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Research Article

Twenty-Four Hour Movement Patterns of Domestic Horses on Pasture and in Stalls as Assessed by a Step Activity Monitor

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Abstract

Objectives: To determine the average daily step activities of domestic horses on pasture and stalled conditions.

Sample Population: 12 mature domestic horses.

Procedure: A Step Activity Monitor (SAM) affixed to distal limb recorded step activity/hour of horses on pasture and in stalls for 4 - 15 days under four time periods: nighttime session (12 am to 8 am), morning transition (8 am to 10 am), daytime session (10 am to 8 pm) and evening transition (8 pm to 12 am). The following sessions show recording sequences: PP: Pasture daylight/Pasture nighttime; PS: Pasture daylight-(10 am to 8 pm)- Stall night (12 am to 8 am); SP-Stall daylight-(10 am - 8 pm)-Pasture nighttime (12 am to 8 am) and SS-stall-horses in stall 24-hours/day. During morning and evening transition periods, horses were moved, fed grain-pellets and hay, and briefly interacted with humans. The Step Watch software collected and analyzed the data in steps/hour for each session. An estimate of distance traveled was determined on pastures. Behaviors were periodically observed and recorded. An ANOVA analysis determined differences in recordings both for effect of time of day and for housing conditions and the interaction of the two. A post hoc Fishers-PLSD test was used for pair wise comparisons. Values of $P < 0.05$ were considered significant.

Results: The pasture only (PP) sessions showed significantly more step activity than any other condition; this increased step activity occurred only during the daylight sessions rather than at nighttime. Recorded step events were greater during the daylight period than during the nighttime for horses in conditions (PP) and (PS), with the 24-hr daily records showing a distinct circadian rhythm. Certain behaviors and step activity were described. Condition (SS) activity had fewest steps per 24-hours and remained unchanged throughout the day. Average daily step total on PP conditions was nearly 10,000 steps, with all other conditions being less.

Conclusions and Clinical Relevance: Domestic horses, on 24-hour pasture turnout, have greater locomotor activity than other conditions and this increased step activity occurred during daylight period and not during nighttime. When stalled fewer steps were recorded than during other conditions, suggesting that being stalled was an overall negative influence on a horse's movements. These data are discussed in relation to movements of feral horses and to the potential usefulness of SAM in correlating step activity and behaviors with other husbandry practices. The data may prove to be clinically useful during rehabilitation of lameness conditions of domestic horses.

Keywords: *Step Activity; Horses; Circadian Rhythm; Locomotion, Behavior*

Abbreviation

SAM: Step Activity Monitor

Introduction

Locomotion in the horse has evolved over many millions of years from the multiple toed ancestors of the Eohippus and Mesohippus to the single digit horse - the *Equus caballus*. The limb structure changed by an effective elongation of the distal limb bones with a proximal migration of the musculature and the adaptation to a single toed foot [1]. Such structural limb changes provided an increased stride length and the possibility of higher rates of limb movements [1-3], thereby, enabling the horse to cover short distances with quick bursts of speeds to avoid predation, as well as to cover longer distances, or endurance runs, in search of food and water [3,4,8,17]. The movements and distances traveled by feral herds illustrate the importance of these evolutionary changes as their travel and migration distances are highly variable, depending upon their environments and the proximity of food and water sources [5-11]. Scientific data collection of feral horses movements represent an ongoing endeavor by many laboratories around the world as they provide insights not only to the movement activity but also to the overall biology and well-being of these equine species [3-5,8,11,12,14,15,18]. Little information, though, is available for movements and spontaneous steps of domestic horses other than anecdotal observations or those associated with racing and endurance horses or how they may affect their overall health and husbandry [12,13].

With many feral herd populations, a common belief is that their hooves are in a state of reasonably good health and conformation, regardless of geographic sites [8,14-17]. These feet have adapted to the different terrains and have been self-maintained through step activity and respective distances traveled [8,14,15,17-19]. Many factors are probably involved in the maintaining these hooves in a reasonably good condition, including genetics, diet and nutrition, environment features and characteristics and the extent of movement, to name but a few. As a result of this self-maintenance of the natural hoof, the hooves of feral horses have long become the standard by which the hooves of domestic horses are compared and serve as a guide for being trimmed [14,15,17]. However, some believe that the natural hoof may not be the best standard of the horse's foot [8,9]. Which of these factors is more involved in contributing to a healthy foot has become a topic of intense interest and discussion among the veterinary, farrier, and barefoot trimming communities as many lameness conditions of the foot among the domestic horse populations appear common as opposed to the feral populations [15,17,20]. However, the factor of movement among domestic horses may be most variable as they are housed and pastured under a wide range of conditions with many horses being confined to either a stall and/or a small paddock for a significant portion of the 24-hour period while other horses have free access to vast pasture settings [2,8,13,21]. Little scientific information is known of the relative movements (steps and distances) covered by the average domestic horse [13,17]. Knowledge of this information may provide insights into the potential differences in horses having healthy hooves or with those having chronically problematic hooves. Furthermore, such information of step activity and movements may demonstrate some of the strengths and/or weaknesses into our management and husbandry practices and how they impact the overall health of the horse [3,15,20]. To date, the daily movement patterns, activity levels and the possible distances traveled by domestic horses are lacking, to the best of our knowledge, and thus, this study represents a starting point for collecting and analyzing such data to assess its contributions to overall foot health.

Materials and Methods

Eleven mature healthy horses and one pony with a mean age of 15.1 years (range- 6 - 30 years) were used in this study. These horses grouped into two herds had been unshod for a minimum of five years and were trimmed regularly (5 - 8-week intervals) by a professional farrier, as well as had a history of routine veterinary care. The pastures of two and five acres consisted of mixed grasses with small trees and autumn olive bushes for browsing with small hills allowing the horses to have free access to run-in shelters and water. In a nearby barn box stalls (12 x 12 feet) were available with the floor having cedar wood shavings as bedding on a conformable base (pea rock and sandy soil mixture) with each stall having a Dutch-door partition leading to the pasture. A small self-contained Step Activity Monitor (SAM-7.5 x 5.0 cm), developed for human gait activity, was applied to the distal forelimb for recording step events of each horse. The SAM was affixed using an initial cotton leg wrap and secured with elastic bandages overlaid by a continuous strip of 2-inch wide adhesive tape to protect the SAM. The sensitivity and cadence of the monitor were adjusted for each horse using the SAM software to detect a limb elevation off the ground surface, rather than merely responding to a shift in the horse's weight without lifting the leg. To ascertain the

level of confidence in the accuracy of the SAM counts with the actual steps of a horse, the limb steps were counted during a casual walk of 50 meters and were correlated with light flashes on the monitor when it registered a step. This procedure was performed four times and averaged for each horse. The observed counted steps were slightly higher than the SAM recorded events but were within 90 - 95% of the SAM detected steps for all twelve horses. For weight shift assessment four horses were individually observed for 30 minutes stall with time being recorded followed by examining the recording for any mark indicating any movements without lifting the foot. No marks were observed in the recording. The monitor was programmed to begin recording approximately one hour after securing it to allow for acclimation to the wrap prior to recording the step activity. During the first fifteen minutes after securing the monitor, each horse was observed for abnormal limb movements suggesting discomfort with the SAM limb positioning. Regarding stereotypical movements, such as pawing or lifting the leg while eating, only one horse exhibited this behavior in one limb and, for this reason, the monitor was placed on the opposite limb for duration of the recording. At the end of the recording sessions the SAM was removed and linked to a computer through an optical dock to download data.

The step activity recordings were obtained during four different time management conditions between late January through August. These management conditions were divided into four time periods of the 24-hour day-night cycle: nighttime session (12 am to 8 am), morning transition session (8 am to 10 am), daytime session (10 am to 8 pm) and evening transition session (8 pm to 12 am -midnight). The transition sessions during the morning (8 am to 10 am) and evening (8 pm to 12 am) periods represented times when horses were moved to the next recording session. During these transition periods the horses interacted with humans as they were fed a grain-pelleted concentrate and hay, were moved between pasture and stall settings and were permitted to acclimate to another surrounding. All horses, especially the distal limbs, were sprayed with an equal mixture of concentrated soap detergent and vinegar during this time period to minimize any annoyance by flying insects. These two transition periods also provided enough time for examination to ensure that the SAM and bandaged distal limb were in satisfactory condition. On the pasture session after the initial feeding of concentrates, grass hay flakes were used as a supplement to pasture grass and were distributed over the pasture surface with each hay flake (one 80-pound bale per 2-3 horses) being placed approximately 10 - 11 meters apart. For illustrating the recording sessions as used in this manuscript, the sessions were identified as to where they occurred, either on the pasture (P) or in the stall (S) followed by when they occurred with the daytime recording period appearing first followed by the nighttime recording period. (1) Pasture day-pasture night (PP) sessions: horses were on a pasture setting for 24-hours a day. During the two transition time periods (8 am to 10 am and 8 pm and 10 pm) when the horses were on pasture 24-hours a day, a similar protocol of feeding grain concentrates, hay flake distributions, physically examining the SAM and the bandaged distal limb and applying insect spray were followed. (2) Pasture day-stall night (PS) sessions: horses were moved to the pasture during the morning transition period (8 am to 10 am) from the stall session for the daylight period (10 am to 8 pm) and returned to their stall during the evening transition period (8 pm to 12 am) followed by feeding and examining the bandage and recording during the nighttime recording period (12 am to 8 am); (3) Stall day- pasture night (SP) session: horses were moved to their stalls from the pasture during the morning transition period for the daylight recording session (10 am to 8 pm) and returned to the pasture during the evening transition period for the nighttime session (12 am to 8 am); they were moved, fed and examined and sprayed with insect repellent during their respective morning and evening transition periods; and (4) Stall day-stall night (SS) session: horses remained in their stalls for 24-hour period and were fed and examined during the two “transition period” times. The hay flakes (4 - 7) were placed in one corner of the stall. Each horse was recorded for 4 - 15 days, after which the monitor was removed, and the data collected and stored on a computer for future analysis. While most recordings consisted of the 14 - 15-day recording, the shorter four-day time period was limited to the Stall day-stall night (SS) 24-hour period as these horses had not been previously confined to a stall for an extended time period of many days. Once the recordings were completed, the SAM was removed, recalibrated and then used again on another horse. Any unusual or unexplained recorded step activity, such as continuous excessive step activity or reduced step activity, observed, the data was discarded from the entire 24-hour recording period. The recording sessions were repeated until the horses in management conditions (PP), (PS) and (SP) were monitored for two sessions several months apart, while horses in (SS) were monitored for only one session. Human interactions with the horses only occurred during the two transition periods. When possible, short time periods (1 - 4 times

per day for 10 - 20 minutes) were used to observe the behaviors of the pastured horses at a distance (approximately 50 - 75 meters). Daily weather information was noted for extreme weather conditions (heavy rain or snow); step activity during these times was not included in the data collection as the horses generally remained in their shelters. To determine the approximate distances traveled by each horse (n=11) during the pasture recording periods the average length of stride was calculated during a walk of 63.7 meters. Each horse walked this distance four times at a slow casual gait with the steps being counted when the same forelimb touched the ground and an average determined. The average stride lengths for all horses ranged between 1.30 to 1.89 meters per stride in this study. The mean distances traveled were calculated by multiplying the average length of stride by the number of steps counted in the recording period to approximate the distances that the horses traveled for that day.

Analyses were performed using the SAM software with the numerical data being exported into Microsoft Excel. The numbers of steps/hour were determined for each of the four time periods described under recording conditions. An estimate of distance traveled was determined when the horses were on pastures. An ANOVA analysis was employed to determine differences both for effect of time of day and for housing condition and the interaction of the two. A post hoc Fishers-PLSD test was used for pair wise comparisons. Values of $P < 0.05$ were considered significant.

Results

General observations

The number of stepping events recorded for this group of horses had a wide activity range during a single 24-hour day period, as well as varying from day to day. However, the activity was consistent for each horse over the recording period of up to two weeks. The recorded steps were collected in one-minute bins with a range of steps being counted from 0 steps to more than 45 steps per minute as shown in figure 1. With zero steps being recorded the horse was either lying down or standing still without moving its feet, while with more than 40 - 45 steps per minute, the horse was running (galloping) from one area of the pasture to another. With these horses most step activity per hour occurred during the daylight recording session period (10 am to 8 pm) with significantly fewer steps per hour being recorded during the nighttime session (12 am to 8 am). The different behaviors were often correlated with the step activity when observations and careful recordings of the time were made. Typical raw records of the 24-hour step activity patterns are shown in figure 1 when the same horse is on PP (Pasture day-pasture night) (Figure 1A) and on SS (Stall day-stall night) (Figure 1B). During the nighttime recording (12 am to 8 am) several long quiescent periods between 12 am and approximately 4:30 am can be seen when no step activity was recorded. The horse was observed to be in a quiescent standing posture with its head relaxed presumably in a state of drowsiness (or possibly quiet or slow wave sleep). One can see on the graph several brief steps (1 - 3) steps were recorded on the graph during this time interval when the horse became aroused and lifted its leg before resuming the stance and relaxed posture before passing into a possible drowsy state again. The behavioral state exhibited by the horse when standing with no step activity was either drowsiness or quiet sleep or slow wave sleep (SWS) phase rather than in rapid eye movement (REM) phase of sleep. The REM phase of sleep only occurs when the horse is recumbent due to atonic proximal musculature. When in a recumbent posture step activity movements or steps are not recorded by the monitor even if the limbs move. Between these drowsy postures were three periods of higher step activity between 15 and 40 steps per minute; during this time the horse walked or trotted to another area of pasture. Most grazing behaviors were indicated by step activity of 1- 5 steps per minute between 8 am to 6:30 pm (approximately) as the horse slowly moved along the pasture eating. while periods of higher step activity were superimposed upon the grazing step activity when the horse was interacting or posturing with another horse (between 10 - 40 steps per minute approximately). The longer periods of this higher step activity were associated with the morning transition (8 am to 10 am) and evening transition (8 pm to 12 am) periods or the anticipation of these times of feeding (slightly earlier in this recording period). The short bursts of higher step activity after arousal (i.e. often exceeding 15 steps and lasting for approximately 20 - 30 minutes) reflected when the horse moved to another area of the pasture to graze. The step activity was not continuous across the recording period but varied with their behaviors: when the horses were grazing on pasture, a slow, but nearly constant, walk occurred as

illustrated by a near-baseline activity of 1 - 3 steps per minute. During this slow walking behavior, a short flurry of increased step activity occurred during an interaction with another horse, such as a threatening response of pinned ears and extended neck. During SS session when horses were in the stall (Figure 1B) often they did not lie down and only had a few steps occurring hourly while slightly higher step activity occurred in anticipation of the morning transition period (6am to 8 am) and during the evening transition period (8 pm to 12 am). These step activities and their associated behaviors were evident in all horses.

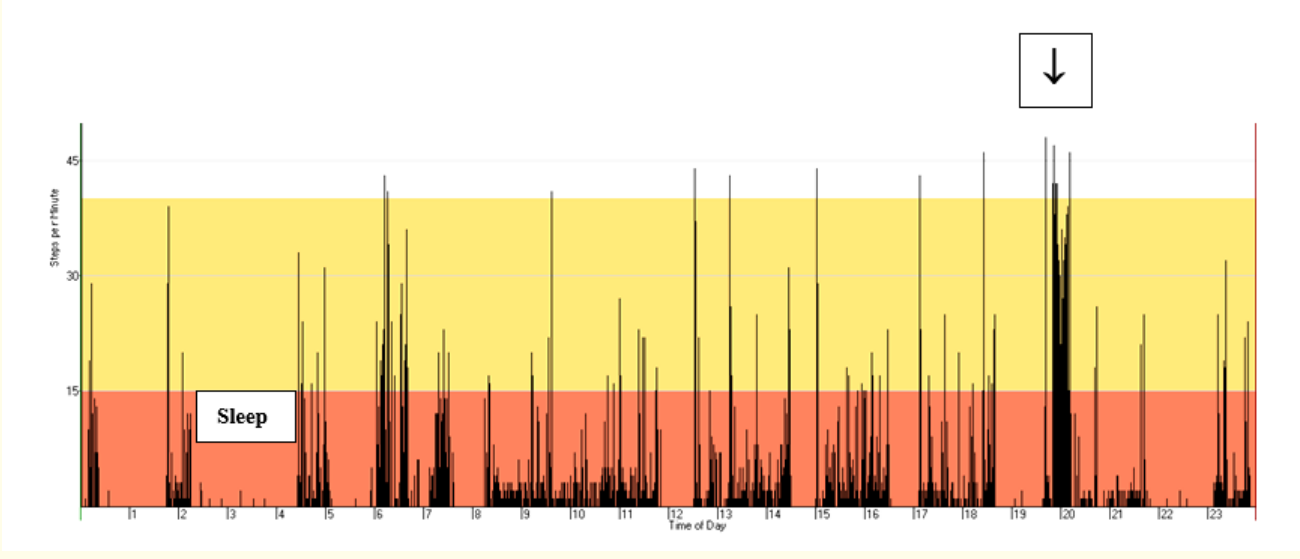

Figure 1A: *A typical example of step activity of one-horse showing steps per minute. Graph shows time of day on X-axis and Step per minute on Y-axis.*

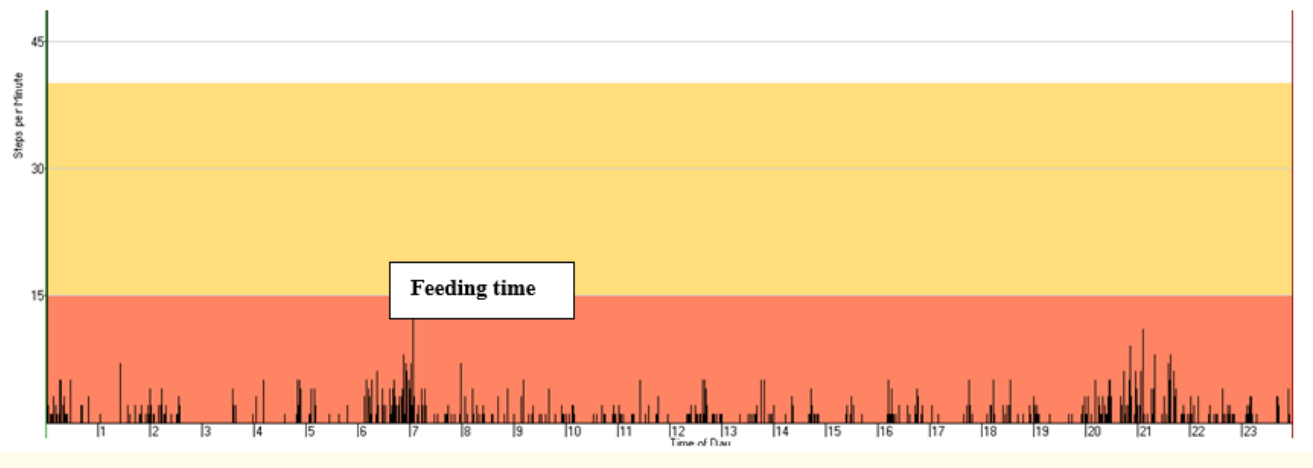

Figure 1B: *Typical example of step activity of stalled horse. Graph shows time of day on X-axis and Step per minute on Y-axis.*

Figure 1: *A typical example of step activity of one horse showing steps per minute.*

Comparison of step activity across time periods within each condition (Figure 2)

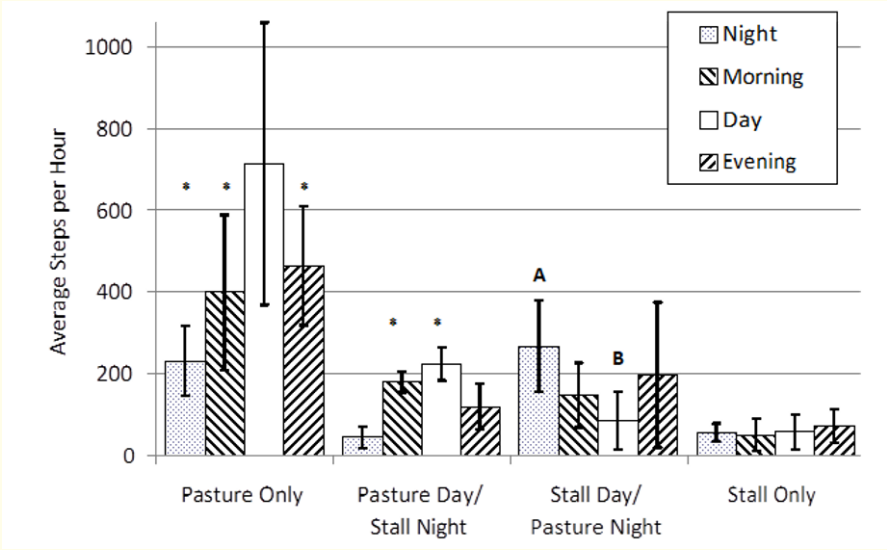

Figure 2: *Step activity of clinically normal horses was compared across time periods, within each of the four condition as follows: PP horses: daytime activity was significantly greater than the other three time periods, but no other post hoc comparison was significant. PS horses: morning and daytime periods were not significantly different from each other while all other pair-wise comparisons were significant. SP horse: nighttime activity was significantly more than daytime, but no other post hoc comparison was significant. SS horses: there was no significant difference in activity between time periods.*

The pasture only (PP) horses showed significantly more step activity during the daytime session (10 am to 8 pm) as compared to the other three time periods. A mean number of 713.7 ± SD 345.3 steps per hour was recorded for all horses during this time period, while their lowest step activity occurred at nighttime session (12 am to 8 am) 231.1 ± S.D. 85.9 steps per hour. This low number of step activity was not significantly different from that of the morning transition (8 am to 10 am) and evening transition (8 pm to 12 am) time periods.

The horses in the PS (Pasture-Daytime, Stall-Nighttime) recording session showed the same pattern of activity throughout the 24-hour day as did the horses on PP, but significantly less step activity per hour was recorded during all time periods. The step activities in the morning transition period (8 am to 10 am) and daytime session (10 am to 8 pm) periods were not significantly different from each other. All other post hoc comparisons were significant.

The horses in the SP (Stall-Daytime, Pasture-Nighttime) condition showed a step activity pattern inverse to that of the horses in the PP and PS (Pasture-Daytime, Stall-Nighttime) conditions, with the majority of activity being recorded in the evening transition period to the pasture and in the pasture session. Step activity per hour during the nighttime session (12 am to 8 am) was significantly more (268.6 ± S.D. 111.9) than the step activity during the day time period (86.5 ± S.D. 71.6 steps per hour respectively) in this SP (Stall-Daytime, Pasture-Nighttime) condition. No other post hoc comparisons were significantly different.

The stall-only (SS) horses maintained an average of 59.5 ± S.D. 27 steps per hour throughout both the nighttime and daytime sessions; statistically there was not an apparent circadian pattern for the stall session as compared to horses in groups (PP) and (PS) (Pasture-Daylight, Stall-Nighttime).

In the evening transition session (8 pm to midnight), a decreased activity for horses in conditions (PP) and (PS) was observed, whereas condition SP-(Stall-Day, Pasture-N) exhibited an increase in activity during this time period when they were initially turned out (Figure 2).

Comparison of step activity across housing conditions within each time period (Figure 3)

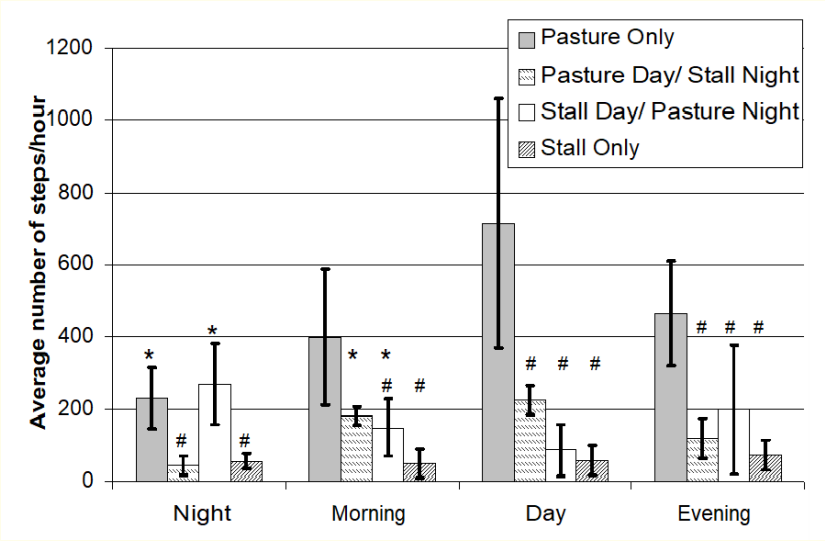

Figure 3: *A Comparison was made of step activity of clinically normal horses across housing conditions within each time periods. Within one-time block, management plans with the same symbol are not significantly different from each other. All other post hoc comparisons are significantly different p < 0.02) d.f. = 9, n = 24.*

There is no significant difference in step-activity observed between stalled horses within any time period. Pasture only (PP) horses showed significantly more step activity than horses in the other three conditions. The horses (SP- Stall Daytime, Pasture Nighttime) on pasture at night were the most active showing about the same step activity as the PP-only horses during the nighttime recording.

Nighttime activity (12 am to 8 am): For horses stalled at night, the mean step activity at night was low [(57.1 ± S.D. 21.6 and 44.4 ± S.D. 26.6 steps per hour for SS (Stalled day and nighttime) and PS (Pasture day, Stall night) groups, respectively]. Behaviorally, the horses spent considerable time either standing motionless (i.e., drowsy or quiet sleep) or lying down as indicated by the observations that their hair coats were covered by wood shavings or the horses were seen to rise to their feet when the morning transition period began. The horses on pasture at night (PP and SP) were significantly more active than the stalled horses at night [PS (Pasture day, Stall night) and SS].

Morning transition activity (8 am to 10 am): During the morning transition period, horses that were on pasture (PP) had significantly more step activity than the other three conditions. The step activity of the Stalled-Stalled (SS) horses was not significantly different from the other three conditions. The step activity during the morning transition period was not significantly different between the two groups of horses that split their days between stalls and pasture [PS (Pasture-Day, Stall-night) and SP (Stall-Day, Pasture-night]. During the morning transition time period, horses that were moved from pasture to stall (PS) (Pasture-Day, Stall-night) were significantly more active than those in the stall only (SS) 181.5 ± S.D. 25.4 and 50.2 ± S.D. 39.8 steps per hour, respectively.

Daytime activity (10 am to 8 pm): During the day, the highest average step activity was recorded for the PP horses, with 713.7 ± (S.D. = 345.3) steps per hour (Figure 3). Horses in pasture condition (PS) (Pasture-Day, Stall-night) had significantly less step activity of 225.6 ± S.D.= 40.2 than those in the pasture only (PP) condition.

Evening transition period (8 pm to 12 am): The step activity was significantly higher for the PP condition as compared to the other three conditions. In the evening transitional period the horses were fed concentrates with hay flakes being distributed, sprayed with insect repellent and interacted with humans. Often a spike of high step activity was seen as the pastured horses appeared to anticipate the feeding period and interaction with humans and other horses prior to the onset of the evening transition (8 pm) time. This activity was higher in step activity but shorter in duration than the step activity generated during grazing of the daylight recording session.

Comparison of the daily average step activity across the different conditions (Figure 4)

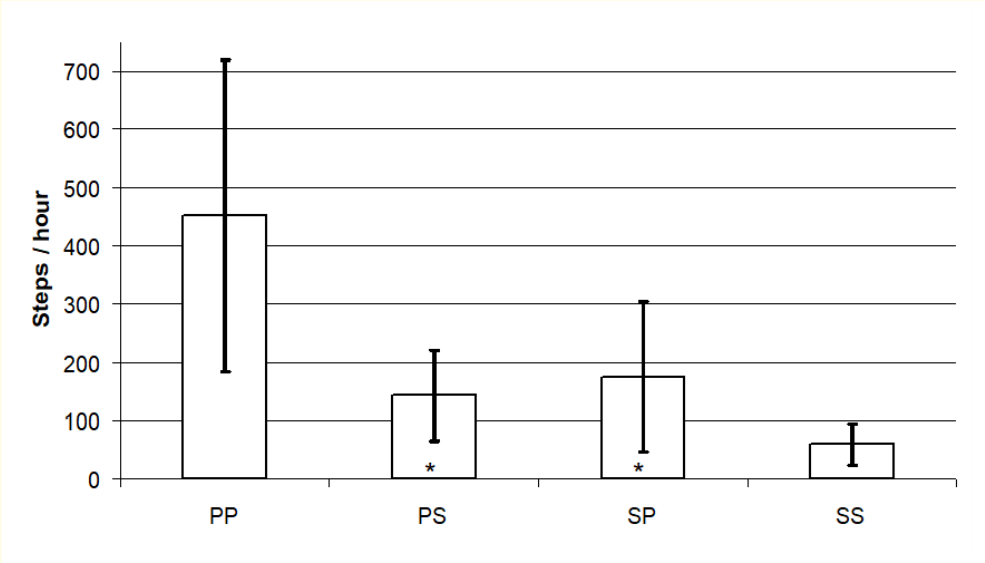

Figure 4: *Overall average total step activity per day for each of the four housing conditions. (Categories with the same symbol are not significantly different from each other). All other post hoc comparisons are significant p < 0.0005).*

The average patterns of locomotor activity per hour is shown for a 24-hour recording period. The step activity for the pasture only (PP) horses was significantly greater than for all other groups. Pasture only horses PP generated an average of 11,063.3 ± (S.D. + 4819.5) steps per day, whereas stall-only horses (SS) produced much less step activity being only 1430 ± S.D. = 647.5) steps per day. Horses that split their day between the stall and pasture (PS) (Pasture-Day, Stall-night) and (SP) (Stall-day, Pasture-night) had daily average step activities of 3452.4 ± S.D. = 631.3 and 4104 ± S.D. = 2358.4), respectively.

Estimates of distance traveled when on pasture

An estimate of the daily distance traveled by each horse was obtained by recording the number of steps of each horse and then multiplying these recorded steps by the average length of stride of each horse recorded during a walk. For the horses in condition pasture-only (PP), an average distance traveled of 16.3 km/day (10 miles/day) with a range of 11 to 21 km per day was determined. These data

provide only an approximation of the average distance traveled for a small herd of domestic horses on 5 acres of pasture with varied landscape of small hills, bushes and small trees in addition to the mixed grasses in a 24-hour recording period. Distance calculations would not be appropriate for any stalled groups at any period, as there was little distance traveled under these conditions. This pattern of distance traveled paralleled the step activity, with greater distances covered during the daylight hours than during the night.

	Pasture-only	Stall night/pasture day	Pasture night/Stall day	Stall-only
Night	231.1 ± 85.9	44.4 ± 26.6	268.6 ± 111.9	57.1 ± 21.6
Morning	399.5 ± 189.3	181.5 ± 25.4	148.5 ± 79.	50.2 ± 39.8
Day	713.7 ± 345.3	225.6 ± 40.2	86.5 ± 71.6	58.3 ± 42.4
Evening	465.4 ± 144.8	119.5 ± 55.3	198.2 ± 177.9	72.5 ± 41.9

Table 1: *Step Activity of horses in four housing conditions with the day divided into four periods. (Steps per hour ± standard deviation).*

Discussion

The SAM was chosen to record limb movements as foot elevations of adult domestic horses in free ranging pasture and stall settings because of its reliability and durability in the data collection over a relatively long time period. The small size and weight of the instrument permitted easy attachment to the distal limb without it affecting the limb movements through instrumentation or the altering behaviors of the horse. By adjusting its sensitivity the monitor can begin to distinguish movements of foot lifts from that of weight or body shifts; while the former indicates elevation of the foot off the ground, body shifts are alternating the horse's weight from side to side or from the forelimb to hind limb or vice versa without either elevating the foot or moving it along the ground surface [22]. While not explored thoroughly in these experiments small to medium, i.e., visible, sized body shifts were not evident in the recordings. Another advantage is that the instrument was resistant to physical trauma as in one instance the monitor and bandage became loose and fell to the ground only to be stepped on a number of times by several horses without any evidence of damage; the SAM was then recalibrated and reused. In initial attempts to monitor the step activity we utilized several mechanical pedometers, but such monitors were unreliable in correlating actual steps with recorded counts and in having long term durability [22,23]. The SAM proved to be very useful on both aspects during this study.

A main finding of the present study revealed significant increases in step activities per hour in the pastured only group (PP) of horses as compared to the other various combinations of pasture and stalled recording sessions. However, this increased step activity of PP horses occurred during the daytime (10 am to 8 pm) session rather than during the nighttime (12 am to 8 am) session. These findings were unexpected; while we expected greater step activity during the 24-hours of the PP sessions, we thought that they would occur more during the nighttime session (12 am to 8 am). This increased steps per hour during this daylight condition (10 am to 8 pm) of the PP session was greater than that recorded on the same horses during the same daylight condition but were stalled at night. With the stalled only (SS) sessions the fewest steps per hour were recorded during the 24-hour recording period in comparison to other conditions. The overall locomotor pattern demonstrated a circadian rhythm with most movements occurring during the daytime condition as compared to nighttime recordings. This study of domestic horse step activity provides an initial basis for limb loading events and their estimated distances of travel on pasture. In addition, during the experiments we realized that the step activity may provide potential insights into the different behaviors exhibited by the horses.

Comparable step activities of stalled horses were recorded in another study [22], using the same SAM technology. In that study a mean step activity of 190 SD +/- 184 loading events per hour as both weight shifts and limb elevations was recorded in comparison to a mean of 60 SD +/- 27 steps per hour in the present study. The present study recorded foot lifts only rather than both foot lift and weight shifts

[22] which may only be one of several reasons for the differences in the two studies. Firstly, the horses may have been less familiar with their stalls and the surroundings of the hospital in their study as the horses were housed in a veterinary teaching hospital and introduced to the new environment only a few (4) hours prior to attaching the SAM instrument to initiate the recordings; in the present study each horse had been familiar with the stall and its barn surroundings for many months. Human contact was minimized as much as possible in the present study as contact was only during the transition periods. In addition, the stall floorings may have been a subtle factor for these differences as often the floors are less conformable or have a greater firmness to it as most large veterinary hospitals use a hard surface material, such as cement overlaid by a firm synthetic material with wood shavings covering it. Horses on hard surfaces usually have greater movements and steps as compared those on a more conformable surface; such firmer surfaces may be interpreted as making the horse uncomfortable as compared to more conformable surfaces [23]. In addition, the sensitivity of the SAM was calibrated for both body shifts and limb elevation in the study by McDuffee., *et al* [22]. Direct observations indicate that both body shifts and stepping can be very common movements of stalled horses [22,24]. In one study [24] a mean of 120 steps per hour was estimated for stalled horses with steps being defined as a lifting and relocation of the foot. The quality and frequency of the limb movements can be influenced by many factors, including familiarity of the environment [3], [the activities of the nearby environment, its varied noise levels, movements of other nearby animals, medical staff and recording equipment], and pain following surgery [22], as well as the texture, composition and even unevenness of the stall floor surface [23], to name but a few. However, while large body shifts may have been recorded without limb elevation in the present study, we believe that they would represent a small number of recorded steps/movements overall. These subtle environmental factors may be more significant than we presently appreciate in contributing to total movement and step activity behavior of this often-flighty herbivore [3] and needs further study.

The present study has provided an initial estimation, at least, on the step movements of pastured and stalled domestic horses during a 24-hour recording period with minimal human intervention. When conditions (PP) (Pasture 24-hours a day) and (PS) (Pasture-Daytime-Stall-Nighttime) were implemented, a range of steps were recorded during the daylight and nighttime recording periods with most of the steps being recorded during the daylight hours, the morning and evening transition periods. The observations of the present study are consistent with other studies of the feral Przewalski horses maintained in a semi-reserve [11] and feral horses in the Camargue [10] and of domestic foals on pasture 24-hours/day [13]. These studies showed that late morning feeding behaviors are consistent with studies of the grazing activities of some feral horse groups whose movements are concentrated between dawn and mid-morning and late afternoon to evening time periods with more temperate humidity and temperature with less grazing during times of high temperatures and humidity [10,11,19,25,26]. A similar time budgeting has been reported for domestic ponies as well [27-29].

In the present study, the horses were observed to graze on pasture or on the distributed hay flakes as they slowly walked (1 - 4 steps/minute), while masticating and occasionally lifting their heads and perusing the landscape, like other observations [3,30]. With domestic horses the dominant one influenced the step activity of other horses as the dominant horse when grazing went from hay flake to hay flake (flake separation- 15 - 20 meters) sampling each one. This behavior usually resulted in a threatening posture (ear-pinning and extended neck (3)) by the dominant horse as he approached the nearby horses causing them to move to other, or unoccupied, hay flakes depending upon their hierarchical position within the group.

With the PP-only horses, step activity was greatest during the daytime period (10 am to 8 pm) when socializing and playful activities in addition to grazing with steps were often observed and step activity recorded. In those SP (Stall Nighttime-Pasture Daylight) sessions these horses had reduced daylight step activity. One possible explanation may have been the reduced step movements due to the horses spending longer feeding times in one area of pasture or at one flake without moving. Also, during the PP session the horses had free access to grazing throughout the entire nighttime session potentially resulting in a greater degree of satiation, thus, allowing for more socializing and moving among other horses. The SP horses usually had consumed their allotted hay flakes during the nighttime while in the stall, making them potentially more interested in food when they were moved to the pasture. This possible idea needs to be examined

more fully in future experiments. Alternatively, These findings may suggest that being stalled anytime may have a negative effect upon the hourly step activity during the 24-hour recording period; however, this notion must be further examined in future studies. During times of heat and/or humidity, feeding behavior may be disrupted [14,30], as feral horses sought relief from the sun and insects, as in the mid-summer's afternoon in southern United States [14]. Similarly, in the daytime sessions the raw charts often indicated little step activity in the early afternoon when the horses were usually standing in their sheds, which is consistent with the observations of feral horses.

Previous studies involving feral horses in different regions of North America have usually investigated movements and behaviors as a time management issue rather than as individual movements or steps [5,7,11,31]. Most works relied upon recording times spent in specific activities, such as feeding, drinking, grooming, sexual activities, etc., all of which usually entailed some step activities or locomotor behavior while doing these activities. The actual movement events and the individual distances traveled were not examined, unless it was an observation of the herd from dusk to dawn when the behavioral observations resumed [5]. Locomotion was defined narrowly in these studies as moving from one place to another along trails or to reach the watering hole and represented only a small amount of time (7 - 8%) [7]. In the Souris., *et al.* [32] study, movements for more than 10 seconds occurred throughout the day with most (> 10%) in late afternoon between 1400 - 1600 hours and then between 1800 - 2000 hours, like the present study. While specific counts of step activity were not recorded as a behavior both step activity and behaviors should be examined and correlated together in future studies. This narrow definition of locomotion commonly used in feral horse studies merely represented one subset of range of behaviors involving movements or step events and would underestimate step activity, as was defined here. From these studies grazing usually represents between 40 - 50% of the 24-hour day, and upwards of 80% of the time on poor quality pasture [30] and during these same time periods considerable numbers of steps by feral horses would be achieved. These observations are consistent with the results of adult domestic horses of the present study.

During the stalled condition there was a significant difference in the step activity from that of the PP-only condition at all time periods as the stalled condition resulted in fewer steps per hour over the 24-hour recording period. In the stall-only condition there was also no significant difference among any of the time periods between night, morning, day and evening nor were there any significant differences in the stalled condition of the PS, SP and SS. In previous works on feral horses having restricted movements a greater incidence of aggression and mutual grooming as well as pacing and milling, suggesting boredom, were the observed behaviors when confined to a small pen [30,33]. With less grazing opportunity stalled horses may be bored and indulge in stall vices, such as cribbing and wood chewing [21,30]. In the current study perhaps due to an established hierarchy and familiarity with surroundings, aggressive, pacing or stereotypic behaviors were rarely or not observed, although mutual grooming over the stall doors was seen in several of the horses. In domestic peri-parturient horses confined to stalls [21], much of the time budget was devoted to standing (> 70%) rather than eating (15%) in contrast to same ponies on pasture (grazing 55% and standing 32%). In another study of stalled mares with access to a small paddock a neck recorder counted more movements during daylight [34]. Also, as their horses were isolated from visual or physical contact of other horses, the total movements may be actually less than if the horses had been able to socialize with others and may have made the movement differences between daylight and night time recordings evident. In the present study the diurnal nature of the step activity in the stalled condition was often evident on the raw data graphs but was not demonstrative statistically.

Both locomotion and sleep that represent two of many periodic activities common to mammals and specifically horses, are called circadian rhythms [34-36]. These activities encompass a widespread group of processes controlled by the brain, specifically the suprachiasmatic nuclear complex. While several studies have documented the hormonal rhythms in horses [36], less is known about the possible locomotor -step activity- changes in the horse. Behavioral studies of body movements have indicated seasonal variations in overall herd movements [13,37]. In the present study step activity was higher during the daylight hours than at night, consistent with other reports of a diurnal rhythm in animals [30]. During the daytime monitoring both grazing and active play behaviors appear to dominate the time period with grazing occupying more than half of the observation period [30]. While light appears to be the primary

entrainment of diurnal behavior, other external environmental factors can influence the activity patterns, including extreme temperatures and humidity, confinement, swarming insects and similar adverse stimuli, to name but a few [11]. Sleep, on the other hand, represents the quiet phase of the diurnal cycle versus the active time of locomotion, and was present in the current study [38]. Total sleep time- 3 - 5 hours per day- as studied in horses [38,39] predominates during the nighttime with each cycle being 30 - 40 minutes in length with the maximum concentration being between midnight and 4 am. In the present study both quiet phase of sleep and REM sleep were observed on the recordings of these horses. It is during this time when paradoxical sleep would most likely occur as they lie down usually in or near their shelter during night-time recordings, or while stalled, consistent with other reports [39]. At other times during the day shorter periods, i.e., one hour, were often evident on the raw record, which presumably were times of drowsiness or perhaps short bouts of slow wave sleep. Much of the time when standing still or are motionless, they appear to be drowsy or pass into slow wave sleep from this position. At that time the head will become gradually lowered as the neck muscle tonus decreases [38]. Future research needs to examine the step activity and sleep behaviors in adult horses.

The estimated distance traveled represents an initial reference point for discussion for a small group of domestic horses on 2 - 5 acres of pasture with ample food supplied. In this study the population of domestic horses had a mean distance of about 16 km per day; however, this distance could range between 8 km to nearly 30 km depending upon the stride length (range of 1.3 - 1.9 meters/stride) and whether the horses were walking or galloping. These horses in this study had access to two areas of approximately two and five acres and could easily cover these distances in these areas within the 24-hour time period. Furthermore, they were all observed to have moved to the multiple diverse different areas of the pastures during different times of the day. The technique of multiplying the average stride length by the step activity provides only a rough estimate of the potential distances traveled, when using the slow walk as a stride measure. The calculated distances will probably be overestimated as during grazing behaviors as the steps will more likely be shorter in length, and this behavior consumes approximately nearly half of the 24-hour time budget [30]. During more purposeful movements, such as during running and galloping between points, the calculated distances for these shorter distances will be underestimated as the stride lengths are longer than the walking stride length, extending up to nearly 7 meters [12]. Also, some number of steps may be recorded merely by lifting the forelimb but without moving a great distance, even though a number of precautions were taken into account to minimize these non-productive steps (fly sprays, leg wraps). While the monitor's shortcoming could be aided by the use of Global Positioning System (GPS), which is capable of accurately measuring distances, but not actual steps, the GPS technology has some significant weaknesses in that overhead barriers, such as a thick canopy of trees, roofs of shelters, etc., can block satellite communication with the monitor, resulting in unrecorded data [13]. Together though these two methods may provide a useful measure of accurate movements of the domestic horse. Another interesting aspect is the observation that many domestic horses are singly pastured without pasture mates. One can speculate that isolated horses would move considerably less, perhaps like that of stalled horses, than several horses pastured together.

Comparing the distances traveled by the feral horses and by the domestic horses of the present study is more difficult as there appears to be a wide range of distances traveled by both domestic and feral horses. Most behavioral studies of feral horse groups rely upon comparisons of changes in their locations during the day or dusk and their subsequent positions at dawn [5,7]. These studies have indicated that herds may be averaging less than one mile per 24-hours and up to 1.5 to 4 miles to per day, especially when food and water sources are close at hand [5,7]. Thus, even though the herd may be restricted by physical barriers they may move great distances by retracing their paths to feed and to seek relief from environmental pests. These estimates are probably an underestimation of the actual distances traveled by the horses since it relies on direct-line measurements between the sightings rather than actually measuring the distances that individual or small groups of horses might have traveled during that time period. However, the possible distances traveled by these horses are relatively short in contrast to the common perception that feral horses normally travel between 25 - 50 miles per day [4,14,15,17]. More recent studies of Australian wild horses using GPS technology [8] indicated an intermediate travel distance of up to 16 km per day. Our calculated findings of domestic horses are like this study, which is interesting; but other studies on domestic horses need to examine this issue further. Generally, though all studies indicate that movements and distances traveled appeared to be related to

the availability of food and water: more concentrated feed stores result in smaller home ranges while more dispersed food sources and a relative lack of water, larger range of step activity or movements were evident. The domestic horse appears to be not that dissimilar with our present husbandry practices of providing food sources near the horse population, which may result in short travel distances.

The interesting question is which of these two factors - the actual distance traveled in a 24-hour day or the relative numbers of steps and limb loading events - is more important in contributing to the overall foot health so commonly observed in the wild state [6,15,16,31] and desired in the domestic horse? In the literature there seems to be support for both arguments. In wild horses from the Southwest US [3,15,16] and Australia [8] the ground surfaces are harsh, consisting of lava rock and scarce vegetation, requiring greater travel distances for food and water, but rasping off the outer hoof wall. On the other hand, where the ground surface is sandier the hoof wall is not worn off and grows beyond the solar surface [8,18]. In other groups of wild horses occupying the sandy beaches of the Assateague Island and plains and hills of western Canada where the environment appears to be variable the hooves also appear to be in between these extremes [6,7,19]. In these latter two examples traveled distances are small, less than 5 km per day. While movement and terrain appear to be obvious contributors to overall wild foot maintenance, they alone are not the only factors to their self-maintenance. Diet, loading areas of the foot, and possibly genetics, could be factors that contribute to a balance between optimal growth, wear and bone deposition for a healthy foot. For the domestic horse diet, proper professional hoof care, and possibly genetics have been discussed thoroughly [20], but for distance traveled and/or steps per day taken, no data are available to the best of our knowledge. In man several studies have quantified steps taken per 24-hour period and related them to over-all health of the person [39] with the steps taken ranging between 5000-10,000 steps. The domestic horse at least appears to be in the range of these figures. In man though movement is related to cardiovascular health, while in the horse movements are discussed with regards to foot health. However, more and more human studies are suggesting greater limb loading events are important in combating osteoporosis in people [40,41]. When humans walk we have what may be called “purposeful movements” from one point to another to produce a covered distance, while in the horse the steps include these movements but also those steps (i.e. lifting the foot off the ground) which do not create distance in moving from one point to another. These latter steps though may be equally important as the limb loading events, which appear to be important for bone growth [42] and fracture healing [22,43] in horses and possibly osteoporosis in both man and horses. Future research will have to dissect out the possible differences between actual distances traveled and the limb loading effects for distal phalanx health.

Conclusion

The main finding of the present study revealed significant increases in step activities per hour in the pastured only group (PP) of horses as compared to the other various combinations of pasture and stalled recording sessions. However, this increased step activity of PP horses occurred during the daytime (10 am to 8 pm) session rather than during the nighttime (12 am to 8 am) session. With the stalled only (SS) sessions the fewest steps per hour were recorded during the 24-hour recording period in comparison to other conditions. The overall locomotor pattern demonstrated a circadian rhythm with most movements occurring during the daytime condition as compared to nighttime recordings. This study of domestic horse step activity provides an initial basis for step activity (limb loading events) and their estimated distances of travel on pasture. In addition, during the experiments we realized that the step activity may provide potential insights into the different behaviors exhibited by the horses.

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Conflict of Interest

The authors have no conflict of interest.

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