Examination of centre of pressure and the association with workload in a cohort of New Zealand Sport Horses

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Abstract

Background: Lameness due to musculoskeletal injuries (MSI) is one of the major reasons for wastage of horses in the equestrian sport. An early detection of lameness may be possible by using pressure plate data and measuring the Centre of Pressure (CoP). In Thoroughbred racehorses, high-intensity training and workload were associated with changes in the CoP displacement and the asymmetry in static loading of the limbs. At present, there is no published data on the CoP displacement or asymmetry of the loading of the limbs in sport horses in New Zealand.

Objectives: To investigate the CoP displacement of sport horses and examine association of this with workload and age.

Methods: CoP data were measured in 30 sound show-jumping and 28 dressage horses. Data was collected by using a 0.5 m Footscan pressure plate and measuring at 15 Hz for a duration of one minute. Horses stood with both front limbs squarely positioned in the centre of the pressure plate. Static images were performed to compare the pressure distribution between the two front limbs. CoP data was filtered and the frequency, velocity and amplitude of the CoP displacement were calculated.

Results: The total loading of the limbs of show-jumping and dressage horses was 52.61 (SE 1.20) % on the right limb and 47.39 (SE 1.20) % on the left limb. There was no differences in CoP displacement between the two disciplines. The mean frequency was 0.34 (SE 0.01) Hz, with a mean velocity of 0.78 (SE 0.05) mm/s and a mean amplitude of 1.66 (SE 0.13) mm. There was no significant association of the CoP displacement with workload or age.

Conclusions: Sport horses showed no clear bias to the right limb as observed within racehorses. The CoP displacement in medio-lateral direction was small compared to racehorses. There is a current lack of precision in describing the workload of training of sport horses wherefore further research is required to determinate workload and to examine association of this with CoP displacement.

Keywords: horses, sport horses, lameness, centre of pressure, workload

Contents

Introduction

The most documented equine industry in New Zealand is the racing industry (Tanner et al. 2013). This is due to the large number of horses breed for export and a large racing industry in New Zealand. Therefore the racing industry is important to New Zealand's economy and generates over $1.4 billion in GDP annually. In contrast, the sport horse industry has less clearly defined structure and regulation. It is estimated that only 30 % of the approximately 32.000 horses used for recreation and sport are registered with the official governing body, Equestrian Sports New Zealand (George et al. 2013; Rogers et al. 1993; Rosanowski et al. 2012). Despite its less formal structure, the sport horse industry is still of economic importance and it is estimated to contribute over $1 billion in GDP annually to the New Zealand economy (Matheson et al. 2012).

In recent years literature examining the equestrian industry in New Zealand has focused on research of wastage and loss of horses (Rogers & Firth, 2010; Tanner et al. 2011; Tanner et al. 2013). Wastage includes days lost from training due to injury and disease and can result in economic impacts due to conditions affecting horses leading to interruptions to training, loss of athletic ability and retirement or death. The major reason for wastage of horses is lameness resulting from musculoskeletal injury (MSI). MSI accounts for approximately one third of all wastage and losses within show-jumping, dressage and eventing horses (O'Brien et al. 2005; Murray et al. 2010; Rogers et al. 2012). Lameness resulting from MSI may become obvious within sport horses as the horse is more likely to be making turns and circles rather than working in straight lines and therefore it is possible that there are features of training and management that predispose sport horses to MSI. There are differences reported in the type and location of injury sustained by horses involved in the different equestrian disciplines, and also differences between elite level and lower level of horses within the same discipline (Murray et al. 2006). Specifically, dressage horses are reported to have a higher risk of injuring the hindlimb suspensory ligaments (Murray et al. 2010). In contrast, show-jumping horses are reported to have a higher risk of injuring the forelimb tendons (SDFT/DDFT). It has been proposed that these specific injury sites of show-jumping horses are related to the high loading these forelimb structures are subjected to when landing after an obstacle (Meershoek et al. 2001; Egenvall et al. 2013).

The competition career of sport horses is relatively short, due to lameness resulting from MSI. The typical sport horse having a competition career of ~ 4 years (Rogers et al. 2012). Therefore, the age of sport horses is a factor that may influence the risk of MSI. It appears that older horses have a greater risk of lost training days than younger horses (< 6 years) (Egenvall et al. 2013; Eisersiö et al. 2015; Dijkstra et al. 2016). One possible reason for this may be that older horses have a greater relative workload, which consist of longer training time and increased complexity of tasks. The trainer and age at which the horse first started in competition can also influence the career length. Recent evidence suggests that exercise early in life has an positive effect on musculoskeletal health (Firth 2006; Rogers et al. 2008). Early exercise in life stimulates the development of the musculoskeletal system. Besides early exercise in life, early introduction of a horse to competitions has also been identified to have positive effect on career length (Rogers et al. 2012). This has been described in racehorses, with those who started their competitions as 2-years-old having longer careers than those who started later in life (Tanner et al. 2013; Tanner et al. 2011). Within dressage and show-jumping horses, the estimates of longevity are greater for those who started their competitions as 3 - 4 years old.

Another consistent variable that might affect lameness within sport horses is the workload. The impact of the physical challenges of the training depends on several factors and include the physical condition of a horse, pre-existing injury and the training programme, such as total workload, variation, intensity and continuity (Egenvall et al. 2013). These factors are associated with whether a horse develops any days lost to training. A lower number at days lost to training has been reported within show-jumping horses (5%) compared to racehorses (20%) (Dyson et al. 2008; Lönnell et al. 2014). Workload of racehorses has been quantified by using a Global Positioning Satellite (GPS) and heart rate (HR) monitors and showed that training consists of galloping at an average speed of 53 km/h (Kingston et al. 2006). Race distance at different speeds and exercise intensity were identified as risk factors for musculoskeletal injuries and fractures (Perkins et al. 2005; Verheyen et al. 2006). However, there is a lack of workload data within sport horses and estimates of workload rely on duration and semi objective scoring of difficulty or effort (Rogers et al. 2012; Veldman et al. 2010; Werhahn et al. 2012). The reason for this may be a result of greater schooling, rather than conditioning aspect, compared to racehorses. Currently, there is no method to determine if there is an optimal workload to proactively reduce orthopaedic injury within sport horses.

One commonly fault reported within sport horses is the occurrence of differently shaped and sized front feet (uneven feet). Uneven feet are an undesirable trait, particularly at elite level of show-jumping, as uneven feet are associated with a reduced competitive life, the magnitude of this negative effect being greater in show-jumping than dressage horses (Ducro et al. 2009; Kaneene et al. 1997; Wallin et al. 2001; Wiggers et al. 2015). Geometry of the foot was found to influence the loading pattern and therefore are important enhancing factors for the development of lameness (Wiggers et al. 2015).

Soft tissue injury i.e. MSI can lead to days lost to training. This is mainly due to a long recovery period that is in most cases 6 to 12 months, resulting in a loss of muscle mass and conditioning, wherefore it is important that the diagnosis is accurate (Bubeck & Aarsvold, 2018). Clinical evaluation can give hints to diagnose soft tissue injury. Soft tissue injury may be characterized by visual and palpable swelling of the limb, focal pain to palpation and increased heat. Lameness is often more pronounced when the horse is worked on soft ground versus on harder ground. Ultrasonic evaluation is mainly used in horses to diagnose soft tissue injuries and MRI is considered the gold standard (Bubeck & Aarsvold, 2018). However, prevention of MSI would most likely benefit from early detection of lameness and can permit efficient training programmes that minimize lameness and wastage. Loading patterns are useful to diagnose an early state of MSI and can be made visible by using force plates. The rationale behind this is that horses with MSI have a different loading pattern from sound horses. With a force plate the Centre of Pressure (CoP) can be measured while the horse is standing on the plate. The CoP is the point of application of the ground reaction force. The centre of mass of a horse is continuously moving, known as postural sway. Measurement of the displacement of the CoP is a way to analyze the postural sway in horses. In humans with musculoskeletal injuries such as osteoarthritis, evaluation of balance control through postural sway analysis is a reliable and valid approach to determining statistic stability (Day et al. 1993; Lafond et al. 2004; Nagano et al. 2006). Pain intensity was in humans positively correlated with balance impairments, which resulted in greater postural sway (Hirata et al. 2013). Postural sway has also been demonstrated in horses to assess locomotor balance, but the association between MSI and the postural sway in sport horses has not been studied yet (Clayton et al. 2014).

Postural sway can be quantified using variables derived from force plate data within horses. Previous studies have validated the use of force plates to determinate the postural sway in horses (Clayton et al. 2014). In contrast, measurements with pressure plate data for horses still needs to validated (Gomes-Costa et al. 2015). The pressure plate is an alternative to the force plate. A major advantage of the pressure plate over the force plate is that it provides a portable tool to measure the CoP displacement. The pressure plate can be taken to stables and the CoP can be measured in an environment that is familiar to the patient. The pressure plate consists a matrix of receptor cells that each individually display the pressure. Instead of reliance on data from only four receptor cells as with a force plate, the pressure plate data can be derived from hundreds of receptor cells (Rogers et al. 2003). Pressure plates have been used to evaluate the equine limb loading and it symmetry, hoof contact area, the pressure distribution within each hoof and the toe-heel and mediolateral hoof balance of the vertical ground reaction force (Oosterlinck et al. 2013; Oosterlinck et al. 2010, 2011). Pressure plates provide non-invasive information about the symmetry in force distribution between limbs and the pressure distribution underneath the hoof. With this method, an unequal loading of the limbs resulting from pain from MSI and differences in hoof balance can be quantified easily (Rogers et al. 2003).

It is hard to theoretically predict what the optimal CoP path for a horse would be. It has been suggested that this method is so sensitive that it could provide an early detection for musculoskeletal issues when CoP path is followed up through time, but the pattern of change over time still needs to be investigated to ensure that the repeatability of the CoP path remains as high over time as it was within one day (Nauwelaerts et al. 2017).

The aim of this study is to examine the displacement of the Centre of pressure (CoP) excursions in a cross sectional population of New Zealand sport horses (show-jumping and dressage) and examine association of this with workload and age. It was hypothesized that there is a differences between show-jumping and dressage horses on the three parameters frequency, velocity and amplitude of CoP displacement. Because of the forelimb loading within show-jumping horses, we expect an asymmetry in show-jumping horses rather than dressage horses. Furthermore, it was hypothesized that older horses with greater accumulated workload have a different CoP displacement from younger horses with less accumulated workload. The expectation is that in older horses, due to unloading the both forelimbs, the amplitude is decreased and the velocity and frequency are increased of the CoP displacement.

Materials and methods

Horses

Data were collected via a cross-sectional survey of 58 sport horses, 30 show-jumping and 28 dressage horses, at national competitions in the lower North Island of New Zealand and at training yards of horse owners in the area Manawatu-Wanganui and Hawke's Bay, during the months March and April 2019 (mean (IQR): age 9 (6-11); height: 165 (162-168) m). These competitions were Horowhenua Dressage Group Autumn Tournament in Levin (n= 17) and North Island Future Stars & U25 National Championships in Taupo (n=11). Data of dressage horses were captured at these competitions and data of show-jumping horses were captured at training yards of nine different horse owners. The survey was based on a convenience sampling protocol at each competition and the interviewer went to the horse trucks or floats, approaching riders and explaining the survey before requesting participation. All horses were in training for competitions at the beginning of the study and did not have any obvious lameness identified by the trainer.

Data collection

Questionnaire design: The questions to the owner were divided in three sections: (1) general horse information (i.e. name, age, height, sex, breed); (2) activities of the horse (i.e. discipline, competition level, number of competitions, lameness history); (3) workload of the horse (i.e. training surface, typical training week). Number of competitions of a horse represented all competed classes in the past four weeks. Competition level was categorized as follows:

Level Category	Show Jumping (m)	Dressage (level)
Advanced	>1.30	5-6
Medium	1.20-1.30	3-4
Low	<1.20	<2

Training records were maintained by asking the trainers to describe a typical training week. The training week described was before a competition weekend. Most trainers declared that the horses get one or two days off after a competition weekend. Trainers estimated if the training week they described a good reflection was of a monthly based training schedule. Records included types of exercise categorised as follows; flat work, advanced dressage training, jump schooling, lung, hack out, competition day and rest day. The time in minutes and number of sessions of the exercise were noted on recording sheets. Time of a competition day was set at 30 minutes for a show-jumping class and 50 minutes for a dressage test to calculate the total workload of a horse. Jump schooling included besides the jumps also warming-up, flatwork and cooling down. The height of the jumps depended on the competition level of the horse and trainers jumped frequently 10 to 30 cm lower than competition level.

Pressure plate data: The pressure plate used for this study was the RsScan footscan® 0.5m high-end system (RSscan International NV, Belgium). Measurement of force with the pressure plate is based on matrix of 4.096 polymer sensors measuring 5 x 5 mm in diameter, providing an average sensor density of 2.6 sensor per cm2. The pressure plate was covered with a 3-mm-thick rubber mat, to reduce the risk of horseshoe nail head penetration on the plate. Around the pressure plate, there was a plywood frame to reduce the possibility of damage to the plate by a horse standing on the edge of the plate. On the plywood frame was also a rubber sheet, so there was no differences between de pressure plate and the plywood frame for the horse. The horses had to stand with the front limbs squarely positioned in the centre of the pressure plate. The ground under the plate was visually evaluated at providing a horizontal surface. During data collection, the handler stood close to the horse to discourage movement but with no physical contact. Data was collected at 15 Hz for a duration of one minute. Of each horse one or two recordings were performed until a valid recording was captured. Recordings were considered to be valid if the horse stood still for at least 15 seconds without any obvious movements. The pressure plate was connect to a laptop and data was collected using the static measurement option of the Footscan® 7 gait and the stability measurement option of the Footscan® 7.72 Balance software.

<u>Data analysis</u>

Questionnaire data were recorded on recording sheet and manually transcribed into Microsoft Excel. Descriptive statistics of continuous variables were tested for normality and presented as median and interquartile range (IQR).

Footscan® 7 gait was used to make snapshots from the distribution underneath the forehooves. The pressure scans from the two forehooves were analysed in the software itself, wherefore the distribution of the pressure of the hooves and between the two hooves could me made visible. Previous studies published a lameness threshold as a reference for defining horses in which asymmetry is considered equivalent to lameness (Pfau et al. 2016). Guideline values based on motion capture were 0.82 for the poll sensor and 0.83 for the pelvic sensor to define the boundaries of lameness (Starke et al. 2012). Therefore, a threshold of 80% symmetry was used to describe any kind of bias within the sport horses.

Footscan® 7.72 Balance software was used for the postural sway recordings. Data from this software was filtered with RStudio to remove high frequency noise. The Entire Centre of Force and the time in seconds were exported from this software into Microsoft Excel. Data were visually screened for acute displacement of the horse. Only the sections were used for analysis without any visible movements of the head, neck or limbs during the recording. CoP amplitudes for each limb in mediolateral directions were less than 30 mm because larger displacements are associated with gross movements of the head or limbs.

The Centre of Pressure of the forehooves was recorded as x and y coordinates in the software. The displacement in mediolateral (ML) direction represents the x coordinate and the displacement in craniocaudal (CC) direction represents the y coordinate. The CoP movements were described by calculating velocity, amplitude and frequency of the mediolateral direction. Amplitude was calculated as the differences between the maximal and minimal values of the x coordinate (Gomes-Costa et al. 2015). Velocity was calculated as the square root of the sum of the squared velocities in the ML direction. Frequency was calculated as the total time divide by the maximal values of the x coordinate.

Statistical analysis

Statistical analysis of the data was performed using RStudio 1.2.1335. Statistics were made for each variable (the velocity, amplitude, frequency) and were tested for normality. The pressure distribution between the two limbs was compared by using t-test. To test if there was a relationship between the CoP displacement and workload and age, scatterplots were made and correlations coefficients were determined. The associations between categorical variables were assessed using linear regression. The significance level was set at $P < .05$.

Results

<u>Horse population</u>

Description of the horse population that was collected are presented in Table 1. Most of the dressage horses were geldings (20/28), whereas there was a more equal distribution of gender in the show-jumping horses. The breed description in both disciplines was heavily skewed toward sport horses (41/58). The majority of the dressage horses were classified as having a competition level defined as low level (19/28), whereas the level of competition in the show-jumping horses was more heterogeneous. Competition level was not significant associated with age within show-jumping horses (P=0.064) and dressage horses (P=0.207). Most of the horses obtained for this study were shod with conventional fullered steel shoes (48/58). One horse had heart bar shoes, two horses had egg bar shoes and seven horses had no shoes.

Table 1: Descriptive demographics of the sample population of dressage and show jumping horses obtained via cross-sectional survey at training yards and two competitions in New Zealand.

Descriptor	**Show-jumping**	**Dressage**	**Total**
Number of horses	30	28	58
Competition level			
Advanced	10	5	15
Medium	12	4	16
Lower	8	19	27
Age	8 (IQR 6-10)	10 (IQR 7-14)	9 (IQR 6-11)
Height (cm)	166.5 (IQR 165 – 168)	163.5 (IQR 160 – 169.25)	165 (IQR 162- 168)
Gender			
Gelding	16	20	36
Mare	14	6	20
Stallion	0	2	2
Breed			
Warmblood	5	6	11
Stationbred	0	4	4
Thoroughbred	1	1	2
Sport horse	24	17	41

Table 2: Training surface and training schedule of a sample population of dressage and show-jumping horses.

Descriptor	**Show Jumping**	**Dressage**	**Total**
Sand	0	4	4
Sand mix	9	5	14
Turf	0	4	4
Turf and sand (mix)	21	15	36
Training schedule			
Workload (mins)	210 (IQR 177.5-230)	225 (IQR 185-270)	210 (IQR 180-240)
Classes per month	6 (IQR 2-8)	2.5 (IQR 1-4.75)	4 (IQR 1.75-6)
Training time consisted of			
Flatwork	*n=28*	*n=23*	*n=51*
Number of sessions	3 (2-3)	3 (2-4)	3 (2-3)
Time (mins) per session	30 (30-35)	40 (30-45)	30 (30-40)
Dressage training	*n=0*	*n=14*	*n=14*
Number of sessions	0	2 (1-4)	2 (1-4)
Time (mins) per session	0	45 (42.5-60)	45 (42.5-60)
Jump schooling	*n=22*	*n=6*	*n=28*
Number of sessions	1 (1-1.25)	1 (1-1.25)	1 (1-1)
Time (mins) per session	30 (30-30)	30 (30-35)	30 (30-30)
Lung	*n=2*	*n=1*	*n=3*
Number of sessions	2	5	2 (2-5)
Time (mins) per session	30	30	30 (30-30)
Hack out	*n=14*	*n=15*	*n=29*
Number of sessions	1 (1-2)	2 (1-2)	1 (1-2)
Time (mins) per session	35 (32.5-48.75)	45 (40-60)	45 (35-60)
Days of competition	*n=25*	*n=5*	*n=30*
Days of competition	3 (2-3)	1 (1-2)	3 (2-3)
Rest days	*n=10*	*n=26*	*n=36*
Days of rest	1 (1-2)	2 (1-2)	2 (1-2)

The majority of the horses trained on surfaces described as turf and sand (mix) in both disciplines (36/58), Table 2. Workload of show-jumping horses (210 (IQR 177.5-230) minutes per week) was similar to the workload of dressage horses (225 (IQR 185-270) minutes per week) and there was no significant difference between the two disciplines (P=0.120). No relationship between the workload in minutes and age within dressage horses and show-jumping horses was found (P=0.128). The number of competition classes per month was of higher frequency within show-jumping horses than within dressage horses. In most cases, show-jumping horses competed every weekend while dressage horses competed once or twice per month. Days of competition were more present within show-jumping horses. Training time of the horses consisted mostly of flat work (51/58) in both disciplines. Dressage horses had more days of rest compared to show-jumping horses.

Loading of the limbs

The static images of the pressure scans showed the weight distribution between the left and right forelimb. Table 3 represents any kind of bias in this population of horses at different thresholds of asymmetry. 80% symmetry reflects the guideline (Starke et al. 2012) and the greatest bias was seen with the threshold set up at 95% symmetry.

Table 3: Horses with bias of the loading of the limbs. Three thresholds of symmetry within show-jumping and dressage horses, showing the number of horses of the population with any kind of bias.

	Show-jumping	**Dressage**
95 % symmetry	27/30	25/28
90% symmetry	24/30	19/28
80% symmetry	11/30	9/28

The relative loading of the limbs are presented in figure 1 and 2. An unequal pressure distribution with more pressure on the right limb than on the left limb was most commonly observed within show-jumping horses (21/30 measurements, P= 0.015) and dressage horses (16/28 measurements, P=0.570) and was significant within show-jumping horses. The show-jumping horses showed that 54.13 (SE 1.67) % of the weight was on the right limb and 45.87 (SE 1.90) % on the left limb, while dressage horses showed that 50.98 (SE 1.71) % of the weight was on the right limb and 49.02 (SE 1.71) % on the left limb. Total loading for both disciplines was 52.61 (SE 1.20) % on the right limb 47.39 (SE 1.20) % on the left limb.

Figure 1: Pressure distribution between left and right forelimb of the show-jumping horses in loading (%).

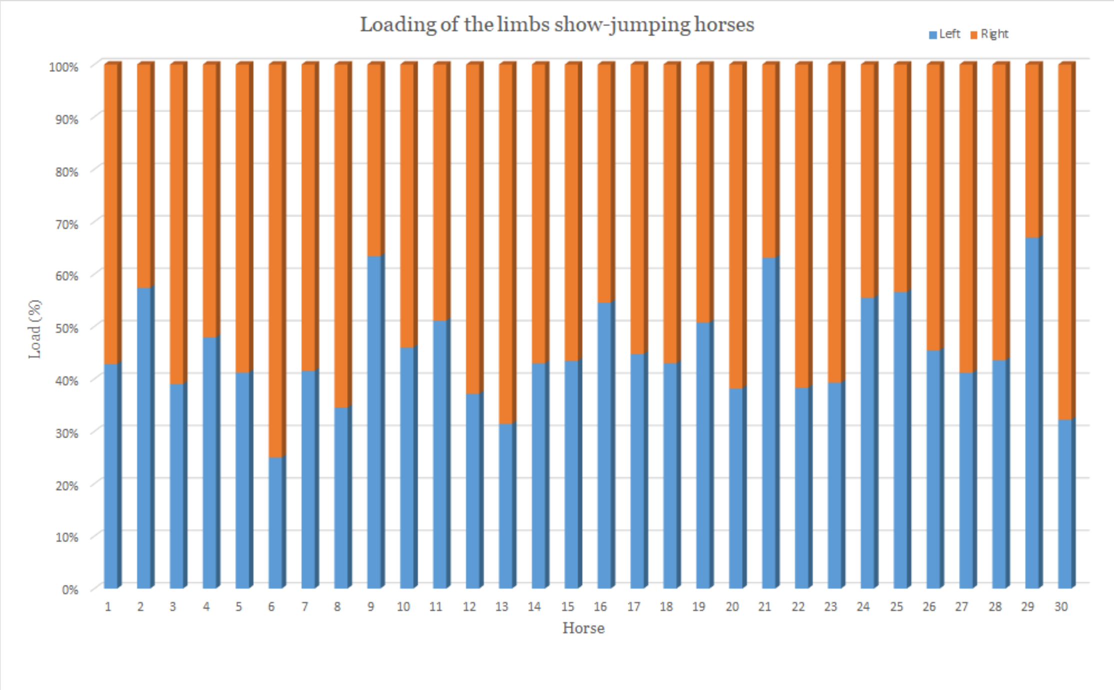
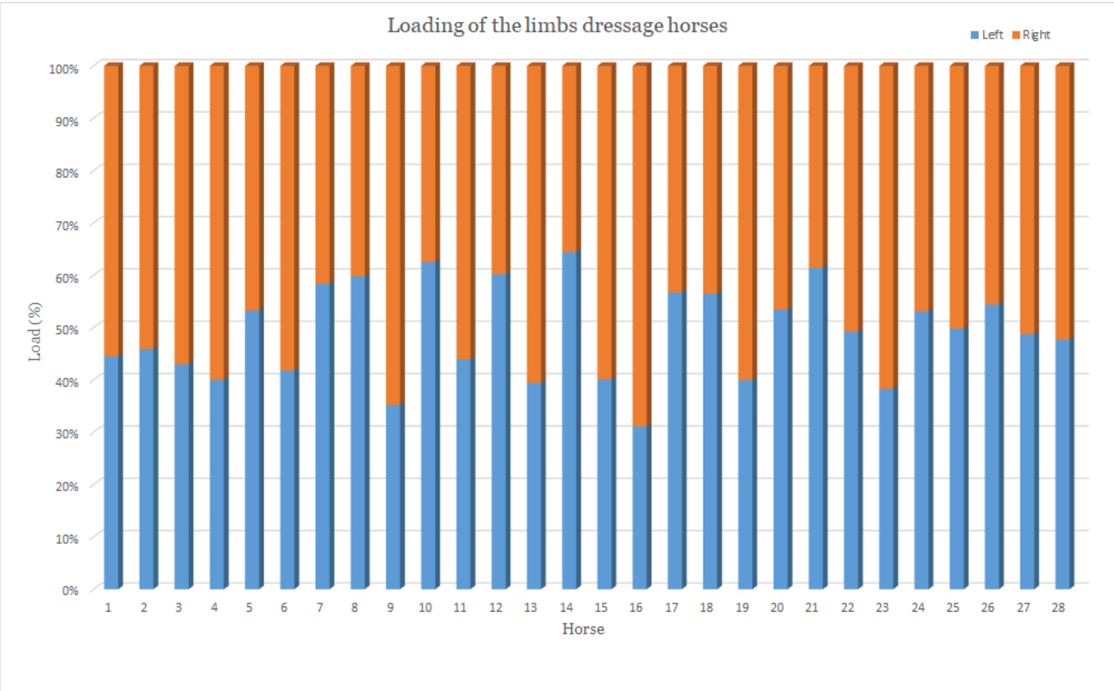


Figure 2: Pressure distribution between left and right forelimb of the dressage horses in loading (%).



CoP displacement

Table 4: Frequency, velocity and amplitude of the CoP displacement of show-jumping and dressage horses, averaged over all horses.

	Show-jumping		Dressage	
	Mean	**SE**	**Mean**	**SE**
Frequency (Hz)	0.34	0.01	0.34	0.01
Velocity (mm/s)	0.76	0.08	0.81	0.07
Amplitude (mm)	1.64	0.18	1.68	0.18

Table 4 shows the CoP displacement of show-jumping and dressage horses. There was no significant difference between show-jumping or dressage horses in frequency, velocity and amplitude. The standard deviation measured for the frequency of the CoP displacement was small. This suggests a consistent value of the frequency within the show-jumping and dressage horses. However, standard deviation measured for the velocity and amplitude of the CoP displacement was large.

The relationship between the CoP displacement and workload and age is presented in figures 3-8. There was no linear relationship between workload or age with any of the measurements of CoP displacement (frequency, velocity or amplitude).

Figure 3: Relationship age and frequency, R^2= 0,0063.

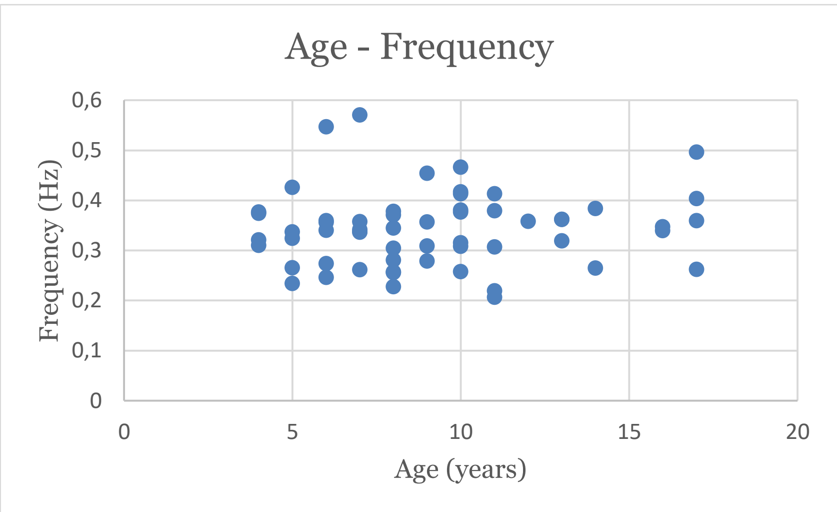


Figure 4: Relationship age and amplitude, R^2= 0,0493.

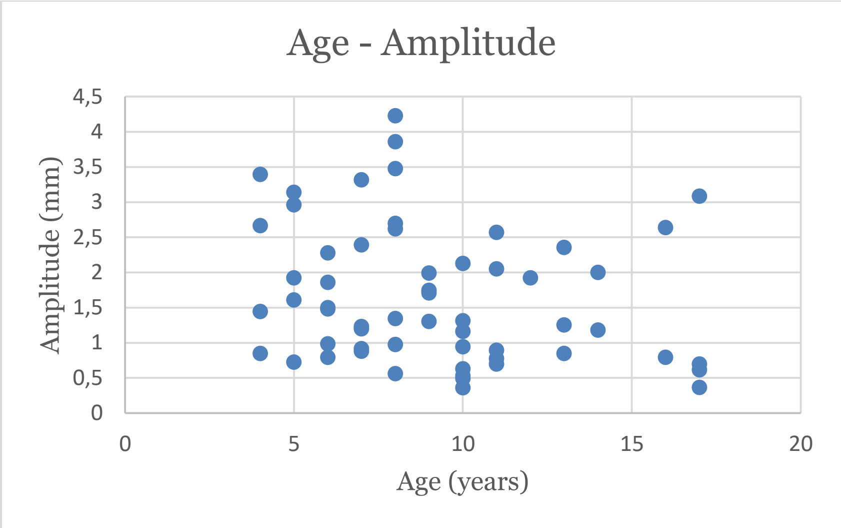


Figure 5: Relationship age and velocity, R^2= 0,0364.

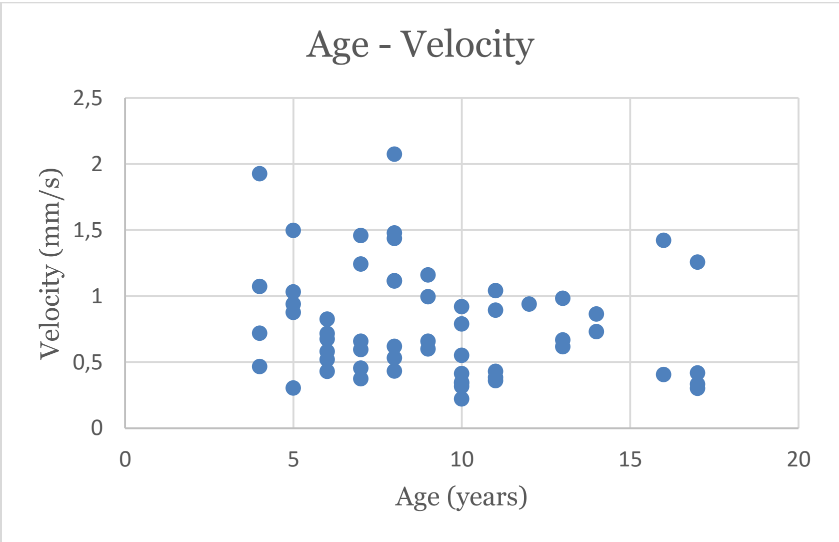


Figure 6: Relationship workload and frequency, R^2= 0,0054.

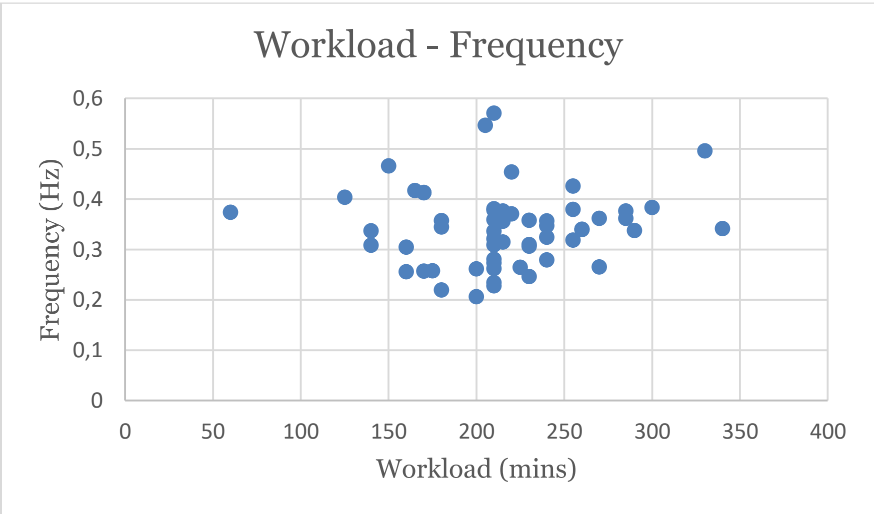


Figure 7: Relationship workload and amplitude, R^2= 0,0007.

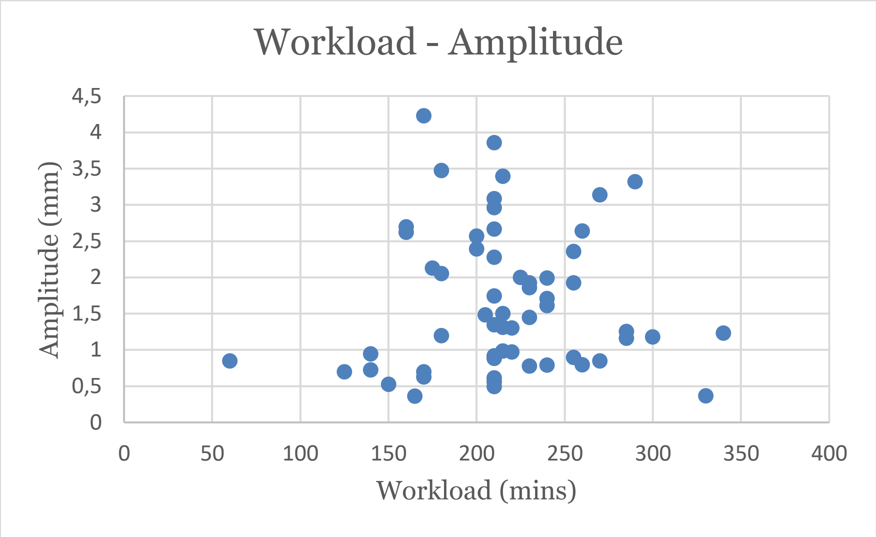
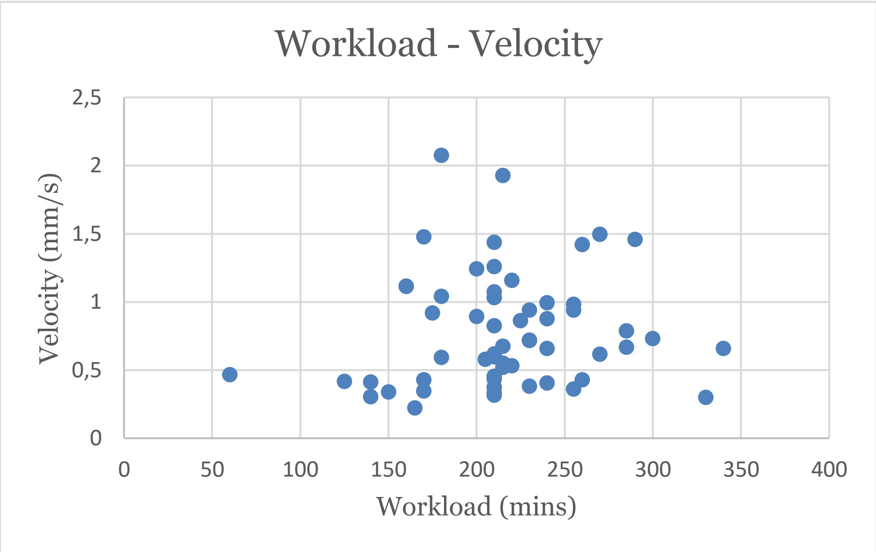


Figure 8: Relationship workload and velocity, R^2= 0,0092.



Discussion

This study is the first to explore the CoP displacement of show-jumping and dressage horses in New Zealand and examined the associations of this with workload and age. The pressure plate allowed qualification of the loading of the forelimbs and the postural sway of the horses. The hypotheses that there was a difference in CoP displacement between show-jumping and dressage horses and that older horses with greater accumulated workload have a different CoP displacement from younger horses with less workload, was not supported.

The data used for this study were collected as part of a convenience sample of horses at competitions and at training yards on the North Island of New Zealand. The collection of data at competitions has previously provided robust data (Dijkstra et al. 2016; Meredith et al. 2011; Verhaar et al. 2014). Sampling at competitions can be advantageous as it reduces the sampling time and this was an important consideration with dressage horses due to most owners having one or two horses (Creagh et al. 2012). Sampling show-jumping horses at training yards provided the chance to sample multiple horses at a venue. It is unlikely that there was a selection bias due to location with most of the show-jumping horses selected at properties on the North Island of New Zealand in the area Manawatu-Wanganui and Hawke's Bay as the horses sampled in this study were similar to those of other reports and reflected the sport horse population in New Zealand (Dijkstra et al. 2016; George et al. 2013).

Selected horses in the current study were not homogenous and included differences in age, height and competitions level. Within sport horses, older and taller horses are more likely to get an injury and the CoP displacement could be different from young horses (Murray et al. 2010; Perkins et al. 2005). Therefore, the variance in horse population could have influenced the balance and have led to more variance in CoP displacement. However, no relationship between age and CoP displacement was established in this study.

The training schedule was similar to those of previous reports and reflects the relative uniformity of the training for sport horses (Dijkstra et al. 2016; Lönnell et al. 2014). Workload of dressage horses (225(185-270) minutes) was similar to the workload of show-jumping horses (210(177.5-230) minutes). Workload reflected the duration of training time of a horse in one week and the intensity of the training was not included. There is limited data on how to easily quantify current training practices and the intensity of the workload of sport horses. Workload within racehorses can be measured with the use of Global Positioning Satellite (GPS) and heart rate monitors (HR) (Rogers et al. 2012). The uptake of this technology within sport horses may not be useful, because estimates of workload rely on semi objective scoring of workload effort or difficulty as result of the greater schooling rather than conditioning aspect. Currently, we lack a method to easily, and with precision, quantify the workload within sport horses and therefore workload was determinate as the duration of training time. Research on racehorses have demonstrated a protective effect of specific aspects of training, such as high-intensity training, against fractures (Lönnell et al. 2014; Parkin et al. 2004; Verheyen et al. 2006). These studies have emphasised that for racehorses time vs. intensity of training needs to be balanced. Lichtenauer reported an unloading of the left limb in racehorses (Lichtenauer et al. 2018). Because of the training of racehorses in counter clockwise direction, the left limb is the leading leg and experiences the most strain. Cyclic overload caused by training may lead to soreness of the overworked limbs. Within racehorses, the training regime might result in unloading the left limb due to cyclic overload. In contrast, training regimen of sport horses consist of making various turns and circles in different directions at lower speeds. There is a variation in loading of the limbs, and if sport horses have overworked limbs, they would be affected bilaterally, unless there is some underlying pathology. However, the impact of physical challenges of sport horses seemed not to induce soreness. Hence, further research on the intensity of the workload and training regimen of sport horses are needed to investigate associations with the CoP displacement.

In the group of New Zealand sport horses examined in this study, different types of shoeing were used. Most of the horses had conventional fullered steel shoes, but some horses were shod with egg bar shoes and some horses had no shoes. A previous study reported that shoe type had an effect on the pressure distribution within the hoof (Rogers & Back 2003). Egg bar shoes showed a decreased pressure in the lateral heel and also a lower mean pressure value. The current study did not examine the difference in CoP displacement due to shoe type within the horses as this study measured the postural sway of horses which was quantified by measuring the CoP displacement. Therefore, the variation in types of shoeing would not have influenced the horse CoP results.

The pressure scans of the front limbs showed an unequal pressure distribution of more pressure on the right limb than on the left limb within show-jumping and dressage horses (37/58 measurements). This is in agreement with a previous report, but the bias within these racehorses was heavily skewed to the right limb (24/30 measurements) (Lichtenauer et al. 2018). As reported before, racehorses train in counter clockwise direction and unequal pressure distribution may be caused by pain due to cyclic overload of the left limb. Sidedness preferences could beneficial due to training counter clockwise and may give horses an advantage. Difference in force distribution on the left and right forelimb is also established in sport horses (Oosterlinck et al. 2013). Unequal pressure distribution cannot be explained by training regimes within sport horses due to making movements in various directions and perform symmetrically. Therefore, preferences are undesirable for sport horses. Explanation of unequal pressure distribution could be that there is a certain asymmetry within the forelimbs that may not be indicative for underlying pathology (Labuschagne et al. 2017). The observed asymmetry may be related to functional differences between limbs. Uneven feet are often related to lameness but are also commonly seen at pre-purchase examinations in sound horses (van Heel et al. 2006). Left hooves appeared to be usually larger (Kummer et al. 2006; White et al. 2008). However, asymmetry and uneven feet can result from lateralised behaviour and has been shown in grazing Thoroughbreds (McGreevy & Rogers 2005; van Heel et al. 2006). These foals developed a preference in grazing position and this will have consequences for the loading of the forelimbs and can result in uneven feet. The relationship between lateralised behaviour or laterality and unevenness in feet continued to increase as the animals aged (Van Heel et al. 2010). Laterality can results in overloading injuries or performance loss, and this might result in a higher incidence of injuries and an increased performance loss or early retirement in sport horses (Van Heel et al. 2010). The study of McGreevy and Rogers (2007) found a preference of left laterality in Thoroughbred horses. However, in the study of van Heel (2010) it appeared that both preferences and unevenness induce laterality in locomotor performance in Warmblood horses. The bias performed in this study was not as strong as performed within racehorses (Lichtenauer et al. 2018). Hence, it is unlikely that laterality is the main factor responsible for the observed asymmetry. Some level of asymmetry must be biologically normal and associated with horse-level laterality and bias.

The frequency of the CoP displacement found in this study (0.34 Hz, table 5) was in agreement with previous reports (0.30 Hz) (Clayton & Nauwelaerts 2014; Lichtenauer et al. 2018; Plantinga et al. 2018). Frequency measurements provides information about the mechanisms underlying physiological control or balance (Clayton et al. 2014). A higher frequency is associated with a more reactive postural control system and rapidly corrects for small drives in the CoP position. Low frequency is associated with larger postural drift. In humans it has been shown that musculoskeletal pain leads to a larger postural sway, which can be quantified by measuring the CoP displacement (Hirata et al. 2011, 2012; Lihavainen et al. 2010; Patel et al. 2014). Sway amplitudes in sound humans are distributed among a number of frequency bands below 1 Hz, with most power concentrated below 0.4 Hz (Clayton & Nauwelaerts, 2014; Rougier, 2008) The constant value of the frequency found in the current and previous studies suggest that this value can be considered as the normal postural sway of horses. Further research on the frequency of equine postural sway in relation to pathologic processes is required.

In previous reports, different values of the velocity and amplitude of the CoP displacement were described. Clayton measured a velocity of 2.2 mm/s and an amplitude of 9.3 mm (Clayton et al. 2014), Gomes-Costa found a velocity of 4.3 mm/s and an amplitude 3.2 mm (Gomes-Costa et al. 2015) and Lichtenauer found a velocity of 1.88 mm/s and a amplitude of 27.31 mm and 22.60 mm. In this study we reported an average velocity of 0.78 mm/s and an average amplitude of 1.66 mm (Table 1). Compared to these previous reports, the amplitude and velocity of the CoP displacement of sport horses is lower. In Europe it is reported that sport horses during training cover an average distance of 4.28 km and a duration of 33.21 minutes within a training session (Werhahn et al. 2012b). Training of Thoroughbred racehorses existed of a pretraining of 4 or 5 weeks at trot or canter over 1.6 km to 2.4 km per day (Hodgson, 2014). After this pretraining, on slow days horses exercised on an average of 5.5 km at speeds between 14 km/h to 25 km/h and on fast days horses exercised 1 km to 2 km at speeds between 43 km/h to 58 km/h. This suggests a different workload of sport horses and racehorses. The training schedule of the sport horses used in this study indicated a low workload compared to racehorses used in previous report (Lichtenauer et al. 2018). High workload may lead to soreness and might result in a larger postural sway and therefore to a great velocity and therefore to a great amplitude of the CoP displacement. Lower workload and less loading of the limbs of sound sport horses might lead to a small postural sway resulting in a small velocity and therefore a small amplitude of the CoP displacement. In addition, due to performing symmetrically of sport horses they might are bilateral sore and they will shift their weight between both front feet. Unloading both front feet can also result in a small velocity and a small amplitude.

Another explanation for the variation in velocity and amplitude of the CoP displacement could be due to the fact that previous studies used different breeds of horses. Clayton used a variety of breeds (Clayton & Nauwelaerts, 2014), Gomes-Costa used Puro Sangue Lustiano (PSL) horses (Gomes-Costa et al. 2015) and Lichtenauer used Thoroughbred racehorses (Lichtenauer et al. 2018). Current study used mostly sport horses and warmblood horses. Differences in breed of horses could result in variation within muscles development or height and therefore could have influenced the CoP displacement. Small immature horses showed a poor postural sway control resulting in a greater amplitude of the CoP displacement (Clayton et al. 2003). To avoid the possibility of differences in CoP variables, horses with similar breed must be compared.

Standard deviation measured in current study was large for the velocity and amplitude of the CoP displacement. Lichtenauer and Plantinga reported also a large variance of the velocity and amplitude (Lichtenauer et al. 2018; Plantinga et al. 2018). Large variance could be due to the fact that the horses used in this research were not a homogenous group. Selected horses differed in age and competition level and this could affect their balance and therefore the CoP displacement. Conditions and environment of measuring varied between the locations, but also hoof placement on the pressure plate within each horse was different. To reduce differences in CoP variables, hoof placement may be standardized to have all horses adopt a similar stance during collection of CoP data. Distracting factors should also be minimized while capturing CoP data such as visual and auditory stimuli, flies and contact of the handler. However, more research needs to be done to determine the velocity and amplitude of the CoP displacement in horses.

Conclusions

The present study indicates a limited left-right asymmetry within sound sport horses, with no clear bias to the right limb as observed within racehorses in New Zealand. Sport horses showed greater postural stability and a small CoP displacement in medio-lateral direction compared to pressure plate data within racehorses. There was no obvious relationship of parameters of the CoP displacement with workload, possibly due to the current lack of precision in describing the workload and the loading of the limbs during the training of sport horses. Further research is required to determinate the workload within sport horses and to examine the association of this with CoP displacement.

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