Effect of Bilateral Stud Position on the Duration of Stride Phases and Length of Stride in Equine Athletes

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Abstract

Introduction: This observational pilot study provides the first objective exploration of the effects of different bilateral stud positions on the duration of stride phases and length of stride, for the purpose of providing optimum performance and welfare of the equine.

Aims: The aims of the study were to investigate the effect of different bilateral stud positions through the duration of the stride phases (midstance, breakover, swing and landing), overall stride length and stride duration, while demonstrating the utility of hoof-mounted inertial sensors to inform the effect of stud position.

Methods: Nineteen equines of “sports horse type” with similar sized feet and no past medical history were tested under standardised conditions. Each horse underwent four test runs of different stud position in the following order: no studs (control condition); bilateral studs in the front; bilateral studs in the centre; and bilateral studs in the rear.

Data Analysis: Data was visualised using boxplots. Non-parametric Friedman tests, followed by post-hoc Wilcoxon signed-rank tests with a Holm-Bonferroni correction, were completed to test for significant differences between the measurements recorded for each stud placement. These tests were appropriate as the data was not normally distributed and sample sizes were small.

Results: Friedman tests revealed significant differences for midstance duration, landing duration and swing duration across different stud placements. Post-hoc Wilcoxon signed-rank tests with Holm-Bonferroni correction identified a significant pair-wise difference in landing duration between the 'Two Front' and 'Two Rear' stud placements and swing duration between the ‘No Studs’ and ‘Two Centre’ stud placements. Data visualizations, specifically boxplots, confirmed that variability between different horses was greater than within the same horse under different conditions, indicating that inter-horse variability could obscure significant effects of stud position.

Conclusions: Overall, the findings suggest that bilateral stud positions do not significantly affect stride duration, stride length, or breakover and midstance durations. However, they do influence swing and landing durations, with 'Two Centre ' stud placements reducing swing duration compared to 'No studs ' and the 'Two Rear' stud placements increasing landing duration compared to 'Two Front' stud placements. Given high inter-horse variability and a small sample size, the results indicate that stud position may need to be personalised for each horse.

Declaration

I, Abigail Bunyard, hereby declare that the work within the fellowship dissertation is my own. Any sources have been duly referenced and any illustrations or diagrams that are not mine are used with permission of the owner.

Signature: Date

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Introduction

Historically, the demand on the equine locomotor system was to meet agricultural, military and transport requirements. Modernisation has shifted that demand to one of a sporting or recreational nature.

Since the introduction of the iron horseshoe, traction devices have consistently been used to enhance stability and grip. As the changes of demand on the equine locomotor system have evolved, so too have the traction methods and devices. The development of screw-in studs now provides riders with an adaptable system by which to enhance equine sports performance.

Equine locomotion consists of four phases within a stride cycle: midstance, breakover, swing, and landing.

Midstance occurs when the hoof is fully loaded, and the limb bears the horse's body weight. Biomechanically the hoof is flat on the ground. Energy is stored in the deep digital flexor tendon (DDFT), superficial digital flexor tendon (SDFT), and the suspensory ligament. The fetlock joint is at its lowest point due to extension, providing shock absorption.

Breakover is the transition from the hoof being flat on the ground to the toe leaving the surface. This phase begins as the heel lifts off the ground and ends when the toe leaves the surface. Involving the flexor tendons and digital joints working together to propel the limb forward. Critical for efficient energy transfer and minimizing strain on tendons and ligaments.

Swing phase is where the hoof is off the ground, and the limb moves forward to prepare for the next landing. Biomechanically Initiated by the flexion of the joints (fetlock, carpus, and elbow for the forelimb; fetlock, hock, and stifle for the hind limb) With the biceps brachii (forelimb) and quadriceps (hind limb) engaging to lift and extend the limb. Ensures clearance of the hoof from the ground.

Landing phase is where the hoof makes initial contact with the ground, absorbing impact forces. With heel-first or flat-footed contact, depending on conformation and gait. The frog, digital cushion, and hoof wall play key roles in shock absorption. The fetlock and pastern, stabilize to prepare for weight-bearing in the midstance phase.

Understanding these phases helps in diagnosing lameness, assessing performance, and optimizing farrier work. Stride length is the linear distance covered by a specific limb during one complete stride cycle, from the point of initial contact to the next contact of the same hoof.

Biomechanically the equine’s bones, muscles, tendons, and ligaments work together in unison to produce movement in different gaits (FACSM, 2013). Trot is a symmetrical gait, making it a preferrable gait to assess straightness, symmetry, and soundness, thus making trot the ideal gait for measurement used in this study.

There is limited published evidenced-based research (Equinews, 2011) on the use and placement of stud position. One paper explored how the use of studs may change how the energy from stride is dissipated, as energy spilled through normal slippage may now be absorbed by the lower limb. The researchers noted that while the use of studs did eliminate some slipping, it was not possible to determine whether the benefits of stabilisation outweighed any potential disadvantages (Kentucky Equine Research Staff, 2011).

Gait analysis in some form has been utilised by equine-related professions since the 1870s. More recent technological and digital advancements delivering 3D optical motion capture and sensor-based technology make it possible to record gait phases that are beyond the resolution of the human eye. These advancements are now being utilised in research to explore in more detail, equine performance (Horan et al, 2023) (Hagan, et al, 2023).

This paper explores an area that has not been previously studied, aiming to enhance understanding of how stud position affects equine performance during the stride phases, as well as overall stride duration and length. By leveraging software tools, this research seeks to contribute to the ongoing debate within the professional equine community regarding the optimal placement of studs.

Study Hypothesis

The author tested that the duration of stride phases, overall stride duration and stride length would be different across the three bilateral stud positions when compared with the 'no stud' position.

Aims and Objectives

The aims of the study were to investigate the effect of different bilateral stud positions on the duration of the stride phases (midstance, breakover, swing and landing), overall stride length and stride duration.

Specific objectives of the study were to:

- Measure and compare the duration of each stride phase (midstance, breakover, swing and landing), overall stride length and stride duration for different bilateral stud positions using hoof-mounted inertial sensors.
- Measure and compare the length of stride for different bilateral stud positions.
- Determine the optimal stud position for balanced and efficient stride phases in terms of stride length and duration.

Study Design

This study is a quantitative cross-sectional pilot study to investigate the effect of different bilateral stud positions.

Methodology

The methodology focussed on standardisation of procedure and robust selection criteria to reduce the variability in the collection of study data.

1 Standardisation of Test environment

A safe, secure 33m x 6m natural turf area was selected at the author's premises to conduct the evaluation. The turf was mown to a height of 20mm and nurtured over six months prior to the date of evaluation. The ground surface was tested using a Clegg Hammer impact soil tester (SDI, 2023) with added GPS tracking system to measure the hardness and shock absorbent properties of the surface across the prepared area.

The principal procedural operation of the machine consists of a 2.25 kg compaction hammer within a vertical guide tube. The released hammer falls through the tube where on impact with the surface at the precise test site a measurement of deceleration is recorded to give the stiffness of the surface. A readout registers the firmness value in units of gravities (G) where firmer surfaces have a higher G reading.

The area was split into a grid of length 8.25m x 1.25m rectangles. The procedure was repeated at each grid point three times with the final reading taken and recorded as the measurement value. Readings across the prepared area ranged from 0075G to 0078G indicating the surface was medium to firm.

Equines were tested over two days. To minimise inconsistency, both test days were dry sunny days with very light consistent winds after a continuation of four dry sunny days and each equine group was tested as a continual loop.

2 Sample Strategy

The author selected a convenience sample of "sport horse" types as these equines are commonly known to be fitted with studs during their sporting disciplines. The calculated required time per test across each equine, when compared with the available hours during the two days of consistent conditions constrained the author to a sample size of no more than 20 equines.

3 Recruitment of Study Participants

The 20 equines were selected with 5 ½ - 6-inch-wide feet, each of a "sports horse" type with no recorded veterinary past medical history of any underlying foot or limb pathology and a near to ideal as possible limb conformation. (Appendix 1 – Equine Sample)

4 Ethical Considerations

The study protocol was approved by Hetty Hill BVM&S CertAVP(EL) PGCertVPS MRCVS. Signed consent was taken by the author for the owner of each participant equine. These are not included within the thesis to ensure anonymity (Appendix 2 – Example Owners Consent Form). Each equine was anonymised and assigned a unique numerical ID to protect the owner and equine's identity.

5 Clinical Methodology, Trimming Shoe Type and Stud Placement

Before testing each equine was clinically examined by an attending veterinary practitioner ruling out any chance of results being skewed by undetected lameness, 19 equines were passed for testing (Appendix 3 – Veterinary Certificate). All equines were trimmed to the long axis in line with the Worshipful Company of Farriers (FARRIERS, n.d.) guidelines and shod to a five-week shoeing cycle no more than five days prior to testing, by the author. All equines were shod with Kerckhaert classic stars of shoe section 22mm x 10mm (Figure 1) and attached using six Mustad slim nails per shoe with three nails in each branch.

***Figure 1**: Kerckhaert classic star*

In relation to stud placement, the choice of stud holes has been driven by two factors:

1. Past history of three positions: Traditionally studs (palmer traction device) were placed in the last point of heel. Over time placement has moved to behind the last nail hole (just beyond the widest point of foot, centre of rotation) and subsequently brought to a mid-point between the two.

2. Increased foot stability in the landing and midstance phases of the stride.

The distance of each stud hole was calculated from the last nail hole to the point of heel (Figure 2). The available distance was divided by four to create three equidistant hole positions.

***Figure 2**: Measuring stud hole placement.*

Each position was marked with a centre dot (Figure 3 and Figure 4) then drilled and tapped with a Colleoni pillar drill, using an 8mm cobalt high speed drill bit to prevent human variability. Each hole was then tapped out using a Colleoni tapping machine with a spiral fluted 3/8wt tap (Figure 5).

***Figure 3**: Marking a centre dot.*

Figure 4: Stud positions marked with point dots.

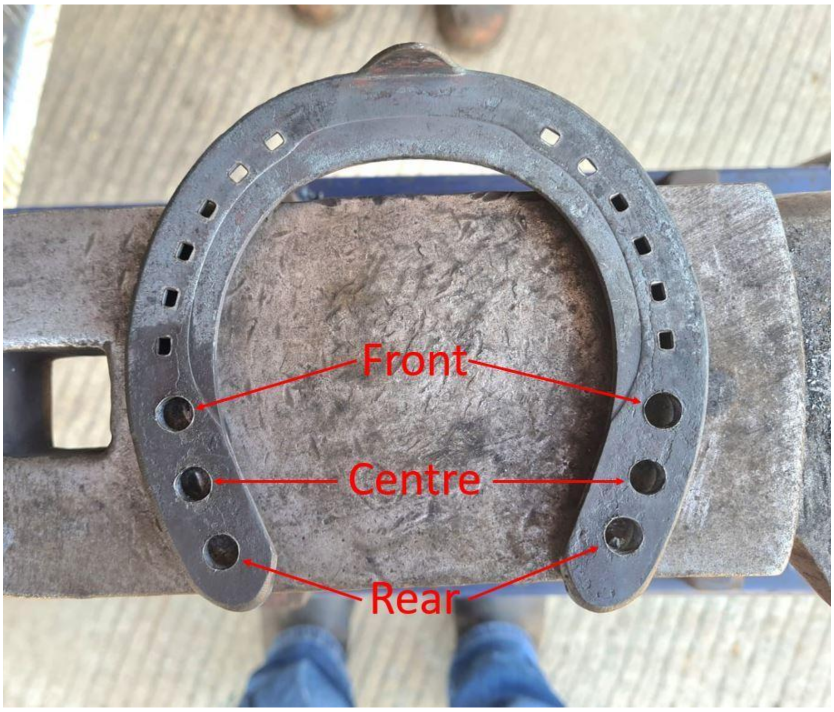

Figure 5: Drilled stud holes with annotated placements

Holes were plugged with oil-soaked cotton wool to protect the thread while not in use and ensure correct subsequent stud placement and fit. Stud placements for all tests are shown in Figure 6, Figure 7, Figure 8 and Figure 9.

Sole view

***Figure 6:** No studs (control test)*

Sole view Palmer view

Figure 7: Bilateral front placement

Sole view Palmer view

Figure 8: Bilateral centre placement

Sole view Palmer view

Figure 9: Bilateral rear placement

Unbranded square pointed studs, sized 12mm by 20mm long (Figure 10) were selected based on market research of average usage trends.

Figure 10: Square Point Stud

6 High Precision Sensors

Gait analysis software (Hoofbeat, n.d), a motion tracking system with high precision wireless sensors (1140 Hertz) was used. Mr Jonathan Nunn FWCF, an endorsed Hoofbeat farrier, fitted all the sensors to both front feet of all 19 equines to ensure the correct application and standardisation. The sensors were placed on the centre line of the dorsal wall just below the coronary band in line with the front of the apex of the frog (Figure 11 and Figure 12).

Figure 11: Sensor position – dorsal view

Figure 12: Sensor position – lateral view

Data recorded by each sensor was relayed in real time to a computer with Hoofbeat software. The software uses an algorithm to generate information for the left and right foot on median stride length and median duration for midstance, breakover, swing and landing stride phases, which is presented in a series of dashboards. Screenshots of the dashboards are shown in Figure 13 and Figure 14. A description of each phase is shown in Table 1.

Raphael	mid. stance	breakover	swing	landing
LF 12/11/2021 - 10:58 2 stud rear	156ms ±21ms	68ms ±6ms	432ms ±31ms	67ms ±20ms
RF 12/11/2021 - 10:58 2 stud rear	173ms ±26ms	62ms ±8ms	429ms ±28ms	58ms ±19ms
Difference	-17ms	6ms	2ms	8ms

Raphael	stride duration
	718ms

Raphael	relative stance time
LF 12/11/2021 - 10:58 2 stud rear	40.1%
RF 12/11/2021 - 10:58 2 stud rear	40.5%

Figure 13: Screenshot of dashboard for stride phase timings.

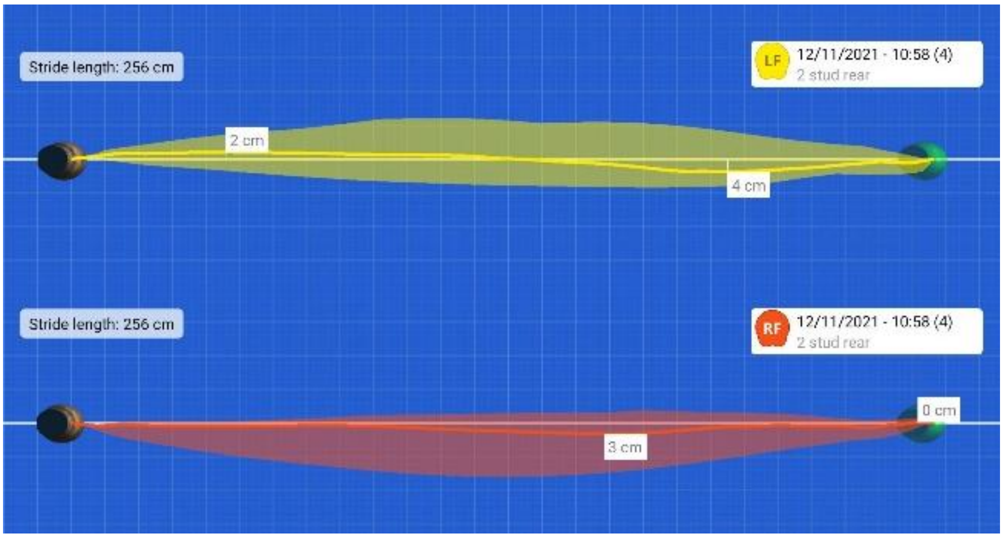

Figure 14: Screenshot of dashboard for stride length

Table 1: Explanation of stride phases

Phase	Description	Unit
Midstance	The time from when the hoof has come to a complete stop on the ground until the heel buttresses start lifting off the ground.	Millisecond (ms)
Breakover	The time from when the heel buttresses start lifting off the ground until the last contact of the toe with the ground.	Millisecond (ms)
Swing	The time the hoof is not in contact with the ground.	Millisecond (ms)
Landing	The time from initial contact until the hoof comes to a complete stop, and stabilisation of the hoof occurs with respect to the ground surface.	Millisecond (ms)
Stride duration	Total median stride duration.	Millisecond (ms)
Stride length	Total median stride length.	Centimetre (cm)

For midstance, breakover, swing and landing, the timings given are reported in the Hoofbeat user guide to be the median values with an indication of the variability given beneath as a ± value. The user guide states that 90% of the results are located within this range.

7 Test Process

Each equine undertook 4 recorded tests on which data was gathered (Table 2). A control test was run with no studs, followed by individual tests with bilateral studs in the front, centre, and rear positions. For each test, the equine was walked and then trotted in a straight line on a loose rein with the same handler to ensure straightness of gait was maintained throughout.

***Table 2:** Test run order*

Test ID/order	Stud Count	Stud Position	Notes
1	0	-	Baseline control test
2	2	Front	Bilateral placement of studs at the front position
3	2	Centre	Bilateral placement of studs at the centre position
4	2	Rear	Bilateral placement of studs at the rear position

Data Management and Analysis

Data Management

The Gait analysis software output provided information on the duration of each stride phase and overall stride distance and duration in PDF format for each equine (Appendix 4 – Gait analysis software pdf distance format).

The duration (ms) and stride distance (cm) data for each equine were manually transcribed from the paper output generated by the Gait analysis software into Excel. Entries were checked and verified by the study author and a student colleague.

Data Exploration

An initial exploration of the data was completed using R version 4.2.2 (R Core Team, 2022). R is an open-source programming language primarily used for statistical computing, data analysis and visualisation.

Summary statistics, comprising minimum, first quartile (25^{th} percentile), median, mean, third quartile (75^{th} percentile), maximum and standard deviation, were generated for midstance, breakover, swing and landing durations, stride duration and stride length for each of the four stud positions. Boxplots and a correlation matrix were generated to visualise the data.

To assess the relationship between left and right foot measurements across various phases and stud positions, Spearman rank correlation tests (Spearman, 1904) were conducted. The results showed significant positive correlations in all phases and stud positions, suggesting a consistent relationship between the left and right measurements. Given the positive correlations, the left and right foot data have been averaged, and the average value used in subsequent analyses.

Shapiro-Wilk normality tests (Shapiro & Wilk, 1965) were conducted for each combination of stud position (none, two front, two centre, two rear) and phase (breakover, swing, midstance, landing) or stride length/duration. The Shapiro-Wilk test is a statistical test used to determine if a dataset is normally distributed. The assumptions of the Shapiro-Wilk test are that data should be continuous not categorical, the sample size should be small-moderate (<50), and the observations should be independent. 'Q-Q plots' were generated to visually compare the quantiles of the data to the quantiles of a normal distribution, a deviation from a straight line indicating the data were not normally distributed.

The assumptions of the Shapiro-Wilk test were satisfied because the data is duration or length, so is continuous not categorical, the sample size is 19, and the observations from each horse are independent. Based on the test results, the data exhibited a mix of normal and non-normal distributions. Examples of Q-Q plot outputs and corresponding histograms are given in Figure 15. Due to the presence of non-normal distributions and small sample sizes, it is justified to use non-parametric tests for subsequent analyses to ensure robust and reliable results.

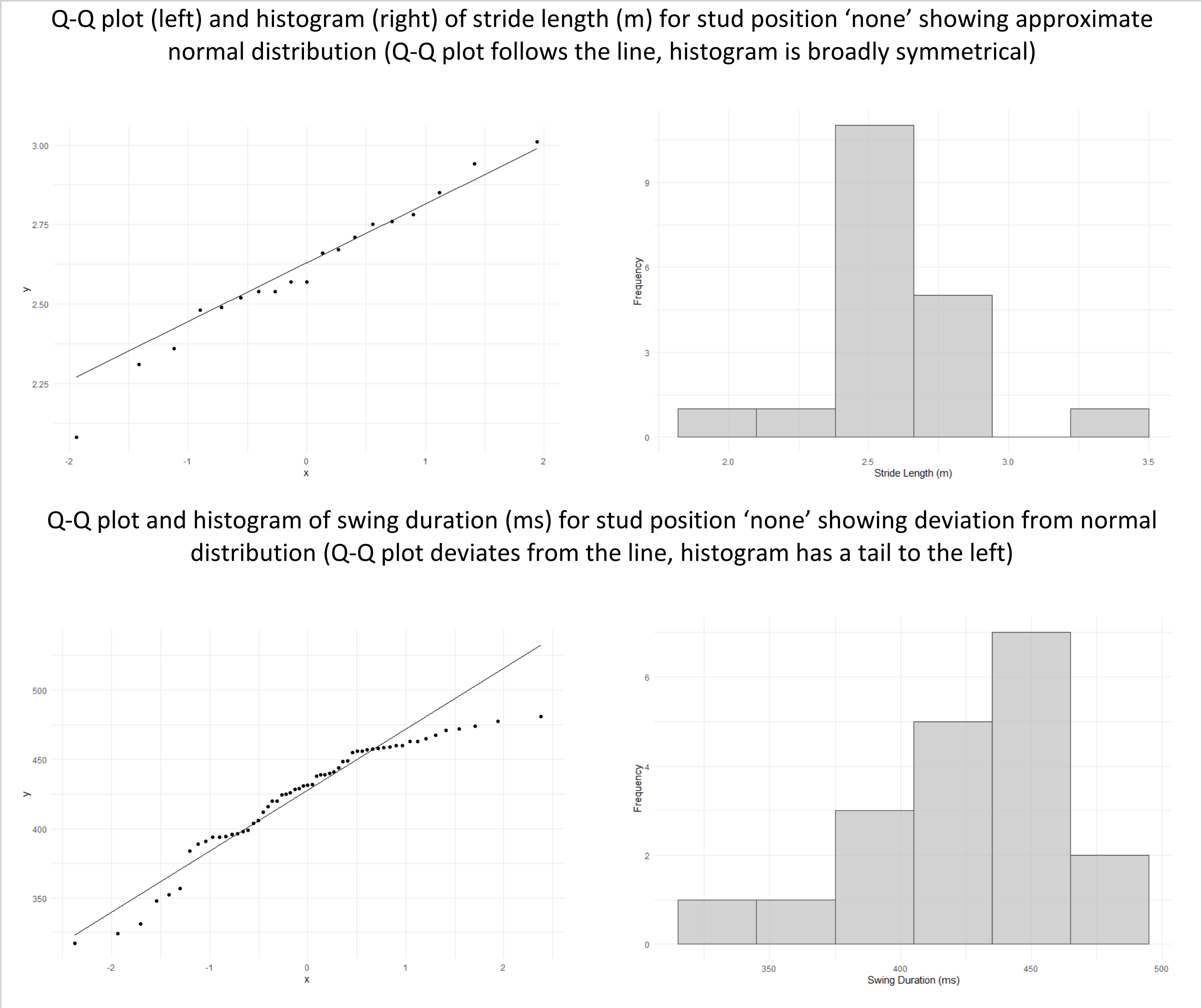

Figure 15: Examples of Q-Q plots and histograms to assess normality of the data.

Primary Analysis

To test whether there are significant differences between the measurements recorded for each stud placement, a Friedman test (Friedman, 1937) has been conducted. This test is appropriate for multiple measurements under different conditions on the same subjects, and where the data is non-normally distributed and continuous, which corresponds with the study data. The limitations of the test include possible low power to detect differences for small sample sizes and sensitivity to tied rankings, and the assumption that measurements are independent within each subject across different conditions.

Secondary Analysis

Where the results of the Friedman tests indicated that at least one stud position leads to significantly different results compared to the others, post-hoc analysis has been undertaken to determine which specific stud positions differ from each other. Pairwise comparisons between the different stud positions have been completed using a Wilcoxon signed-rank test (Wilcoxon, 1945) with Holm-Bonferroni correction (Holm, 1949).

Results

Descriptive statistics

Stride duration

Summary statistics for stride duration are tabulated in Table 3 and shown as boxplots in Figure 16.

Table 3: Summary statistics for stride duration (seconds)

Stud Position	**Minimum**	**Q1**	**Median**	**Mean**	**Q3**	**Maximum**	**Standard Deviation**
None	0.650	0.704	0.739	0.733	0.772	0.781	0.0383
Two Front	0.629	0.709	0.737	0.732	0.761	0.811	0.0431
Two Centre	0.656	0.705	0.729	0.723	0.748	0.770	0.0336
Two Rear	0.625	0.697	0.739	0.727	0.755	0.786	0.0405

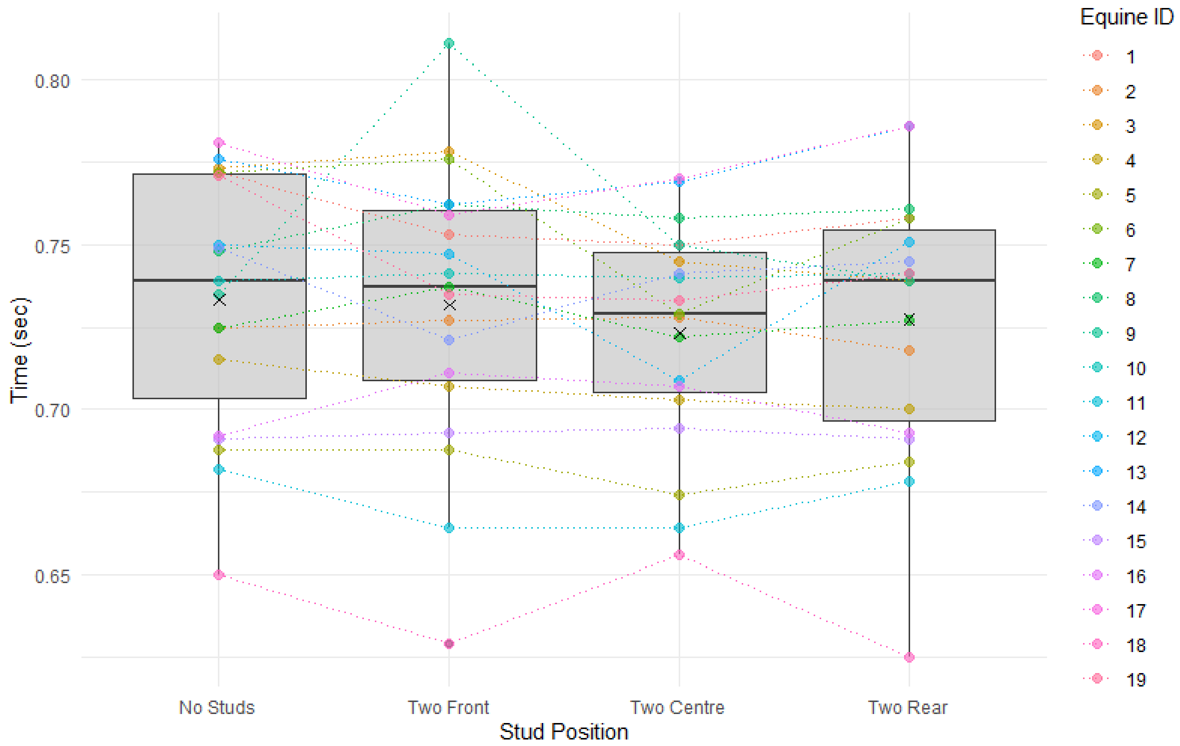

Figure 16: Boxplot of stride duration (seconds)

The median and mean stride duration are lowest when stud placement is 'Two Centre.' The spread of stride duration is also smaller for this stud placement group than other stud placements, indicating more consistency in stride duration between equines when studs are placed at the centre. In contrast, the 'Two Rear' and 'Two Front' stud placements introduce a broader range of stride durations suggesting that different horses react differently to the presence of studs in these positions. The lowest point on the 'Two Front' stud position boxplot, associated with equine 18, is identified as an outlier on the plot (the point is not connected to the whisker as its value is more than 1.5 times the interquartile range below the first quartile (Q1) value).

Stride length

Summary statistics for stride duration are tabulated in Table 4 and shown as boxplots in Figure 17.

Table 4: Summary statistics for stride length (metres)

Stud Position	Minimum	Q1	Median	Mean	Q3	Maximum	Standard Deviation
None	2.08	2.43	2.59	2.57	2.70	3.31	0.259
Two Front	2.08	2.47	2.59	2.57	2.71	2.86	0.194
Two Centre	2.08	2.51	2.57	2.61	2.76	3.01	0.224
Two Rear	2.07	2.43	2.56	2.57	2.71	3.15	0.234

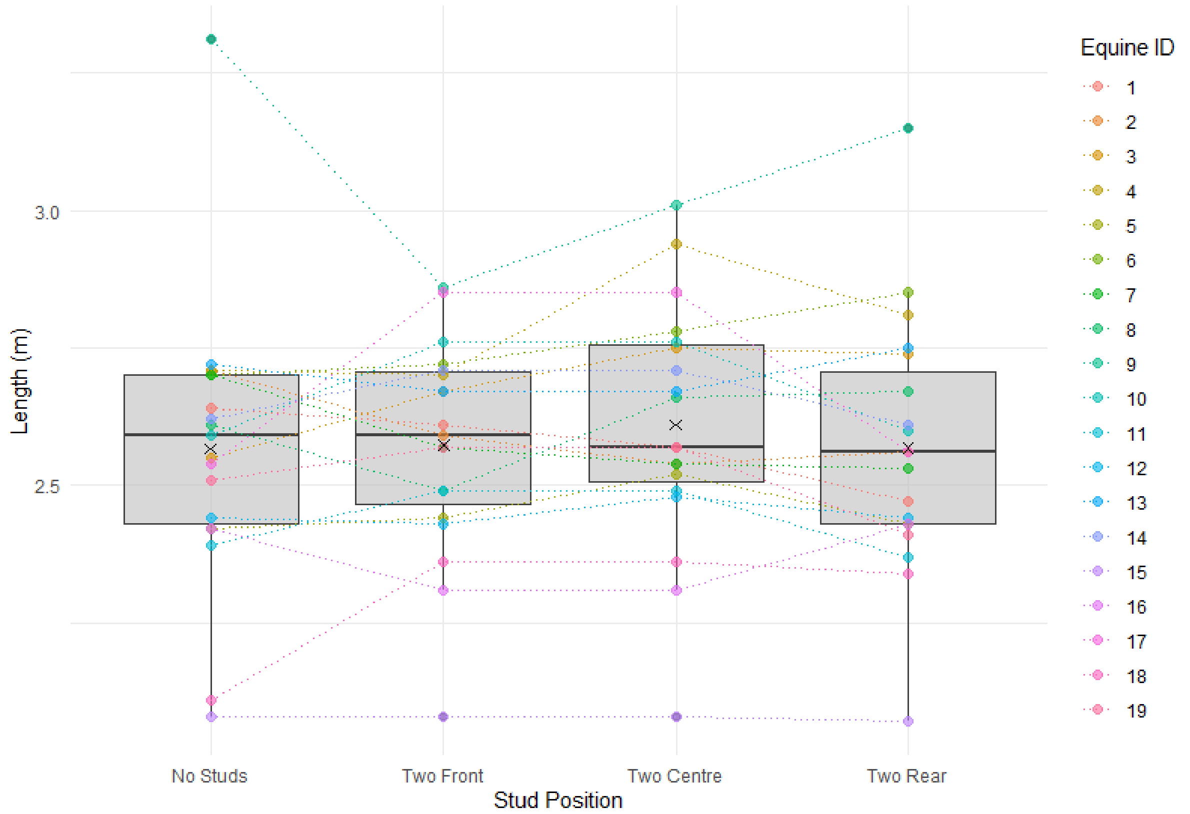

Figure 17: Boxplot of stride length (metres)

The mean and median stride length do not vary much between the stud placement groups. The interquartile ranges are quite small and there is significant overlap across the stud placement groups, indicating that many equines exhibit similar stride lengths regardless of stud position. Notable exceptions are equine 9, which exhibits a much higher stride length than other equines with 'No Studs' and 'Two Rear' stud placements, and equine 15, which exhibits a much lower stride length than other equines with 'Two Front' and 'Two Centre' stud placements. These points are identified as outliers.

Phase durations

Summary statistics for stride duration are tabulated in Table 5 and shown as boxplots in Figure 18 to Figure 21.

Table 5: Summary statistics for stride phase durations (milliseconds)

Phase	Stud Position	Minimum	Q1	Median	Mean	Q3	Maximum	Standard Deviation
Midstance	None	140	182	192	191	200	218	19.1
	Two Front	147	178	192	188	196	223	19.7
	Two Centre	153	170	184	183	195	223	16.6
	Two Rear	154	171	180	181	196	209	16.6
Breakover	None	48	54	59	60	65	79	8.7
	Two Front	50	56	61	61	65	75	7.0
	Two Centre	51	55	59	60	65	74	6.7
	Two Rear	50	55	59	60	65	79	7.6
Swing	None	324	401	432	425	457	478	40.5
	Two Front	327	398	421	418	442	504	40.6
	Two Centre	340	390	424	414	440	465	35.0
	Two Rear	332	394	416	417	446	475	39.0
Landing	None	28	43	51	57	65	122	22.4
	Two Front	37	52	57	62	72	104	16.3
	Two Centre	44	56	63	64	70	94	12.6
	Two Rear	43	56	63	67	76	98	14.6

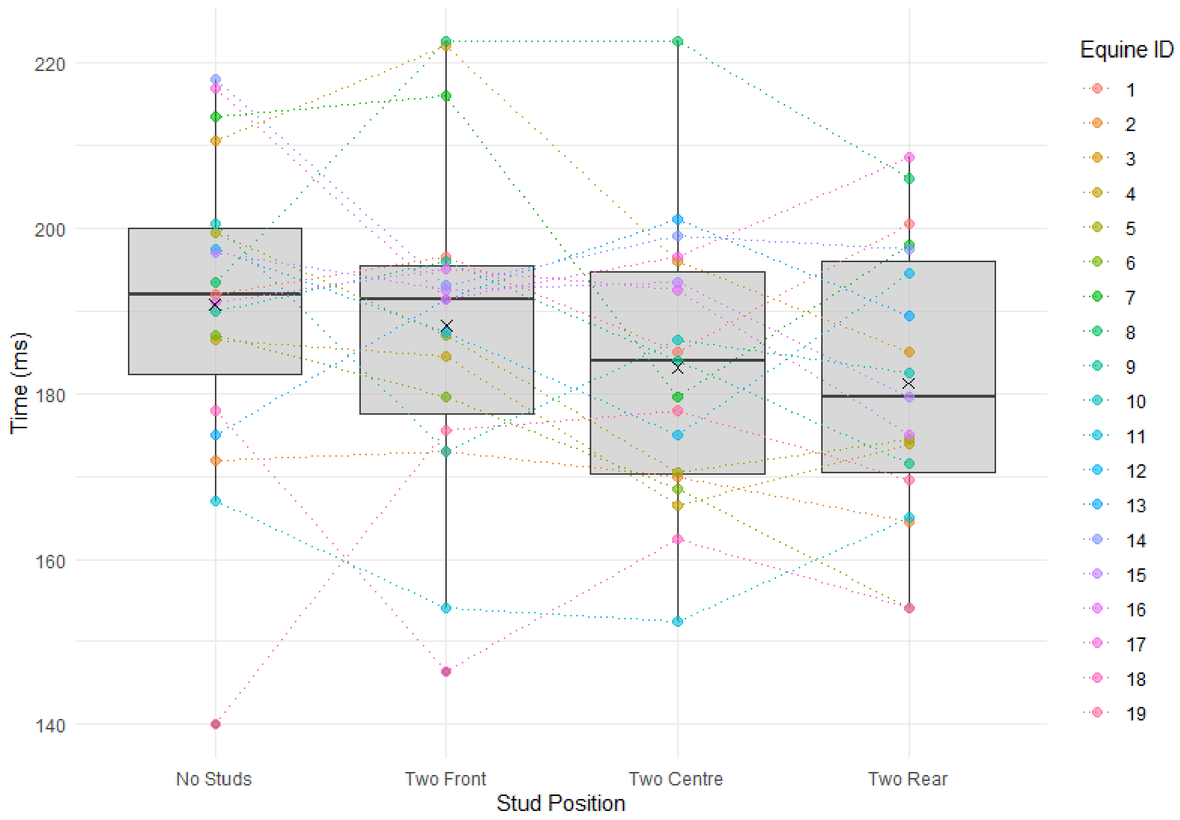

Figure 18: Boxplot of midstance duration averaged across right and left foot (ms)

The mean and median midstance duration do not vary much between the 'No Stud' and 'Two Front' placement groups. The mean and median midstance durations in the 'Two Centre' and 'Two Rear' stud placement groups appear to be much lower, indicating that these stud placement positions reduce the duration of the midstance phase. The lowest value for 'No Studs' and 'Two Front' are identified as outliers (equines 19 and 18, respectively).

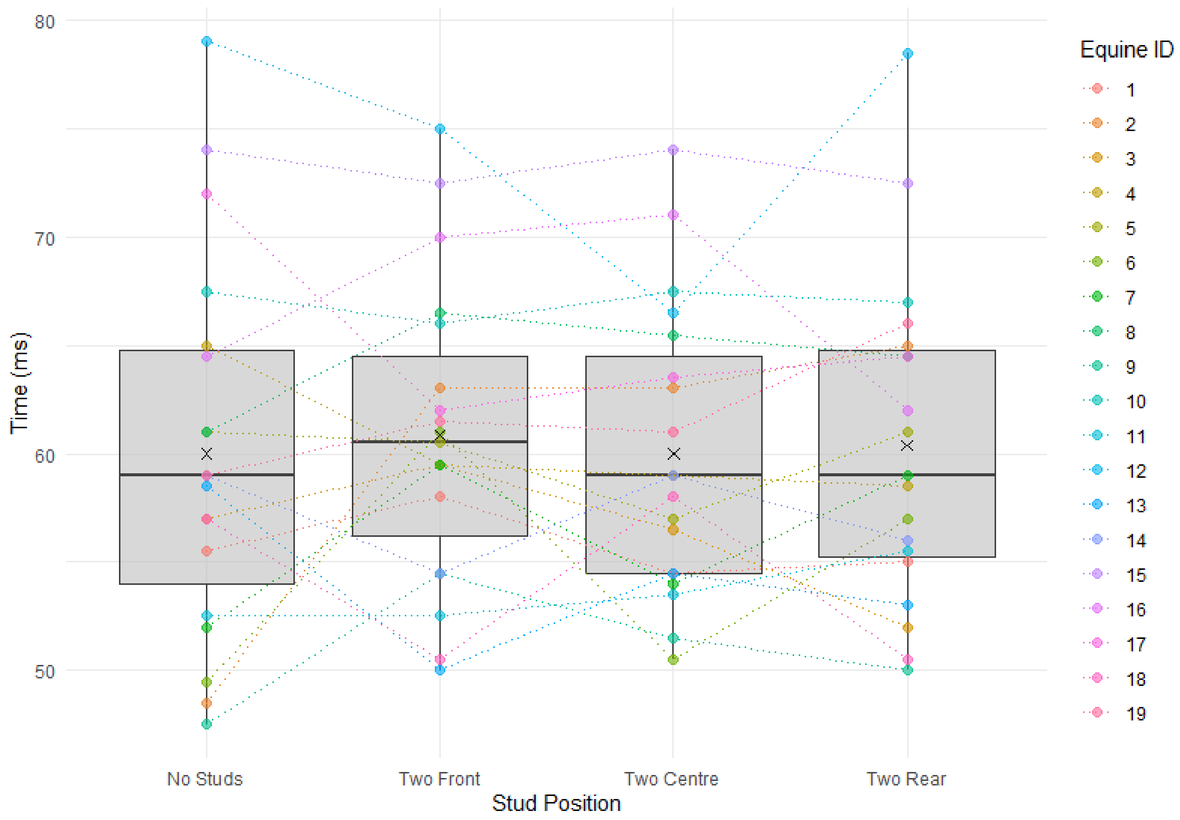

Figure 19: Boxplot of breakover duration averaged across right and left foot (ms)

The mean and median breakover duration do not vary much between the stud placement groups. The interquartile ranges are quite wide and there is significant overlap across the stud placement groups, indicating that many equines exhibit similar breakover durations regardless of stud position.

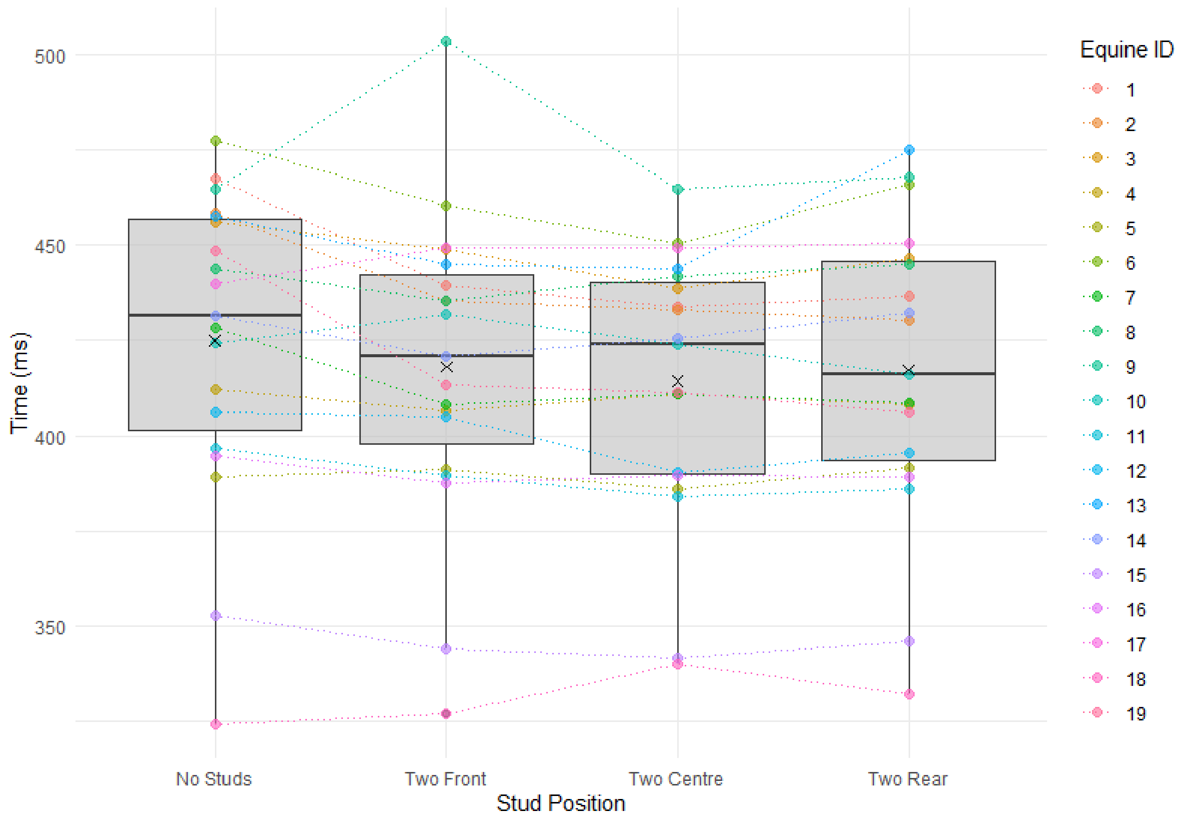

Figure 20: Boxplot of swing duration averaged across right and left foot (ms)

The mean and median swing durations vary between the stud placement groups, with all three bilateral stud placements having lower mean and median swing durations compared to the 'No Stud' placement group. There is some overlap across the interquartile ranges.

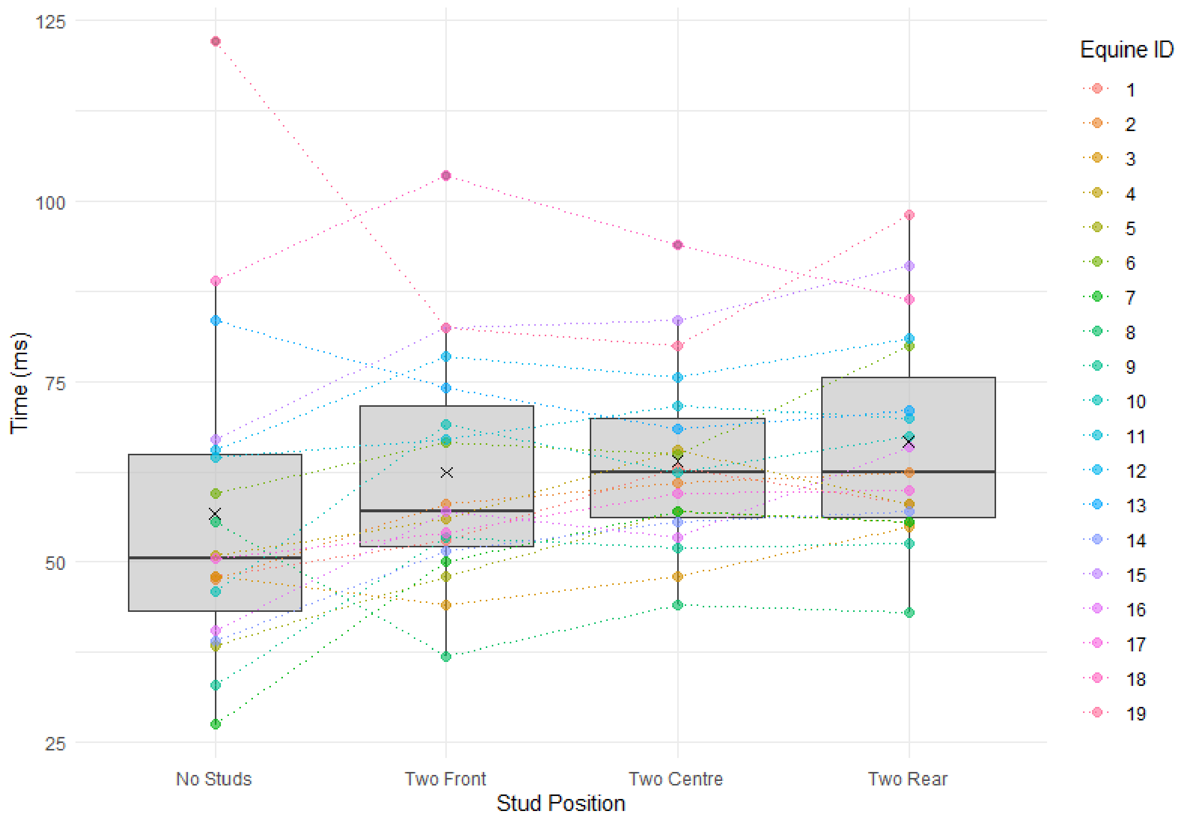

Figure 21: Boxplot of landing duration averaged across right and left foot (ms)

The mean and median midstance durations are lowest in the 'No Stud' placement groups and highest in the 'Two Rear' and 'Two Centre' stud placement groups, although duration in the 'Two Front' stud placement is also higher than the 'No Stud' placement, indicating that stud placement generally increases the duration of the landing phase.

A correlation matrix (Figure 22) was produced to identify whether any of the variables are correlated. Horse age and height were also included. Strong positive correlations (correlation coefficient greater than 0.5) were identified as follows:

- Horse height was positively correlated with swing duration, stride duration and stride length (i.e., as horse height increases, swing duration, stride duration and stride length also increase)
- Swing duration was positively correlated with stride length and duration.

- Age was negatively correlated with height, swing duration and stride duration (i.e., as age increases, height, swing duration and stride duration decrease)
- Breakover duration was negatively correlated with stride length.
- Landing duration was negatively correlated with midstance duration.

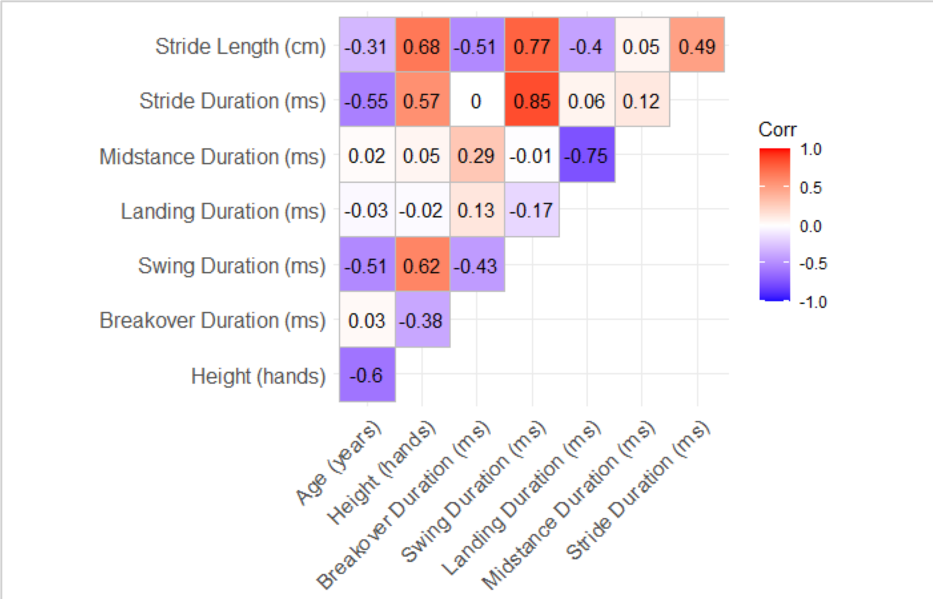

Figure 22: Correlation matrix

Primary analysis results

Friedman tests have been conducted for the variables stride duration, stride length, midstance duration, breakover duration, swing duration, and landing duration. For each variable, the following hypothesis was tested:

- **Null Hypothesis (H_0)**: There are no differences in the distributions of the stud placement groups.
- **Alternative Hypothesis (H_1)**: There is at least one stud placement group that has a different distribution compared to the others.

The results of the Friedman tests (Table 6) show significant results (where the p-value is less than 0.05) marked with an asterisk (*).

Table 6: Friedman test results

Variable	Chi-Squared Statistic	P-Value
Stride duration	3.2742	0.3513
Stride length	3.5424	0.3153
Midstance duration	9.0000	0.02929*
Breakover duration	0.18132	0.9805
Swing duration	11.601	0.008883*
Landing duration	15.825	0.001231*

For midstance, landing and swing duration, the p-value is less than 0.05, therefore we can reject the null hypothesis. This suggests that there is a statistically significant difference in the ranks of results across the different stud positions for the midstance, swing and landing duration.

Secondary Analysis Results

A Wilcoxon signed-rank test with Holm-Bonferroni correction has been completed for the midstance, landing and swing duration data with the following null and alternative hypotheses:

- **Null Hypothesis (H_0)**: The median difference between the paired observations for each stud placement group is zero.
- **Alternative Hypothesis (H_1)**: The median difference is not zero.

The results are presented in Table 7 (midstance duration), Table 8 (landing duration), and Table 9 (swing duration). Significant results are marked with an asterisk (*).

Table 7: Wilcoxon signed-rank test results for midstance duration.

Group 1	Group 2	Statistic	P-Value	Adjusted P-Value
No Studs	Two Front	110	0.546	1
No Studs	Two Centre	138	0.0835	0.334
No Studs	Two Rear	153	0.0206*	0.124
Two Front	Two Centre	118	0.157	0.471
Two Front	Two Rear	142	0.0602	0.301
Two Centre	Two Rear	109	0.587	1

The Wilcoxon signed-rank test indicates significant differences for midstance duration between the 'No Studs' and 'Two Rear' stud placement groups, although the difference is not significant when the p-value is adjusted for multiple comparisons.

Table 8: Wilcoxon signed-rank test results for landing duration.

Group 1	Group 2	Statistic	P-Value	Adjusted P-Value
No Studs	Two Front	44.5	0.0442*	0.132
No Studs	Two Centre	34.5	0.0278*	0.111
No Studs	Two Rear	32.5	0.0126*	0.0628
Two Front	Two Centre	63.5	0.212	0.366
Two Front	Two Rear	27.5	0.007*	0.0420*
Two Centre	Two Rear	61.5	0.183	0.366

The Wilcoxon signed-rank test indicates significant differences for landing duration for the following groups: 'No Studs' and 'Two Front;' 'No Studs' and 'Two Centre;' 'No Studs' and 'Two Rear'; and 'Two Front' and 'Two Rear'. Only the 'Two Front' and 'Two Rear' stud placement groups differ significantly when the p-value is adjusted for multiple comparisons. The difference between the 'No Studs' and 'Two Rear' stud placement groups is near to significance.

Table 9: Wilcoxon signed-rank test results for swing duration.

Group 1	Group 2	Statistic	P-Value	Adjusted P-Value
No Studs	Two Front	147	0.0381*	0.191
No Studs	Two Centre	152	0.00404*	0.0243*
No Studs	Two Rear	145	0.0463*	0.191
Two Front	Two Centre	120	0.144	0.433
Two Front	Two Rear	98	0.920	0.920
Two Centre	Two Rear	63.5	0.212	0.433

The Wilcoxon signed-rank test indicates significant differences for swing duration between the following groups: 'No Studs' and 'Two Front;' 'No Studs' and 'Two Centre;' and 'No Studs' and 'Two Rear'. Only the 'No Studs' and 'Two Centre' stud placement groups differ significantly when the p-value is adjusted for multiple comparisons.

Further examination of the data (Figure 23) suggests that the differences in results between different horses is greater than the differences in results within the same horse under different conditions. High between-horse variability means that the differences between the horses might overshadow the differences between the stud positions within the same horse. This could lead to a situation where the test fails to detect a significant effect of stud position because the variability between horses dominates the analysis. Hence, the tests might return a non-significant result even if there is a genuine effect of the stud positions within each horse.

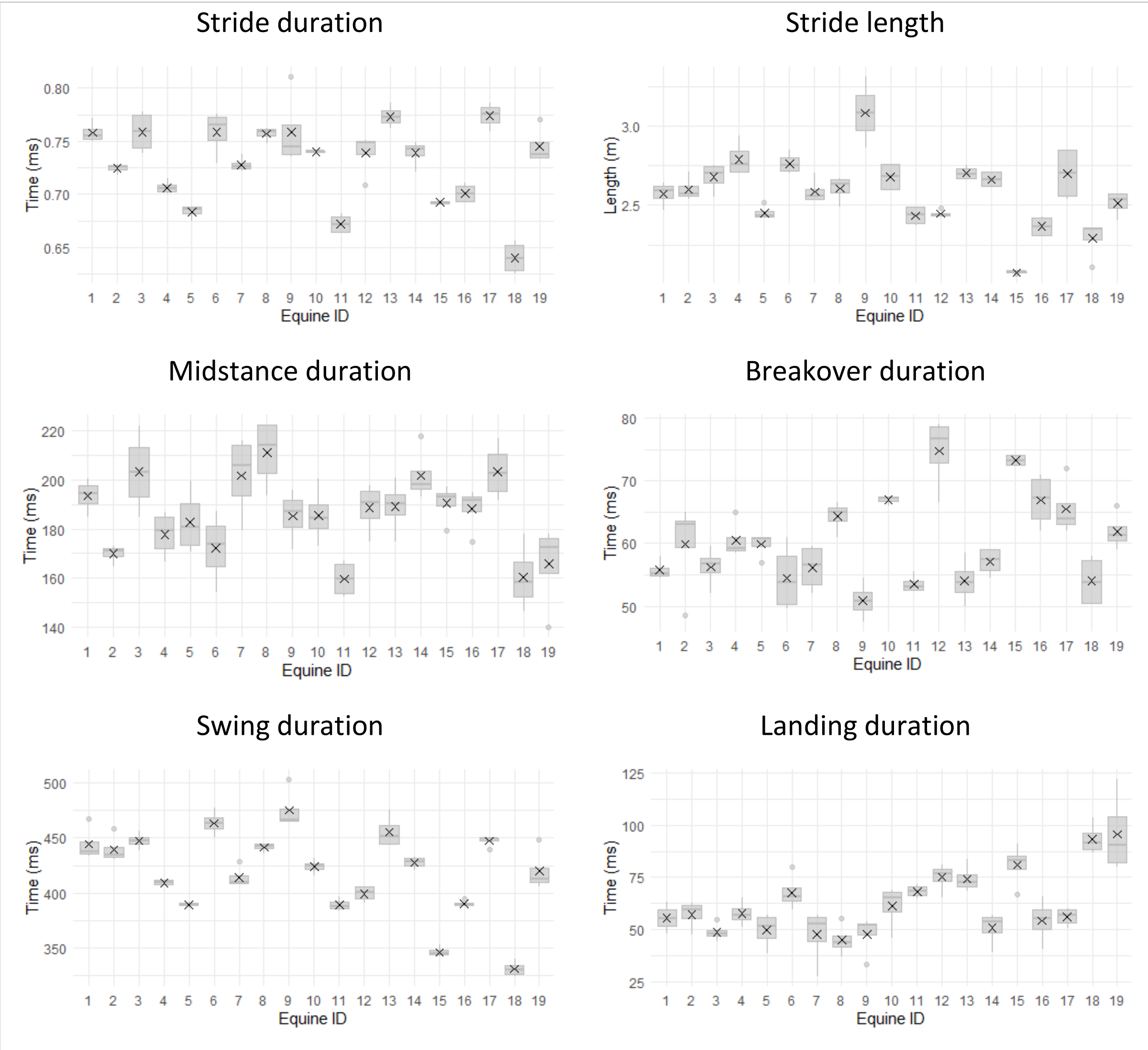

Figure 23: Inter-horse variability

Discussion

It was hypothesised that the duration of stride phases, overall stride duration and stride length would be different across the three bilateral stud positions when compared with the 'No Stud' position.

The primary analysis (Friedman tests) identified statistically significant differences in the results across the different stud positions for midstance, swing and landing duration but not for stride length, overall stride duration or breakover duration.

Secondary analysis (post-hoc Wilcoxon signed-rank tests) identified the following statistically significant differences before applying the Holm-Bonferroni correction:

- Midstance duration: difference between 'No Studs' and 'Two Rear.'
- Landing duration: difference between 'No Studs' and all three stud placement groups, and difference between 'Two Front' and 'Two Rear.'
- Swing duration: difference between 'No Studs' and all three stud placement groups

The following statistically significant differences remained after applying the Holm-Bonferroni correction:

- Landing duration: difference between 'Two Front' and 'Two Rear.'
- Swing duration: difference between 'No Studs' and 'Two Centre.'

Midstance and landing durations are negatively correlated (as midstance duration decreases the landing duration increases). This relationship can be seen in the boxplots (Figure 18 and Figure 21). All stud placements led to an overall decrease in midstance duration and an overall increase in landing duration compared to the 'No Studs' group. The difference was greatest in the 'Two Rear' and 'Two Centre' stud placement groups and least in the 'Two

Front’ stud placement group. Some of these differences, as outlined above, were statistically significant.

Reduced midstance duration suggests that the horse's weight is not borne for as long on each limb, reducing the load on the limb. Increased landing duration suggests a more controlled and gradual transfer of weight onto the limb, helping spread the impact forces more evenly across the hoof and limb. Studs in the ‘Two Rear’ and ‘Two Centre’ positions appear to provide additional traction, which can enhance stability. This may be particularly useful on soft or uneven ground, where additional traction is crucial for preventing slips and falls.

Reduced swing duration suggests that a horse can cycle through its strides more rapidly, improving overall speed and agility. With studs providing better grip, the horse can push off more effectively, contributing to a more powerful and efficient stride. A reduced midstance and swing duration would indicate the horse’s confidence thus improving the horse’s speed and agility as by optimising the traction the horse can push off with a shorter duration, making them more responsive and faster in activities that require rapid movements. The boxplot (Figure 16) does suggest a slight reduction in stride duration in the ‘Two Centre’ stud positions compared to the ‘No Studs’ position. However, a statistically significant reduction in stride duration was not observed in the present study.

The lack of a significant difference may be because the study did not control for any horse-specific differences. The correlation matrix showed that taller horses have longer stride durations and older horses have shorter stride durations. The boxplots showing inter-horse variability also suggest that differences between horses are much greater than the differences in a single horse resulting from the different stud placements. These differences may have affected the results, making it harder to see the true impact of stud placement on stride duration. To overcome this, future studies should control these factors by either dividing the horses into groups based on important factors such as age or height or including these variables in the analysis by undertaking multi-variate analysis or fitting a mixed-effects model to the data to account for both fixed effects such as stud positions and random effects such as differences between horses (Horan et al, 2023).

It is the author's view that this pilot study has shown that bilateral stud placement can produce a difference in duration of an equines stride phases, overall stride duration and stride length shown; however, the extent of the difference can vary across individual equines.

Limitations of the pilot study

Each equine was tested from start to finish in the same order, which may have caused fatigue, bias or settling down effect. Randomisation would have been preferable to limit fatigue, remove bias and give no time for the equine to settle with each stud position. In contrast the author does see a benefit in normalising and conditioning the equine to be comfortable with studs before testing, akin to a human wearing heeled shoes regularly.

The author acknowledges that although every precaution was taken to ensure the equine moved in a straight line, if replicated they would advise a handler on both sides (replicating cross ties) to minimise any side bias.

Future Directions

A larger sample size would provide a more comprehensive set of data upon which further statistical analysis could be conducted and provide insight into potential variables such as height, weight, age. The author acknowledges that a larger sample size may present challenges in keeping variables to a minimum (e.g., equine handling, time taken to conduct the study, ground, and weather conditions).

Future studies could aim to control for horse-specific factors by either dividing the horses into groups based on important factors (e.g. age or height) or including these variables in the analysis by undertaking multi-variate analysis or fitting a mixed-effects model to the data to account for both fixed effects (such as stud positions) and random effects (such as differences between horses).

This paper acknowledges that tests were run on a straight course without any turning involved. Further research would need to be undertaken to understand if the extra grip from bilateral studs would cause health risks through unwanted grip as the equine athlete turns at speed (Huiling & Wilson, 2010), potentially causing a torsion-related injury to the soft tissue, hoof capsule, or bone fractures. (Equus, 2023)

In order to bypass a “try until you fail” injury, an approach could be taken to extract data direct from the software and mathematically simulate the hoof-ground interactions with machine learning models. This would involve collaborations with academic institutions to gain further insight into the future of stud placement in the equine and could also incorporate knowledge of asymmetry within the individual equine giving room for research into the placement of stud in each individual forelimb.

The author advises creating an information sheet for equine owners about the study, ensuring they are fully informed of ethical considerations before giving consent.

Conclusions

Overall, the findings suggest that bilateral stud positions do not significantly affect stride duration, stride length, or breakover and midstance durations. However, they do influence swing and landing durations, with 'Two Centre ' stud placements reducing swing duration compared to 'No studs ' and the 'Two Rear' stud placements increasing landing duration compared to 'Two Front'. Given high inter-horse variability and a small sample size, the results indicate that stud position may need to be personalised for each horse.

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Manufactures Addresses

Clegg Impact Soil Tester - Clegg CIST/882.DR Baden Clegg, PTY ltd Australia

Colleoni Drill - The Shoeing Lab, Sandpitt Forge, Walton Lane, Grimley, Worcester, WR2 6LR

Kerckhaert Shoes - Stromsholm Limited, Wood Court, Chesney Wold, Bleak Hall, Milton Keynes MK6 1NE

Mustad Nails - Richard Ash, Witherleigh Farm, Mill Road, Barton St David, Somerton TA11 6DF

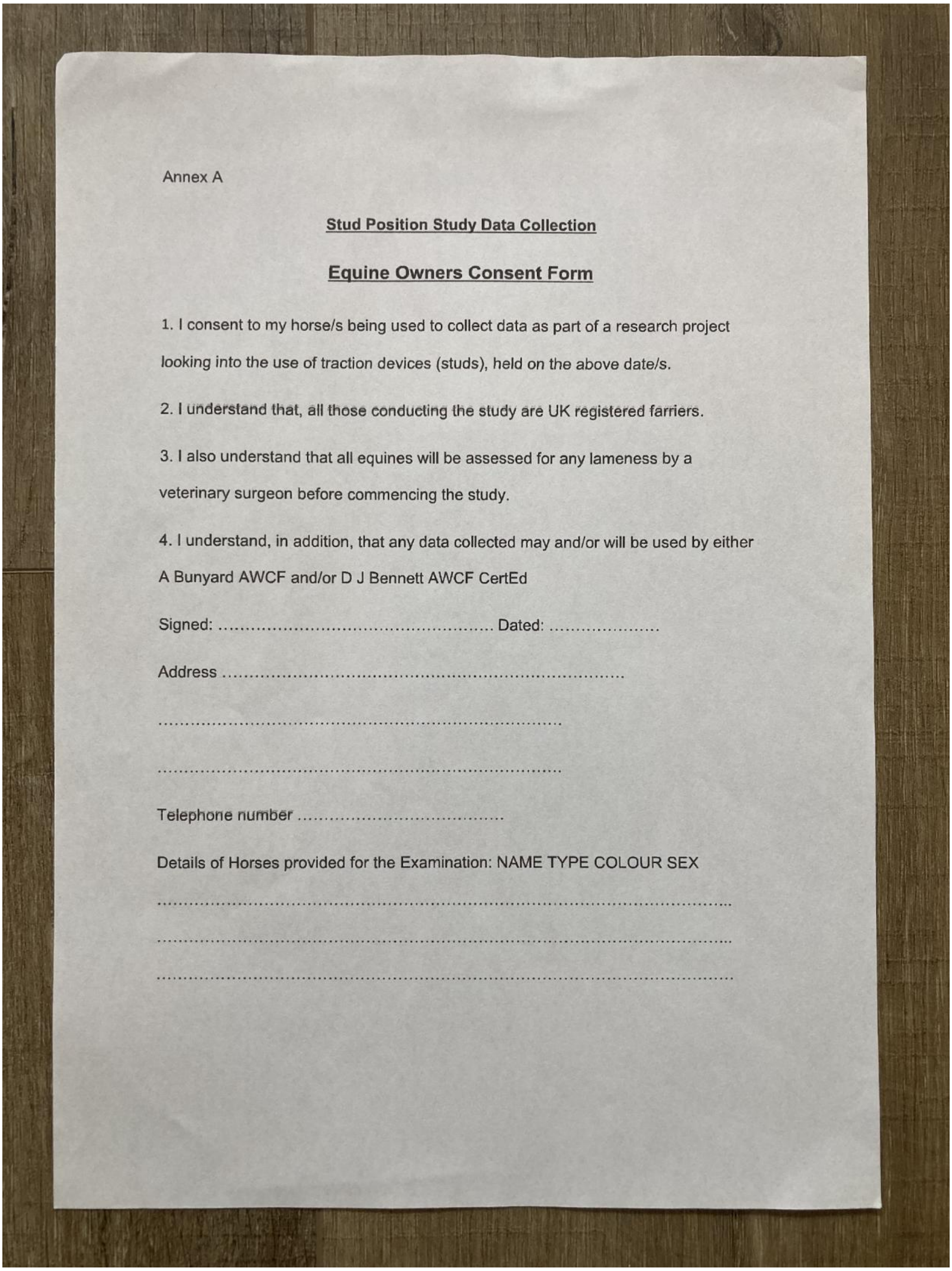
Gait analysis software - Hoofbeat B.V. Hoofdstraat 53 9356 AV, Tolbert, The Netherlands

APPENDICES

Appendix 1 – Equine Sample

No.	Breed	Age	Temperament	Type	Last Shod (No. Days)	Cranial View Long Axis	Hoof Pastern Axis	
1	Oldenburg X	4	Fractious	Eventer	3	Ideal	Upright	16'1
2	Hanoverian	13	Fractious	Dressage	4	Ideal	Ideal	16'0
3	Oldenburg X	11	Docile	Eventer	3	Ideal	Ideal	16'3
4	Warmblood	10	Docile	Leisure	2	Ideal - Slight Toe In	Ideal	16'2
5	Anglo Arab	20	Docile	Leisure	2	Ideal	Ideal	15'3
6	Warmblood	6	Docile	Eventer	2	Ideal - Slight Outward Knee Rotation	Upright	16'1
7	Spanish	9	Docile	Dressage	1	Ideal	Ideal	16'0
8	Warmblood	10	Docile	Dressage	3	Ideal	Ideal	16'2
9	ISH	12	Docile	Eventer	1	Ideal	Sloped	16'3
10	Oldenburg X	9	Docile	Leisure	2	Ideal	Sloped	16'0
11	Connemara	15	Docile	leisure	3	Ideal	Ideal	15'2
12	Thoroughbred	5	Fractious	eventer	3	Ideal	Upright	16'1
13	Thoroughbred x Warmblood	16	Docile	leisure	3	Ideal	Upright	16'3
14	British Sports Horse	19	Docile	eventer	1	Ideal	Sloped	16'2
15	Connemara	19	Docile	leisure	3	Ideal	Ideal	14'2
16	Irish Sports Horse	21	Docile	leisure	3	Ideal	Ideal	14'3
17	Thoroughbred	8	Fractious	eventer	2	Ideal	Sloped	16'2
18	Irish Sports Horse	15	Docile	leisure	2	Ideal	Ideal	16'1
19	Thoroughbred x Warmblood	9	Fractious	leisure	2	Ideal – slight toe out	Upright	16'0

Appendix 2 – Example Owners Consent Form



Annex A

Stud Position Study Data Collection

Equine Owners Consent Form

1. I consent to my horse/s being used to collect data as part of a research project looking into the use of traction devices (studs), held on the above date/s.

2. I understand that, all those conducting the study are UK registered farriers.

3. I also understand that all equines will be assessed for any lameness by a veterinary surgeon before commencing the study.

4. I understand, in addition, that any data collected may and/or will be used by either A Bunyard AWCF and/or D J Bennett AWCF CertEd

Signed: .... Dated: ....

Address ....

....

....

Telephone number ....

Details of Horses provided for the Examination: NAME TYPE COLOUR SEX

....

....

....

Appendix 3 – Veterinary Certificate

Annex C

EQUINE SOUNDNESS EVALUATION

I ....HETTY HILL............, certify that the following equines are sound and fit for dynamic assessment.

1. Allegra
2. Trigger
3. Raphael
4. Betty
5. Calypso
6. Sible
7. Mac
8. Cash
9. Thor
10. Tui

H Hill BVM&S CertAVP
Gibbs Marsh Equine Veterinary
01963362699

Veterinary Surgeon Name ...HETTY HILL MRCVS.......

Veterinary Surgeons Signature .... Date.....11/12/2021...

Annex C

EQUINE SOUNDNESS EVALUATION

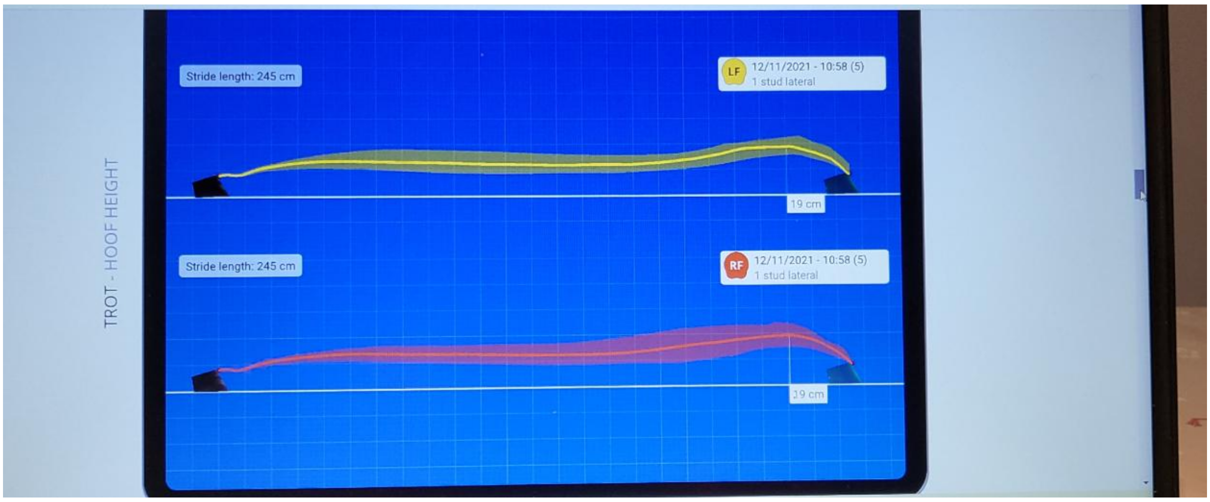
I ....HETTY HILL..., certify that the following equines are sound and fit for dynamic assessment.

11. Corrie
12. Dilly
13. Lad
14. Millie
15. Polo
16. Bob
17. Charlie
18. Crunchie
19. George
20. Tosca - LAME - EXCLUDED FROM STUDY GROUP

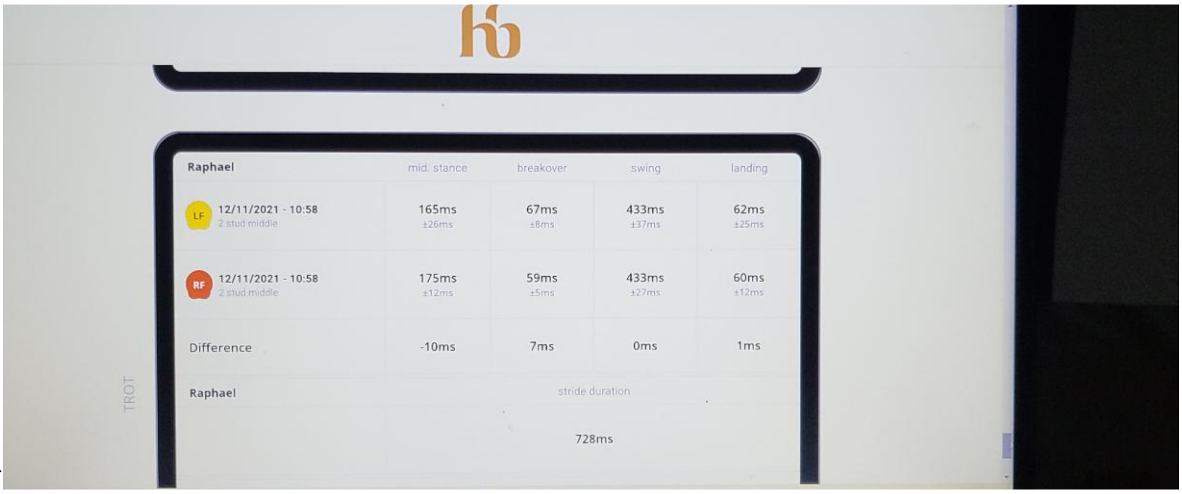
Veterinary Surgeon Name ....HETTY HILL MRCVS......

Veterinary Surgeons Signature .... Date ...20/4/24.................................

Appendix 4 – Gait analysis software pdf distance format



Gait analysis software pdf time format



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