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A cross sectional survey examining centre of pressure and training load in Thoroughbred racehorses in New Zealand

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Abstract

Musculoskeletal injury is the single largest reason for involuntary wastage from the racing industry. One-third of the Thoroughbred racehorses will be withdrawn from training due to musculoskeletal injury. Therefore, the development of sensitive techniques to monitor a horses response to training may help reduce the risk of injury. A pressure plate is able to quantify balance by calculating centre of pressure (COP) movement during quiet standing and differences in limb loading underneath the hooves. The aim of this study was to investigate the pattern of the COP in a cohort of Thoroughbred racehorses exposed to different training regimes and stages of a race preparation programme. COP data was measured in 39 Thoroughbred racehorses for a period of one-minute. COP movement was defined as the Total path length (mm), Amplitude (mm) of the COP in mediolateral (ML) direction, the COP Velocity (mm/sec) in ML direction and the Frequency (Hz). The results showed a consistent right limb loading bias irrespective of training load (1408±240 vs 827±234 N, $p<0.05$). The mean COP Frequency was 0.3 ±0.08 Hz, Amplitude 16.9±12.3 mm and Velocity of COP 1.1±1 mm/s. There was a linear relationship between Amplitude (mm) and total COP path (mm), $R^2=0.58$, $p<0.05$ and Amplitude and Velocity ($R^2=0.59$, $p<0.05$). The relationship between Amplitude and Frequency was moderate and curvilinear ($R^2=0.28$, $p<0.05$). Furthermore, there were two distinct groups based on training load (0-10 gallops vs. >10 gallops). Horses with >10 training gallops had smaller COP Amplitude (10.5 (IQR 7.22-17.42) vs 21.7 (IQR 11.61-29.26) $p<0.05$)). There was less variation in velocity in the >10 gallops group, but no difference in mean velocity between the groups. The unloading of the left limb may be present irrespective of the training load. Furthermore, the reduced amplitude may be associated with greater muscular tone due to greater training load.

Introduction

Horses are important animals for the economy in New Zealand and they are used in several ways. The horse population in New Zealand is high, estimated at 30 horses per 1000 people and 3.7 horses per 1000 hectares. The value of horses is obtained through racing, sport or the breeding of race and sport horses. There are five main categories for the use of horses in New Zealand: Thoroughbred racing, Standardbred racing, sport, recreation and work (Rogers et al., 2017).

Breeding, racing and the sport-horse industry are the three most prominent sectors of the equine industry in New Zealand (Bolwell et al., 2017). The racing sector (Thoroughbred and Standardbred racing) in New Zealand has a great impact on the New Zealand economy. The racing sector generates over NZ$1.4 billion in Gross Domestic Product, which equates to ~1% of New Zealand's Gross Domestic Product (Fenessy, 2010).

In New Zealand the production of horses has primarily an export focus especially in the Thoroughbred industry. Forty percent of the annual Thoroughbred foal crop is exported as yearlings or as two-year-olds. Internationally, the Thoroughbred breeding industry generates 4% of the global Thoroughbred foal crop. The success of New Zealand's Thoroughbred industry might be through the management of the racehorses. Thoroughbred breeders in New Zealand are able to manage horses at pasture all year round in contrast to other international Thoroughbred breeders. This gives the young foals the opportunity to stimulate their musculoskeletal system because of the ability to move freely (Bolwell et al., 2017; Rogers et al., 2007).

Most Thoroughbred racehorses in New Zealand start race training as two-year-olds and most of the racehorses will start racing as three-year-olds (Bolwell et al., 2017; Perkins et al., 2005a). The period between entering the stable until the first trial start is longer for two-year-olds as the two-year-olds require education, they have to develop their musculoskeletal system and they have to improve their fitness (Bolwell et al., 2010, 2012b; Perkins et al., 2005a). Therefore, only 30% of the two-year-old Thoroughbred racehorses will have a race start at this age. Most of the two-year-old Thoroughbred horses will be trained according to a standard training programme with the first gallop days and the official trial start (at ~ 10 – 12 weeks in training) as a training milestone (Bolwell et al., 2017; Tanner et al., 2016). Previous study showed that the majority of Thoroughbred horses reached a trial or race within 71 – 84 days from starting training (Perkins et al., 2005a).

Wastage in the racing industry is of major concern because it has an economic impact on the racing industry and compromises animal welfare. Wastage in the racing industry is defined as losses during the production of horses to race (Tanner et al., 2013). Wastage can be due to several factors such as lack of talent, physical injury, or can be based on financial considerations (Tanner et al., 2012). The study of Tanner et al. (2013) showed that 46% of Thoroughbred racehorses registered with a trainer never trialled and 55% of the racehorses never started a race due to lack of ability or poor performance. Furthermore, after lack of ability, one of the main reasons for involuntary wastage from training is musculoskeletal injury. Musculoskeletal injuries are the main restriction to Thoroughbred racehorses to achieve their potential on the racetrack (Perkins et al., 2005a). Early studies showed that one-third of the Thoroughbred racehorses will be withdrawn from training due to musculoskeletal injury (Perkins et al., 2005a; Rogers et al., 2007). Many musculoskeletal injuries are a consequence of cyclic overload combined with a short recovery period. Muscles become sore and bone remodelling is insufficient during their training period. This results in chronic accumulated damage and injuries (Martig et al., 2014). Risk factors for musculoskeletal injuries were identified in previous studies and included horse age, race distance and exercise intensity (Maeda et al., 2016; Perkins et al., 2005b; Verheyen et al., 2005, 2006). The study of Tanner et al. (2013) identified a positive influence of early race training at two years of age on the career length and racing success of Thoroughbred racehorses. This was hypothesised to be due to the fact that early exercise stimulates the development of the musculoskeletal system (Bolwell et al., 2010; Rogers et al., 2012; Van Weeren et al., 2000). In addition, recent studies imply the essence of spontaneous locomotion activity in young foals for the development of their musculoskeletal tissue. It seems that free pasture exercise at foal age has a positive influence on the quality of the musculoskeletal tissue (Bolwell et al., 2012a; Kurvers et al., 2006; Rogers et al., 2007, 2008; Van Weeren et al., 2000, 2008).

As mentioned above, musculoskeletal injuries are the most common reason of loss of training days and loss of racing. As a consequence of the cranial position of the horse's centre of mass and therefore a higher vertical loading on the forelimbs most of the musculoskeletal injuries are located in the (distal) forelimb. (Gustås et al., 2004; Maeda et al., 2016; Oosterlinck et al., 2011, 2013b). During racing the distal limb and the hoof play an important role in the attenuation of the impact and loading (Labuschagne et al., 2017). The hoof is a dynamic entity which responds to loading and environmental factors. Foot shape and balance is of great importance in high performance Thoroughbred racehorses. However, the Thoroughbred hoof is light with thin walls and soles. This makes the Thoroughbred hoof more susceptible to injury and hoof conformation (Morrison, 2013). The prevalence of flat feet and more acute dorsal hoof angles in Thoroughbred racehorses is high (Labuschagne et al., 2017). This hoof conformation has been associated with musculoskeletal injuries and lameness. Thoroughbred racehorses with less acute dorsal hoof angles were associated with less musculoskeletal injuries and a greater racing success compared to Thoroughbred racehorses with more acute dorsal hoof angles (Labuschagne et al., 2017).

Most Thoroughbred racehorses in New Zealand are trained and raced counter clockwise (left handed). The left forelimb is subjected to the greatest strain when galloping counter clockwise. Galloping counter clockwise results in a larger and flatter left hoof (Firth & Rogers, 2005a; Van Heel et al., 2010). Data from cohort studies have identified that training and racing counter clockwise has been associated with differences in Bone Mineral Density (BMD) between the left and right forelimb (Firth et al., 2005b). A recent pilot trial following Thoroughbred racehorses from one racing stable identified asymmetry in the pattern of the centre of pressure (COP). This result was proposed to be related to the left handed training protocol (Lichtenauer et al., 2016). The study of Lichtenauer et al. (2017) showed that the pressure in Thoroughbred racehorses is greater under the right forelimb than the left forelimb during quiet standing. However, as the data was collected from one racing stable it was unknown if this effect was a specific response to the training programme of that specific racehorse trainer.

In this study the loading pattern and the COP movement will be obtained by using a pressure plate. The importance of quantifying the loading pattern and the COP movement is that it may detect an early stage of injury and reduce the risk of musculoskeletal injuries. Asymmetric loading of the forelimbs might occur due to the left handed training protocol. The pressure plate is able to quantify contralateral differences in hoof contact area, differences in limb loading and COP location underneath the hooves (Lichtenauer et al., 2016). Previous studies of pressure analysis in horses were based on force plates (Clayton et al., 2003, 2013). However, the use of force plates is limited in practice as it requires a laboratory setting in contrast to the pressure plate. Furthermore the use of a force plate is costly and the plate is not movable (Oosterlinck et al., 2011). Because of these limitations the force plate is not applicable for practicing veterinarians (Oosterlinck et al., 2010b). The study of Oosterlinck et al. (2010b, 2011) showed that the pressure plate could be an alternative instrument for the measurement of hoof contact areas and COP locations. Differences between the pressure plate and the force plate are the sampling rate and the sensors. The sampling rate (Hz) of the pressure plate is lower (0-250 Hz vs. 960-1000 Hz). The lower sampling rate results in a smoother COP movement with less high frequency noise. Furthermore, the pressure plate includes resistor-based sensors which have an increased latency compared with the piezoelectric sensors used in a force plate. Despite these differences it has been shown that the pressure plate can be a mobile, inexpensive and efficient instrument for pressure analysis in horses (Gomes-Costa et al., 2015).

The horse's centre of mass is continuously moving, known as postural sway. Movements of the COP reflect postural sway activity. Postural sway is essential for maintaining the horse's centre of mass within narrow limits in a horizontal plane (Clayton & Nauwelaerts, 2014; Gomes-Costa et al., 2015). Small adjustments of muscle tension during quiet standing result in movements of the COP. The movements of the COP during quiet standing are an indicator of the stability and balance of the horse's centre of mass (Clayton et al., 2003). In humans, postural sway measurements are routinely used for balance assessments. It is known that individuals with musculoskeletal injuries have impaired balance, which results in greater postural sway. In horses it might be useful to measure the postural sway activity for assessing the musculoskeletal condition. It is likely that horses with musculoskeletal injuries or altered muscle activation have impaired motor control. Impaired motor control results in changes in postural sway which can be quantified by measuring the COP movements (King et al., 2013).

The aim of this study is to investigate if the pattern of the COP between the forelimbs in the standing horse is consistent across a cohort of Thoroughbred racehorses which are exposed to different training regimes and are in different stages of race preparation. Because of the counter clockwise training and racing regime it was hypothesised that there is a linear relationship between the loads of the left versus the right forelimb and accumulated training load in current practices of racing preparation. Furthermore, it was hypothesised that the velocity and frequency of the oscillation of the COP movement during quiet standing will have a linear relationship with accumulated training load due to the accumulated musculoskeletal damage.

Materials and methods

Horses and Training programme quantification:

Data were collected from 39 Thoroughbred racehorses ranging in age from two to nine years old in race training, with four different trainers at the local Awapuni race track. All the Thoroughbred horses in the study were in "regular work" (training or pretraining) and at differing stages of their race preparation programme. During field data collection brief demographic data was collected for each horse (sire, brands, age and racing name). Data on training history were collected as months in training and number of accumulated gallop days during this preparation at the time of COP data collection. Further information on racing career and racing history was obtained from the New Zealand racing online database.

Pressure plate:

The COP data was captured using a $0.5m^2$ footscan pressure plate. The surface of the pressure plate was covered with a 3 mm thick rubber mat to minimize the risk of horseshoe nail head penetration from horses when standing on the plate. The pressure plate was inserted into a plywood frame which was also covered with a rubber mat to provide a uniform level surface for data collection and minimise the risk of plate movement during data collection. During data collection the horse had to stand square in the centre of the plate. Data on the oscillations of the COP were collected at 15Hz for a one-minute period. If there was gross movement of the horse during capturing data such as shaking its head or lifting its feet, these data were excluded from analysis. The pressure plate was connected to a laptop running the Footscan Balance 7.7 Second Generation and Footscan 7 gait 2^{nd} Generation software (RSscan International).

Data processing:

The COP of the forelimbs was recorded as x and y coordinates. One axis (X) represents the Medio Lateral (ML) direction and the Y axis represents the displacement in the Cranio Caudal (CC) direction. The COP movement is described as the total COP path, Amplitudes of the COP in Right Left (RL) direction, the COP Velocity in RL direction and the Frequency. The COP movements between all successful data points are summed to calculate the total COP path. The Amplitude is calculated as the difference between the minimal and maximal values of the COP position of the x coordinates (Gomes-Costa et al., 2015). The COP Velocity is calculated as the magnitude of the time of the displacement between data points in RL direction (Clayton & Nauwelaerts, 2014; Gomes-Costa et al., 2015). Furthermore, the Frequency is calculated by the occurrence of the COP displacement. Finally the Base Width is calculated. The Base Width describes the COP of each individual forelimb and gives information about the distance between the forelimbs.

The pressure load describes the loading (loading bias) on the right/left part of the plate (right/left forelimb), calculated as the vertical ground reaction force on the right/left side of the plate divided by the total vertical ground reaction force of the whole plate.

The COP data was filtered using Rstudio (3.1.1) to remove high frequency noise and the filtered COP data was imported to Excel 2013 for calculating the COP movement.

Statistical analysis:

Descriptive statistics (mean ± standard deviation) were generated to describe the population mean and variation. Linear regression and a general linear model were used to describe the relationship of the parameters measured with the training load and horse specific variable. All statistical tests were performed using R (R studio) with significance set at $p < 0.05$.

Results

Horses, age distribution and workload:

Data were collected from 39 horses in total (32 in work with 28 horses that had started galloping) ranging in age from two years to nine years old (median = 5, interquartile range [IQR] = 4 – 6) at four different trainers (Figure 1). However, only 34 horses were included in the final dataset and were analyzed as five horses were excluded from analysis due to errors during data collection.

Figure 2 illustrates the total workload and the total numbers of gallops of each horse at the moment of capturing the COP data. Horses 3, 4, 35, 38 and 39 were the horses that were excluded from analysis. Horses 29 and 32 were not in training or pre-training during capturing of COP data and had hence not raced yet. Horses 7, 23, 28 and 31 were conducting some pace work, but had not had a gallop yet. The median training duration was 3.00 (IQR = 1.625 – 5.00) months and median number of gallops was 11.00 (IQR 2.75 – 20.25).

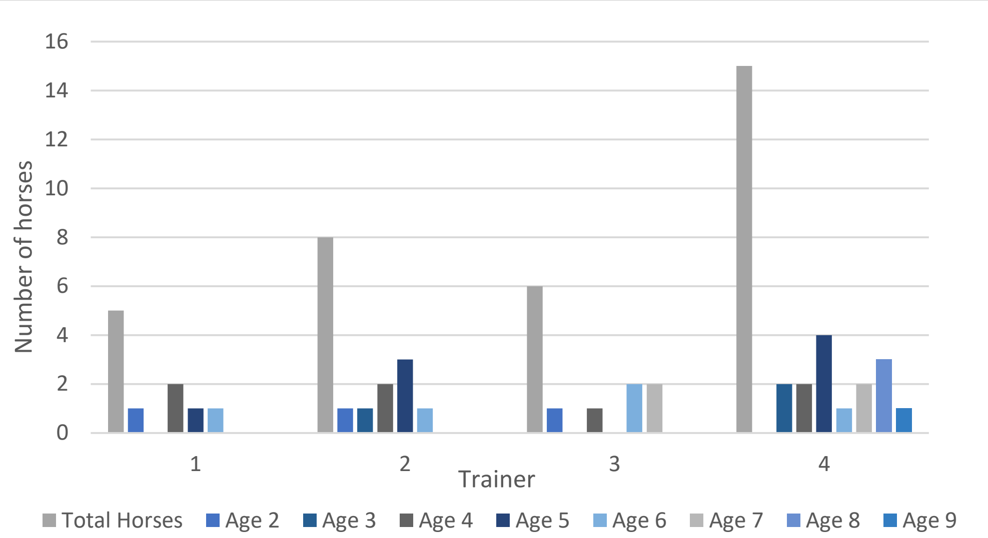

Figure 1: Age distribution of the horses at four different trainers.

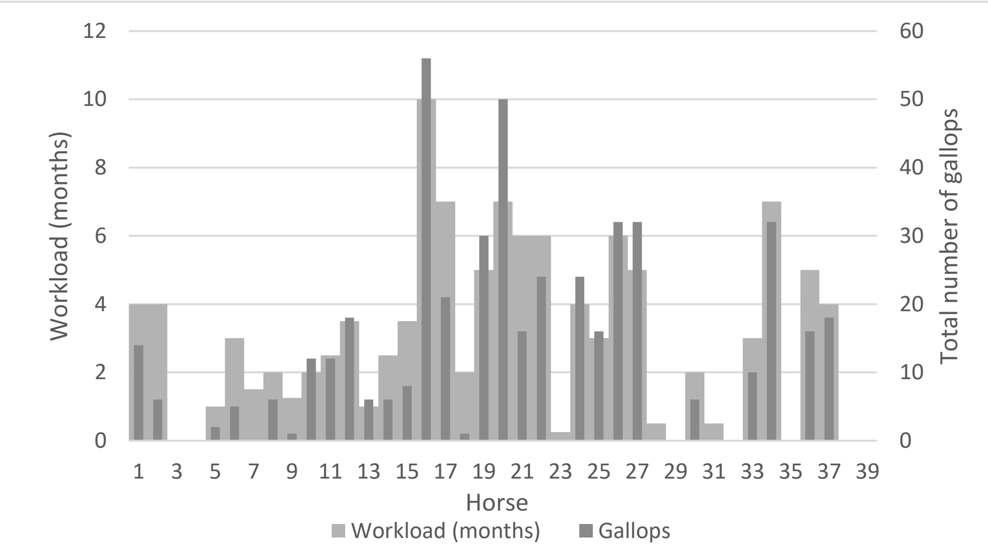

Figure 2: Total workload and total numbers of gallops of each individual Thoroughbred racehorse.

Loading Forelimbs:

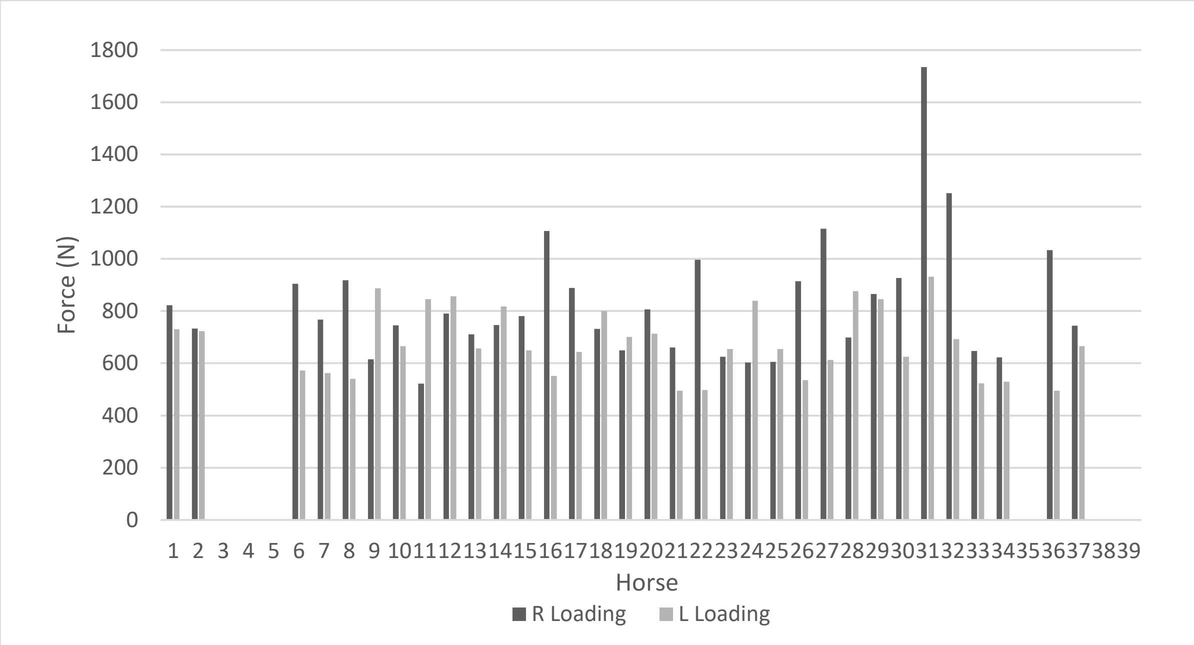

Figure 3: Pressure pattern between the Right (R) and the Left (L) forelimb.

Figure 3 shows the pressure pattern between the right (R) and left (L) forelimb. Horse 5 was excluded from data analysis for the static loading as the total force (301 N) was unreliable for a Thoroughbred racehorse (average of 400 – 450 kg). Mean total load was 1456 N (SD 157) with mean right load of 786 N (SD 151) and mean left load of 671 N (SD 125) ($p<0.05$). The pressure was greater under the right forelimb than the left forelimb in 23 / 33 (69.7%) horses with right forelimb median 53.81% (IQR 48.10-58.00) vs. left forelimb median 46.14% (IQR 42.00-51.80), $p<0.05$.

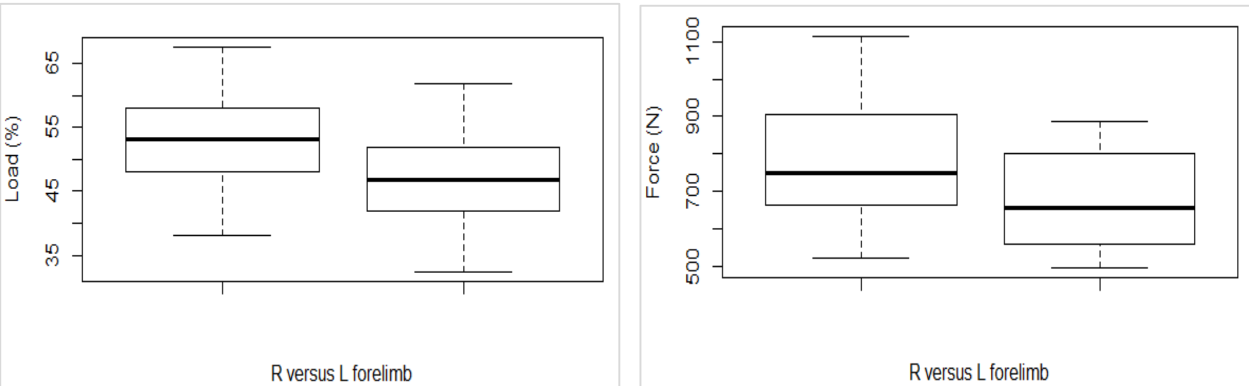

Figure 4: Box plots of the pressure pattern in % and Force (N) between Right (R) versus Left (L) forelimb.

Figure 4 presents box plots with the distribution of the loading of the right versus the left forelimb in % and in Force (N). The box plot illustrates the variation of each forelimb and the variation between the right versus the left forelimb. It shows that there is a consistent variation in each forelimb and between the forelimbs.

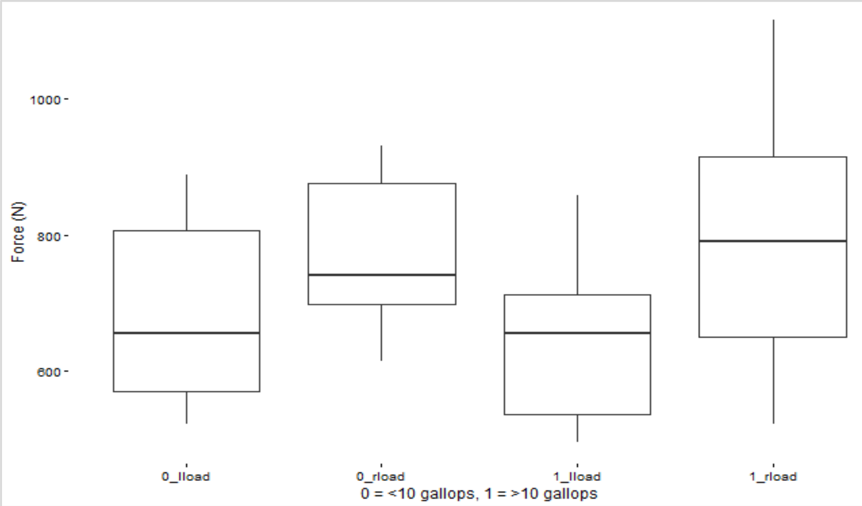

Figure 5: Box plots of the loading on the Left and Right Forelimb in Force (N).

The horses were divided into two distinct groups based on training load; 0-10 gallops vs. >10 gallops (Figure 5). Horses with >10 gallops (Group 1) had more variation in the right forelimb force (N) and less variation in the left forelimb force (N) compared to horses with 0-10 gallops (Group 0). In horses with 0-10 gallops the mean force distribution (N) was 47% (IQR 38.6 – 54.7%) under the left forelimb and 53% (IQR 48.1 – 60.3%) under the right forelimb. In horses with >10 gallops the mean force distribution (N) was 45% (IQR 37.2 – 49.4%) under the left forelimb and 55% (IQR 44.6 – 62.7%) under the right forelimb with no significant differences between the Groups (p>0.05).

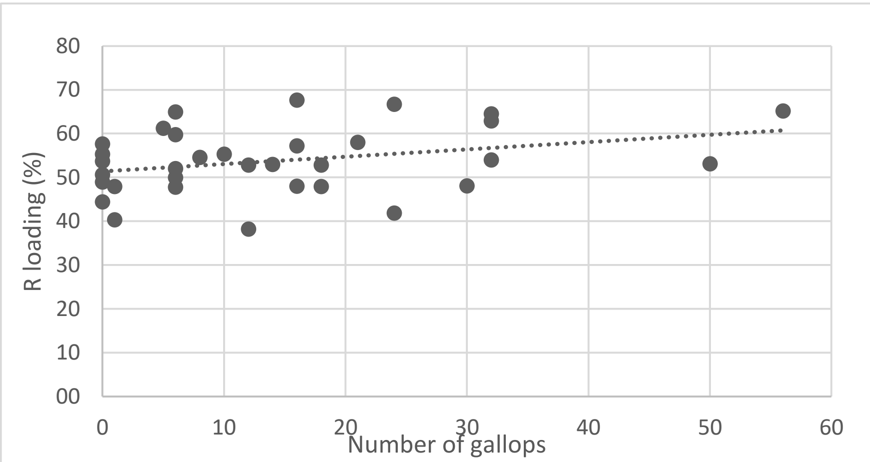

Figure 6: Relationship between the number of gallops and the Right pressure pattern (%).

There was no significant linear relationship of the number of gallops and the pressure pattern under the right forelimb (R^2 = 0.099; p>0.05) (Figure 6). Fifty-six percent of the horses with 0-10 gallops had more pressure load under the right forelimb (9/16). On the horses with >10 gallops, 71% had more pressure load under the right forelimb (12/17) with p>0.05.

COP displacement:

Table 1
An overview of the mean (SD) values of the COP data collection of the 34 horses

	Mean	SD
Frequency (Hz)	0.30	0.08
Velocity (mm/s)	1.07	0.89
Amplitude (mm)	16.89	12.34

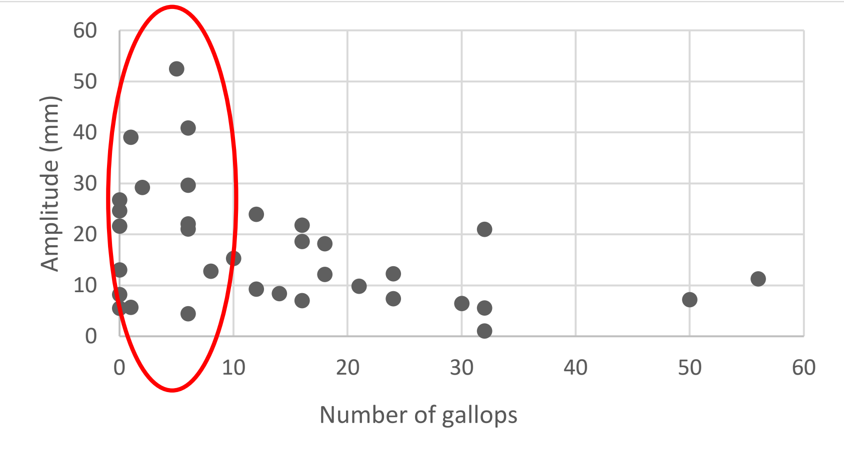

Figure 7: Relationship between the number of gallops and the Amplitude.

There was a significant relationship between the number of gallops and the amplitude (mm) (R^2 = 0.161, $p<0.05$). Figure 7 illustrates more variation in amplitude in horses with 0-10 gallops. The amplitude reduced when horses had more than 10 gallops.

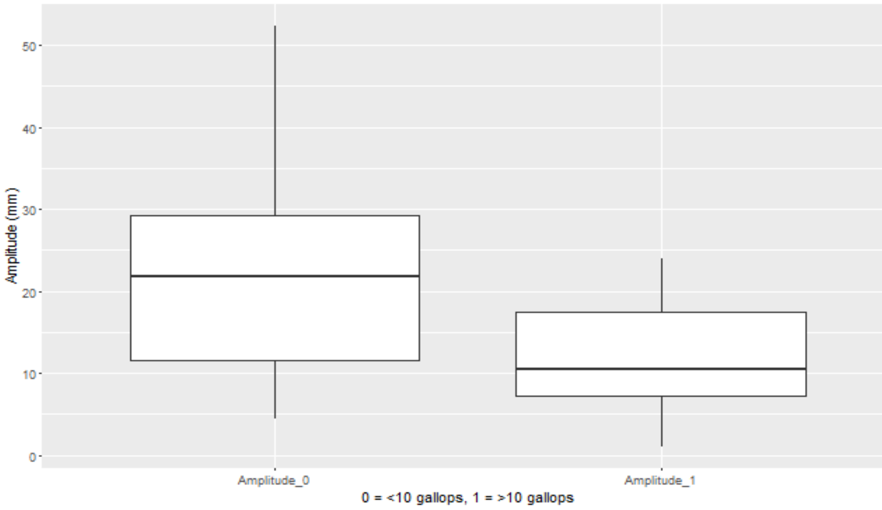

Figure 8: Box plot of the relationship between the number of gallops and the Amplitude .

The mean amplitude of horses with 0-10 gallops was 22.28 mm and the mean amplitude of horses with >10 gallops was 11.99 mm. The median amplitude in horses with 0-10 gallops was 21.79 mm (IQR 11.61-29.26) and the median amplitude in horses with >10 gallops was 10.52 mm (IQR 7.22-17.42).

There was a significant difference in the mean amplitudes between the Groups ($p<0.05$) using an ANOVA test.

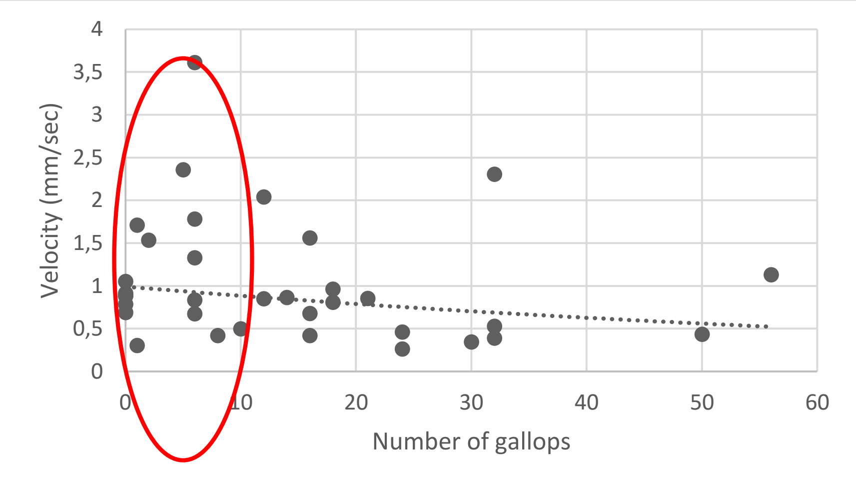

Figure 9: Relationship between the number of gallops and the Velocity.

Figure 9 illustrates the number of gallops against velocity (mm/sec) with more variation in horses with 0-10 gallops and less variation in the >10 gallops group. This variation is consistent with Figure 7. If a lot of variation in the amplitude in horses with 0-10 gallops is found, consequently there is also a lot of variation in the velocity of the 0-10 gallops group.

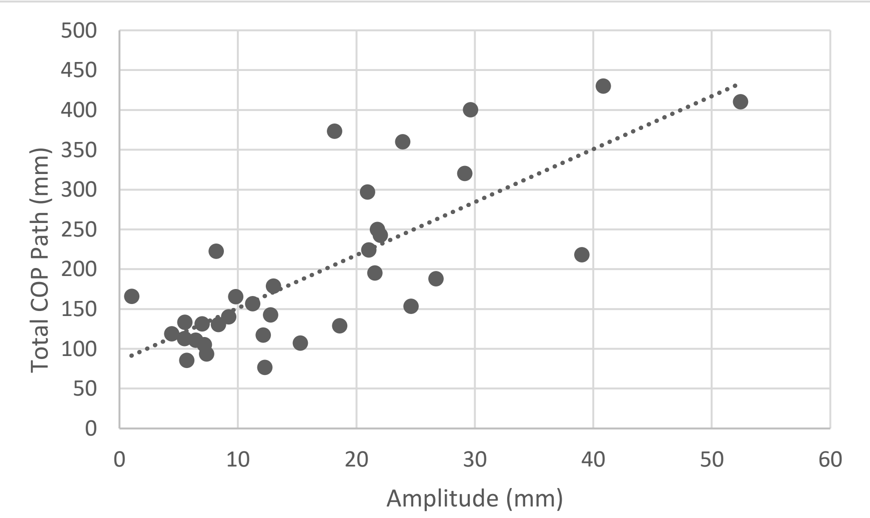

Figure 10: Linear regression analysis between the Amplitude and Total path.

Regression analysis between the amplitude (mm) and the total COP path (mm) resulted in a regression formula of $y = 84.70 + 6.65x$ with $R^2 = 0.58$, $p<0.05$. If the amplitude is low, consequently the total COP path is shorter. In comparison, when the amplitude is higher, the distance between L-R COP is greater so the total COP path is also longer.

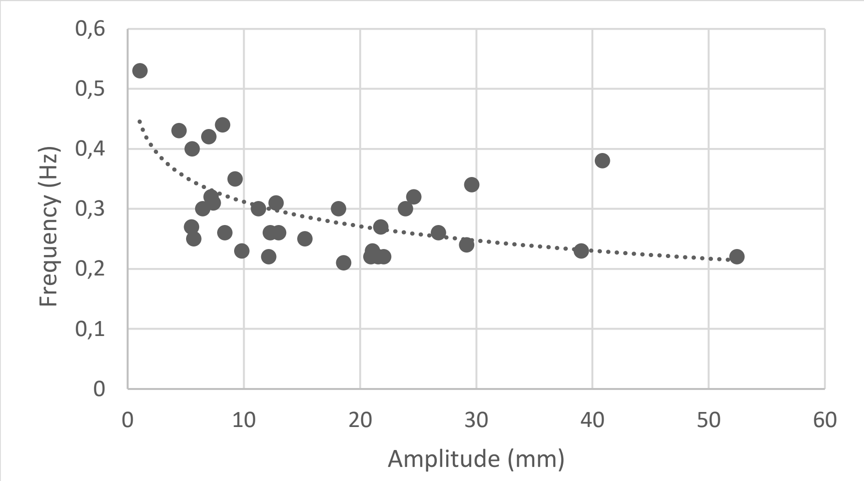

Figure 11: Relationship between the Amplitude and Frequency.

The frequency was within a narrow range (0.22 – 0.53 Hz) (Figure 11). When the amplitude (mm) increased the variation in frequency (Hz) decreased and converges to the mean (R^2 = 0.287, p<0.05). The only way the horses can keep the frequency in a narrow range if the amplitude increases is if the horses are moving faster (higher velocity), shown in Figure 12.

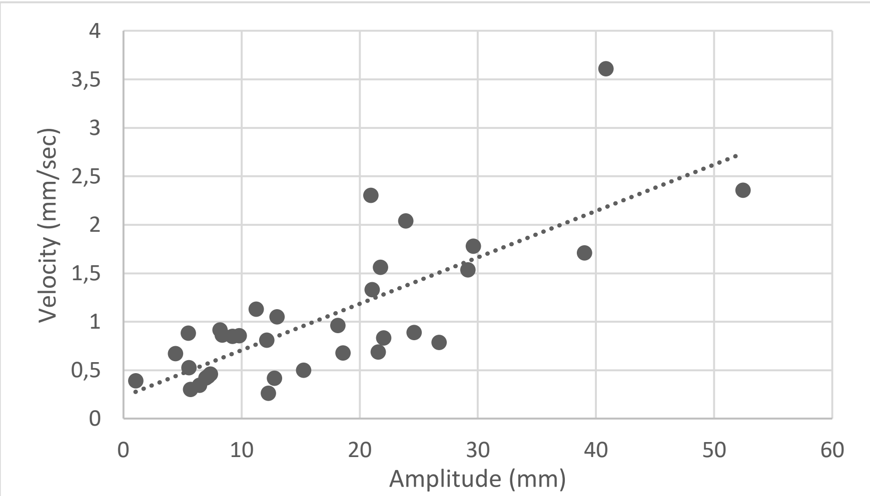

Figure 12: Linear regression analysis of the Amplitude and the Velocity of COP movement.

Figure 12 shows a linear regression with a significant effect between amplitude (mm) and velocity (mm/s) (R^2 = 0.597, p<0.05). If the amplitude is low consequently the total COP path is also lower (Figure 10); in comparison, when the amplitude is higher the distance between L-R COP is greater, which results in a longer total COP path in the same range of frequency resulting in a higher velocity.

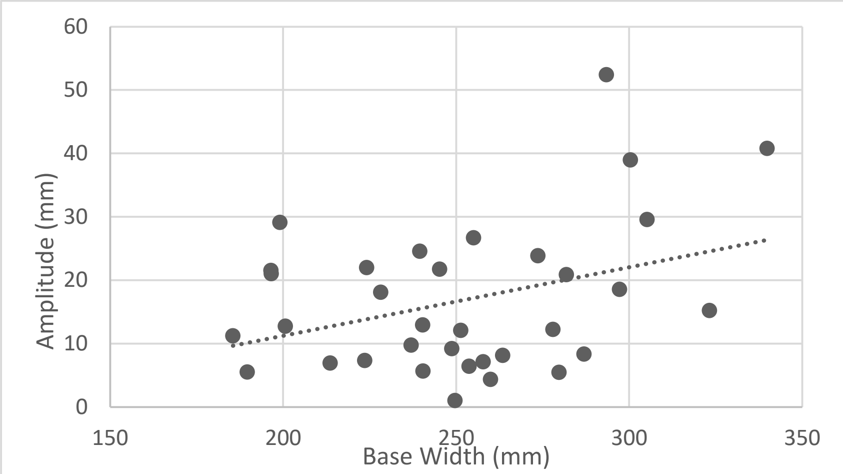

Figure 13: Relationship between the Base Width and the Amplitude.

Figure 13 illustrates a weak linear regression between the Base width (mm) and the amplitude (mm) (R^2 = 0.130, $p<0.05$). This result shows a weak correlation, however no conclusions can be made about the way horses are standing (wide or narrow stance).

Effect of trainers:

There was no significant effect on amplitude of the different trainers ($p>0.05$). However, there was a significant difference ($p<0.05$) in amplitude between horses with less than 10 gallops and horses that did more than 10 gallops, with the latter having an amplitude of 10.1 mm less.

Discussion

The aim of this study was to investigate if the pattern of the COP and pressure pattern between the forelimbs in the standing horse is consistent across a cohort of Thoroughbred racehorse which are exposed to different training regimes and stages of race preparation. Loading of the forelimbs and COP movements were measured. The Thoroughbred racehorses used in this study were in ‘’regular work’’ and were at different stages of their race preparation programme. It was hypothesised that there would be a linear relationship between the load of the left versus the right forelimb and accumulated training load during the current racing preparation. This effect may be related to the left handed training protocol. However, no linear relationship between left-right load and accumulated gallops was observed in this study. This result is consistent with the study of Oosterlinck et al., (2013a) were no correlation between symmetry ratios and duration of careers was found in a sample of carousel ponies.

However, there was a trend for the pressure pattern. The pressure was greater under the right forelimb than the left forelimb in 23 / 33 (69.7%) horses. This result is in agreement with the study of Lichtenauer et al., (2017), where the pressure in Thoroughbred racehorses was also greater under the right forelimb (55 %) than under the left forelimb (45%) with no effect of weeks of training (8 weeks).

This result is consistent with this study where no linear relationship is found between the load of the left versus the right forelimb and accumulated training load during racing preparation (0-10 gallops vs. >10 gallops). An explanation of this could be that the accumulated training load was below the limit where negative consequences would become on the loading and unloading of the limbs. Another explanation could be that a certain extent of asymmetry between the forelimbs has to be considered as normal and may not always be indicative for underlying pathology or disorders (Colborne et al., 2009; Labuschagne et al., 2017; Nauwelearts et al., 2017; Oosterlinck et al., 2010a, 2013b; Weller et al., 2006, Wilson et al., 2016). Asymmetry and unevenness between the forelimbs developed in an early stage of life due to laterality may possibly result in uneven loading patterns (Van Heel et al., 2006). Uneven and asymmetrical feet are frequently related to lameness but are also often observed at pre-purchase examinations in sound horses (Van Heel et al., 2006). Hoof asymmetry may develop in an early stage of life due to preferred stance during grazing in foals (laterality) (Labuschagne et al 2017; Van Heel et al 2010). When a foal develops a preference in grazing position this will have consequences for the loading of the forelimbs and feet become asymmetrically. As foals are kept for long periods on pasture, often 24 hours per day, hoof asymmetry may develop and hooves become uneven (Van Heel et al., 2010). Hoof asymmetry developed in an early stage of life may have an influence on the development of the musculoskeletal tissue and may have an influence on injury incidence later in life (Kroekenstoel et al., 2006). The hoof of the protracted limb develops an acute hoof angle and the retracted limb develops a steeper hoof angle (Van Heel et al., 2010). In addition, the hoof asymmetry seems to remain as the horses age (Van Heel et al., 2010). It is unknown if this unevenness in foals has consequences for internal structures or if the unevenness will be compensated through adaptions during growth and development of the foals (Kroekenstoel et al., 2006). However, there are indications that asymmetrical in front feet may have the same effects on limb loading in mature horses as in foals. The study of McGreevy & Rogers (2005) showed a preference of left laterality in a population of Thoroughbred horses. If these preferences in laterality are already presented at young age, it is likely that this preference may have consequences for the loading of the limbs in a later stage of life and can be seen as normal loading of the limbs. More research is required to understand the cause of locomotor asymmetry and to determine the relationship between symmetry ratios and clinical lameness in Thoroughbred racehorses (Oosterlinck et al., 2010a). It may be appropriate to do a longitudinal evaluation of Thoroughbred racehorses throughout their career to further investigate this issue.

The calculated frequency of the COP displacement in this study (Table 1) is consistent with the frequency found in the study of Clayton & Nauwelaerts (2014) on a force plate in sound horses with a ML COP oscillation of 0.30 Hz. The velocity and amplitude of the COP displacement in the study of Clayton & Nauwelaerts (2014) were 2.2 mm/sec and 9.3 mm. The study of Gomes-Costa et al., (2015) reported a velocity of 4.3 mm/sec and amplitude of 3.2 mm of COP movement in sounds horses. In both studies the velocity was higher than the velocity reported in this study (mean = 1.07 mm/sec), while the amplitude reported in both studies was lower compared to this study (mean 16.89 mm) (Table 1). An explanation of the differences could be breed differences. None of the studies used Thoroughbred horses; the study of Clayton & Nauwelaerts (2014) used a wide range of sizes and types of horses and Gomes-Costa et al., (2015) used Puro Sangue Lusitano horses**.** Furthermore, Clayton & Nauwelaerts (2014) analysed the COP data for 15 seconds and Gomes-Costa et al., (2015) for only 10 seconds. This time frame can be questioned and may be not representative for the COP movement. As the frequency was about 0.30 Hz, only 3-5 COP movements could be captured during the recording. In the study more COP movements were captured (mean = 28.3 sec quiet standing) which may provide a better indication of the COP movement. In addition, the higher velocities found in the study of Clayton & Nauwelaerts (2014) and Gomes-Costa et al., (2015) may be due to the used recording speed, 960 Hz and 50 Hz vs. 15 Hz used in this study. A detailed COP movement can be captured using a high recording speed, but also the risk of including noise in the measurements will increase.

A significant relation was observed between the number of gallops and the amplitude with more variation of the amplitude in horses with 0-10 gallops. The greater variation of the amplitude in horses with 0-10 gallops may be due to poorer developed muscles and poor postural sway control. The study of Clayton et al., (2003) studied COP values to measure postural sway in two-year-old horses. They found that small immature horses that had never been in regular work had poor postural sway control with a greater amplitude of COP motion than trained horses. Young horses with poorer developed muscles may have less postural sway control resulting in a greater COP amplitude to create a better balance. Training and accumulated workload increase muscular size, so training may enhance locomotor and postural control (Gomes-Costa et al., 2015). Summarised, the reduced amplitude in horses with >10 gallops can be associated with greater muscular tone due to greater historical training load rather than a negative response to accumulated cyclic overload. However, to verify this hypothesis a larger study population is required with more horses with >10 gallops. Furthermore, it would be interesting to look at the amplitude in racehorses in (pre)training and racehorses during their spell period. In addition, information about the race career history of the Thoroughbred racehorses would be interesting in relation to the amplitude, velocity and the frequency of COP movement.

The musculoskeletal system adapts to workload. How the musculoskeletal system adapts is dependent on the balance between work and recovery. The muscles can develop positively and increases in size after every training. When the recovery period is too short, the muscles cannot recover and become sore with a higher risk of musculoskeletal injuries. In this study we compared different stages of race training preparation. However, there was no relation with accumulated training load and oscillation / frequency of the COP movement. In contrast, the study of Lichtenauer et al., (2016) found an increase in the frequency of the COP movement over an 8-week period of race preparation. This difference could be explained by the fact that the accumulated training load in this study was between physiological limits (no presence of cyclic overload), allowing the muscles to recover properly to keep the frequency of the COP movement between a narrow window.

The study of Clayton et al., (2013) suggests that the distance between the forelimbs may have an influence on the captured COP data. Wider standing could imply a better balance and may reduce COP movement. In addition, the study of Henry et al., (2001) suggests that with a narrow base conformation there is more need for active muscle force to keep the horse's centre of mass within narrow limits in a horizontal plane. This may result in an increase of the COP amplitude (Henry et al., 2001). However, no relationship between the way horses are standing (Base Width) and the amplitude was found in this study. In this study the Base Width stayed within a narrow range, with no effect on the amplitude. It may be useful to standardize hoof placement within each horse to have a similar stance during capturing the COP data. This may avoid differences in COP variables due to changes in standing (Clayton & Nauwelaerts 2014). On the other hand, altered hoof position from natural to a standardized position may also provide an increase in COP movement (Clayton et al., 2003).

No significant difference in amplitude was observed between the four different trainers. This result implies that the COP movement is independent of the trainer and different training regimes. As mentioned before, there was a significant effect in amplitude between the different groups (0-10 gallops vs. >10 gallops). This may be due to the fact that training and accumulated workload would be expected to improve locomotor and postural sway control.

In this study data of training load was collected as months in training and number of gallops during the race preparation programme at the time of COP data collection. However, no information was collected about the last training day at the time of COP data collection. This data may have an influence on the COP data. Recently trained horses may have a higher frequency comparable with horses that did not train recently as the recovery period may be too short in that case and muscles become sore.

Training of the racehorses to stand on the pressure plate may facilitate COP data collection and improve the reliability of study outcome (Clayton et al., 2003). Training may increase the time period of quiet standing on the pressure plate and reduce fear. Furthermore, COP movements are influenced by the input of three sensory systems; proprioceptive, visual and vestibular. Capturing of COP data took place at the stables of the racehorses. However, this environment contained several distractions of visual and auditory nature. In addition, the activity of the handler and annoying insects were also factors that could distract the horses. Such stimuli have to be minimized during further research when capturing COP data. Further, additional video recording during capturing COP data could be useful for data processing.

Conclusion

In conclusion, this study of Thoroughbred racehorses gave reliable data of the pressure pattern underneath the forelimbs. The pressure was greater under the right forelimb than the left forelimb. However, no relationship was found between the magnitude of the left versus right forelimb and accumulated gallops during the racing preparation programme. The consistent right limb loading bias may be present irrespective of training load. More research is required to investigate if the right bias is due to the left handed training protocol or due to laterality developed in an early stage of life. Furthermore, there was no relation of the centre of pressure parameters with the different training stables. Finally, it seems that accumulated training load has an influence on the amplitude of the COP motion. There may be breed / morphology bias in the COP frequency and amplitude measurements. Reduced amplitude is proposed to be associated with greater muscular tone due to greater historical training load rather than being a negative response to accumulated cyclic load.

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