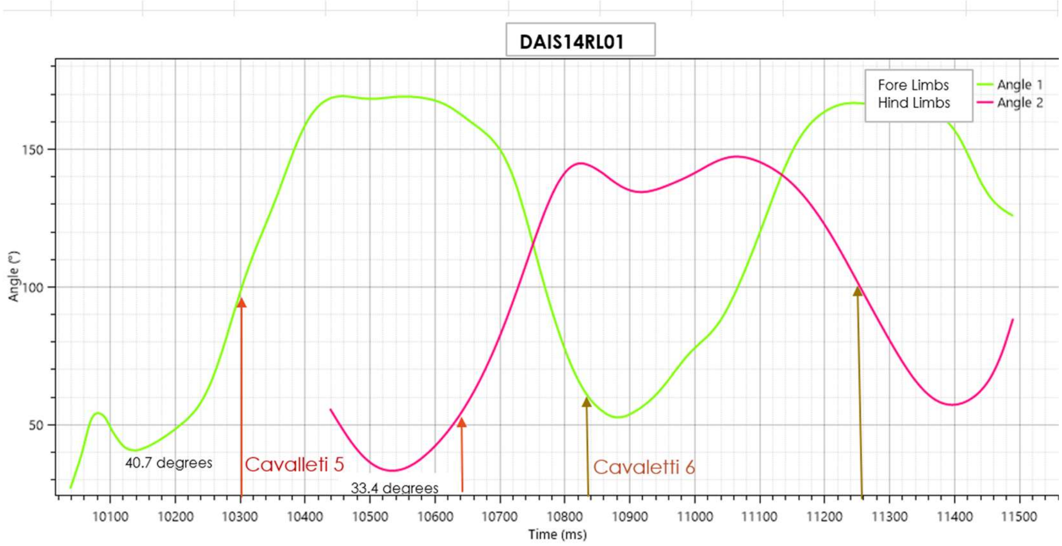
Left Limbs



BERT07

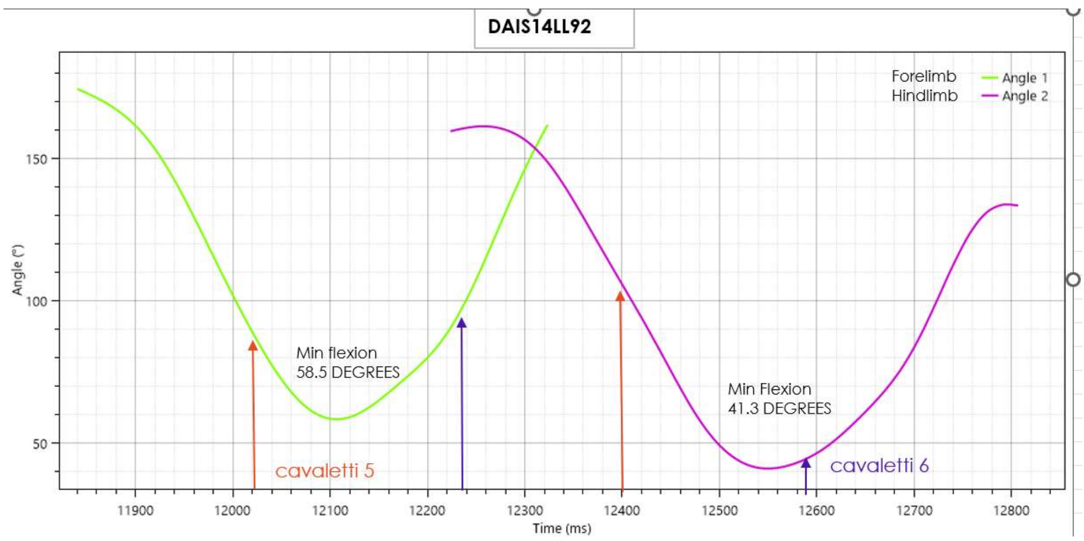
Baseline

Right limbs



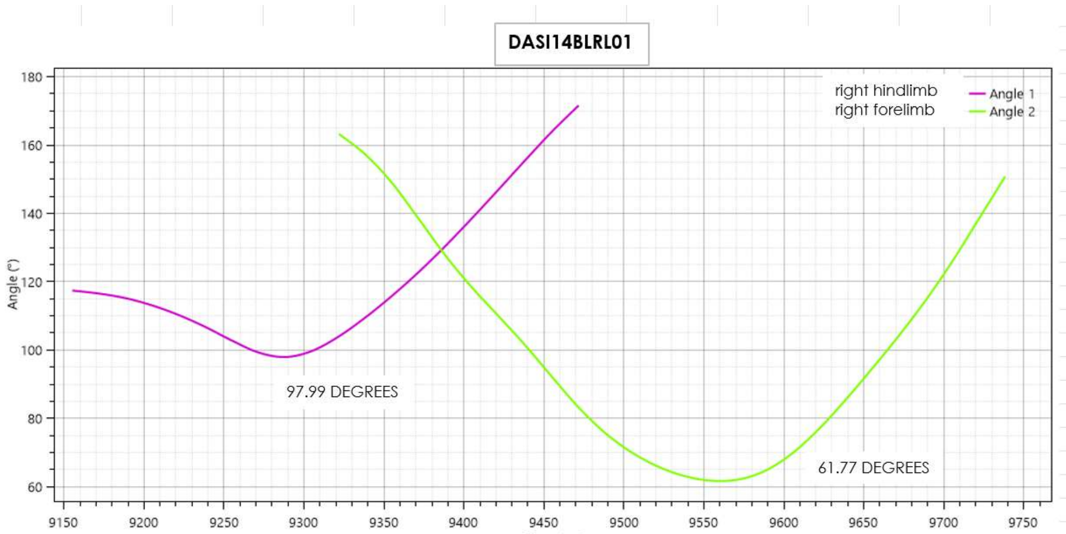
DAIS14

Right Limbs



DAIS14

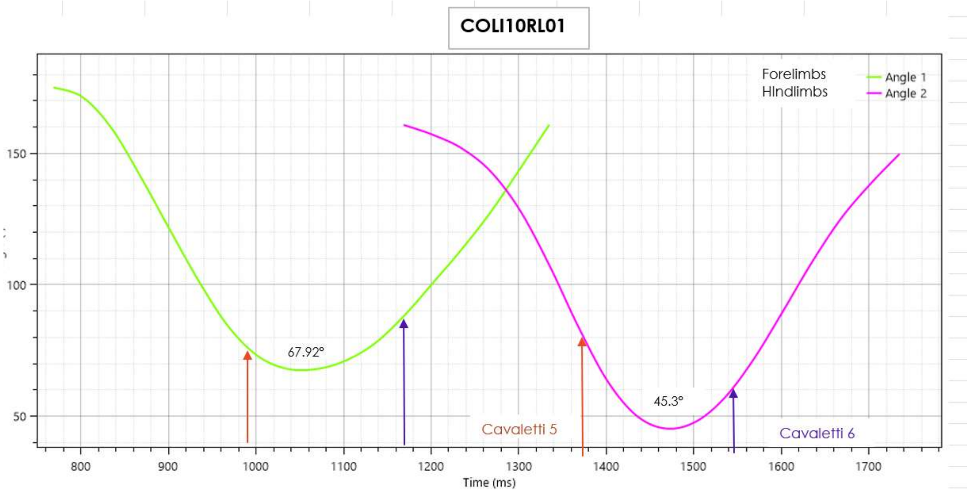
Left Limbs



DAIS14

Baseline

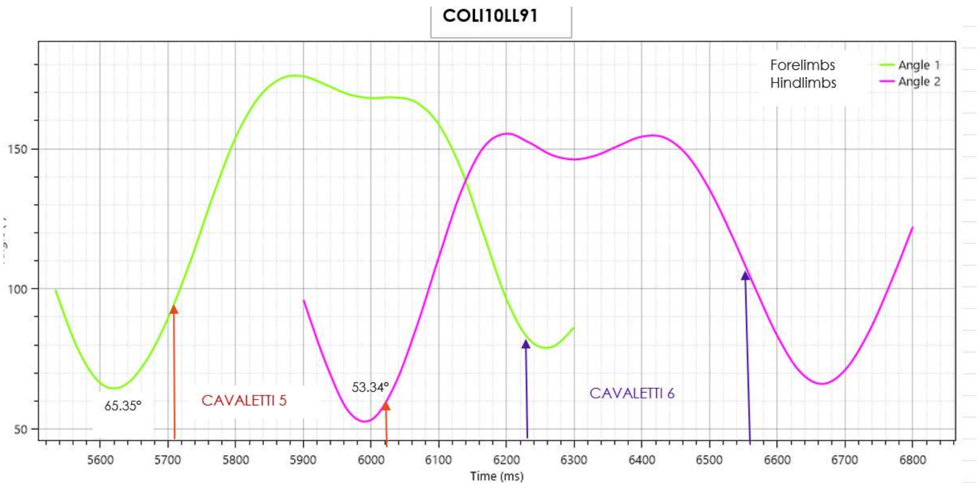
Right Limbs



COLI10 : right limbs trailing fence 5 and leading fence 6

COLI10

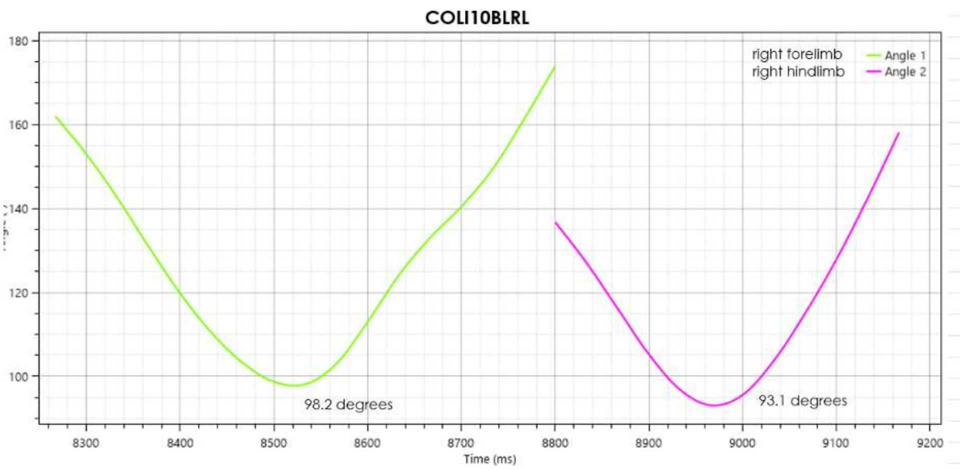
Right Limbs



COLI10: Left limbs leading fence 5 trailing fence 6

COLI10

Left Limbs

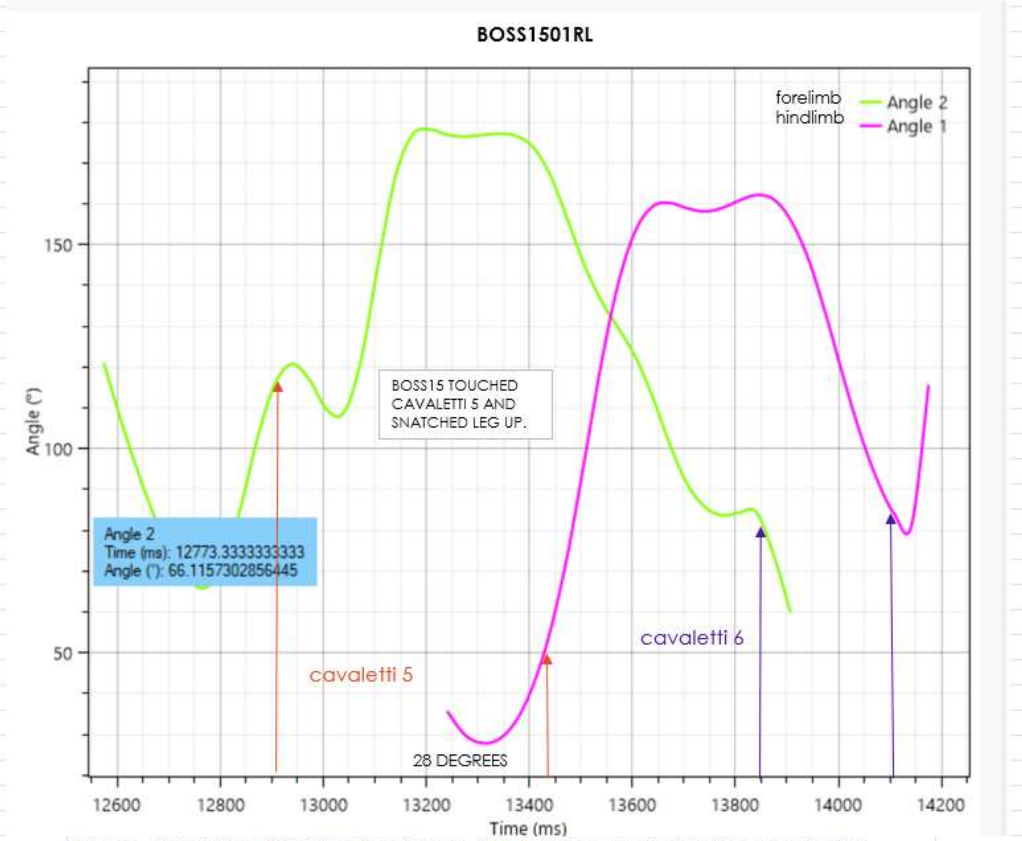


Base Line flexion angles measured over cavaletti 1 and 2 for right forelimbs pass 01

COLI10

Baseline

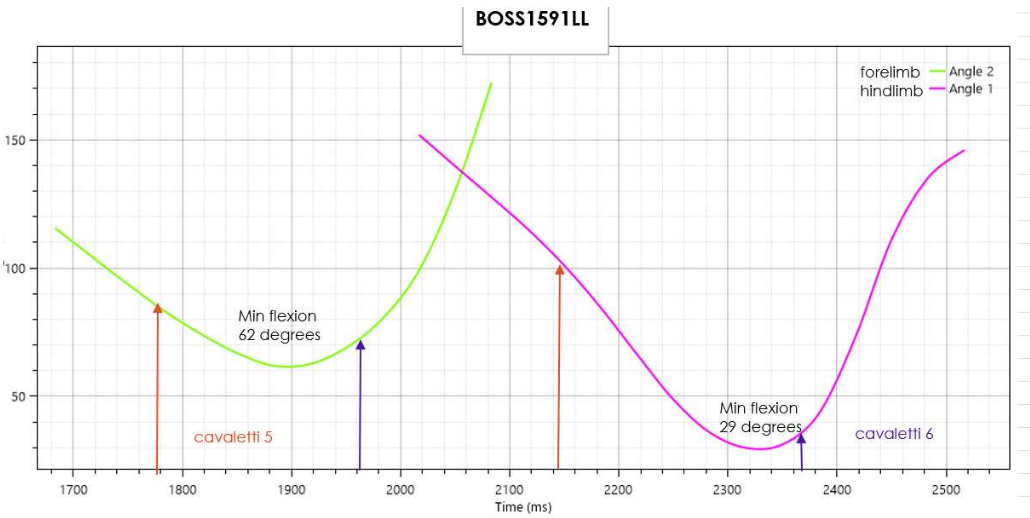
Right limbs



Pass 01 - right limbs with right laterality, RFL/RHL leading cavaletti trailing cavaletti 6

BOSS15

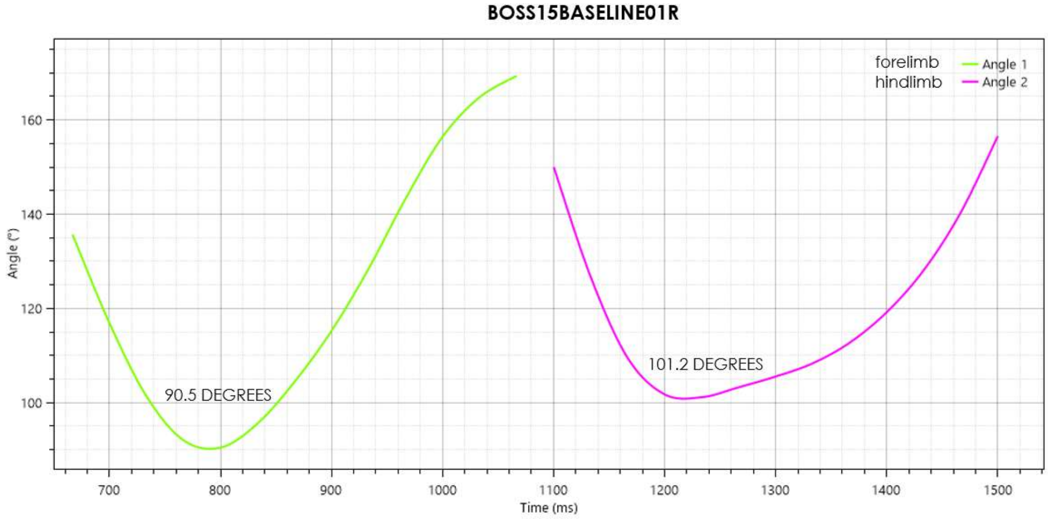
Right limbs



Pass 91, left limbs trailing at cavaletti 5 and leading at cavaletti 6

BOSS15

Left limbs

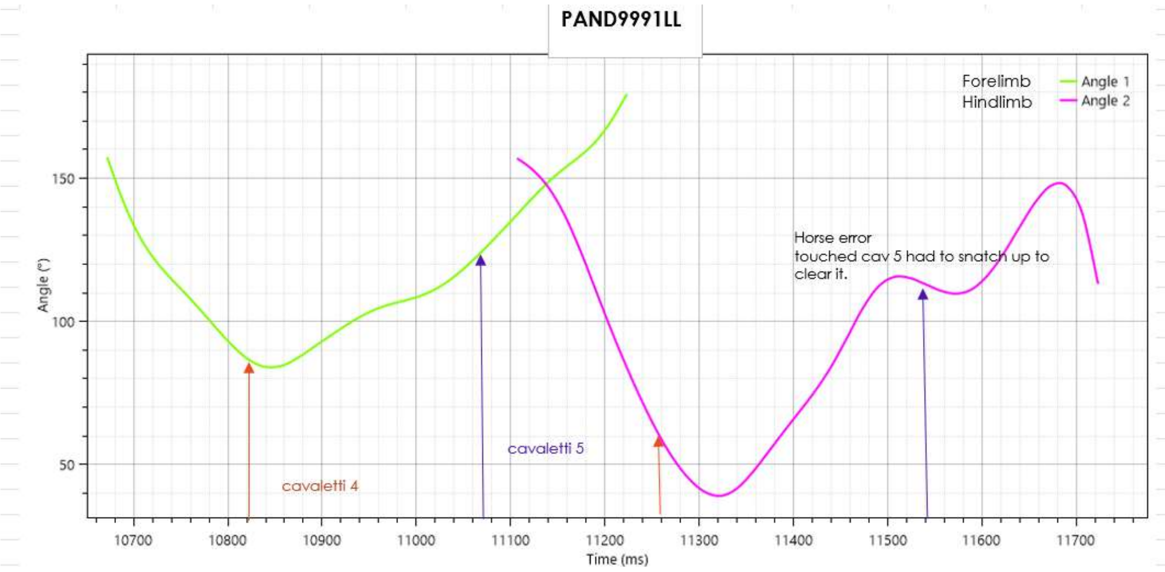


Pass 01, base line minimum flexions right limbs cavaletti 1 and 2.

BOSS15

Baseline

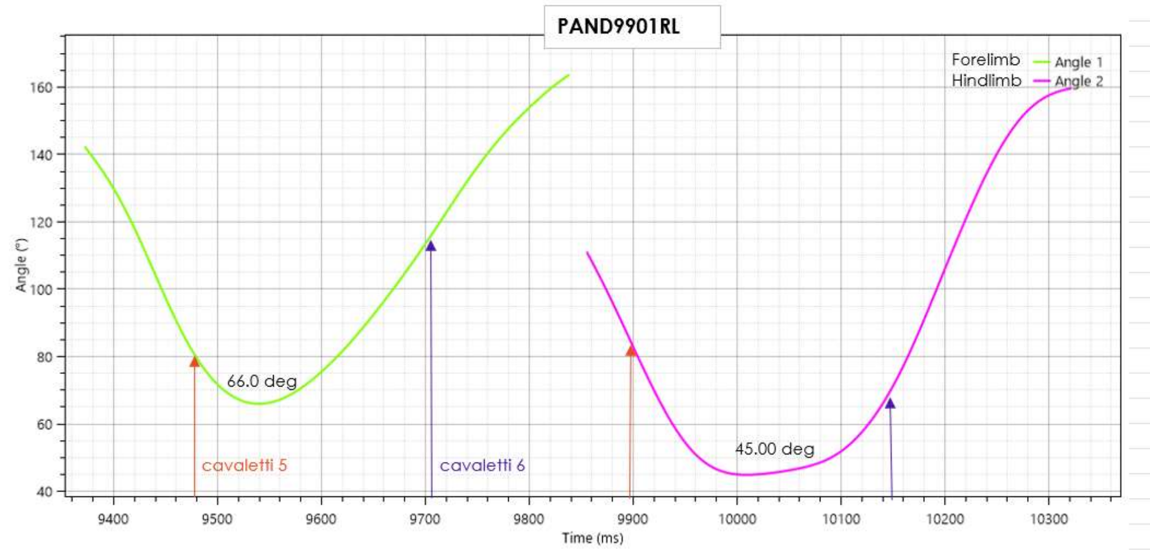
Right limbs



Pass 91 cavaletti 4, trailing and cavaletti 5 leading limb.

PAND99

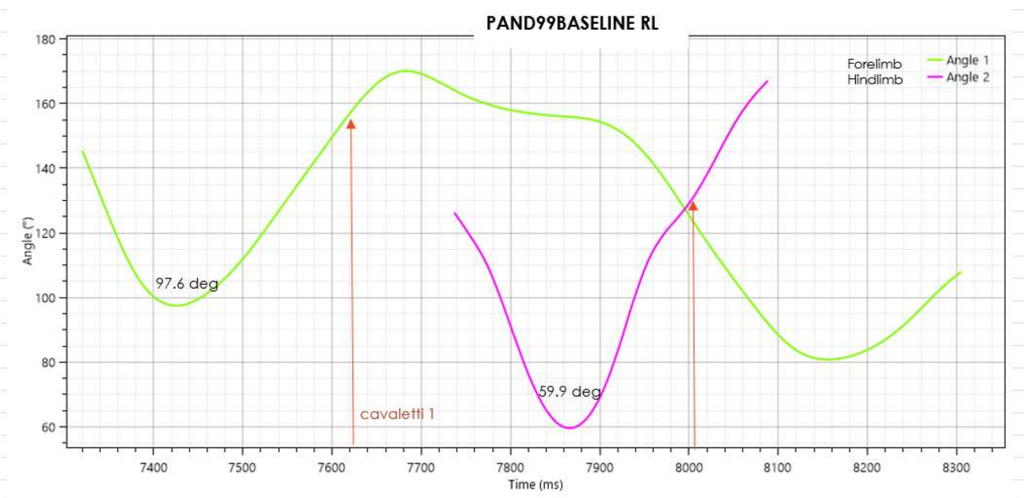
Left limbs



Pass 01, right limbs trailing cavaletti 5 and leading cavaletti 6

PAND99

Right limbs



PAND99

Baseline

Right limbs