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Sensor Placement Effects Acceleration Data for Monitoring Equine Activity

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SENSOR PLACEMENT EFFECTS ACCELERATION DATA FOR MONITORING EQUINE ACTIVITY

by

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SENSOR PLACEMENT EFFECTS ACCELERATION

DATA FOR MONITORING EQUINE ACTIVITY

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Monitoring horse activity continually is a valuable aid for horse caretakers to provide recommendations to help users meet their goals and improve overall horse health. Activity trackers commonly use an accelerometer to determine steps and exercise intensity. The activity level capabilities using a 3-axis accelerometer were tested in three locations on the horse. The objectives were to determine which location results in the most accurate step count, threshold values for each gait and to identify correlations between the thresholds and horse characteristics. Twenty-four horses wore three identical smartphone accelerometers, one in each of three locations: right side of the head attached to a halter, right front leg, and right back leg attached to a boot slightly above the fetlock. Acceleration data was collected as the horses performed each gait (walk, trot, canter) for one minute. The accelerometer output was compared to step count and exercise intensity as determined from video recordings. MATLAB was used to process the acceleration data using a Fourier transform to calculate step frequency and total step count for each trial. Threshold values to delineate between gaits were determined by the maximum and minimum acceleration values observed during each gait for all horses in the study. Additionally, threshold values for the average frequency (cycles per second) were identified for each gait. The results revealed a significant difference ($p=0.02$) between all

three sensor locations and the video analysis. While all the sensors significantly underestimated the step count, the front leg location was the most accurate with no significant difference between calculated steps and video analysis at the walk. Analysis of step frequency allowed for the definition of distinct step frequency ranges for walk, trot, and canter. The height of the horse significantly interacted with step frequency for the canter only. An equine activity monitor using an accelerometer yields more accurate step counts when placed on the front leg of the horse for future energy expenditure estimates, though horse height needs to be considered for the canter.

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Nicholas Richard Young, thanks for putting up with my crazy stressed out self.

Philippians 4:6-7, Matthew 7:1-5

Be the light and the change you want to see in the world – Gandhi (paraphrased)

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CHAPTER I

INTRODUCTION

Wearable technologies are an increasingly popular avenue for people to monitor their health and eating habits. Limited information is available regarding the benefits of horse wellness and nutrition using data from biometric and movement sensors to make changes to dietary care plans. However, smartphone applications and fitness trackers can accurately track human activity levels and monitor fitness levels (Higgins, 2016). Advanced devices are able to provide recommendations to help users meet their goals and improve their overall health. Human medical professionals are able to use fitness trackers and activity monitoring to tailor health and wellness plans to their individual human patients (Higgins, 2016).

The question posed is: Where would be the most accurate location for the horse to wear a sensor to allow people to determine accurate movement and distinguish between three horse gaits (walk, trot, and canter). The horse will wear the sensor to collect necessary data to develop the required algorithms to indicate the horse's activity. In future research, these algorithms can be incorporated into a website and correlated to nutrient requirements to indicate feeding recommendations for the horse. The sensor can serve to educate owners on horse nutrition and health care as related to activity level.

The research portion of the project will determine the most appropriate place for the horse to wear the sensor to get the best readings and remain on the horse during the activity. Algorithms will be created from the data collected on the sensor and tested to determine the accuracy of determining movement of the horse performing the three

common horse gaits (walk, trot, and canter). The data can be correlated with nutrition concepts to determine if a horse is meeting its daily requirements.

Ideally, common horse illness could be prevented with such a device. For example, an accurate estimate of caloric expenditure could help horse owners prevent equine obesity (Harris, 2011). Furthermore, colic is the number one leading cause of death of horses in the United States and proper nutrient management plan can help mediate the risk of colic (Traub-Dargatz et al., 2001). Given the success of fitness trackers for humans and the similarities in equine weight loss, activity trackers for equines could provide similar benefits.

Therefore, the objectives of this study are threefold:

1) To determine the most accurate location for a horse to wear the sensor for determining number of steps and intensity of exercise compared to video recordings.
2) To discreetly define the step frequency thresholds for the three main gaits of horses (walk, trot, and canter).
3) To determine any correlations between horse characteristics and gait thresholds.

CHAPTER II

LITERATURE REVIEW

Colic, or abdominal pain, is the leading cause of death in horses. Gas colic and feed related factors are the two most common causes of owner-reported colic (Traub-Dargatz et al., 2001). Obesity in horses is prevalent and can be a precursor for a variety of health and lameness problems (Dugdale et al., 2010). The cost of medical care for both obesity and colic in horses is a huge financial drain on private owners and horse businesses. Therefore, prevention through nutritional management could be a solution to avoid such expenses.

The technology of movement sensors can be applied in a multitude of ways in the horse industry regarding health and illness. Colic and obesity management plans often have both a nutrition and exercise component (Gordon et al., 2009). Additionally, stress management was investigated by Erber et al. (2013) involving many different sensors including locomotion using pedometers, salivary cortisol, heart rate, and heart rate variability. The accuracy of inertial sensors was comparable to motion capture cameras for ponies wearing a 3-axis accelerometer, a 3-axis gyroscope, and a 3-axis magnetometer placed on five different vertebrae of the back (Warner et al., 2010).

Since a system of motion capture plus inertial sensors has proven inertial sensors to be similar to the results of motion capture and force plates, Keegan et al. (2013) compared inertial sensors to visual assessment for detecting lameness. The inertial sensors were set up to record single axis acceleration of the head, single axis acceleration of the pelvis, and single axis gyroscope of the pastern. For their lameness evaluation,

three veterinarians experienced in lameness detection using a universal lameness scale evaluated each limb on every horse and assigned a lameness score. The inertial sensor system was statistically associated with the veterinarians' lameness evaluation. The sensor system had high repeatability and a high degree of accuracy for determining the strides of the horse for lameness evaluation (Keegan et al., 2013).

A study by Olsen et al. (2012) focused on gait event detection related to lameness using inertial sensors on several leg and back locations. The sensors measured acceleration, angular velocity, velocity, and displacement compared to motion capture. A low percentage of error was obtained and thus high accuracy for the front limbs and hind limbs using custom MATLAB algorithms. The fetlock sensors had greater accuracy than the trunk mounted sensors and did not experience any vibration issues (Olsen et al., 2012).

Researchers at the University of Nebraska-Lincoln seek to develop such a device to monitor the fitness and activity of horses. This study addresses the beginning stages of developing a small wearable device for horses that monitors their steps, and intensity of exercise. The objectives of this study are to determine which location results in the most accurate step count, threshold values for each gait and to identify correlations between the thresholds and horse characteristics such as height, weight, breed, primary discipline, and age.

Application of technology to horses

Wearable technologies are an increasingly popular avenue for people to monitor their health and eating habits. Small fitness trackers or "Fitbit" devices that allow people to monitor their step count and relate their activity level to caloric expenditures and

nutrition are becoming a common tool. Such smartphone applications and fitness trackers can accurately track human activity levels and monitor fitness levels. Advanced devices are able to provide recommendations to help users meet their goals and improve their overall health. Medical professionals are able to use fitness trackers and activity monitoring to tailor health and wellness plans to their individual human patients (Higgins, 2016).

Individuality in horses

Many horse owners believe each horse is an individual and has their own personality. In a study done by Lloyd et al. (2008), the researchers defined personality characteristics for the questionnaire in an attempt to discern the potential personality differences between breeds and reduce interpretation error. In this manner, the data showed significant differences in traits between breeds, but also variations between the individual horses of the breed. There was greatest variance between breeds for the traits of anxiousness and excitability and the least variation in dominance and protection. The results support the traditional belief that horse breeds differ in their typical personalities (Lloyd et al., 2008). Therefore, any individualized horse care and management plan must take the particular horse's breed and personality differences into consideration (Lloyd et al., 2008 and Mills, 1998).

In addition to an individual horse's personality and breed, they can vary in activity level. Tracking individual movement is essential to customizing a horse's care and management plan as it is based on each specific horse's needs and activity levels. It will give an actual estimate of the horse's exercise level which could have an impact on

the horse's health and management provided by their caretaker, and any necessary adjustments can be made to the calorie intake the horse requires based on exercise levels.

Equine Gaits

Horses have three main ways of going or gaits – the walk, trot, and canter. Each step the horse takes can be defined by the swing phase and the stance phase of each limb. The swing phase is when the limb is not touching the ground and in motion, and the stance phase is when the limb is in contact with the ground. Since horses are quadrupeds, in addition to a step they also have a stride, which is the repeated pattern cycle of the limbs for each gait. The different gaits have a different beat, or cadence, of the footfall pattern. The walk is a four beat gait and is the slowest of the three gaits. The trot is a two beat gait made possible by the diagonal front and hind legs moving together. The fastest gait is the canter, which is a three-beat gait where two of the diagonal legs are paired and the remaining front and hind legs act independently. A horse that has an acute or chronic unevenness of gait is often called lame. Lameness is usually the result of pain somewhere in the horse's body. A horse that performs the gaits with cadence and smoothness is called sound (Evans et al., 1990).

2. Types of Movement trackers

Global Positioning System (GPS) Trackers

One method for tracking movement and activity is with Global Positioning System, more commonly known as GPS, which is a system of satellites in orbit used in location and navigation technology. The location is found by triangulating the signals from three or more satellites, known as fixing the location or fix. Depending on the

conditions, the accuracy for a GPS tracker can be within three meters of the actual location (Garmin, 2016).

To cater to an individual animal's exact needs, GPS trackers used previously assessed animals' movements. Turner et al. (2000) successfully used GPS trackers in cattle to monitor and determine grazing time versus inactive time. In addition to the GPS tracker, the cattle had two other sensors: a temperature sensor and a dual axis motion sensor sensitive to horizontal and vertical motion of the head and neck. At each GPS location fix, the motion sensor data was summed and classified as active or inactive. Based on visual confirmation, the GPS trackers had a 91% success rate of classifying the data as active or inactive correctly (Turner et al., 2000).

Furthermore, Brooks et al. (2008) successfully determined three different categories of activity in zebras using only GPS. The activity of the zebras and the rate of travel was calculated by analyzing the whole movement path of the zebras using only the GPS location fixes. In this manner, the data determined where the animal was, what it was likely doing, and how long it took them to travel between points (Brooks et al., 2008).

However, caution should be used with GPS trackers regarding their potential impact on the animal being monitored. The size of the tracker, and the influence it has on the animals should be reduced as much as possible to avoid altering the animal's natural movement and behavior. When examining the effect the collar weight on the behavior of zebras, as little as 0.2% difference in the collar weight had a significant effect on the movement (Brooks et al., 2008). The zebras did not show signs of rubbing under the collar thus movement of the collar on their neck was not a factor (Brooks et al., 2008). It

was determined that radio collars weighing more than 0.6% of the animal's body weight had a significant influence on the behavior of the animals. Therefore, for a sensor to be successful for tracking movement, it must be comfortable and lighter than 0.6% of the animal's body weight to decrease the effect it has on the horse's behavior and to avoid interference with the animal's individual natural tendencies.

Hampson et al. (2010a) used a lightweight GPS collar to track the movement of domestic horses in paddocks. A paddock is an enclosure of different shapes and sizes for horses. The researchers found the GPS data logger to be 100% reliable over 384 data logging days for the horses paddock travel comparisons. The collar also did not appear to disturb the movement of the horses or cause skin abrasions (Hampson et al., 2010a). These collars and a GPS tracker could be used to successfully track horses over a period of time even in a relatively small location (30m x 20m) to a high degree of detail (Hampson et al., 2010b, 2013). Thus, GPS collars successfully track the movement of animals including horses. Furthermore, the GPS accuracy is high enough to observe distance, activity, and travel behavior patterns. When the weight of the GPS tracker is low enough, the collars can give a good representation of the activity of the horses without altering their behavior or causing pain and discomfort. This is significant as it eliminates the need for constant human observation and allows for remote tracking of the animals.

For the previously mentioned GPS radio collars, the animals had to be recaptured to obtain the information gathered. This is a time and labor-intensive procedure and would not be desirable for most horse caretakers in the long term, especially if they were caring for many horses. Mann et al. (2014) designed a GPS collar that was able to

transmit the data to a relay station when the horses naturally came into range. This allows the horses to remain at liberty for the duration of the experiment and increases accuracy in future behavioral data analysis since the horses stay close to their natural rhythms and environment. In addition, this opens the possibility for longer-term study and decreased storage space since the data is transmitted to a relay station while the study is in progress (Mann et al., 2014).

The previous researchers were able to obtain the data they required from GPS tracking, but many horses spend some or all of their day inside a building. Being inside a building or under dense tree coverage does not allow the GPS signal to get an accurate fix (D'Eon and Delparte, 2005). In the current study at the University of Nebraska-Lincoln, all horses are housed indoors and testing of the sensor would take place inside an indoor arena. Thus, the use of GPS technology was not applicable for this current experiment.

Motion Capture and Force Plates

While GPS can determine the distance the animals are travelling and approximate the movement, it cannot tell the gait with detail. The optimal measurement of accurate stride and movement is achieved with force plates. Force plates are diagnostic surfaces that measure the force exerted on the ground by the contact of a foot, commonly used in human and sports medicine to detect small changes in mobility patterns (Kistler, 2016). Boye et al. (2014) successfully determined exact stance phase timings in the horse's gait using motion capture and force plates. Motion capture is the use of cameras to digitally record specific motions of a person or object with reflective markers placed on key anatomical landmarks and translating the recordings into computer animated images (Merriam-Webster, 2016). The researchers concluded that motion capture was highly

accurate compared to force plate results, however, the front and hind limbs required different algorithms to achieve these results (Boye et al., 2014).

Due to the need for extensive equipment for both motion capture (reflective dots and camera network) and force plates (dedicated runways with imbedded plates), neither one is suitable for the design of this current experiment, which is the beginning of the process of developing a small, standalone device that the horse could wear performing any activity in any location. However, this research did demonstrate high accuracy between force plates and motion capture, which allows for the comparison of other methods for accuracy.

Inertial Sensors

Inertial sensors are devices that measure motion, most commonly acceleration and deceleration of an object; however, they can measure a multitude of motion including acceleration, vibration, shock, tilt, and rotation. Velocity contains information on the rate of displacement and direction of movement. Acceleration is the change in velocity over time, usually measured in meters per second squared (m/s^2). Deceleration is acceleration with a negative value. Tilt, also referred to as inclination, includes gravity and is a type of acceleration over time. When multiple axis are combined, inertial sensors can detect rotational motion, which is an extension of tilt in a single axis device. These inertial measurement units (IMU) are commonly called gyroscopes. The sensor returns a measurement, commonly steps or activity level, depending on the program to record data (such as how frequently) and processing method (Analog Devices, 2009).

A study done by Warner et al. (2010) compared the accuracy of inertial sensors with motion capture using six ponies hand trotted past motion capture cameras while

wearing a 3-axis accelerometer, a 3-axis gyroscope, and a 3-axis magnetometer placed on five different vertebrae of the back. The inertial sensor was accurate and consistent when compared with the motion capture (Warner et al., 2010).

A system of motion capture plus inertial sensors has proven inertial sensors to be similar to the results of motion capture and force plates without the need for tightly controlled laboratory settings. The next step after determining that inertial sensors are accurate would be to determine if they can detect differences within a gait, such as for lameness. Keegan et al. (2013) compared inertial sensors to visual assessment to determine their use in detecting lameness. The inertial sensors were set up to record single axis acceleration of the head, pelvis, and pastern. For their lameness evaluation, three veterinarians experienced in lameness detection using a universal lameness scale to which they were accustomed evaluated each limb on every horse and assigned a lameness score. The researchers' inertial sensor system was able to determine if the horses were sound or lame. In addition, the inertial sensors had high repeatability and a high degree of accuracy for determining the strides of the horse (Keegan et al., 2013). A study by Olsen et al. (2012) had success focused on gait event detection related to lameness. Motion capture was compared to inertial sensors on several leg and back locations measured acceleration, angular velocity, velocity, and displacement. The inertial sensor system was able to determine gait events accurately and precisely (Olsen et al., 2012).

Another study used motion capture and an accelerometer-gyroscope system to quantify lameness. They used eight horses with a single axis accelerometer measuring vertical velocity attached to the horse's head and pelvis and a gyroscope measuring angular velocity on the right front and hind legs. The researchers found that an

accelerometer-gyroscope was more accurate than the video based motion analysis for detecting lameness (Keegan, 2004). The correlation between the inertial sensors and the video analysis was r^2= 0.954 for the front leg and r^2 =0.824 for the hind leg (Keegan, 2004). However, this system focused on lameness evaluation still required many sensors and would not be suitable for horses at liberty. The high correlation of the lameness evaluation for the accelerometer-gyroscope system with the motion capture is encouraging for use of the inertial sensor independently.

Pedometers

The previous studies have been investigating the use of inertial sensors for use largely in lameness detection compared to other methods of gait and movement analysis such as force plates. However, another option for determining movement of horses is with pedometers. A pedometer utilizes the capabilities of a 3-axis accelerometer to determine steps from the peaks and cycles of acceleration and deceleration of the gait (Zhao 2010). Erber et al. (2013) performed a stress response study involving many different measurements including salivary cortisol, heart rate, heart rate variability, and locomotion using activity, lying, and temperature (ALT) pedometers placed on a tendon boot on the hind leg of eight Warmblood mares. The system worked well to determine the amount of time the horses spent actively moving and the number of steps taken, but was not utilized to determine what gait the horse was in (Erber et al., 2013). In humans, Treuth et al. (2004) was able to determine sedentary, light, moderate, and vigorous activity level thresholds of adolescent girls wearing two accelerometers. Accelerometer data determined discrete threshold categories by finding balance between false positives and false negative results (Treuth et al., 2004). Additionally, evaluating the number of

steps taken by a horse using a pedometer holds potential since in humans the number of steps determines an approximate energy expenditure in conjunction with height and weight (Zhao, 2010). The pertinent VO_2 and heart rate values necessary for such calculations in horses have been assessed using horses on a treadmill (Aerts et al., 2008; Eaton et al., 1995).

A pedometer utilizes the capabilities of an accelerometer to determine steps from the peaks and cycles of acceleration and deceleration of the gait (Zhao, 2010). Mechanical accelerometers have a common application as pedometers for fitness. A weight is attached to a spring inside the device. As the pedometer moved up and down with the motion of the person walking, the weight compresses and stretches the spring recorded by an internal counter. This simple method counted any activity that moved the weight causing compression and lengthening of the spring as a step. The method still serves as an excellent model for accelerometers, though the technology of measuring movement and counting steps has made many advancements (Azmy, 2013).

Combinations of pedometer and accelerometer-gyroscope

Therefore, utilization of both a pedometer and accelerometer-gyroscope could be useful in determining activity level and steps. The accelerometer-gyroscope is able to fill in the desirable areas where the pedometer alone falls short. Bachmann et al. (2014) used an accelerometer and a pedometer as an indicator of parturition for mares about to foal. They used two different ALT sensors, one attached to a neck collar, one attached to either the right or left front leg using a custom water and dirt proof case attached with leather and felt straps. The devices accurately determined moving activity, lying bouts and lying time, except for the neck collar mounted pedometer. The pedometer categorized all non-

motion as lying due to its pendant nature on the neck. The sensor design allowed for easy application, cleaning, and appeared to have minimal effect on the mare's movement or behavior (Bachmann et al., 2014).

Furthermore, Burla et al. (2014) used an accelerometer and pedometer combination to determine a horse's gait based on acceleration values. The researchers used adult horses of mixed gender and breed and attached a 3-axis accelerometer and an ALT pedometer capable of determining step impulses, ventral and lateral position, and temperature to the cannon of the left front leg positioned just above the fetlock. The horses were either ridden, lunged, or a combination of the two at the walk, trot, and canter for five minutes at each gait, though due to the condition of the horses, some of the 5 minute totals were composed of shorter intervals. The accelerometer was set to sample 10 measurements per second (10Hz) with a sensitivity of 10g (gravity). The accelerometer used in this study was easy to use due to the adjustable strap to place the sensor on the horse, and USB data transfer ability. Furthermore, it had a high degree of reliability and versatility shown by its ability to be used on horses and horse and pony crosses of various heights, breeds, and being worked on multiple surfaces. There was a significant breed by gait interaction ($P = 0.028$). Distinct acceleration limits defined each gait without overlap after considering breed class. Even with variation in the size of the horses, distinct acceleration ranges for the gaits were defined that had no overlaps. The differences in breed class were determined to be more due to the gaited or non-gaited breed of the horses, rather than the size. The data between the two devices were closely correlated, with the accelerometer being the most suitable for gait determination and pedometer for overall steps taken during movement. The researchers concluded the

accelerometer to be suitable for use as a monitoring system for activity and rest (Burla et al., 2014).

Expanding on this research, Fries et al. (2016) used an omnidirectional piezo-electric accelerometer with a built in activity function and a step count program measuring at 32Hz. The locations of interest investigated with this sensor were head, withers (shoulders), the heel of the hoof (foot) of the front leg, and left hind leg. The activities the horses performed included moving at liberty in an enclosure, grazing, walking at six different speeds, trotting on a lunge line, and cantering on a lunge line. The horses wore one sensor in each location for each test and were video recorded with a standard camcorder during their activities. The pedometer step frequency was verified by video footage. Using the activity feature of the accelerometer, distinct cut off values for the hind leg data were statistically different for each gait except for moving at liberty and grazing activities. This activity feature was pre-programmed into the sensor by the manufacturer to output a numerical activity value and was not able to be adjusted. The hind leg data was best able to discriminate between all of the gaits compared to the other locations (Fries et al., 2016). It had high sensitivity and specificity for all activity levels for all horses and had a linear correlation with walking speed. The location that performed the worst was the wither location, with the head and heel of the front leg having middling accuracy. While the step count on the hind leg did have high accuracy with the manually counted steps, the step count alone was not sufficient to differentiate between all of the speeds of the walk and other gaits. The pedometer recorded the same number of steps at the walk as the faster gaits. Thus, the pedometer alone would not be suitable for determining gait. However, in combination with the activity function of the

accelerometer, the researchers were able to determine each of the gaits correctly (Fries et al., 2016).

Human activity monitors are typically pedometers with a 3-axis accelerometer using microelectromechanical systems (MEMS) inertial sensors. With this method, such sensors can determine steps, distance, speed, and calories burned. It is possible for a similar system to be modified for horses. Zhao (2010) used a 32-level first-in, first-out (FIFO) buffer with 13-bit resolution sensor to measure acceleration on three axes for human activity monitoring. With a pedometer such as this, no matter which direction is the vertical axis, at least one (x, y, or z) will have relatively large periodic acceleration changes (Zhao, 2010). Furthermore, a time window program eliminated vibrations that are not due to real steps. For humans, the time window was set at one step every two seconds necessitating two steps to take place between 0.2 seconds and 2 seconds, otherwise the step would be discounted. Count regulation was also utilized to determine valid steps from a rhythmic pattern; one invalid step in a four-step pattern would eliminate that four-step pattern as a valid step. Using this hardware and software calculations allowed a minimally obtrusive device to estimate the calories expended by a person (Zhou, 2010). This research with humans shows potential for modification and application to horses.

3. Energetics

Nutritional Energetics

An important part of the energy expenditure of the horse is the activity level, but additional data is needed to create a unique estimate for each horse. The nutritional energetics of horses is an important aspect of equine health and performance in the horse

industry. Inadequate energy intake or excessive intake of nutrients will decrease the capabilities of the horses and thus are less productive for the horse producer. Many components contribute to the digestive process of the horse that affects the actual energy intake. Knowing this system and the numerous factors that influence it for each individual animal should maximize the horse's potential, at least in the area of nutrition and keep costs to the horse producer to a minimum.

Energy System

The net energy system of horses is based on two concepts. Maintenance is the major component of energy expenditure of most horses. Net energy of nutrients for both maintenance and work (physical activity) depends on the free energy (ATP) produced by oxidative catabolism. Thus, maintenance is the greatest energy expenditure rather than for other bodily functions such as work or gain.

Net energy is not as simple as the total energy of the feed the horse consumed. The net energy value for horse feeds is calculated by a step-wise procedure (Martin-Rosset et al., 2006). First, the gross energy is measured or calculated from chemical composition of the feed. The first factor to influence the gross energy value is the digestibility of the feed. The digestible energy is measured or predicted from the gross energy and the organic matter digestibility of the feed (Martin-Rosset et al., 2006). As such, one of the methods of measuring organic matter digestible energy is via the utilization of plant waxes containing n-alkanes or from acid-insoluble ash (AIA). This allows for the use of an internal marker rather than performing a total collection method for apparent digestibility to estimate apparent digestibility. With total collection, the exact input and output of the horse must be accurately collected. This often requires the

horse to be secluded into digestibility stalls to ensure accurate collection, prohibiting the horse from performing its normal behaviors during the study resulting in this method being cumbersome and unpleasant (Miraglia et al., 1999; Peiretti et al., 2006).

Metabolizable Energy

There are additional losses in energy after digestible energy. The horse will have urinary losses in the form of nitrogen in urea and gaseous losses in the form of combustible gasses such as methane and carbon dioxide. The calculation of energy with these losses taken into consideration is called metabolizable energy (Martin-Rosset et al., 2006). For determination of methane production, Danson et al. (2015) fed four Welsh pony geldings two diets, roughage only and roughage plus concentrate, in a crossover design measuring carbon dioxide production, methane production, and oxygen consumption in respiration chambers for three consecutive days. Feed and fecal analysis were also taken. The researchers found that methane production was significantly higher on the roughage diet than on the roughage and concentrate diet. Carbon dioxide production varied slightly between the two diets, but was not statistically significant. However, the study did still conclude increased levels of roughage in horse diets does cause increased methane production and thus energy loss (Danson et al., 2015).

Additionally, energy losses in urine need to be taken into consideration. Urine and urea recycling is closely linked to nitrogen. Different types and levels of protein in the diet will cause a change in urine energy losses of the horse. Obitsu et al. (2015) looked at the nitrogen digestion and urea recycling of horses fed four diets with two different protein sources. As the dietary nitrogen increased in the higher protein diets, the amount of urea nitrogen also increased. Because horses are hindgut fermenters and efficient at

nitrogen recycling, horses were able to produce more urinary nitrogen than the amount of apparent nitrogen digestion. This allows the horses to provide additional nitrogen sources to microbes in their cecum when fed low protein roughages (Obitsu et al., 2015). However, the production status of horses alters methane production. Methane production was the least in foals and greatest in nursing mares of draft breeds (Martin-Rosset et al., 2012).

Previously, Vermorel et al. (1997b) did similar work looking only at the differences between methane production of horses and ponies fed at maintenance. Methane production, energy expenditure, and energy balance of the animals were determined by indirect calorimetry over a four day period. The methane production between ponies was not statistically different. However, overall methane energy losses related to digestible energy were higher in ponies than in horses for both of the diets used even though the maintenance energy requirements of ponies is smaller than that for horses. This was thought to possibly be due to the higher digestibility of neutral detergent fiber (NDF) and acid detergent fiber (ADF) in ponies (Vermorel et al., 1997b).

Net Energy of Foodstuffs

The final step in determining the energy value is determining the net energy of the feed. Martin-Rosset et al. (2006) determined an equation to determine the net energy of the feed. The equation takes into consideration the cost of eating, which is not used when calculating concentrate feeds. From this net energy value, accurate rationing measures can be taken from the feed for individual horses (Martin-Rosset et al., 2006).

Simply knowing the energy value of a feed does not necessarily mean that is what the horse will be consuming. For example, Edouard et al. (2008) looked at the effect of

forage quality on the voluntary intake of horses, theorizing the composition of the feed might have an impact on the amount of the feed the horse would be willing to eat. As expected, dry matter digestibility decreased significantly with declining forage quality. There was a significant decline in intake as the energy density of the diet approached the level of grain and concentrates. This is unlike the plateau seen in ruminant animals. The intake level of alfalfa hay was greater than grass hay, even at the same digestibility, possibly due to the decreased amount of lignin in alfalfa than grass. However, individual horses responded with varying degrees of compensation to each of the factors in the diet. Thus, individual animal response is too variable to predict accurately from the feed composition and estimates may have a high degree of error for certain horses. Thus, even at a particular feed calculation, it does not guarantee that is what every horse is obtaining (Edouard et al., 2008).

Further confounding adequate energy intake is the conflict between the relationship of perceived workload and actual workload. Dekker et al. (2007) investigated the differences in actual energy expenditure to maintain body weight versus the estimated energy intake by experienced horse professionals. Both the calculated relative workload and the instructor's estimated workload agreed that the horses were in light work. However, the horses had different body weight (BW) and required significantly different energy intakes to maintain weight even when blocking for weight and age. The researchers determined that there are more factors contributing to differences in energy expenditure at the same workload, such as individual digestive efficiency and non-structured activity such as pacing and pasture activity. Thus, even if a caretaker estimates the amount of work the horse is performing, the activities the horse voluntarily engages

in should be considered for a total assessment of the horse's energy expenditure (Dekker et al., 2007).

Another potentially confounding factor looked at by Brinkmann et al. (2014) is the breed of the horses. They investigated the energetic adaptations of Shetland pony mares hypothesizing that they would have the ability to save energy during hard times when feed is scarce and available forage quality is low. Energy expenditure of ponies dropped significantly during winter conditions and the ponies were able to adjust their expenditure according to food supply and climate conditions. Furthermore, food restriction in harsh winter conditions resulted in nocturnal hypothermia and a reduction in energy expenditure similar to other wild ungulates such as red deer and Alpine ibex (Brinkmann et al., 2014).

Therefore, while the energetic value of feed has been determined to an acceptable degree of accuracy, the individual responses of horses to the feeds varies greatly. All of these factors are of value to the casual horse owner, horse producer, and others in the horse industry. Without proper nutrition, no animal will perform to its peak potential. Thus, knowing the net energy of a feed is vital to formulate the appropriate ration for each animal. However, there are several nuances that have been shown in the aforementioned studies that individual horses do not always follow the calculated model for a variety of reasons.

Workload Categories

The National Research Council (NRC) has determined the digestible energy requirements of horses based on body weight into four workload categories: light, moderate, heavy, and very heavy. The exercise category 'light' being defined as having a

mean heart rate of 80 beats per minute during work, 1-3 hours per week, with approximately 40% of the activity being walk, 50% trot, and 10% canter (NRC, 2007). Examples of such work including recreational riding, beginning of training programs, and horses shown on an occasional basis. Moderate was defined as 90 beats per minute on average, 3-5 hours per week, with 30% walk, 55% trot, 10% canter, and 5% low jumping, cutting or other skill work with examples such as school horses, recreational riding, beginning of training/breaking, frequent show horses, polo, and ranch work (NRC, 2007). Heavy work was defined as 110 beats/minute, 4-5 hours per week, 20% walk, 50% trot, 15% canter, and 15% gallop, jumping and other skill work. Such examples include ranch work, polo, and show horses frequently competing in strenuous events (NRC, 2007). Finally, very heavy work was categorized as 110-150 beats/minute, with work time ranging from one hour per week speed work to 6-12 hours per week of slow work with examples including racing Quarter horses, Thoroughbreds, Standardbreds, endurance horses, and elite 3-day event horses (NRC, 2007). The authors do caution that these workload groups should be seen as a continuous function rather than by discrete categories. Furthermore, the NRC also outlines the nutrient requirements of digestible energy, crude protein, vitamin, and mineral requirements based on the weight of the horses and the type of horse, such as work and gestation state (NRC, 2007).

Total activity measurement

The workload categories are useful in giving a closer estimate, but do not take into account the activity the horse performs voluntarily and requires the caretaker to have the experience to correctly assign the horse to a workload category. Therefore, estimates that are more accurate are required in order to be of benefit. Oxygen consumption via

indirect calorimetry is a common way to measure calorie expenditure. This method has been used in some of the previous studies (Danson et al., 2015; Vermorel et al., 1997b). However, the intensive set up of equipment does not allow for its use in horses at liberty. Eaton et al. (1995) investigated the relationship between oxygen consumption and heart rate. The protocol used five Thoroughbred horses fitted with a respiratory collection system that were worked on a treadmill at prescribed inclines and speeds. The data showed a significant linear relationship between heart rate and oxygen consumption that was unaffected by changes in the incline of the horses on a treadmill (Eaton et al., 1995). This relationship between heart rate and oxygen consumption and between oxygen consumption and energy utilization is corroborated and summarized by the NRC (NRC, 2007).

In the interest of using heart rate as an estimate of energy expenditure, Aerts et al. (2008) investigated several metabolic factors including speed and rider effect on heart rate. The horses wore a heart rate monitor and GPS unit for determining speed while being worked at various speeds and gaits at an outdoor equestrian facility. The data showed the presence of a rider did have a significant effect on the speed of the horse, but not on the heart rate. This was possibly due to the horse naturally choosing the most efficient way of going with the increased load. An additional part of the study looked at the possibility of using the heart rate monitor to aid the rider in keeping the horse in a particular heart rate during a workout, such as making sure the horse is adequately warming up, cooling down, or working at peak. This led to a dynamic model of the horse's heart rate as the horse was working. The heart rate responded to changes in speed within 5 seconds of the change, lending itself well to a dynamic model as the horse

worked (Aerts et al., 2008). This data was supported by the work done by Eaton et al. (1995) and the additional data collected in that study included strides per minute.

In addition to the linear increase of heart rate with speed, there was a curvilinear relationship between stride frequency and speed (Eaton et al., 1995). The predictable relationship of heart rate and speed and the relationship of step frequency and speed demonstrates the possibility of using the number of steps the horse takes over time to find the heart rate. This alone could be useful to horse owners in determining the exertion and fatigue level of the horse or could be further used to calculate the oxygen consumption and energy expenditure of the horse. Such equations using heart rate to predict energy expenditure have been computed for large domestic dogs resulting in a regression equation with a coefficient of determination of 0.90 (Gerth et al., 2015). This use of formulas from the step count would allow a number of possible computations of interest.

Using an accelerometer-gyroscope with pedometer software, it is possible to determine the nature of the movement a horse is performing, namely the steps, intensity, and duration characterized by the gait of the horse. From this information, a workload category can be assigned to the horse based on its actual movement rather than an estimation. Combined with body weight and basic physiological status such as age and gender, it is possible to estimate the energy expenditure of the horse based on individual work and activity level. These calculations could be looked at during an acute period, such as workout intensity, and long term as an average activity level over weeks. Thus, the horse is receiving the nutrients it needs rather than an estimation based on rough average categories that do not take into account the horse’s voluntary movement. This will provide horse owners and caretakers the information they need to tailor an individual

plan for each horse to ensure that each horse maintains a healthy, productive body weight rather than estimating the amount of feed needed and over or under feeding the horse resulting in decreased performance. This also provides the horse owners and caretakers with more detailed information than the feed label may provide to determine the amount of feed necessary. Further applications of the device could include alerts for abrupt changes in movement or behavior such as colic or stress related to new housing or pasture arrangements.

CHAPTER III

MATERIALS AND METHODS

The experiment was conducted at the University of Nebraska located in Lincoln, NE. The University of Nebraska-Lincoln Institutional Animal Care Program approved all animal procedures and facilities utilized in this study.

Animals

The study used twenty-four horses (10 mares and 14 geldings) used for riding and educational purposes at the University of Nebraska-Lincoln. The population of horses had a mean weight of 544.31 kg and height of 157.48 cm (15.2hh) and the majority were stock type horses (Table 1). The horses were kept in individual stalls with turnout either singularly or in small groups. The testing took place in a familiar indoor arena (R. B. Warren) with sand footing. All horses were healthy, routinely ridden, and accustomed to the activities and manipulations performed during the study.

Activity monitor

Acceleration was measured using the onboard sensor of a POSH Micro X S240 smartphone running Android 4.4 Kit Kat. The smartphone had a Mediatek MT6572M Dual core 1.0GHz processor, 512MB of RAM and 4GB of storage, powered by a rechargeable 650maH Lithium-ion battery (Figure 1, 2, & 3). A 32GB micro SD card was added to the smartphone for additional storage. The smartphone measured 89x47x11.6 mm and weighed 51.03g (Posh Mobile, 2016). The phone was inserted into a neoprene athletic armband with Velcro strap (Figure 4), which weighed 36.85g and measured 4.06x3.56x2.79cm (Tune Belt, 2016).

Table 1: Participating horses (n=24) weight, height, sex, age, breed, primary discipline, and shod status

Horse	Weight (kg)	Height (cm)	Sex[a]	Age (yrs)	Breed[b]	Primary Discipline[c]	Shod[d]
1	547.48	154.94	M	13	AQH	W*	4
2	523.89	157.48	G	3	AQH	W*	0
3	628.22	170.18	M	9	QHX	H**	2
4	573.79	160.02	G	8	AQH	H/W	2
5	560.18	160.02	G	9	SH	H	0
6	601.00	162.56	G	11	AQH	H/W	2
7	669.04	172.72	G	5	QHX	H	0
8	540.68	154.94	G	20	AQH	W*	2
9	468.10	149.86	M	26	AQH	W*	2
10	no data	no data	M	6	QHX	H**	0
11	512.55	167.64	G	21	SH	H**	4
12	504.39	154.94	M	10	AQH	W	2
13	570.16	157.48	M	17	AQH	W	2
14	546.57	157.48	G	13	AQH	W	2
15	521.63	152.4	G	18	AQH	W*	4
16	508.02	152.4	M	11	AQH	H**	2
17	586.04	165.1	G	14	AQH	H	2
18	535.23	144.78	M	23	AQH	W	2
19	542.04	160.02	G	15	AQH	H**	2
20	547.48	157.48	G	7	AQH	W	0
21	494.41	152.4	G	23	AQH	W	2
22	544.31	170.18	M	11	QHX	H**	2
23	no data	no data	G	16	SH	H**	2
24	no data	no data	M	9	QHX	H	0

[a]Sex: M = Mare, G = gelding
[b]Breed: AQH = American Quarter Horse, QHX = Quarter Horse and Thoroughbred cross, SH = Sport horse
[c]Primary Discipline: W = Western horse, H = Hunt type horse, W* = Western reining horse, H** = Hunt jumping horse
[d]Shod: 0 = Barefoot, 2 = Front shoes, 4 = All 4 feet shod

Figure 1. Three Posh Micro Smartphones, screen view while turned on

Figure 2. Three Posh Micro Smartphones, screen view while turned off

Figure 3. Three Posh Micro Smartphones, viewed from the back

Figure 4. Neoprene armband that the phone was inserted into during testing

The phone utilized the onboard accelerometer to record the accelerometry data to a file using a downloaded Android application, AndroSensor (Fiv Asim, 2015). The data was saved onto an SD card and emailed to the phone's Gmail account (Figure 5).

Figure 5. Androsensor application recording on Posh Micro smartphone

A USB cord transferred the Excel file to a computer. The onboard accelerometer was set to record acceleration on the x-, y-, and z-axis and at a sampling rate of 8Hz. This sampling frequency was chosen based on previous research by Burla et al. (2014) and on the highest capabilities of the sensor. Burla et al. (2014) used a sampling frequency of

10Hz, using only the y-axis, and at this frequency could determine gait and frequency acceleration threshold for the 20 horses utilized. The frequency of 8Hz was the highest frequency the AndroSensor application could process without the risk of crashing which is why this frequency was utilized for this study.

Each horse was fitted with three identical Posh Micro smartphones. The smartphones were individually secured inside an identical armband strap and attached in three different locations. The locations were chosen because they would not interfere with the horse's movement and for horse caretaker ease. The locations being investigated were the head attached to a halter, the right front and hind leg above the fetlock attached to boots. The smartphone in the head location was attached to the horse's halter on the right hand side of the horse via the armband strap (Figure 6).

Figure 6. Attachment of the smartphone placed inside the neoprene armband strap to the right side of the halter at the junction of the crownpiece and the check piece on the horse's head

The weight of the halter was not included in the weight of the sensor because the horses were accustomed to the weight of the halter. The additional weight of the armband

and smartphone was 93.55g. The handlers worked the horses on a lunge line with a chain end and a simple flat halter without any additional equipment (Figure 7).

Figure 7. Subject horse with all equipment in the canter phase of data collection

Brooks et al. (2008) determined that radio collars for tracking the movement of zebras that weigh more than 0.6% of the animal's body weight had a significant influence on the behavior of the animals. The weight of the sensor used in this study even on the smallest horse (468.10kg) did not exceed 0.6% of the horse's body weight (Tables 2 and 3).

Table 2. Weight of sensor broken down into components and weight of attachments onto the horse including range of final total weight of sensor and attachment methods

Phone	Plastic stabilizing insert	Neoprene armband	Overall sensor weight[a]	Small splint boot	Large splint boot	Smallest overall weight[b]	Largest overall weight[b]
51.03g	5.67g	36.85g	93.55g	141.75g	204.12g	235.30g	297.70g

[a] Total additional weight added to the halter of the horse; the horses were accustomed to the weight of the halter

[b] Total additional weight added to the distal leg of the horse, distributed between the fetlock and mid-cannon area

Table 3. Weight of sensor components in locations (head, front leg, hind leg) of interest and the corresponding percentage of body weight for each participating horse

Horse #	BW[a] (kg)	BW (g)	Head (g)[b]	% of BW[c]	Leg (g)[d]	% of BW[e]	Leg (g)[f]	% of BW[g]
1	547.48	547480	93.55	0.01	235.30	0.04	297.70	0.05
2	523.89	523890	93.55	0.01	235.30	0.04	297.70	0.05
3	628.22	628220	93.55	0.01	235.30	0.03	297.70	0.04
4	573.79	573790	93.55	0.01	235.30	0.04	297.70	0.05
5	560.18	560180	93.55	0.01	235.30	0.04	297.70	0.05
6	601.00	601000	93.55	0.01	235.30	0.03	297.70	0.04
7	669.04	669040	93.55	0.01	235.30	0.03	297.70	0.04
8	540.68	540680	93.55	0.01	235.30	0.04	297.70	0.05
9	468.10	468100	93.55	0.02	235.30	0.05	297.70	0.06
10	no data	no data	93.55	no data	235.30	no data	297.70	no data
11	512.55	512550	93.55	0.01	235.30	0.04	297.70	0.05
12	504.39	504390	93.55	0.01	235.30	0.04	297.70	0.05
13	570.16	570160	93.55	0.01	235.30	0.04	297.70	0.05
14	546.57	546570	93.55	0.01	235.30	0.04	297.70	0.05
15	521.63	521630	93.55	0.01	235.30	0.04	297.70	0.05
16	508.02	508020	93.55	0.01	235.30	0.04	297.70	0.05
17	586.04	586040	93.55	0.01	235.30	0.04	297.70	0.05
18	535.23	535230	93.55	0.01	235.30	0.04	297.70	0.05
19	542.04	542040	93.55	0.01	235.30	0.04	297.70	0.05
20	547.48	547480	93.55	0.01	235.30	0.04	297.70	0.05
21	494.41	494410	93.55	0.01	235.30	0.04	297.70	0.06
22	544.31	544310	93.55	0.01	235.30	0.04	297.70	0.05
23	no data	no data	93.55	no data	235.30	no data	297.70	no data
24	no data	no data	93.55	no data	235.30	no data	297.70	no data

[a] Body weight

[b]Added weight to the horses head of sensor components - phone, stabilizing insert, and armband attachment. The horses were accustomed to the weight of the halter the sensor was attached to

[c] The added weight of the sensor components attached to the head of the horse expressed as a percentage of the horse's body weight (BW)

[d] Overall weight of the sensor and components added to the distal portion of the horse's leg when the smallest size splint boot was used. Splint boots of two sizes were used to accommodate for the different sizes of horses

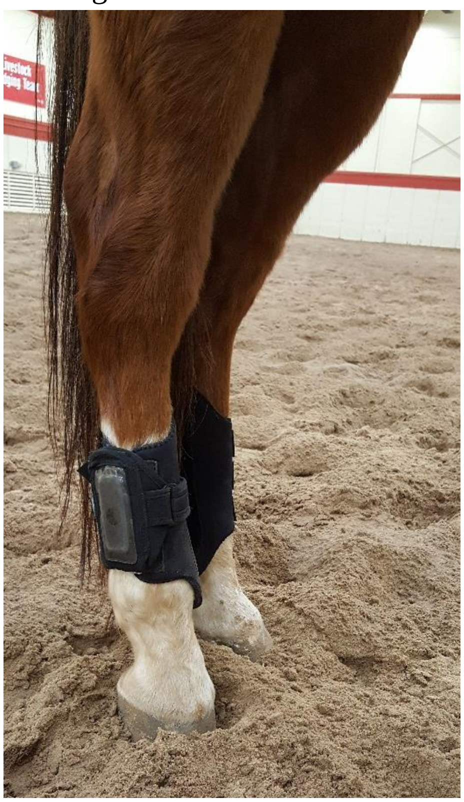
[e] The added weight expressed as a percentage of the horses body weight of the sensor components attached to the distal portion of the leg when the smallest size splint boot was used

[f] Overall weight of the sensor and components added to the distal portion of the horse's leg when the largest size splint boot was used. Splint boots of two sizes were used to accommodate for the different sizes of horses

[g] The added weight expressed as a percentage of the horses body weight of the sensor components attached to the distal portion of the leg when the largest size splint boot was used

The smartphones on the front and back right limbs were secured by the armband strap to the outside (lateral aspect) of a neoprene splint boot just above the fetlock (Figure 8). Similarly, previous researcher used a strap to secure a plastic tube housing the sensor onto the horse's left foreleg just above the fetlock or a Velcro strap over a splint boot to secure the sensor on the hind leg (Burla et al., 2014; Fries et al., 2016).

Figure 8. Attachment of the smartphone in the armband strap on the outside of the right hind leg of the horse



The weight of the splint boots worn on each leg was between 141.75 and 204.12g due to variations in size necessary to fit the different sizes of horses. The total weight of all the components worn on the leg, which included the splint boot, smartphone, and armband, was between 235.3 and 297.7kg (Table 2). On the smallest two horses (468.10kg and 494.41) the added weight of the sensor did not exceed 0.6% of the horse's body weight (Table 3). For this study the horses wore additional splint boots, without the

smartphone and armband, on the front and back left legs (Figure 9). This was done to make the weight and sensation on all four of the horse's legs similar to ensure the horse's way of going was not altered.

Figure 9. All splint boots, with and without sensor, worn by the horse and the halter sensor

Data recording

Three handlers exercised the horses in the study at the walk, trot, and canter on a 6.1m lung line in a counter clockwise circle once the three smartphones were activated and attached. The handlers determined the order of the gaits. Data was collected for one minute at each gait after the handler determined that the horse was performing the gait consistently. Previous research done by Burla et al. (2014), Fries et al. (2016), and Keegan et al. (2004) collected data at each gait for 30 sec to 5 min during their studies and preliminary data collection trials determined that one minute at each gait was

sufficient for collecting acceleration data. Video recording of each horse exercising at the three gaits during the data collection was used to visually count steps. The data was downloaded at the end of the day's session. Each horse performed the above procedure five times with several hours or days between each trial.

Step frequency

To validate the number of steps determined by the smartphone accelerometer, the sensor outcome was compared with the number of steps counted from the video footage of the right front leg. The video was watched by two individuals blinded to the others results. In the event of a difference between the individual's counts greater than two steps, a third individual counted the steps from the video. This was done for each gait for each horse's trial. The final step count number from the video was compared to the outcome from the three different locations as determined by the smartphone accelerometer processed by MATLAB. This is similar to what was described by Fries et al. (2016) where steps from video recordings were compared to a sensor's step count.

Data Analysis

The accelerometer data was imported into MATLAB (Mathworks 2015) from Excel files (Microsoft 2016) and processed using a Fourier transform. Acceleration is the change in velocity over time, usually measured in meters per second squared. The Fourier transform measures every possible repeating pattern, or cycle, in the acceleration data. One acceleration cycle is an increase in acceleration, followed by a plateau, then deceleration followed by a plateau before resuming acceleration. Then the transform returns the overall representation of the signal as a superposition of sinusoids (Azad,

2013). That is, a graph of all of the possible cycles per second (hertz or Hz) plotted against how often that frequency matched the cycles of the data set, or magnitude of the frequency. Thus, a frequency with a high peak is the frequency that often matches the cycles of the acceleration data. A pedometer utilizes the capabilities of an accelerometer to determine steps from the peaks and cycles of acceleration and deceleration of the gait (Zhao, 2010).

The orientation of the three axes for each sensor while on the horse can be seen in Figure 10 and 11.

Figure 10. Orientation of sensor inside smartphone; orange arrows indicate the X axis, green arrows indicate the Y axis, and yellow arrows indicate the Z axis.

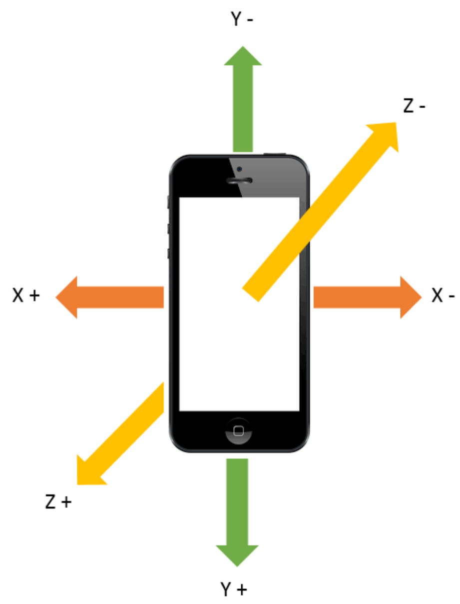


Figure 11. Orientation of sensor on the horse; orange arrows indicate the X axis, green arrows indicate the Y axis, and yellow arrows indicate the Z axis.

A Fourier transform performed the analysis of accelerometer data for each of the three gaits and each sensor location for every trial independently. The MATLAB code (Appendix A) required a lower bound statement when finding the peak frequency. This lower bound will focus the Fourier transform to a plausible level, rather than returning a value in the noise area below the area of interest. From visually counting the steps in the video files, approximate ranges of steps for each gait were known and peaks with frequency outside that range were eliminated. The minimum number of steps counted from the video for each gait was divided by 60 seconds to find the lower bound. Using this method, the lower bound for the walk was set at 0.6 cycles per second, trot at 1.1, and canter at 1.5. This resulted in a frequency of peak magnitude that was multiplied by 60 seconds to calculate the number of steps taken.

The Fourier transform culminated in a frequency spectrum for the x, y, and z axis overlaid on the same graph to get a clearer picture of the data and determine the true frequency. The peak with the highest magnitude after the preset lower bound was the frequency that corresponds with the desired outcome (Figure 12). Any of the peaks below the lower bound were considered noise and occurred too infrequently to be the desired frequency. The MATLAB program found the first high peak after the preset lower bound because the peaks at very high frequencies occurred too frequently to be the desired frequency for the step count. That frequency, when multiplied by the number of seconds in each test, resulted in a step count (Figure 13). This step count was then compared to the steps counted from the video. In this manner, the accelerometer data was used via the Fourier analysis to determine steps.

Figure 12. Frequency spectrum from MATLAB Fourier transform of 3-axis accelerometer data. Lower bound preset at 0.6. The peak for all three axes (x, y, z) were in alignment and all exhibit a frequency at 0.81667 with high magnitude

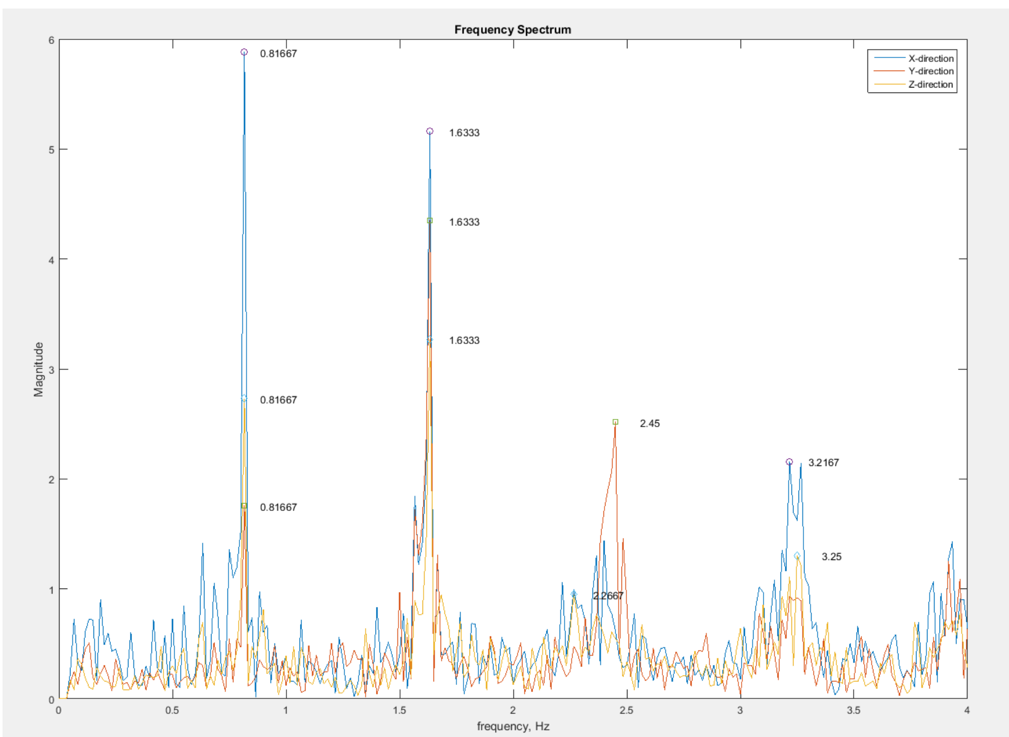


Figure 13. MATLAB output from code found in Appendix A for the corresponding data set found in the graph in Figure 12. The returned frequency was 0.81667 as was visually evident in the graph. That frequency when multiplied by 60 sec results in a step count of 49.

```
>> Equimove_step_an
Sorting in 5cycle. OK.
Frequency is 0.81667Hz
Total Steps in 60 seconds is 49
Calculation Completed.
```

This is similar to a study done by Burla et al. (2014) where the researchers used an accelerometer and pedometer combination to determine a horse's gait based on acceleration values. The researchers used a three axis accelerometer and an activity, lying, temperature (ALT) pedometer (capable of determining step impulses, ventral and lateral position, and temperature) to the horse. The sensor had a high degree of reliability and versatility in its use on horses and pony crosses of various heights, breeds, and being worked on multiple surfaces.

Statistical Analysis

SAS was used to determine significant differences between numbers of steps counted from the video and determined by the sensor for each of the three gaits and the three locations. PROC GLIMMIX was used in a split plot with blocking design with repeated measures. Repeated measures was used since each horse had five trials and accounts for the correlations of the five measurements for each horse. The horses were the random block, which allowed for maximum variance between blocks and minimized the variance within the blocks. The whole plot was horse*gait*location*method where "horse" was each individual subject horse, "gait" was each of the three horse gaits (walk,

trot, and canter), “location” was the location where the sensor was attached (head, front leg, and back leg), and “method” was the method of step count (video analysis or calculated with MATLAB). The Normal distribution with LSMEANS was used with repeated measures with an AR(1) covariance structure. Normal distribution was used for the frequency distribution as well, but did not have the “method” component. Finally, a regression using PROC MEANS was used to determine if there were any interactions between the characteristics of the horses (Table 1) and the frequency for each gait.

CHAPTER IV

RESULTS AND DISCUSSION

To determine the most accurate location to provide acceleration data for step analysis, the horses (n=24) wore sensors in three locations. The sensor attachment locations investigated were the right side of the head attached to the halter of the horse, the right front and right hind leg attached on the distal portion of the horse's leg on a boot slightly above the fetlock joint.

After the trials, the accelerometer data was imported into MATLAB and a Fourier transform was performed. The process analyzed the accelerometer data detecting repeating cycles and returning a graph of the corresponding frequencies and magnitudes. Each gait (walk, trot, canter), location (head, front leg, hind leg), horse (n=24), and trial (5) were analyzed individually. The MATLAB code returned a step frequency (Hz) that was multiplied by the length of the trial data collection period (60 sec) resulting in a step count.

The calculated step count was compared to the number of steps counted from visual analysis of the video footage of the trial. SAS compared the two numbers for each horse, gait, location, and trial to determine which location was closest to the number of steps obtained from video analysis. Furthermore, MATLAB analyzed the step frequency to determine the frequency range for each gait. The characteristics of the horses were examined to determine if there were any interactions between the characteristics of the horse and the resulting frequency for each gait.

Step analysis

A total of 1029 observations were compared and the breakdown of the number of observations for each gait and location can be found in Table 4.

Table 4. Number of observations compared for 24 horses, five trials, two measurement methods[a], three gaits[b], and three locations[c]

	Location			
Gait	**Head**	**Front leg**	**Back leg**	**Total**
Walk	117	113	117	347
Trot	115	114	118	347
Canter	110	112	113	335
Total	342	339	348	1029

[a] The two step measurement methods were visual analysis from video of the trial, and calculated number of steps from MATLAB data analysis
[b] The three horse gaits investigated were walk, trot, and canter
[c] The three sensor locations of interest were the head attached to the halter, the front and the back leg attached to the distal portion of the horse's leg slightly above the fetlock joint

The mean, minimum, maximum and SD of the step count from each of the three gaits for the three locations on the horse are in Table 5. SAS determined any significant differences between the numbers of steps counted from the video and determined by the sensor for each of the three gaits and the three locations. The overall correlation between the calculated number of steps and the video number of steps using Spearman Correlation showed a strong, positive linear association ($r=0.926$, $P<0.001$). Spearman's correlation coefficient allowed for the variables to not be normally distributed and only required the assumption that there was a monotonic (just increasing or just decreasing) relationship between the variables. The correlation ranges from 1 to -1, thus a score of 0.926 indicates a very strong, linear relationship between the two variables. This means that as the video

step count is increasing, the calculated step count is mimicking the increase. This demonstrates that the calculated step count is returning a value similar to the video step count and increasing in the same manner. Previous research has shown a strong correlation between calculated step count and video step count (Burla et al., 2014, and Fries et al., 2016).

This strong, positive linear correlation shows that the calculated number of steps can be used to provide an accurate estimate of the number of steps the horse is taking. The slope and intercept of the correlation can be modified based on the horse's characteristics if necessary to provide a closer estimate. At the walk, the correlation was 0.610 ($P<0.001$). This correlation still shows association, but it is not as strong. This is likely due to the number of outliers, as can been seen in Figure 14. The overall correlation at the trot was 0.599 ($P<0.001$), and the canter was 0.766 ($P<0.001$). Thus, as the video step count increases, the calculated steps are increasing at a nearly identical rate.

When broken down by location, the head location had an overall correlation of 0.868 ($P<0.001$). The walk was 0.513 ($P<0.001$), the trot was 0.542 ($P<0.001$), and the canter was 0.743 ($P<0.001$). For the front leg location, the overall correlation was 0.963 ($P<0.001$). The walk was 0.797 ($P<0.001$), the trot was 0.640 ($P<0.001$), and the canter was 0.832 ($P<0.001$). The overall correlation for the hind leg location was 0.952 ($P<0.001$). The walk was 0.586 ($P<0.001$), the trot was 0.630 ($P<0.001$), and the canter was 0.723 ($P<0.001$). Therefore, the front leg demonstrated the highest correlation between the calculated steps and video steps compared to the other two locations.

Table 5. Step count for 60 seconds determined by video analysis or measured by MATLAB calculation of acceleration data of horses (n=24) for three horse gaits (walk, trot, and canter)

Gait	**Walk**				**Trot**				**Canter**			
Location	**Head[a]**	**Front leg[b]**	**Back leg[c]**	**Video[d]**	**Head**	**Front leg**	**Back leg**	**Video**	**Head**	**Front leg**	**Back leg**	**Video**
Mean	53.6	46.1	45.2	47.0	79.4	79.5	78.1	81.1	102.0	103.0	102.0	107.0
Max	105.0	97.0	84.0	53.5	108.0	102.0	102.0	96.0	127.0	159.0	123.0	120.0
Min	38.0	37.0	37.0	40.0	67.0	69.0	68.0	68.5	93.0	93.0	92.0	93.0
SD[e]	17.6	6.7	5.2	3.1	6.5	5.6	5.7	4.0	5.3	7.9	5.2	5.3

[a] The sensor attached to the right side of the halter of the horse and step count calculated from acceleration data imported into MATLAB and run through a Fourier transform to determine step count

[b] The sensor attached to the distal portion of the right front leg of the horse slightly above the fetlock with a neoprene case over a neoprene horse splint boot. Step count calculated from acceleration data imported into MATLAB and run through a Fourier transform to determine step count

[c] The sensor attached to the distal portion of the right hind leg of the horse slightly above the fetlock with a neoprene case over a neoprene horse splint boot. Step count calculated from acceleration data imported into MATLAB and run through a Fourier transform to determine step count

[d] Steps from visual video analysis of the trial

[e] Standard deviation

The Type III tests of fixed effects were all significant (P<0.0001), so the simple effects were analyzed (Table 6). The gait*method interaction is the interaction between the gait of the horse (walk, trot, and canter) and the method used to determine steps (video analysis or MATLAB calculation). A difference was noted when examining the gait*method interaction between each of the three gaits (Table 6). This means that the gaits were distinct from one another and the mean number of steps counted was significantly (P<0.05) different for each gait. This is in agreement with previous studies showing the number of steps is different for each of the gaits. When a pedometer was used to determine the step activity of horses, ponies, and Icelandic horses, significant differences in step counts were noted when the horse was standing compared to the walk. The pedometer utilized was not capable of recording step counts at gaits faster than the walk (Burla et al., 2014). Similarly, Fries et al. (2016) distinguished step count ranges from video recordings and from accelerometer data for the walk, trot, and canter and developed an activity count algorithm. The step ranges for people performing either a walk, jog, or sprint can be distinguished using an accelerometer (Zhao, 2010). When plotted, the step counts from both the video and the calculated steps showed distinct ranges of step counts for each gait. Figure 14 shows the step count data from all three locations pooled together for each gait.

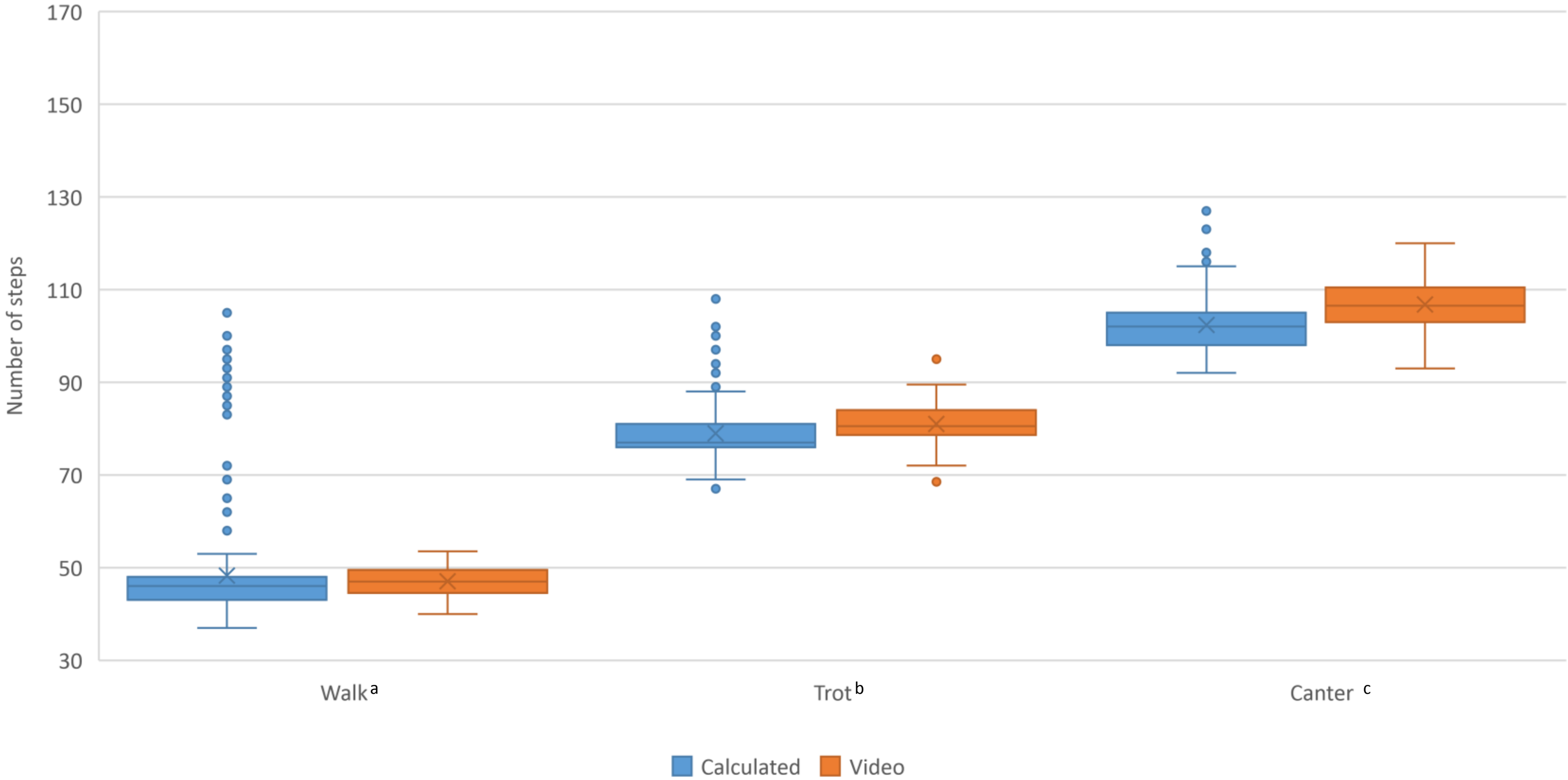
For the video analysis of the steps, only one overlap between the ranges of steps was found between the trot and canter where the trot had five outliers above the canter minimum (Figure 14). For the calculated step count, the sensor did occasionally have difficulty distinguishing between the walk and the other two gaits when looking solely at the number of steps calculated. This is similar to Fries et al. (2016) who also was unable

Table 6. Summary of the PROC GLIMMIX analysis for repeated measures comparing the step count measured by the accelerometric device placed in three different locations (head, front leg, hind leg) on the participating horses (n=24) with visually counted steps from video recordings performing three different gaits (walk, trot, and canter)

		Mean step count (SEM[a])			
Gait	**Location**	**Calculated**	**Video[b]**	**Difference**	**P-Value**
Walk	Head[c]	53.61 (0.7510)	47.02 (0.7458)	6.60	<0.0001
	Front leg[d]	46.01 (0.7582)	47.02 (0.7458)	-1.00	0.1861
	Hind leg[e]	45.20 (0.7508)	47.02 (0.7458)	-1.81	0.016
Trot	Head	79.39 (0.7546)	81.07 (0.7458)	-1.68	0.0267
	Front leg	79.33 (0.7563)	81.07 (0.7458)	-1.74	0.022
	Hind leg	78.14 (0.7491)	81.07 (0.7458)	-2.92	0.0001
Canter	Head	102.19 (0.7621)	106.75 (0.7546)	-4.56	<0.0001
	Front leg	102.80 (0.7583)	106.74 (0.7546)	-3.94	<0.0001
	Hind leg	102.05 (0.7562)	106.75 (0.7546)	-4.70	<0.0001
Main effects					
Gait* Method	**LSMeans**	**Mean (SEM)**			
Walk		48.28 (0.5734)	47.02 (0.5701)	1.2605	0.004
Trot		78.95 (0.5734)	81.07 (0.5701)	-2.1117	<0.0001
Canter		102.35 (0.5759)	106.75 (0.5740)	-4.4008	<0.0001
Location*Method		**Mean (SEM)**			
Head		78.40 (0.5745)	78.28 (0.5714)	0.1194	0.7844
Front leg		76.05 (0.5753)	78.28 (0.5714)	-2.2262	<0.0001
Hind leg		75.13 (0.5728)	78.28 (0.5714)	-3.1453	<0.0001
Interactions		**P-Value**			
Gait		<0.0001			
Location		<0.0001			
Gait*Location		<0.0001			
Method		<0.0001			
Gait*Method		<0.0001			
Location*Method		<0.0001			
Gait*location*method		<0.0001			

[a] Standard error of the mean
[b] Steps from visual video analysis of the trial
[c] The sensor attached to the right side of the halter of the horse and step count calculated from acceleration data imported into MATLAB and run through a Fourier transform to determine step count
[d] The sensor attached to the distal portion of the right front leg of the horse slightly above the fetlock with a neoprene case over a neoprene horse splint boot. Step count calculated from acceleration data imported into MATLAB and run through a Fourier transform to determine step count
[e] The sensor attached to the distal portion of the right hind leg of the horse slightly above the fetlock with a neoprene case over a neoprene horse splint boot. Step count calculated from acceleration data imported into MATLAB and run through a Fourier transform to determine step count

Figure 14. Step counts calculated using MATLAB and from video footage for 60 seconds from all three locations the sensor was worn on the horse (head, front leg, back leg) pooled together given as boxplots with median, interquartile ranges, outliers, and step counts for all horses (n=24)



[a]Mean for calculated number of steps independent of location (locations pooled) = 48.28, mean for video analysis= 47.02, P = 0.004
[b]Mean for calculated number of steps independent of location (locations pooled) = 78.95, mean for video analysis = 81.07, P <0.0001
[c]Mean for calculated number of steps independent of location (locations pooled) = 102.35, mean for video analysis = 106.75, P <0.0001

to distinguish the walk from other gaits by number of steps alone when investigating step count ranges for horses with an accelerometer on the hind leg. However, the accelerometer's pre-programmed activity feature was not designed for horses. Thus, the activity count was not able to distinguish the trot from the walk due to an unintended doubling of the steps calculated. This was possibly due to the quadruped nature of the horses. Based off the video step analysis, the distinct upper bound cut off for number of steps for the walk was 53.5 steps per minute. Out of the 343 calculated step counts for the walk, 26 (7.6%) were outside the cut-off of 53.5 steps. Of those 26 instances, 21 (81.8%) occurred in the head location, three (11.5%) in the front leg location, and two (7.7%) in the hind leg location (Figure 15). The outliers above the upper cut-off might have been experiencing similar errors to the work done by Fries et al. (2016) and required an additional halving factor.

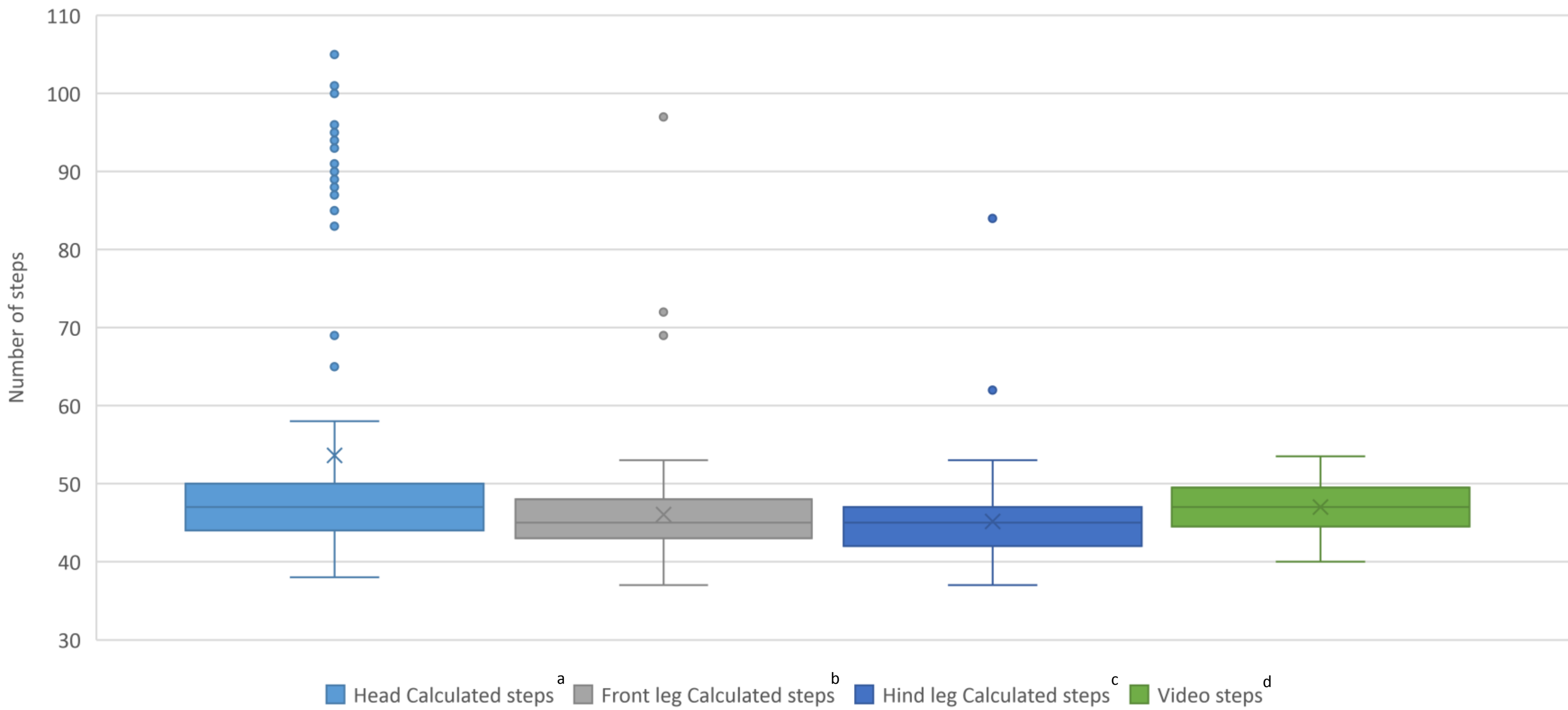
For the trot, the video analysis had a distinct upper bound of 89.5 steps. When applied to the 342 data points that were calculated, 19 (5.6%) were outside the cut-off of 89.5 steps. Nine (47.4%) were in the head location, five (26.3%) in the front leg location, and five (26.3%) in the hind leg location (Figure 16). Using an upper bound cut-off of less than or equal to 53.5 steps in one minute for the walk and less than or equal to 89.5 steps for the trot is supported by Fries et al. (2016) who found an upper bound of 50 and 90 respectively. However, Burla et al. (2014) used a pedometer on the front leg of the horse, calculated a higher number of steps per minute (116.4 for the walk), and was not able to distinguish distinct step bounds for the trot and canter. The distribution of the steps for each sensor location from video analysis and calculated can be found in Table 5 for the three gaits (walk, trot, and canter).

A significant difference ($P<0.05$) existed between the calculated number of steps and the steps counted from the video for all three gaits when the location was pooled (Table 6, Figure 14). When calculating step count using accelerometer data, step counts were 4.4 fewer ($P<0.0001$) for horses at the canter. At the trot, calculated steps measured 2.11 fewer steps than the video analysis indicated ($P<0.0001$). For the walk, calculated steps measured 1.26 more steps than the video analysis ($P=0.004$).

When the gaits were pooled, a significant difference between calculated and video steps for two of the locations was noted. The front leg location calculation resulted in 2.23 fewer steps than the video analysis ($P<0.0001$) across the gaits. Finally, the third location, the hind leg, calculated 3.15 fewer steps than the video analysis ($P<0.0001$). The head location was not significant with a $P=0.78$ and a mean difference of 0.12. Fries et al. (2016) found the hind leg to be the most accurate across the gaits compared to the front limb. Burla et al. (2014) was unable to distinguish differences in the step counts using a pedometer on the front limb.

Next, the gait*location*method LSMeans were investigated, which is the interactions between the gait of the horse (walk, trot, and canter), the location of the sensor (head, front leg, hind leg), and the method used to determine steps (video analysis or MATLAB calculation) (Table 6). When the horses were cantering, the calculated step count was underestimated ($P<0.01$) compared to the video step count at all three locations. When the accelerometer was placed on the head, the calculated step count was underestimated ($P<0.0001$) by an average of 4.56 steps. The difference for the front leg location was underestimated by 3.94 steps ($P<0.0001$). Step count for horses with the accelerometer placed on the hind leg were underestimated ($P<0.0001$) by 4.70 steps with

Figure 15. Step counts calculated using MATLAB and from video footage for 60 seconds at the walk from all three locations the sensor was worn on the horse (head, front leg, back leg) pooled together given as boxplots with median, interquartile ranges, outliers, and step counts for all horses (n=24)



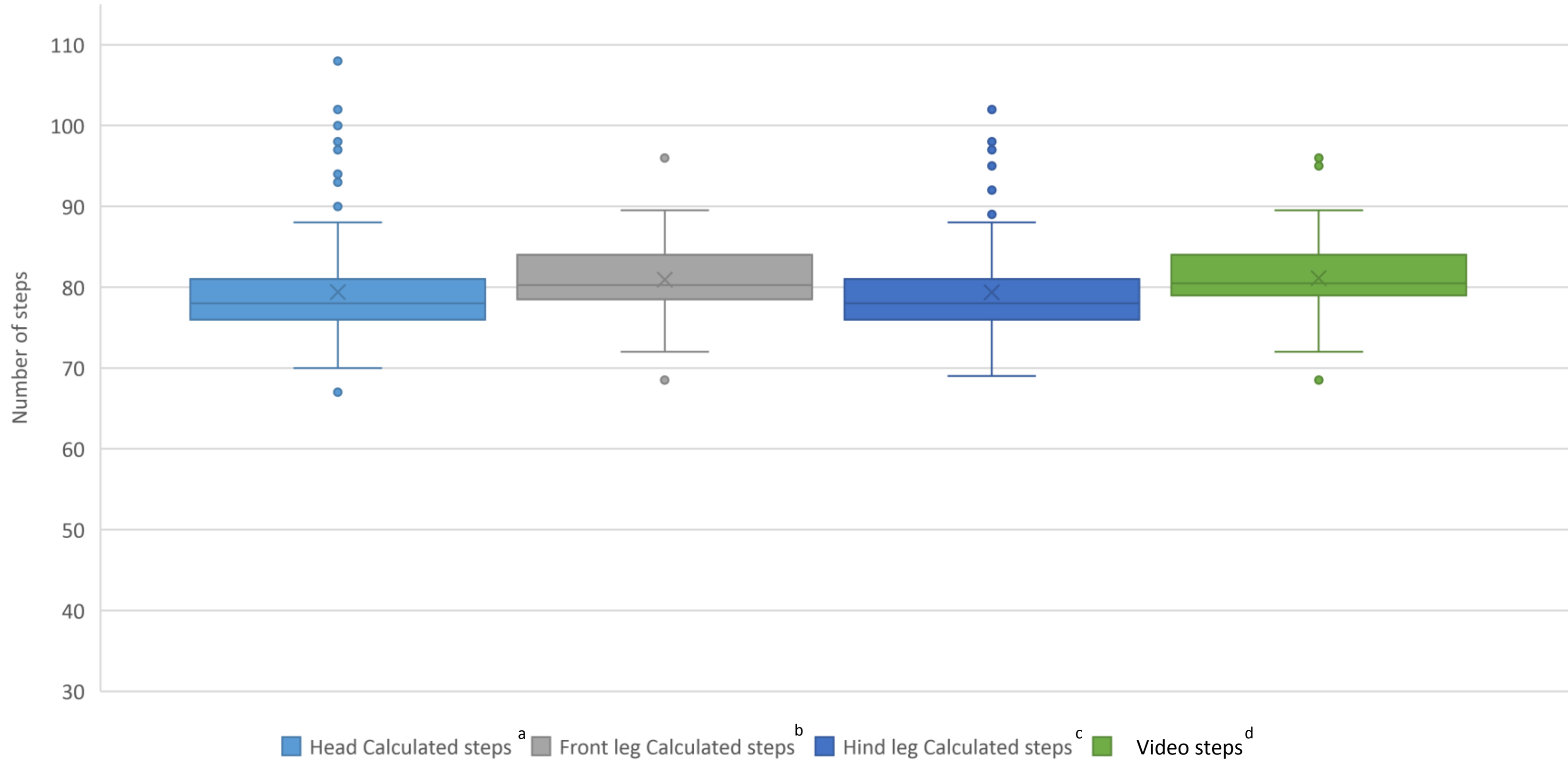
[a]Mean for head location calculated with MATLAB = 53.56, $P < 0.0001$

[b]Mean for front leg location calculated with MATLAB = 46.03, $P = 0.2101$

[c]Mean for hind leg location calculated with MATLAB = 45.15, $P = 0.0163$

[d] Mean video analysis step count = 47.00

Figure 16. Step counts calculated using MATLAB and from video footage for 60 seconds at the trot from all three locations the sensor was worn on the horse (head, front leg, back leg) pooled together given as boxplots with median, interquartile ranges, outliers, and step counts for all horses (n=24)



aMean for head location calculated with MATLAB = 79.39, P = 0.0267

[b]Mean for front leg location calculated with MATLAB = 79.33, P = 0.022

[c]Mean for hind leg location calculated with MATLAB = 78.14, P = 0.00011

[d] Mean video analysis step count = 81.07

the calculation method. For all three locations at the canter, use of the calculation underestimated the number of steps by approximately four steps.

At the trot, calculated step counts for the sensor in the head location were lower (P=0.0267) by 1.68 steps compared to the video step count. The front leg location also underestimated the steps at the trot with a difference of -1.74 steps (P=0.022). Similarly, the hind leg location had a difference of -2.92 steps (P=0.0001). Therefore, all three locations at the trot resulted in a calculated number of steps lower than the number of steps from video analysis.

There was not a significant difference between the calculated and video step count at the walk for the front leg location. On the other hand, both the head location and the hind leg location were significantly different. At the head location, the calculated method was overestimating (P<0.0001) the number of steps by 6.60 steps on average compared to the video analysis. The outliers at the walk contributed to the average overestimation being quite large. The hind leg location underestimated step counts by 1.81 steps (P=0.016).

Based on the collected data on the interactions and estimates of the difference, the front leg location is the most accurate at providing data to calculate the number of steps from the three locations observed. The front leg location resulted in a higher overall correlation (r=0.963, P<0.001) than the other two locations. The front leg location also had a higher correlation than the other two locations when the correlation was broken down by gait. This showed the relationship between the calculated step count and the video step count was strong and allows for an accurate step count estimate. In the front leg location, the difference between calculated and video was not significant at the walk,

though it was significantly different at the trot and canter. When the gaits were pooled, the mean for the head location was not statistically different from the video analysis. However, when the differences were broken down by gait it became apparent the reason was that the head location greatly overestimated the number of steps for the walk and underestimated the steps in the other two gaits. This increased the overall mean making the head location appear to provide an accurate step count. However, the front leg location proved the most accurate compared to the other two locations when the difference was broken down by gait. The absolute value of the differences across the gaits for the head location was 12.84 steps, front leg location was 5.68 steps, and hind leg location is 9.43 steps. While the front leg location was significantly underestimating the number of steps at the trot and canter, the absolute difference was not as large as the other two locations.

Fries et al. (2016) compared the head, front leg, back leg, and withers and found the hind leg to be the most accurate, though it was similar to the sensitivity and specificity of the front leg. The front leg and withers were comparable at the slower speeds, but at the trot and canter, the accuracy went down. This is also reflected in the present data. Fries et al. (2016) showed only the hind leg had an acceptable percentage of error (<3%) at all three gaits and concluded it to be the most accurate. However, only six horses were used which may have allowed the algorithm to conform to that smaller subset of horses. On the other hand, Burla et al. (2014) used only the front leg and was not able to distinguish the gaits other than the difference between standing and walking. This difference might have been due to the researchers using a pedometer, rather than

utilizing an accelerometer to collect acceleration data to process into step counts as was performed presently.

Frequency analysis

The step counts calculated from MATLAB discussed previously were determined from a Fourier transform of the raw acceleration data, which output a frequency in hertz (Hz) that when multiplied by 60 seconds provided the step count. The distribution of the frequency from each of the three gaits for the three locations are present in Table 7. SAS determined the differences in the frequency across location and gait. The normal distribution was used with repeated measures with an AR(1) covariance structure with horse*gait*location. The Type III tests of fixed effects were all significant, so the simple effects were analyzed starting with gait*method interaction which means the gait of the horse (walk, trot, and canter) and the method used to determine steps (video analysis or MATLAB calculation) (Table 8). The LSMeans of the gait*location provided estimates of the mean frequency for each gait at each location and the standard error of the means (SEM). Figure 17 shows statistically significant differences between the three gaits walk, trot, and canter plotted with a 95% confidence level. The mean frequencies are distinct for each gait with no overlap. At the trot and canter, the three locations all had similar frequencies distinct for the respective gait. However, at the walk, the outliers at the head location had a significantly increased mean frequency.

Table 8 shows the simple effect comparisons of the LSMeans with P-values adjusted with Holm-Tukey to reduce the Type I error rate. Therefore, there were no statistically significant differences between the step frequencies obtained from each location except at the walk. The frequency at the walk for the head location was lower

than the frequency for the front and hind leg locations (P<0.0001). This is consistent with the step counts discussed previously. Table 8 shows the distribution of the step frequencies obtained from the three locations at the three gaits. As with the step counts, while the mean frequency is distinct and has no overlap, there are outlying values that cross over into the slower or faster gait. This allows distinct frequency ranges for each gait to be produced for each location from Table 8.

Table 7. Frequency (Hz) determined by MATLAB using Fourier transform of all accelerometer data from horses (n=24) for three horse gaits (walk, trot, canter) for 60 seconds; mean, maximum, minimum, and standard deviation (SD)

Gait	**Walk**			**Trot**			**Canter**		
Location	**Head**[a]	**Front leg**[b]	**Hind leg**[c]	**Head**[a]	**Front leg**[b]	**Hind leg**[c]	**Head**[a]	**Front leg**[b]	**Hind leg**[c]
Mean	0.89	0.76	0.77	1.32	1.32	1.30	1.70	1.72	1.69
Max	1.75	1.61	1.81	1.80	1.70	1.70	2.11	2.65	2.05
Min	0.63	0.61	0.61	1.11	1.15	1.13	1.55	1.55	1.53
SD[d]	0.29	0.11	0.18	0.10	0.09	0.09	0.08	0.13	0.08

[a] The sensor attached to the right side of the halter of the horse and step count calculated from acceleration data imported into MATLAB and run through a Fourier transform to determine step frequency

[b] The sensor attached to the distal portion of the right front leg of the horse slightly above the fetlock with a neoprene case over a neoprene horse splint boot. Step count calculated from acceleration data imported into MATLAB and run through a Fourier transform to determine step frequency

[c] The sensor attached to the distal portion of the right hind leg of the horse slightly above the fetlock with a neoprene case over a neoprene horse splint boot. Step count calculated from acceleration data imported into MATLAB and run through a Fourier transform to determine step frequency

[d] Standard deviation

Table 8. Summary of the PROC GLIMMIX analysis for repeated measures comparing the step frequency (in Hz) processed by Fourier transform from measurements from an accelerometric device placed in three different locations (head, front leg, hind leg) on the participating horses (n=24) performing three different gaits (walk, trot, and canter)

				Confidence Interval[a]	
Gait	**Location**	**Estimate**	**SEM[b]**	**Lower bound**	**Upper bound**
Walk	Head[c]	0.8942	0.01431	0.8660	0.9224
	Front leg[d]	0.7676	0.01453	0.7389	0.7963
	Hind leg[e]	0.7793	0.01430	0.7510	0.8075
Trot	Head[c]	1.3228	0.01442	1.2944	1.3513
	Front leg[d]	1.3222	0.01447	1.2936	1.3508
	Hind leg[e]	1.3023	0.01425	1.2742	1.3304
Canter	Head[c]	1.7050	0.01464	1.6761	1.7339
	Front leg[d]	1.7144	0.01453	1.6858	1.7431
	Hind leg[e]	1.7016	0.01446	1.6731	1.7301

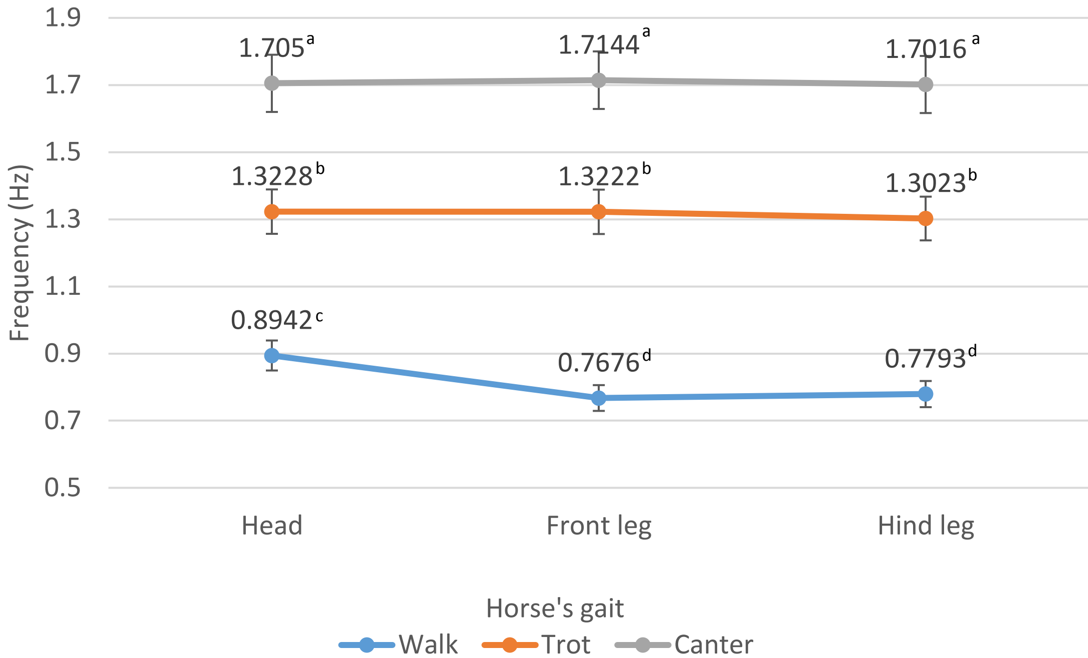
Simple effects

Gait	**Location**	**Location**	**Adj. P-value[f]**
Walk	Head[c]	Front leg[d]	<0.0001
Walk	Front leg[d]	Hind leg[e]	0.8009
Walk	Head[c]	Hind leg[e]	<0.0001
Trot	Head[c]	Front leg[d]	0.9994
Trot	Front leg[d]	Hind leg[e]	0.5224
Trot	Head[c]	Hind leg[e]	0.4997
Canter	Head[c]	Front leg[d]	0.8688
Canter	Front leg[d]	Hind leg[e]	0.7677
Canter	Head[c]	Hind leg[e]	0.9816

Interactions	**P-Value**
Gait	<0.0001
Location	<0.0001
Gait*Location	<0.0001

[a] 95% Confidence interval
[b] Standard Error of Means
[c] The sensor attached to the right side of the halter of the horse and step count calculated from acceleration data imported into MATLAB and run through a Fourier transform to determine step frequency
[d] The sensor attached to the distal portion of the right front leg of the horse slightly above the fetlock with a neoprene case over a neoprene horse splint boot. Step count calculated from acceleration data imported into MATLAB and run through a Fourier transform to determine step frequency
[e] The sensor attached to the distal portion of the right hind leg of the horse slightly above the fetlock with a neoprene case over a neoprene horse splint boot. Step count calculated from acceleration data imported into MATLAB and run through a Fourier transform to determine step frequency
[f] Adjusted with Holm-Tukey

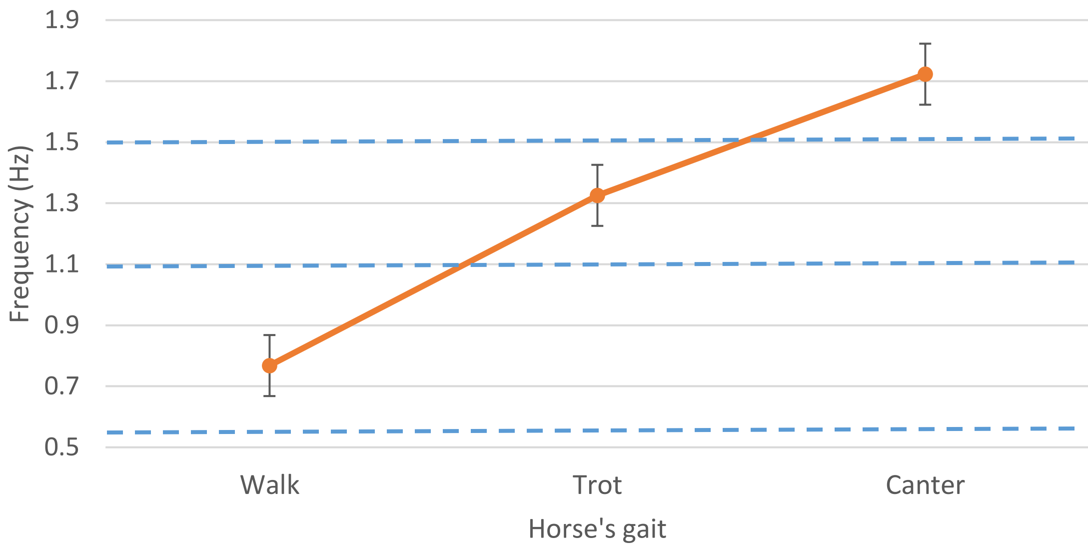
Figure 17. Mean step frequency (Hz) calculated using MATLAB for 60 seconds at three gaits (walk, trot, canter) from three sensor locations on the horse (head, front leg, hind leg) by location with 95% confidence intervals



Superscript letters indicate groups showing statistically significant differences (P≤0.05).
[a] the mean frequency for the canter was not statistically different (P>0.05) across the three locations but was statistically different from the trot and walk (P<0.0001).
[b] the mean frequency for the trot was not statistically different (P>0.05) across the three locations but was statistically different from the canter and walk (P<0.0001).
[c] the mean frequency for the head location at the walk was significant different (P<0.0001) from the front leg and hind leg locations, and from the trot and canter (P<0.0001).
[d] the mean frequency for the front leg and hind leg locations at the walk were not significantly different from each other (P>0.05) but were different from the trot, canter, and head location (P<0.0001).
For the head location the sensor was attached to the right side of the horse's halter and for the front leg and hind leg locations the sensor attached to the distal portion of the leg of the horse slightly above the fetlock with a neoprene case over a neoprene horse splint boot.

Figure 18 presents limits for each gait. The frequency range for the walk is greater than or equal to 0.54Hz and less than 1.1Hz. For the trot, the frequency range is greater than or equal to 1.1Hz and less than 1.5Hz. Finally, the frequency cutoff for the canter is greater than or equal to 1.5Hz. This range contains two standard deviation of the mean or greater for all of the gaits.

Figure 18. Mean step frequency (Hz) and one SD[a] calculated from MATLAB Fourier analysis from accelerometer data from horses (n=24) wearing an acclerometric device on the distal portion of the front leg[b] at three gaits (walk, trot, canter). Dotted lines show determined frequency limits[c] to distinguish the gaits.



[a] Standard deviation
[b] The sensor attached to the distal portion of the right front leg of the horse slightly above the fetlock with a neoprene case over a neoprene horse splint boot. Step count calculated from acceleration data imported into MATLAB and run through a Fourier transform to determine step frequency
[c] Frequency range for the walk: ≥0.54Hz to <1.1Hz, trot: ≥1.1Hz to <1.5Hz, canter: ≥1.5Hz

Interactions with horse characteristics

The characteristics of the horses utilized (Table 1) include the weight, height, sex, age, breed, primary discipline, and number of shoes. A stepwise regression analysis was performed first for each horse characteristic and the step frequency, and then for each component separately and the frequency. In order to do this, PROC MEANS in SAS took the average frequency of the five trials for each horse for each gait. Then a regression was performed including linear effects of all the horse characteristics together.

There were no significant interactions between the weight, sex, age, breed, primary discipline, or shod status of the horses (Table 9). However, there was a significant interaction ($P<0.0001$) with the horse's height and the step frequency at the canter. Therefore, SAS obtained the stepwise regression parameter estimates for canter. The intercept was 2.42 ($P<0.0001$) and the height estimate was -0.01161 ($P<0.0001$). Thus, the following regression equation for the step frequency at the canter is as follows: Canter frequency = 2.4213 – 0.01161 x Height of the horse. This equation will allow for a more accurate estimate of the step frequency at the canter.

When SAS performed the regression with linear effects for each characteristic by component, there were no significant interactions ($P>0.05$). Burla et al. (2014) investigated the potential interactions of breed class, height, sex, age, and shoeing, and found no significant difference for height. Rather, a significant difference ($P=0.028$) was found between gait and breed class, leading to the analysis of the step frequency separated by breed class. The horses used in the present study were of a homogenous group compared to the horses utilized in the Burla et al. (2014) study which used horses, ponies, and gaited horses.

Table 9. Summary of the regression analysis comparing the step frequency (Hz) processed by Fourier transform on the characteristics of the participating horses (n=24) performing three different gaits (walk, trot, and canter)

Regression for each horse characteristic
Type I test of Fixed effects P-values

	Walk	**Trot**	**Canter**
Weight	0.6812	0.9528	0.0562
Height	0.6064	0.2047	<.001
Sex	0.8427	0.1543	0.7969
Age	0.5225	0.8534	0.2205
Breed	0.3727	0.9227	0.0857
Discipline	0.7001	0.6285	0.7449
Shod	0.7590	0.8119	0.9509

Stepwise regression parameter estimates for canter

Intercept	2.4213	P<0.0001
Height	-0.01161	P<0.0001

Regression with linear effects for each characteristic by component

	Walk	**Trot**	**Canter**
Weight	0.9903	0.4009	0.5678
Height	0.2234	0.7684	0.1346
Mare	0.8796	0.1831	0.3653
Age	0.3075	0.9702	0.7179
AQH[a]	0.1931	0.5788	0.7706
QHX[b]	0.6905	0.4669	0.4376
Western[c]	0.3676	0.1982	0.7298
Hunt[d]	0.2890	0.9997	0.3203
WR[e]	0.7267	0.7135	0.6461
HJ[f]	0.5824	0.6587	0.6348
All[g]	0.8654	0.9775	0.7891
Front[h]	0.6624	0.7214	0.5294

The population of horses had a mean weight of 544.31 kg and height of 157.48 cm (15.2hh) and the majority were stock type horses. There were 10 mares and 14 geldings.

[a] American Quarter Horse
[b] American Quarter Horse cross
[c] Primary discipline of the horse was western
[d] Primary discipline of the horse was hunt
[e] primary discipline of the horse was western reining
[f] Primary discipline of the horse was hunt jumping horse
[g] Horse had shoes on all four feet
[h] Horse had shoes on front feet only

CHAPTER V.

CONCLUSIONS AND IMPLICATIONS

Advanced activity monitors are able to provide recommendations to help users meet their fitness and nutrition goals and improve their overall health. Human medical professionals are able to use fitness trackers and activity monitoring to tailor health and wellness plans to their individual human patients. The current study tested the most appropriate place for a horse to wear a sensor to retrieve accurate data during the activity. Algorithms can be created from the data collected on the sensor to determine the gait of the horse.

Ideally, common horse illness could be prevented with such a device. For example, an accurate estimate of caloric expenditure could help horse owner prevent equine obesity (Harris, 2011). Furthermore, colic is the number one leading cause of death of horses in the U.S. and a proper nutrient management plan can help mediate the risk of colic (Traub-Dargatz et al., 2001). Given the success of fitness trackers for humans and the similarities in equine weight loss, activity trackers for equines could provide similar benefits.

The comparison of video analysis step count and accelerometer data processed through a Fourier transform in MATLAB determined the accuracy of the locations for the horse to wear the sensor. The Fourier transform returned a step frequency (Hz) to determine discreet thresholds for each gait. In addition, the characteristics of the horses were analyzed to determine any interaction with frequency values.

Conclusions

The three locations of interest investigated in the study were the head attached to the right side of the halter, the distal portion of the right front and right leg attached to a splint boot slightly above the fetlock. The correlation between the calculated step count and the video step count shows a strong, positive linear relationship in the front leg location (r_s=0.963, P<0.001). Overall, all three locations produced data that underestimated the step count (Table 6). At the walk, the front leg location step count was not significantly different from the video analysis, though it was significantly different (P<0.05) at the trot and canter. The absolute value of the differences across the gaits for the head location was 12.84, front leg location was 5.68, and hind leg location is 9.43. While the front leg location was significantly underestimating the number of steps across the gaits, the absolute difference was not as large as the other two locations. Therefore, accelerometer data collected from the right front leg was more accurate and closer to the steps counted from video analysis than the head or hind leg locations. The calculated step count could be adjusted with a constant to correct the value closer to the video step count by using the difference in the means. Thus, adding 3.9 steps to the calculated step count at the canter and 1.7 steps at the trot. The difference in the means at the walk was not significant and does not require a modifier.

The step frequency can be used for dynamic threshold algorithms that determine if the motion was sufficient to count as a step at each gait. The mean frequency for each gait is discussed in Table 7, along with the standard deviations. Therefore, the limits for each gait are presented in Figure 18. The frequency range for the walk is greater than or equal to 0.54Hz and less than 1.1Hz. For the trot, the frequency range is greater than or

equal to 1.1Hz and less than 1.5Hz. Finally, the frequency cutoff for the canter is greater than or equal to 1.5Hz. This range contains two standard deviation of the mean or greater for all of the gaits.

For the interactions of frequency and characteristics of the horses, there were no significant interactions between the weight, sex, age, breed, primary discipline, or shoe status of the horses (Table 9). However, there was a significant interaction ($P<0.0001$) with the horse's height and the step frequency. Thus, the following regression equation for the step frequency at the canter is as follows: Canter frequency = 2.4213 – 0.01161 x Height of the horse. This equation will allow for a more accurate estimate of the step frequency at the canter.

Recommendations for Future Research

In the interest of determining the most accurate estimate of caloric expenditure, horses wearing the sensor would need to be tested simultaneously with heart rate and indirect calorimetry. Oxygen consumption via indirect calorimetry is a common way to measure calorie expenditure. This method has been used in previous studies such as Dansen et al. (2015), Vermorel et al. (1997), and Eaton et al. (1995). Currently, there are published values that can be used to calculate energy expenditure from a variety of sources. However, the computed sensor threshold values need to be compared with heart rate and indirect calorimetry to validate the caloric expenditure values for each threshold to ensure the most accurate estimate.

The published values should provide a close estimate to the actual caloric expenditure, but the sensor will need custom calorie estimates that match the threshold

values. Additionally, threshold values are dependent on height. Breed has been shown in previous research to have significant interactions on gait and acceleration threshold, and on metabolic rate and methane production (Burla et al., 2014; Brinkmann et al., 2014; Martin-Rosset, 2012). Thus, additional characteristics of horses such as breeds should be collected for analysis for differences to tailor not only the threshold value, but also the caloric expenditure.

Typically, indirect calorimetry is performed while the horses are worked on a treadmill due to the equipment necessary for the analysis. However, given the level of detail desired for the sensor project, working the horses on a treadmill is not ideal. Barrey et al. (1993) reported the horse's stride frequency was significantly greater on the track versus on the treadmill. Similarly, the stride length was significantly shorter on the track than on the treadmill. Furthermore, on a treadmill, the horse does not encounter wind resistance and variance in terrain. This could potentially cause significant variances in the caloric expenditure. Thus, a portable respiratory gas analyzer should be used to obtain the most accurate caloric estimate for each horse. Fortier et al. (2015) compared such a portable gas analyzer with estimated oxygen uptake from heart rate and individual oxygen consumption relationship using trotter horses.

Therefore, the study requires at least one fully programed movement sensor, heart rate monitor, portable gas analyzer, and a variety of horses. The movement sensor will be fastened in the location determined by the current research, and the heart rate monitor and portable gas analyzer affixed according to manufacturer guidelines. To determine the power analysis for the number of horses required, two past studies could be used to estimate the variance. The study performed by Gerth et al. (2015) found a regression

coefficient of 0.90 when determining caloric expenditure from heart rate in dogs and Fortier et al. (2015) had a Pearson's correlation coefficient of 0.79.

Additionally, the data involving the interaction of individual horse factors on threshold value should be considered. The variety of horses may need to increase to verify or eliminate interaction on threshold and caloric expenditure. Previous work done by Eaton et al., (1995) worked horses on a treadmill for 2-4min to determine heart rate and caloric expenditure. However, Fortier et al., (2015) worked the horses from 1.5min to 52 min, depending on the intensity of the exercise. These examples can be used to determine the optimal length of time to work the horses at each threshold level. Once the caloric expenditure for each horse at the programmed threshold has been obtained, the horses' information should be analyzed to determine if there are any significant differences between characteristics of the horses. This information can be used to tailor the energy expenditure to the horse for more accurate estimates.

The recommended research would give valuable information on the caloric expenditure for a variety of horse characteristics. Additionally, it would allow for a frequency for each horse that would correspond with tailored caloric estimate. The research is needed to better understand the individual calorie expenditure at a given step frequency in various horses. The results from this study indicate accelerometry data collected from an accelerometer placed on the lateral aspect of a horse's front right leg is strongly correlated with the step count from video analysis and can be adjusted with a constant to correct the step value closer to the video step count by using the difference in the means.

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APPENDIX A. Code for MATLAB to convert 3-axis accelerometer data into step count and step frequency using Fourier transform

```
%   import the time series as array 't'

X = fft(x); %   import the accelerometer data series in x-axis as array
'x'
Y = fft(y); %   import the accelerometer data series in y-axis as array
'y'
Z = fft(z); %   import the accelerometer data series in z-axis as array
'z'

Fs = 8;      %   Sampling frequency (Hz)
L = length(x); %    Data Length (number of data)

% disp('Fast Fourier Transformation OK.');

% Fourier Analysis in x-direction
A2 = abs(X/L);
A1 = A2(1:round(L/2)+1);
A1(2:end-1) = 2*A1(2:end-1);
A1(1)=0;
A1(2)=0;
A1(3)=0;

% Fourier Analysis in y-direction
B2 = abs(Y/L);
B1 = B2(1:round(L/2)+1);
B1(2:end-1) = 2*B1(2:end-1);
B1(1)=0;
B1(2)=0;
B1(3)=0;

% Fourier Analysis in z-direction
C2 = abs(Z/L);
C1 = C2(1:round(L/2)+1);
C1(2:end-1) = 2*C1(2:end-1);
C1(1)=0;
C1(2)=0;
C1(3)=0;

% disp('Frequency Domain Transformation OK.');

f = Fs*(0:round(L/2))/L;    %   Frequency domain series

%plot the result in combine frequency spectrum
plot(f,A1);
hold on;
plot(f,B1);
plot(f,C1);

title('Frequency Spectrum');
xlabel('frequency, Hz');
ylabel('Magnitude');
```

```
legend('X-direction','Y-direction','Z-direction');

% disp('Frequency Spectrum Plot OK.');

%locate the peak frequency
[pks1,locs1] =
findpeaks(A1,f,'MinPeakProminence',max(A1)/4,'MinPeakDistance',0.5);
[pks2,locs2] =
findpeaks(B1,f,'MinPeakProminence',max(B1)/4,'MinPeakDistance',0.5);
[pks3,locs3] =
findpeaks(C1,f,'MinPeakProminence',max(C1)/4,'MinPeakDistance',0.5);

% disp('Peak Finder OK.');

%combining the peaks with locations
g1 = vertcat(locs1, pks1.');
g2 = vertcat(locs2, pks2.');
g3 = vertcat(locs3, pks3.');
g = horzcat(g1, g2, g3);

%sorting in ascending order
c = 1;
co = zeros(2,1);
cu = 0;
while c == 1
    cu = cu +1;
    c = 0;
    for i = 1:(length(g)-1)

        if  g(1,i) > g(1,i+1)
            co = g(:,i);
            g(:,i) = g(:,i+1);
            g(:,i+1)=co;
            c = 1;
        end
    end
%     if cu >= 10
%         break;
%     end
end

disp(['Sorting in ',num2str(cu),'cycle. OK.']);

%actual number of peaks
ps = 0;
if length(locs1) > length(locs2)
    ps = length(locs1);
else
    ps = length(locs2);
end

if length(locs3) > ps
    ps = length(locs3);
end
```

```
if ps == 0
    disp('Error');
end
%allocating the arrays
s = zeros(1,ps); % x coordinate
p = zeros(1,ps); % y coordinate

%find the peak
m = 0; %allocate peak's frequency
n = 0; %allocate peak's height
j = 1;

for i = 1:length(g)
    if m < g(1,i)
        % new location
        if m > 0.6 %% <<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<
          p(j) = n;
          s(j) = m;
          j = j + 1;
        end
        m = g(1,i);
        n = g(2,i);
    elseif n < g(2,i)
        % same location higher peak
         n = g(2,i);
     end
end

%plot the peaks
% plot(s,p,'o');
% text(s+.07,p,num2str(s.'));

plot(locs1, pks1, 'o');
text(locs1+.07,pks1,num2str(locs1.'));

plot(locs2, pks2, 's');
text(locs2+.07,pks2,num2str(locs2.'));

plot(locs3, pks3, 'd');
text(locs3+.07,pks3,num2str(locs3.'));

hold off;

%calculate the steps
T = L/Fs;
steps = T*s(1);

%showing the results
disp(['Frequency is ',num2str(s(1)),'Hz']);
disp(['Total Steps in ',num2str(T),' seconds is ',num2str(steps)]);
disp('Calculation Completed.');
```

APPENDIX B. Impact of horse program involvement on youth development of life skills

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Abstract. Increased knowledge and personal development are key goals of any youth horse program. Horse projects encourage youth to exhibit life skills such as decision-making, communicating, and critical thinking. By participating in such projects, youth develop life skills while improving their horse knowledge at the same time. To be successful with their horse project, youth must develop self-motivation and dedication, in addition to patience and persistence. Youth involved in popular horse programs were surveyed to evaluate the impact of their horse project participation on their knowledge and career goals. Target youth included members of 4-H, the Nebraska Quarter Horse Association, Nebraska Dressage Association, and the Iowa-Nebraska Hunter Jumper Association. The objective of this study was to evaluate the influence of 4-H horse project involvement on horse knowledge, future plans, and life skills of youth participants compared to youth involved in other horse projects. A total of 160 responses were collected, and of those responses 148 were enrolled in a 4-H horse project and 12 were not members of 4-H. The results of the survey indicated involvement in horse projects had a positive influence on youth's desire to help others and to continue their involvement with animals. While there was a slight numerical difference between the responses of youth in 4-H and non 4-H horse programs, the difference was not statistically significant in this study ($P>0.05$ in all instances). On a scale of 1 to 5 with 1 being strongly disagree and 5 being strongly agree, the mean response of 4-H youth asked if they felt their communication skills had improved through their horse project

involvement was 3.99, and non-4-H youth had a mean of 4.36. 4-H member's responses were numerically higher in regards to leadership skill improvement with a mean of 4.34 and non-4H youth had a mean of 4.17. Positive organizational skill development was nearly identical for both groups with a mean of 4.16 for 4-H youth and 4.18 for non-4-H youth. Participation in horse projects encourages youth to teach others, analyze animal husbandry, grow their knowledge, and lead them towards animal related careers.

Introduction

Increased knowledge and personal development are key elements of horse programs for youth. Horse projects encourage youth to exhibit life skills such as decision-making, communicating, and critical thinking (Smith et al., 2006). By participating in such projects, youth develop life skills while improving their horse knowledge at the same time. To be successful with their horse project, youth must develop self-motivation and dedication, in addition to patience and persistence. Anderson and Karr-Lilienthal (2011) previously reported positive influences on science based knowledge and life skill enhancement in youth participating in 4-H horse programs, resulting in more productive young people.

The objective of this study was to evaluate the influence of 4-H horse project involvement on horse knowledge, future plans, and life skills of youth participants compared to youth involved in other sanctioned horse projects.

Materials and Methods

A survey was developed using a mixture of Likert-type scaling, multiple choice, and select all that apply questions to assess the development of life skills. It was sent out

by email to youth in the Nebraska 4-H horse program, the Nebraska Quarter Horse Association (AQHA), Nebraska Dressage Association (NDA), and the Iowa-Nebraska Hunter Jumper Association (INHJA). There are approximately 1000 youth in Nebraska 4-H who were sent individual emails, the other associations provided the survey to their participants in a newsletter. The survey was completed online via Google Forms (Google, 2016) and developed for the variety of youth participants. The survey gathered demographic information such as gender, age group, and years in 4-H. Questions were categorized to ascertain the influence participation of a horse project had on the development of life skills, increased general horse knowledge, and future educational plans.

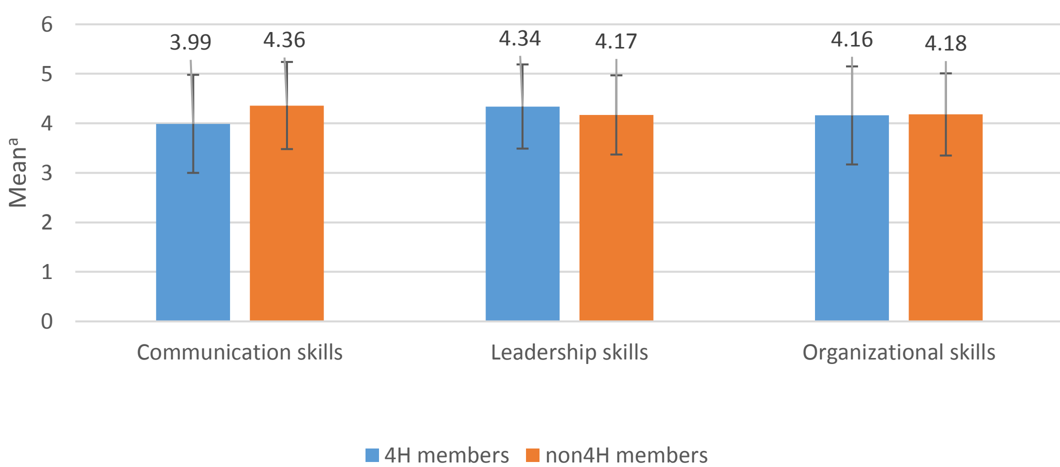
The survey was emailed to participants between July 20th, 2016 and August 9th, 2016. Responding to the survey was on a completely voluntary basis and no identifying information was collected. All survey procedures were approved by the University of Nebraska-Lincoln Institutional Review Board. SAS was used to run a Proc tTest on the data. All statistics were performed with SAS 9.4 for Windows.

Results and Discussion

A total of 160 responses were collected. A majority of respondents (73%, 116/159) were between 15 and 18 years of age, and 86.3% (138/160) were female. Two respondents were 5 to 8 years old, five were 9 to 11 years old, and the remaining 36 individuals were 12 to 14 years old. Of the respondents, 148 were enrolled in a 4-H horse project and 12 were not members of 4-H. Most (62.9%) of the participants had been in 4-H for 7 or more years, with 20.9% 5 to 6 years, and 46.2% 4 years or less.

Participation in a horse project had a positive impact on life skill development in youth, regardless of the program they participate (*P*>0.05 in all instances). The groups were kept separate for all analyses. There were no statistical difference between life skill developments of 4-H members versus non-4-H members. The life skill with the greatest numerical difference between 4-H members and non-4-H members was communication; however, this was not statistically significant. Youth in 4-H indicated talks, demonstrations, county fairs, district and state horse shows, seminars, and teaching others helped with their communication skills. Non-4-H youth responded speaking in front of a group, demonstrating skills with their horse, volunteering, leadership roles, and their friends helped improve their communication skills (Table 1). Numerically, the life skill most influenced by participation in a horse program was leadership skills (Figure 1) and influenced by county fairs and teaching others (Table 2).

Figure 1. Influence of horse project participation on life skills gained from either 4-H horse program or other horse programs



[a]1 = strongly disagree, 2 = slightly disagree, 3 = neither agree nor disagree, 4= slightly agree, 5 = strongly agree. N=160; 4-H members n=148, non 4-H members n=12

Table 1: Youth responses[a] where they had gained communication skills from their involvement with their horse project.

Activity	4H	Non4-H
Demonstrations	49	3
Mentoring	16	0
Talks/Speeches	15	0
Friendships/talking to others	15	2
Leadership roles	12	1
Contests	12	0
Other	9	0
Chose not to respond	73	6

[a]Youth were allowed to write in their own responses. The responses were then filtered into categories. N=160; 4-H members n=160, non-4H members n=12.

Table 2. Youth responses[a] where they developed leadership skills through involvement with their horse project.

Activity	4H	Non-4H
County fairs	125	6
Teaching others	102	6
Demonstrations	92	7
District horse shows	79	4
Talks	74	7
State horse shows	72	3
Seminars	28	1
Breed shows	27	1

[a]Youth could select all that applied to them. N=152; 4-H members n=142, non-4-H members n=10.

Other studies have reported positive influences and life skill development of youth participants in animal projects (Ward, 1996; Smith et al., 2006). In a survey of youth involved in 4-H horse projects, a positive influence on life skills such as handling pressure, respecting officials, sportsmanship, goal setting, self-motivation, and leadership was reported (Anderson and Karr-Lilienthal, 2011).

Ninety-one percent of 4-H members responded they gained a great deal of knowledge from 4-H shows, followed by 4-H advancement levels (68.9%). Advancement levels are tests proctored by 4-H leaders over specific knowledge areas related to the horse project such as riding safety, health, and nutrition. Nebraska 4-H members must complete these level test to advance in their 4-H horse project and be eligible to participate in some classes. The majority of 4-H youth indicated 4-H shows, advancement levels, talks/demonstrations, and clinics/seminars helped them gain knowledge. The non 4-H youth cited they also gained knowledge from 4-H activities, in addition to AQHA, Dressage, and hunter jumper shows (Table 3). The non-4-H youth that indicated they gained knowledge from 4-H activities may have previously been 4-H members. In addition, some 4-H clinics and seminars are open to non-4-H youth.

Table 3. Youth responses[a] where they had gained a great deal of knowledge from the following organizations and activities.

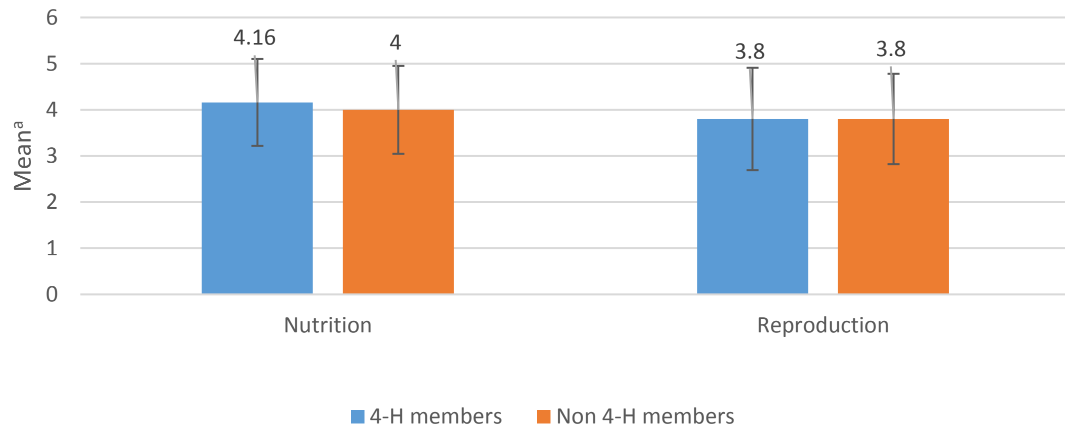
Organization/activity	4-H members	Non 4-H members
4-H shows	135(26.6%)	4(16.7%)
4-H advancement levels	102(20.1%)	3(12.5%)
4-H talks and demonstrations	94(18.5%)	3(12.5%)
4-H clinics and seminars	76(15.0%)	3(12.5%)
AQHA shows	42(8.3%)	1(4.2%)
Breed expositions	18(5.6%)	2(8.3%)
Rodeo, team roping	11(2.2%)	1(4.2%)
Hunter jumper	10(2.0%)	2(8.3%)
Pony Club	8(1.6%)	1(4.2%)
Lessons/schooling shows	6(1.2%)	1(4.2%)
Dressage	1(0.2%)	2(8.3%)
Other	14(3.6%)	1(4.2%)
Total	**507**	**24**

[a]Youth selected all the organizations and activities that applied to them and could write in their response in the “other” category. N=160; 4-H members n=148, non 4-H members n=12.

While not statistically different, eighty-seven percent of 4-H youth responded they have helped less experienced people with their horse projects, compared to only 70% of non 4-H youth. However, the majority of non 4-H respondents (81.8%) said they teach their friends about what they have learned with their project at least once a month compared to only 56.9% of 4-H members. Both groups are teaching and helping their friends about what they have learned through their horse project, even if in slightly different ways.

Respondents in both groups indicated the area they have gained the most knowledge from their participation in their horse project is in horse showing (93.9% for 4-H members and 90% for non 4-H youth). This was followed by horse tack (89.2%% for 4-H members and 90% for non 4-H youth) and horse care (86.2% for 4-H members and 80% for non 4-H youth). Showing horses is a large component of the equine industry, thus it is logical youth would gain the most knowledge in areas related to exhibiting horses. When asked if they had gained a better understanding of the nutrition of horses after participating in a horse program, 43.9% of 4-H youth and 36.4% of non 4-H youth said they strongly agreed and 34.5% and 30%, respectively, slightly agreed (Figure 2). The response was slightly less when asked about their understanding of reproduction; 33.1% of 4-H youth and 30%% of non 4-H youth said they strongly agreed and 31.1% and 30%, respectively, slightly agreed participation in a horse program increased their understanding of reproduction (Figure 2).

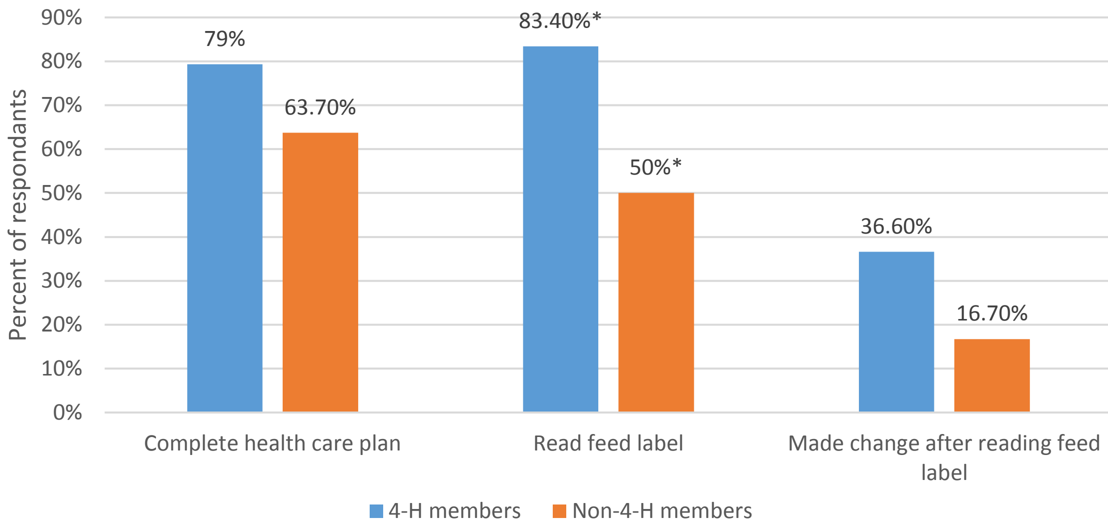
Figure 2. Influence of horse project on increased horse knowledge gained from either 4-H horse program or other programs



[a]1 = strongly disagree, 2 = slightly disagree, 3 = neither agree nor disagree, 4= slightly agree, 5 = strongly agree. N=160; 4-H members n=148, non 4-H members n=12

When the participants were asked if they had developed a health care plan for their horse, 79.3% of 4-H youth and 63.7% of non-4-H youth reported they had, or were in progress. This difference was not significant (*P*>0.05). In regards to their horse's nutrition, when asked if the youth had read the feed label and decided to make a change resulting from their involvement in a horse program, 83.4% of 4-H youth responded they had looked at the label and 36.6% made a change to their horse's diet. However, only 50% of non 4-H youth had looked at the label and 16.7% made a change as a result. The difference between 4-H and non-4-H youth reading the feed label was significant when equal variances were assumed (*P*=0.004). Whether or not the youth made a change was not significant (Figure 3). This disparity could be due to the 4-H advancement levels, which require youth to understand a feed label, what they feed their horse, and to develop a heath care plan. Other programs may not stress this area and focus more on showing their horses.

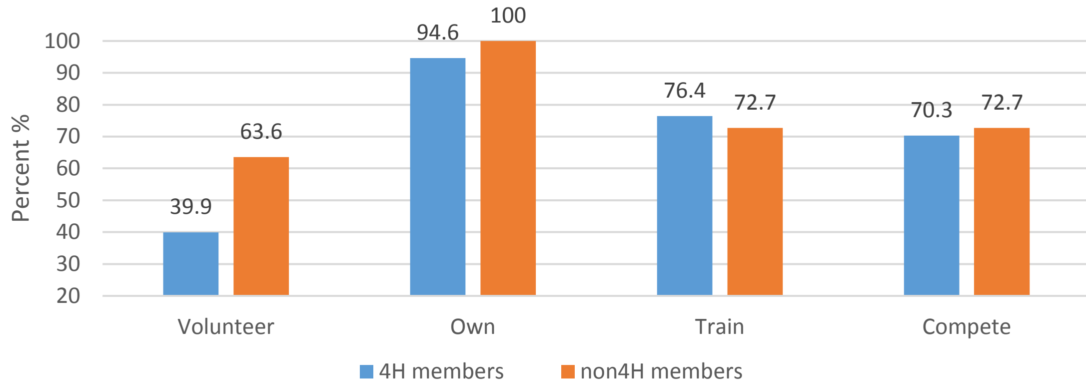
Figure 3. Health care and feed label knowledge of 4-H youth vs non-4-H youth



N=160; 4-H members n=148, non 4-H members n=12

Involvement with horse programs has fostered a desire to continue working with animals as an adult. For example, 94.6% of 4-H youth and 100% of non 4-H youth responded that as an adult they wanted to continue to own animals. Over 70% of both the 4-H and non 4-H groups wanted to continue to train and compete with their animals as adults, and 39.9% of 4-H youth and 63.6% of non 4-H youth wanted to give back and volunteer with an organization related to animals later in life (Figure 4). Only 6 (six) of the 4-H participants indicated they did not want to be involved with animals as an adult.

Figure 4. Desire of Youth to Continue Working with Animals as an Adult in 4-H and non 4-H Youth



Youth were allowed to select all that applied to them.
N= 160; 4-H youth n=148, non 4-H youth n=12.

Horse programs also appear to be excellent at recruiting potential candidates for academic programs. The majority (144/148 (98%) of 4-H members and 10/11 (90.9%) of non 4-H members) indicated after high school they plan to obtain a college degree. For this degree, 63.9% of 4-H members and 81.8% of non-4-H members stated their desired degree is related to animals. However, 58.1% of 4-H youth and 90.9% of non 4-H youth strongly agreed their participation in horse related activities influenced their career path. An additional 27.7% of 4-H youth slightly attributed the influence to their participation in horse related activities. These results indicated horse projects support life skill and career development and can assist youth in making educated career choices and help them become productive citizens.

Conclusions

Horse enthusiasts have understood the value of connecting kids with horses. Smith et al. (2006) demonstrated that individuals who exceled at horsemanship also had a positive relationship in developing life skills such as decision making, communication,

goal setting and problem solving. Additionally, Anderson and Karr-Lilienthal (2011) showed participants in 4-H horse programs feel better prepared for college and want to go to college because of their experiences in 4-H. The work and effort youth put into their horse projects helps create a positive motivational experience that encourages learning and career exploration. The results of this study suggest the impact on youth is not significantly different between youth enrolled in a 4-H horse program versus other horse programs, however the number of non 4-H respondents was only 12 compared to 148 4-H members. Participating in horse projects of any nature allows kids to utilize the experiences as a conduit for increased science based knowledge and life skill development, helping to make the youth more productive members of society presently and in the future.

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