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Quantifying Equine Behavior Utilizing GPS

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QUANTIFYING EQUINE BEHAVIOR UTILIZING GPS

by

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ABSTRACT

GPS tracking systems have been around for many years and are used to track, map, determine precise locations, navigate, and get precise time measurements on a number of different animals, devices, vehicles, and much more. The use of GPS tracking systems on animals has been a huge breakthrough in the cattle industry since this means farmers no longer have to monitor their cattle manually, but can do remotely. The research that has previously been done on cattle tracking can now be applied to horses, although as horses are used in a much different manner than cattle the data will go on to indicate the overall movement of the horse, the use of pasture, and time spent grazing. This information can then be used to potentially lower cost of living for horses as well as potentially improve quality of life for them, since we may be able to detect changes in movement or behavior which are indicative of injury or other problems. Technological advances over the past several years makes the use of GPS cost effective and open the opportunity to monitor different types of animals remotely, making it easier to alert farmers, or other horse owners, to possible problems on their property. Taking all of this into consideration, the question at hand is: how can the use of a GPS collar indicate behavioral changes and pasture usage of horses? I hypothesized that the GPS monitors would be able to detect small movements of horses which would indicate position in their pasture, or grazing, and also detect movements that are outside of each horse's normal movements which may indicate some kind of illness or issue in their pasture. The results of this study show that using GPS to track equine movement can indicate their behavior. Though without more precise devices, it is difficult to differentiate between certain movements like resting or grazing.

ACKNOWLEDGEMENTS

I'd like to first thank Dr. Colt Knight for taking on the role as my thesis advisor, as well as all of my other committee members including Dr. James Brophy, Dr Robert Causey, Dr. Melissa Ladenheim, and Dr. David Marcinkowski. The continuous support they've all provided me not just with my thesis but as educators as a whole has truly made me into the student I am today. Their unwavering confidence in my abilities to put my best foot forward is what gave me the strength to stick with the Honors College and complete my thesis. I'd also like to thank my parents; their constant love and support was key to my success through college, and I can't thank them enough for all of the things they continue to do for me. Lastly, I'd like to thank my sister for being the best role model I could have asked for. I know without a doubt I wouldn't be where I am without her support.

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LITERATURE REVIEW

October 4th, 1957 is marked in history by Russia launching Sputnik 1, the first satellite to successfully orbit the earth. From this satellite scientists from the Applied Physic Laboratory (APL) at John Hopkins University noticed that the satellite gave off a frequency of radio signals which got stronger the closer the satellite was to earth, and weaker the farther away the satellite was to earth, meaning they were able to track the satellite's movement in relation to the satellites distance from the earth. This is known as the Doppler Effect (Brief History of GPS: The Aerospace Corporation., 2021; Dunbar., 2015). From this, the idea for a Global Positioning System or GPS was created, instead of tracking the satellite from the ground, they could potentially track something on the ground with the satellite. This led to the creation of the Technology Review Assistance Notification Standards Integration and Testing Program (TRANSIT) by the United States Navy which was created as a satellite navigation program specifically made for the Polaris ballistic missile submarines, but was withdrawn from service in 1996 (United States Department of Agriculture., 1999).

The Department of Defense created the first Global Positioning Systems satellite in 1978 better known as Navigation System with Timing and Ranging (NAVSTAR), and it was meant to service all branches of the military. NAVSTAR GPS is made up of 24 satellites that run in 6 orbits which circle earth every 12 hours (United States Department of Agriculture., 1999; Brief History of GPS., 2021). The satellite design has two downlink frequencies: L1 and L2. Both downlink frequencies are used by civilians and are broadcasted on a frequency of 1575 MHz and L2 is broadcasted at 1227 MHz (United States Department of Agriculture., 1999: Maddison et al., 2009). The key to the abilities

GPS possess is triangulation. To do this, a receiver takes a precise measurement of the time that it takes for the satellite signal to make it to earth, which is less than a tenth of a second (Logsdon., 2021). Signals from three other satellites are processed in a similar manner and from there the built-in computer is able to calculate the point where all 4 frequencies intersect.

The initial creation of the GPS was for military use, but as time went on civilians were given access to it, opening the door for further research to be conducted with GPS devices in many different areas. Wildlife biologists were the first researchers to modify these early GPS devices to map out wildlife locations and movements. This data was a large breakthrough for the time, but in today's terms the data wasn’t very precise, with coordinates being considered accurate if they fell within a 5 km distance (Kenward., 1987). Spatial resolution was poor because in the beginning receivers for the GPS device required 10-30 minutes to find GPS satellites and correlate their position, and then further needed a complete download of an almanac upon powering up. Speeding this process up was necessary to be able to conduct accurate research on animals in the future (Tomkiewiczet et al., 2010). Before GPS systems were created and utilized, farmers kept their cattle fenced in, thus limiting the area they had access to and therefore also limiting the forage they had access to. Management of these areas relied upon consistent observation either on foot, horseback, or in a vehicle equipped with a light source to see the area in the dark (Roath and Krueger., 1982; Turner et al., 2000). This didn’t allow for consistently accurate measurements since tracking abilities were limited to a day or two at most, and reliability of accurate information from a human source can’t be guaranteed. Being able to utilize GPS devices that had the ability to track livestock grazing patterns for 24 hours a day for weeks or months at a time allowed for more consistent and reliable data than had been previously available.

The next biggest hurdle facing researchers working with livestock was the cost per GPS device, most costing upwards of $1800. More recently Knight et al. have been able to develop a low cost animal collar, costing about $250 per collar with the ability to track in 10 minute increments for over 5 months. Another low cost GPS tracker is the HeraLogger. It was developed to be a lightweight wearable GPS made of PVC casing (165 mm x 71 mm x 25 mm) which contained the GPS, data logger, and battery pack as well as an external magnetic patch antenna and in total weighed 170 grams (Rainham et al., 2008). Furthermore, the HeraLogger is accurate within 2-5 m of its positioning and has 16-71 hours of running time. This unit costs $450 not including the labor cost associated with making it. Though the price of a GPS device has gone down considerably in the past few years, it is still a large investment to make. Putting GPS collars on only some of the herd would lessen the cost but wouldn’t provide as accurate data since it wouldn’t depict the entire herd's movements. This could lead to skewed data depending on which cattle are wearing the devices, so to ensure the most accurate data an entire herd should have their own GPS tracker. Creating a GPS on one's own requires a certain amount of skill and an investment of the individual's time to create a working device, make modifications, and test it. The benefits of creating a GPS system on ones own stem from being able to customize the device to fit a specific person's parameters, is much more cost effective and can be recharged multiple times until the battery in the VHF transmitter runs out (Allan et al., 2013). If a person does not have the ability to create their own GPS tracker they can invest in the low cost trackers.

While GPS devices are continuously being improved and updated, there are still potential inaccuracies in their data. In a study done by Matthews et al., they reviewed 24 studies that were conducted over 13 species, and not all locations provided by the GPS collar were found to be accurate enough to use in specific studies without having a coarse resolution meant for that specific research. Using a Horizontal Dilution of Precision (HDOP) or position dilution of precision (PDOP) is what most researchers use to distinguish data points that are inaccurate and should be excluded from the data report. Obstructions can also occur between the GPS receiver and satellites which may cause locational errors in the data, consistent equipment testing can lessen these performance errors (Tomkiewicz et al., 2010). Data collected by Hansen et al, 2008 showed that errors in precision occurred when there was low availability of sky as compared to areas with high available sky. Other factors which may affect the accuracy of GPS devices include clock errors, ephemeris errors, atmospheric delays, multipathing, and satellite geometry (Perry et al., 2009). There has not been a set protocol for GPS utilization, so even with the increased research not only in cattle management but in wildlife management as well there is no set standard protocols in place to correct errors in Geographic information system (GIS) software or in analyzing the GPS software (Knight., 2016).

Though not much research has been done in the equine industry in relation to GPS monitoring, there have been a few studies conducted. In one study conducted by Hampson et al., 2010 they found that domesticated horses lived a far more sedentary lifestyle than their feral counterparts. This could be affecting their overall health and hoof quality because of their low level of movement within a paddock and/or stable from an early age. In another study done on race horses, it was found that GPS units provided a more accurate measure of daily workload and could provide further insight into horse training with connection to injuries (Kingston et al., 2006). Understanding workload on multiple horses could help prevent injury in the future if researchers are able to find correlation between movement on GPS and injury. Research into using GPS collars on feral equines showcased an increase in understanding their foraging habits as well as their movement behaviors at any given time since the collars allow for consistent data collection (Hennig et al., 2020). Turner et al, 2000 states that manipulations of paddock shape and size, fence design, and different grazing systems could affect the grazing efficiency of cattle. Taking this research into account then, the possibility of improving horse movement efficiency within a paddock depends on the overall size and distribution of feed within it.

When describing behavior collected by GPS the time interval should be similar to the length of the behavior exhibited by an animal. Though using less than 1 minute intervals would capture behaviors that do not encompass an entire minute, this does not improve classification (De Weerd et al., 2015). Choosing the proper time interval for different animals may depend on the overall size and body mass of the animal. Larger animals display fewer behavior traits within the same time frame as smaller animals, so further research should be done to ensure the best tracking (Mueggler et al., 1965). Understanding behavior and movement metrics that use the Global Navigation Satellite System (GNSS) is important because this system shows how data is affected by using different time intervals by providing positioning, navigation, as well as timing on any satellite. Finding deviations in typical livestock behavior could potentially pinpoint when an animal is going into oestrus, has contracted a disease, or succumbed to predation (Muybridge et al., 1957). This would benefit researchers in the future to identify heat cycles more efficiently resulting in more pregnancies, providing aid to animals that have gotten sick before they show actual signs of illness, and to identify when cattle have passed away sooner than they typically would since they wouldn't need to wait until they found the carcass to confirm the death.

Cattle behavior varies widely in comparison to equine behavior, but identifying equine behavior based on previously conducted research on cattle behavioral patterns allows for a better understanding of animal movement as a whole. Cattle most typically have more land available to them than horses, and they tend to stay away from the rougher terrain, preferring the flatter areas found in valley bottoms, fields, or ridge tops (Mueggler., 1965). Even though they may prefer a flatter terrain, Arnold, 1981 found that environmental situations can have an effect on animals behavior as time goes on. Another study done by Bennett, 1985 found that dominant animals may prevent the more submissive animals from using certain areas, and would go as far as to control feeding area, shade, mineral supplemental feed, as well as shelter, which could go on to alter typical grazing behavior.

Identified abnormal horse behavior includes wood chewing, cribbing, stall kicking, or weaving and circling. Each of these behaviors has been researched and reasons have been identified as to why they happen. Wood chewing may mean there is a lack of fiber in their diet or be a result of boredom. Cribbing is when the horse grasps something between their teeth and swallows air. Although this does not have a specific reason for occurring, it can cause the horse to lose weight, wear their top incisors down, and be prone to colic. Stall kicking includes pawing the walls and floor as well as kicking of the stalls, and most typically happens at feeding time. Weaving and circling is when a horse shifts its body from side to side or in a circling motion as suggested by the name. These habitual movements can be caused by lack of companionship, or lack of exercise. Horses are considered to be social animals, so some of these problems may stem from boredom if they're housed alone. A solution would be to provide them with a companion, even from different species like chickens or goats which have been used successfully to provide companionship to horses that were lonely and helped curb those bad habits (Depew., 2019).

Equine behavior analysis began with frame-by-frame photographs in the 1870's, and was created by Muybridge and Marey. This time period was coined the first "golden age" of equine gait analysis (Muybridge et al., 1957). Continuation of research into movement and horse gait has resulted in the ability to detect age, disease, injury, or fatigue with overall health changes or sport performance (Lamoth et al; Moe-Nilssen et al., 2005). Using inertial measurement units (IMU) allows for determining objective gait measurements in horses by mounting the sensor on the midline of the horse (e.g. pelvis and head) which uses a signal decomposition routine (Pfau, 2005). A study done with the IMU system software (R version 3.2.3) collected statistical data using a package called 'nlme' (version 3.1-121) which compares linear and nonlinear mixed effects models, 'BlandAltmanLeh' (version 0.1.0) calculated the motion captured. This took into account 150 stance phases, 77 of which were for the front limb with 37 of those being for walking and 40 of them for trotting. The IMU error percentage increased with trotting over walking; when walking the error percentage was 3.7% and 1.9%, whereas when trotting it was 8.4% and 9.1%. In daily use the IMU system works well to show gait changes which can alert an owner to lameness as well as other diseases. Using both this system with a GPS collar or combining both into one given system has the potential to lower the cost and make it more available to the public since it has shown to be effective in identifying gait abnormalities.

Understanding the different gaits of a horse is important in tracking movement since they're all characterized by specific movements of the horse. A walk is typically between 3.5-5 mph and is the natural gait for every breed, each foot leaves the ground and strikes it again all at different times. A trot is characterized by a diagonal set of legs raised before the other set touches the ground, and has an average speed of 7-10 mph, but if it's an extended trot it can average from 10-30 mph. This gait is also considered to be normal and functions on a 2 beat gait type. A canter is a neutral gait for all horses and is a 3 beat gait with an average speed of 6-10 mph. This gait type is considered as either a collected or restrained gallop and is defined by the base support changing from one to two diagonal then back to one leg supporting the weight. A gallop is a four beat gait and is the fastest gait for a horse with an average of 12-20 mph; though this is a natural gait for all breeds, thoroughbreds are bred specifically for this speed of gait. This gait is very similar to a canter except that the set legs do not land at the same time and the lead can change depending on the direction being traveled (Stone).

The digestive system of equines is also much different than cattle as they're able to utilize very large quantities of forage, making them continual grazers. Continual grazing means they spend between 13-18 hours per day grazing without needing to stop like ruminants, such as cattle, which spend about a third of their day ruminating. Grazing time is mainly dependent upon the type of forage available, the animals consumption behavior, and level of nutrient needed. This means that when horses have feed readily available they will develop their own personal grazing habits, but if feed is limited they will eat whatever forage, hay, or grazing material is offered to them (Griffin., 2019; USDA., 2010). Equines are biting top grazers, meaning that they will eat the top half of plants until that specific area is grazed short, then they'll move onto areas where the grass is longer and more appealing. Equines will graze what they enjoy eating the most until they run out of it, whether that be forage, hay, or the available grass in their pasture. The more grazing options a horse has available to them the more likely they are to be more selective in what they eat. If horses inhabit one pasture for an extended period of time, the area can experience leaf removal of the plants from overgrazing which results in the plant being unable to photosynthesize. Without photosynthesis the plant cannot produce their own food and then rely on their root system to create energy to regrow after each grazing period. If these spots are overgrazed too often it can cause bare spots, weed growth, as well as soil erosion. If overgrazing happens too often it can destroy the entire pasture instead of just leaving a few bare spots (USDA., 2010).

The two most common types of grazing systems most typically used on horse farms are rotational and continuous. Rotational grazing moves horses between pastures during the grazing season to allow the pasture to rest and regrow. This system is meant to increase pasture productivity since it fragments pastures into several smaller paddocks. The length of rest for each pasture is dependent upon the amount of horses grazing as well as how many pastures there are, but typically most pastures will need 30 days of rest for every 7 days of grazing. Advantages of this system include the potential to manage more horses with less acreage but still have the ability to improve the quality and availability of forage. It also leads to better manure management; since the horses are being moved around more often, the dropping areas are more spread out. The disadvantages of this system include higher cost since it requires more fence management. Continuous grazing systems are when horses are put onto a singular pasture for longer periods of time. This system is less expensive and requires less daily management. A disadvantage to this system is that it is difficult to manage how intensely the pasture is being grazed which can lead to over grazing. It is important to enforce proper stocking rates in continuous grazing systems which are dependent on pasture size (Horses., 2020).

BACKGROUND

Horse management protocols differ extensively from livestock management, especially in the case of smaller stables, but previously conducted research done on livestock management on rangelands have paved the way for scientists to conduct similar research on different animals in varying environments. Over 20 years ago ranchers relied on human observation to locate their animals, which was not always accurate because of weather conditions, fatigue of the observer, and physical limitations (Turner et al., 2000). Advancements in global positioning systems (GPS) tracking as well as motion sensors have provided researchers with a more accurate way to collect data since GPS collars allow for 24 hour monitoring. Improvements in the mechanical operations of collars came with a decrease in their cost. Initially collars could cost upwards of $2000, but with technological improvements and time, collars can now be built between $150 to $450 making them more affordable and accessible. (Bailey et al., 2018; Knight et al., 2018; Rainham et al., 2008). Affordability in GPS collars allows for more scientists to conduct their own research, which would create more data to compare new research findings with. Current collar static testing proved to be 95% accurate over a 24 hour period (Turner et al., 2000). Previous research conducted on livestock with accelerometers, which is a device that measures acceleration or vibration, and from this they were able to identify illnesses and other welfare concerns in cattle when these conditions created a change in movement or behavior (Bailey et al, 2018). These findings suggest that similar conclusions could be made in horses, meaning GPS collars could be a preventative measure in their overall health.

Taking all of this into consideration, the question at hand is: how can the use of a GPS collar indicate behavioral changes and pasture usage of horses? I hypothesized that GPS monitors would be able to detect small movements which would then indicate position in their pasture, or grazing, and also detect movements that are outside of each horse's normal movements which may indicate some kind of illness or issue in their pasture.

METHODOLOGY

To begin, Dr. Knight had several GPS' units which were Columbus P-1, Professional GPS Data Loggers which are shown in Figure 1. The GPS was pried open gently to remove the battery since the battery that it came with only had a 1900 mAh (milliampere/hour) capacity and is shown in Figure 2. In figure 2 the opened GPS is shown with the original battery still inside. We replaced the battery with one that has 5200 mAh which allows for up to 7 days of use before needing to be charged again. A comparison between the two batteries is shown in Figure 3. The two wires that connected the original battery to the GPS were severed and the battery was then removed. The new battery wires were spliced to then be attached into the GPS. In figure 3 a comparison between the old and new battery are shown. Two holes were drilled into the device for those wires to be run through to allow for the attachment of the new battery which is shown in figure 4. To ensure no water damage would occur to the device we added liquid electrical tape to cover the two holes that were drilled. This dried over a 24 hour period before the GPS was then put back together. Once completely dried the GPS was snapped back together and the finalized GPS is shown in figure 5.

Figure 1. Columbus GPS prior to being taken apart.

Figure 2. Opened Columbus GPS showcasing the 1900 mAH battery that was removed to input the larger 5200 mAH battery.

Figure 3. A comparison between the smaller 1900 mAH battery and the larger 5200 mAH battery.

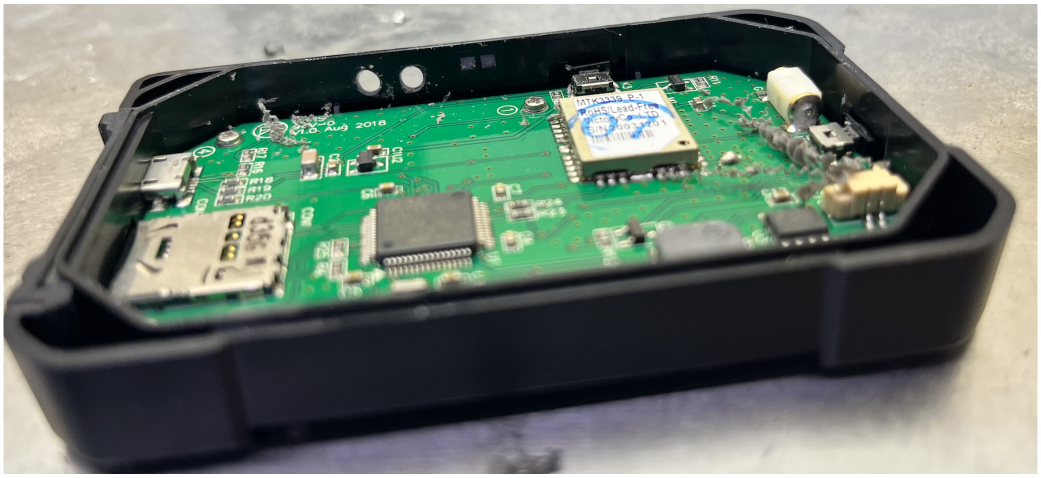

Figure 4. The motherboard of the GPS, showing the two drill holes in the sidewall where the wires for the 5200 mAH battery were put through to connect it to the GPS.

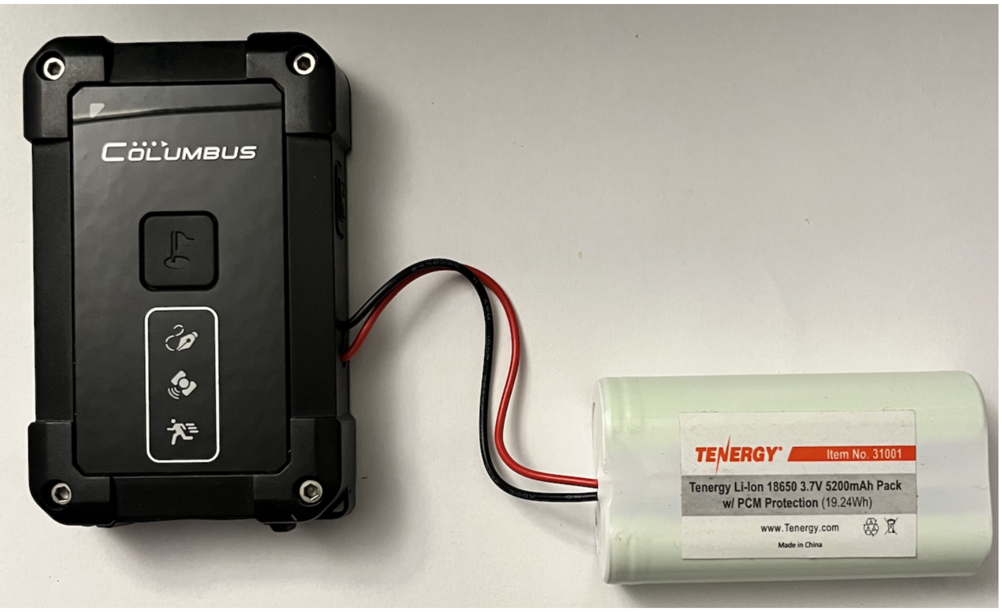

Figure 5. The finished GPS model used for the study with the longer lasting 5200 mAH battery.

A weaver halter was purchased from Tractor Supply and then Dr.Knight sewed in the GPS pouch to ensure a secure holding for the physical GPS. The pouch that will hold the GPS was made from 5 ounce vegetable tanned leather and cut from a premade paper template as shown in Figure 6. In figure 7 the actual cut out from the vegetable tanned leather is shown, the leather was cut using a box cutter which was given a new blade to ensure the cleanest cuts were made so that the leather would not rip it while the collars were being worn due to wear and tear while the horses are roaming. The finished product is shown in Figure 8 after being sewn shut so it would be able to hold the actual GPS. The GPS was then turned on and allowed to warm up during each data collection until the tracking sensor began to blink. At this point the GPS was then placed into the pouch on the halter and secured in. For each individual horse the halter was put on and then adjusted to fit each horse accordingly to ensure it would not affect grazing or drinking abilities. Once fitted to each horse they were led out to pasture by a student or teacher from the University of Maine, once placed into the pasture they were allowed to roam freely.

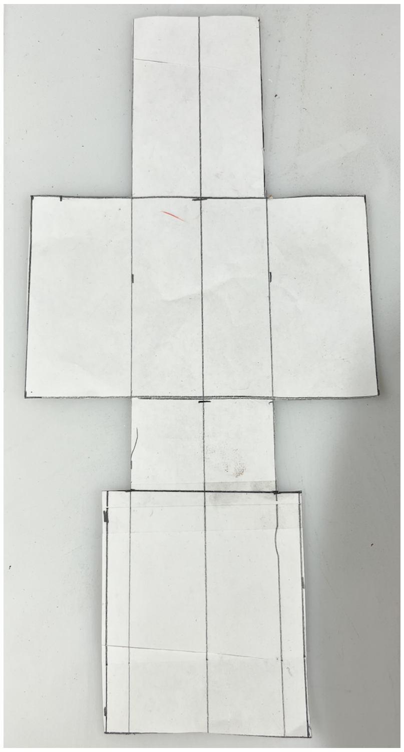

Figure 6. Paper cut out template for the pouch that holds the GPS.

Figure 7. The cut vegetable tanned leather prior to being sewn shut in the shape of the paper cut out shown in Figure 6.

Figure 8. The finished version of the vegetable tanned leather pouch.

A total sample of four adult thoroughbred mares were used for this pilot study. The horses were part of the University of Maine's J. Franklin Witter Teaching and Research Center and chosen out of a total of 8 mares that the Witter Center had. Inclusion criteria were based on age and length of time spent at the Witter Center to ensure the horses included in the study had a varied background which could showcase behavioral differences. Diva was born on 4/4/2017, making her five years old when the research was conducted; she joined the Witter Center on 7/27/2020 which means she had been getting handled by students for approximately 21 months. Diva is the youngest horse at the Witter Center and the shortest inhabitant at the equine extension as well as the only mare included in the study that had a companion mare, named Laney, in her pasture area. Suzie was born on 4/11/2009 making her 13 years old during this study, she was brought to the Witter Center on 9/12/2013 meaning she has been part of the equine extension for over 8 years. Gina was born on 4/14/2003 making her 19 years old during this study and had been brought to the Witter Center on 9/5/2013 meaning she had been part of the equine extension for 8 years. Bliss was born on 3/22/1998 and was 24 years old during this study. She was brought to the Witter Center on 10/9/2006, Bliss is the oldest mare at the Witter Center as well as the longest inhabitant at the equine extension. Each horse is given approximately 1/4th of an acre of pasture to roam.

Visual observation began when the horse was released from their lead rope. Initial observation began on April 17th, 2022 with Gina. The GPS began collecting data from 7:49 am and ended at 9:12 am, for a total of one hour and twenty three minutes in total. Bliss was the second horse to be observed on April 18th, 2022 starting at 7:35 am and continuing until 9:35 am for a total of two hours. The third house to be observed was Diva on April 20th, 2022 beginning at 7:32 am and ending at 9:48 am for a total of two hours and sixteen minutes. The final horse to be monitored in the initial data collection was Suzie, on April 21st, 2022 starting at 7:28 and going until 7:55 am for a total of 27 minutes. A written observation was made each time the horse did an activity, those included; grazing, traveling, rolling, and resting. Each of these activities were then manually time stamped, and later correlated to certain behavioral movements based off of the standard deviation of velocity given by the GPS.

The second round of data collection was done with the same four horses, all of which was conducted on April 22nd, 2022. Gina was once again the first horse to be observed, this time starting at 7:32 am and ending at 8:03 am for a total of 31 minutes. Suzie was the next horse to be observed, The halter was removed from Gina and transferred to Suzie to begin collecting data at 8:05 am and was removed at 8:36 am for a total of 31 minutes once again. The halter was then removed from Suzie at that time and placed on Bliss at 8:39 am and collected data until 9:09 am for a total of 30 minutes. The halter was then removed from Bliss at that time and placed on Diva at 9:11 am and removed at 9:42 am for a total of 31 minutes and the device was then shut off.

RESULTS

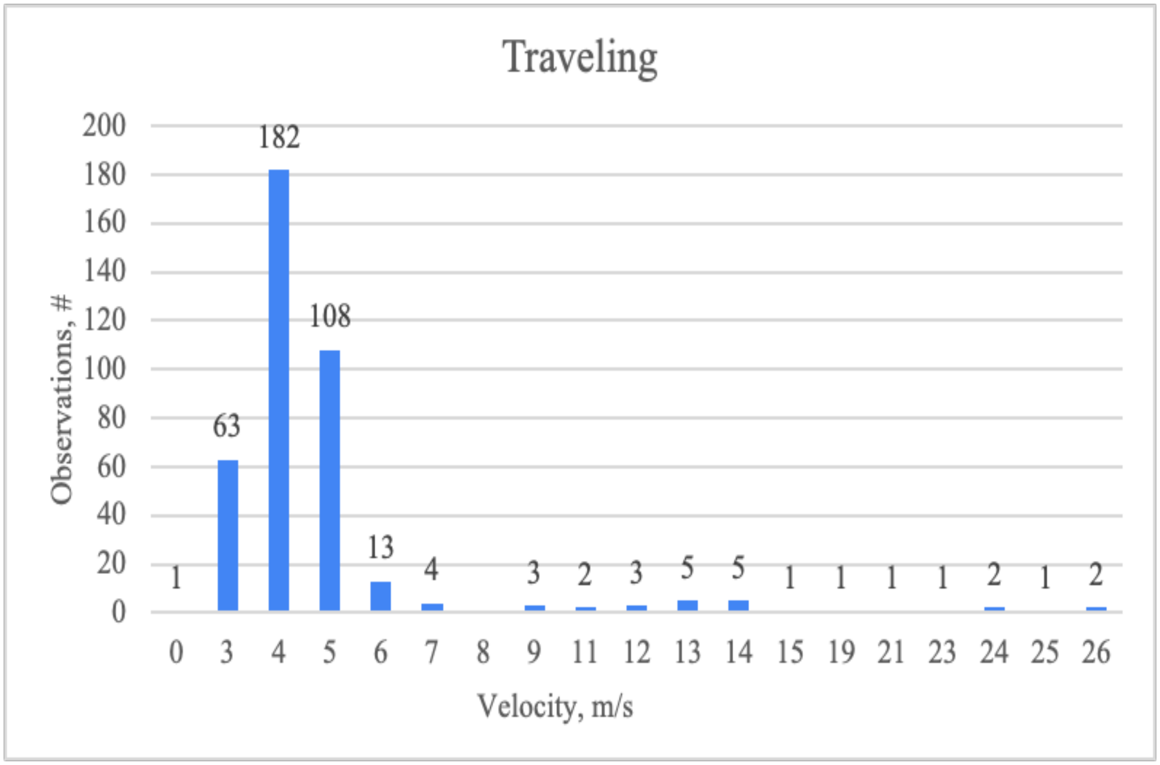

Figure 9.The number of times traveling behavior was detected at each velocity from 0-26 m/s .

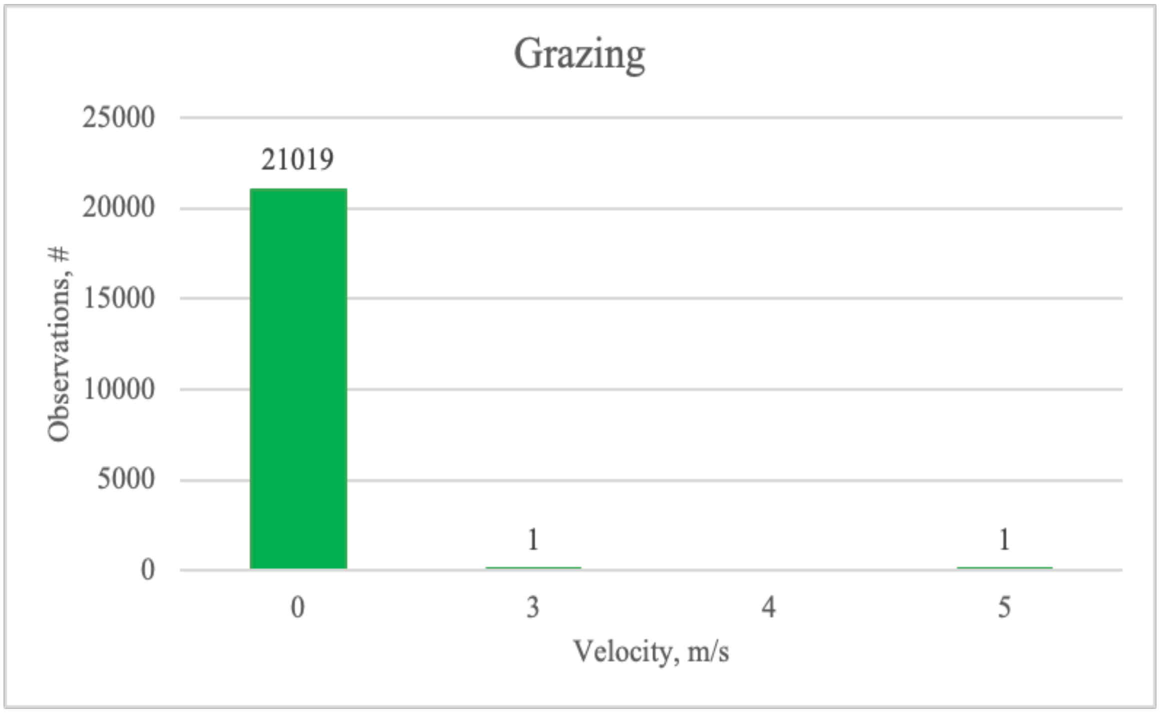

Figure 10. The number of times grazing was detected by the GPS tracker and the velocity at which they happened, showing two variations detected at 3 m/s and 5 m/s.

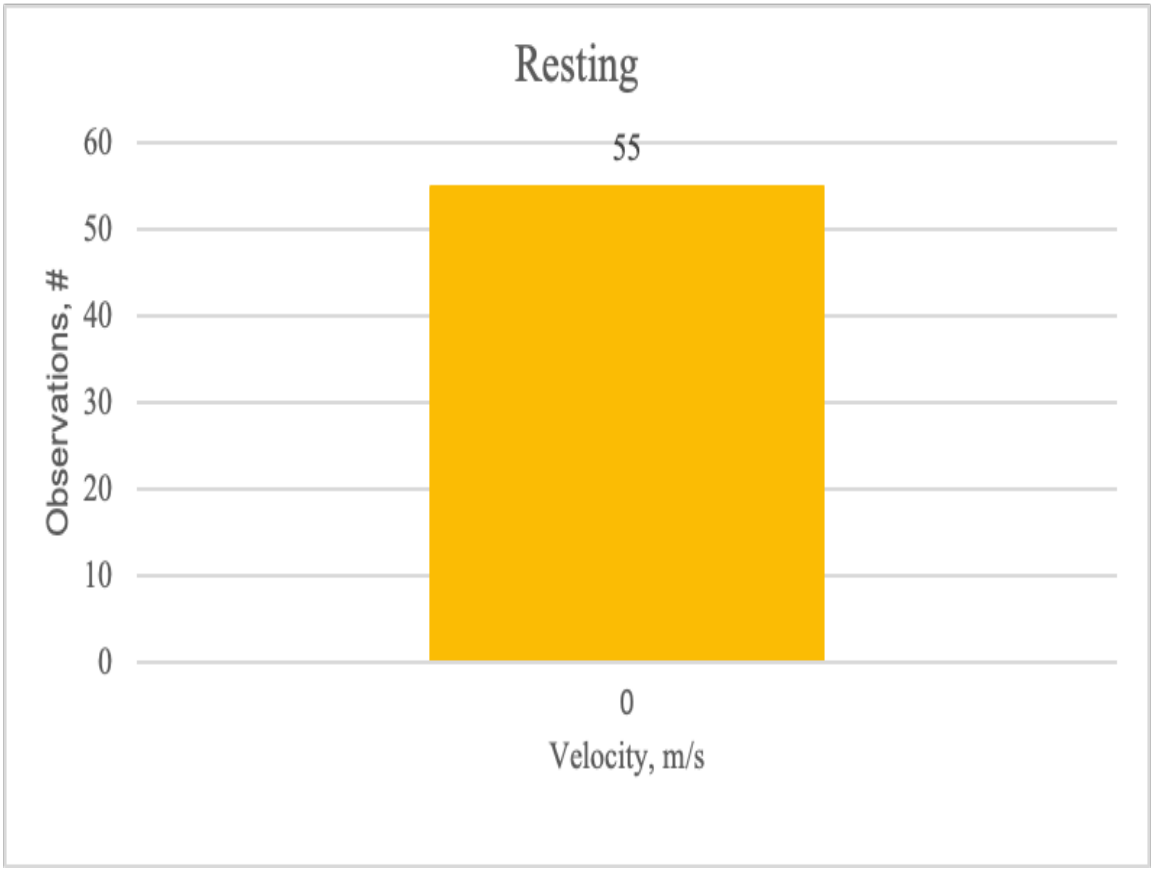

Figure 11. Number of times resting was detected by the GPS and the singular velocity at which the behavior was detected.

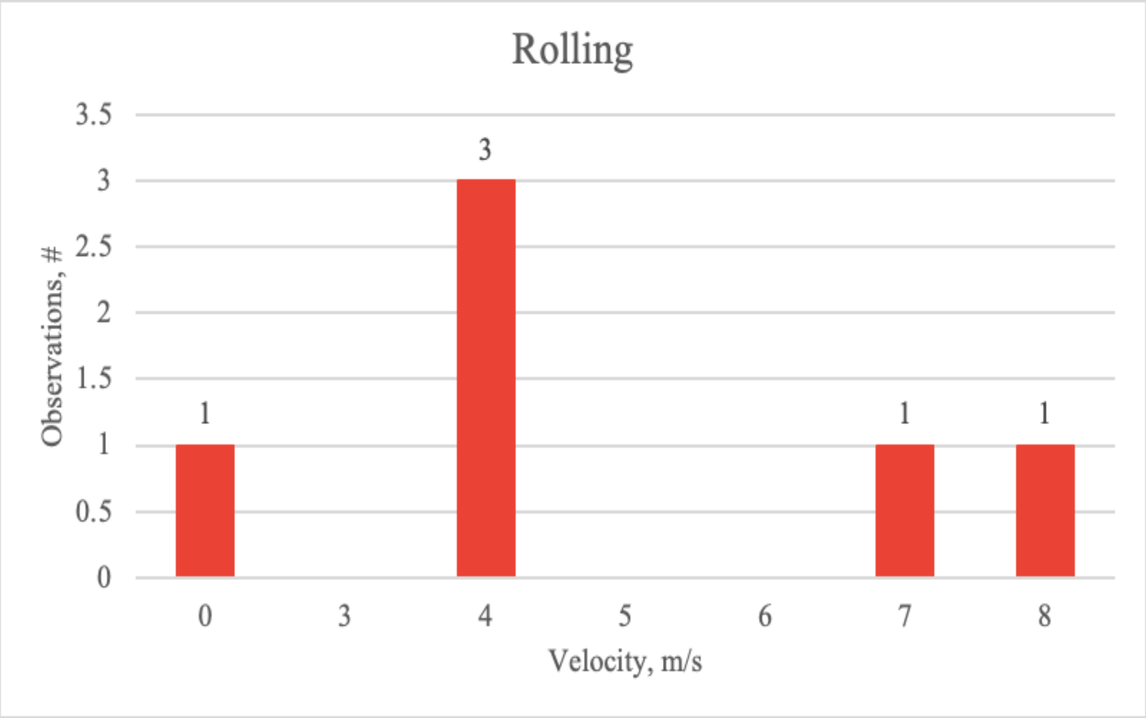

Figure 12. The number of times rolling was detected and their associated velocities.

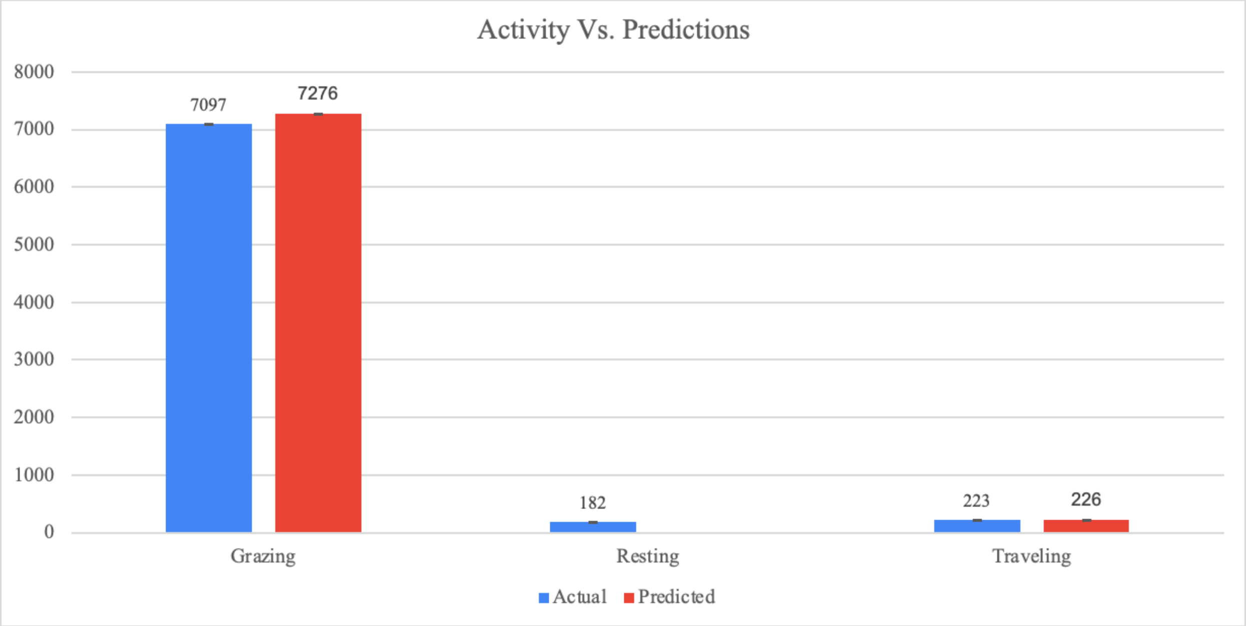

Figure 13. A comparison of accuracy between each activity and the number of times it was actually recorded and the predicted number of times it was supposed to happen.

A total of four mares were observed, ranging from the age of 5 years old up to 24 years old. The GPS data showed that there were a total of 21,480 observations made in the first round of data collection between all four mares. In that data it was found that the horses spent a total average of 97.9% of their time grazing, 0.3% resting, 0.03% rolling, and 1.9% traveling. This categorization was made based on visual observations that were later connected to GPS data points. Grazing velocity fell between 0-5 m/s, as shown in Figure 10, with a standard deviation of +/- 0.0 m/s. Overlap was seen between grazing velocity and resting velocity since resting velocity stayed at 0 m/s for all of the observations and grazing velocity most typically ran at 0 m/s as well. Traveling velocity as shown in Figure 9 ranged from 0-26 m/s but most notably fell between 3-6 m/s. Traveling has a total average velocity of 4.7 m/s and a standard deviation of +/- 5.4 m/s. Rolling had a maximum velocity of 8.1 m/s and a minimum of 0.0 m/s with an average velocity of 4.7 m/s and a standard deviation of 2.8 m/s.

There were noticeable numerical differences in behavior among mares. Diva had an average velocity of 0.0 m/s when grazing, but an average traveling velocity of 4.1 m/s with a standard deviation of 0.27 m/s. Her minimum traveling velocity was 3.7 m/s and her maximum was 4.5 m/s. In comparison Suzie also had an average grazing velocity of 0.0 m/s but had an average traveling velocity of 6.9 m/s with a standard deviation of 4.84 m/s. The minimum traveling velocity was 3.6 m/s and the maximum was 26.9 m/s. Suzie was observed completing a behavior that the other three horses did not complete, she spent some time rolling. The minimum velocity of this was 0.0 m/s and had a maximum of 8.1 m/s, with an average of 4.7 m/s and a standard deviation of 2.81 m/s. Gina contributed to one of the outliers in the data for grazing velocity, her minimum velocity was 0.0 m/s but her maximum velocity was at 5 m/s, still leaving with a standard deviation of 0.0 m/s but had a standard deviation of 0.07 m/s. Her traveling minimum was once again 0.0 m/s with a maximum of 7.0 m/s, making her average velocity 4.5 m/s and a standard deviation of 0.73 m/s. Lastly Bliss had the one other outlier for grazing velocity with her minimum grazing velocity being 0.0 m/s but a maximum of 3.6 m/s, the average velocity came out to 4.6 m/s and had a standard deviation of 0.69 m/s. Each of these observations is shown in Table 1 breaking down each mare's movements and total collected observations. In Table 2, it is shown that in the first study the mare's spent 97.9% of their time grazing, meaning that the majority of the time spent in their pastures was spent grazing rather than resting, rolling, or traveling.

In Table 3, the second study observations are broken down from horse to horse. All 4 mare's averaged 0.0 m/s while grazing as well as while resting. Bliss averaged 4.54 m/s while traveling, Diva averaged 4.37 m/s while traveling, Gina averaged 4.58 m/s, and finally Suzie averaged 8.69 m/s while traveling. None of the mare's in the 2nd study were found to roll so this data section was left out. In Table 4 it is shown that a total of 95% of the mares' time was spent grazing and only 3% of their time was spent traveling.

	Activity	**Min Velocity, m/s**	**Max velocity, m/s**	**Avg Velocity, m/s**	**SD**	**Observations**
Bliss						
	Grazing	0.0	3.6	0.0	0.04	7139
	Resting					
	Rolling					
	Traveling	3.6	6.5	4.6	0.69	62
Diva						
	Grazing	0.0	0.0	0.0	0.00	7605
	Resting					
	Rolling					
	Traveling	3.7	4.5	4.1	0.27	14
Gina						
	Grazing	0.0	5.0	0.0	0.07	4817
	Resting					
	Rolling					
	Traveling	0.0	7.0	4.5	0.73	164
Suzie						
	Grazing	0.0	0.0	0.0	0.00	1460
	Resting	0.0	0.0	0.0	0.00	55
	Rolling	0.0	8.1	4.7	2.81	6
	Traveling	3.6	26.9	6.9	4.84	158

Table 1. GPS data collected from study 1 over each individual mare's behaviors.

Activity	**Min Velocity, m/s**	**Max velocity, m/s**	**Avg Velocity, m/s**	**SD**	**Observations**	**Time Spent, Activity**
Grazing	0.0	5.0	0.0	0.0	21021	97.86%
Resting	0.0	0.0	0.0	0.0	55	0.26%
Rolling	0.0	8.1	4.7	2.8	6	0.03%
Traveling	0.0	26.9	5.4	3.3	398	1.85%
				Total	**21480**	**100.0%**

Table 2. GPS data collected from study 1 with each mare's data added together.

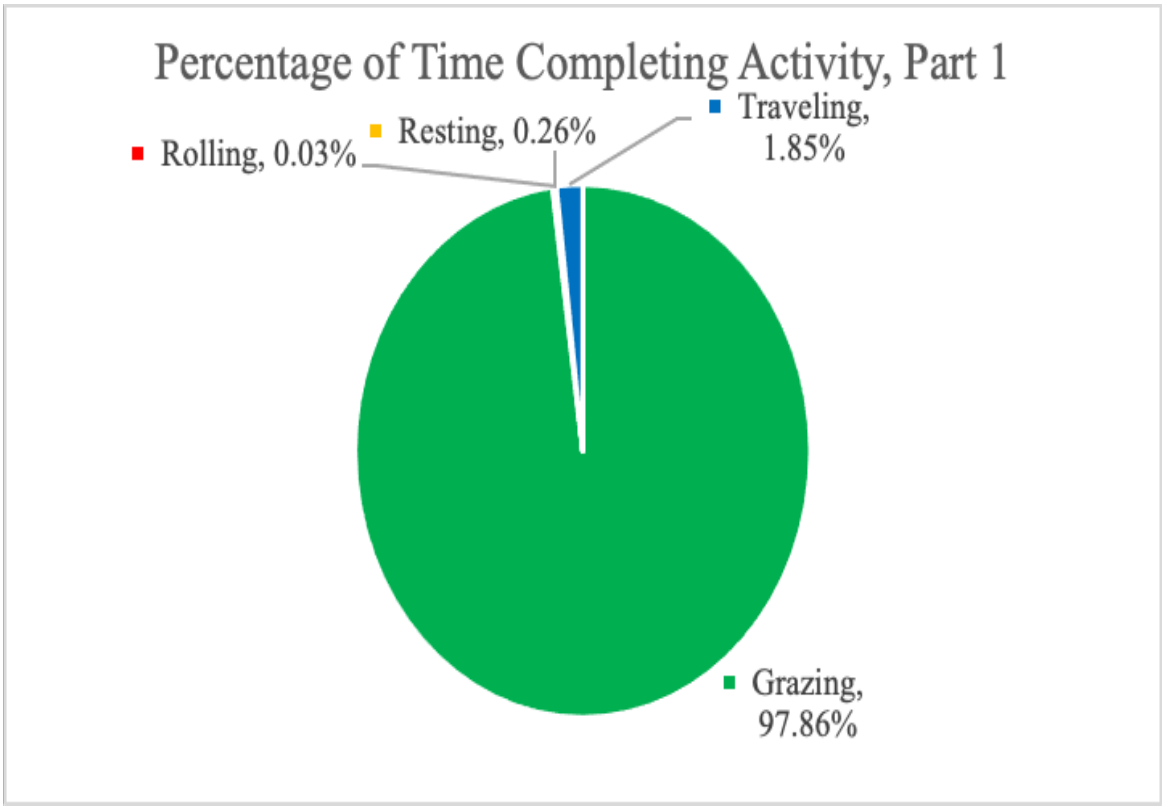

Figure 14. Comparison of time spent in study 1 doing each activity with all 4 mare's added together

	Activity	**Min, m/s**	**Max, m/s**	**AVG, m/s**	**SD**
Bliss					
	Grazing	0	0	0	0
	Resting				
	Traveling	3.6	6.4	4.537037037	0.6822745602
Diva					
	Grazing	0	0	0	0
	Resting	0			
	Traveling	3.8	5.7	4.37	0.5926400444
Gina					
	Grazing	0	0	0	0
	Resting	0	3.8	0.08131868132	0.5440612754
	Traveling	0	6.1	4.576521739	0.7983898747
Suzie					
	Grazing	0	0	0	0
	Resting				
	Traveling	3.6	32.9	8.685915493	7.842800079

Table 3. GPS data collected from study 2 over each individual mare's behaviors.

Activity	Min, m/s	Max, m/s	AVG, m/s	SD	Observation, #	Time Spent, Activity
Grazing	0	0	0	0	7097	95%
Resting	0	3.8	0.08131868132	0.5440612754	182	2%
Traveling	0	32.9	5.870852018	4.848822899	223	3%
				Total	7502	100%

Table 4. GPS data collected from study 1 with each mare's data added together.

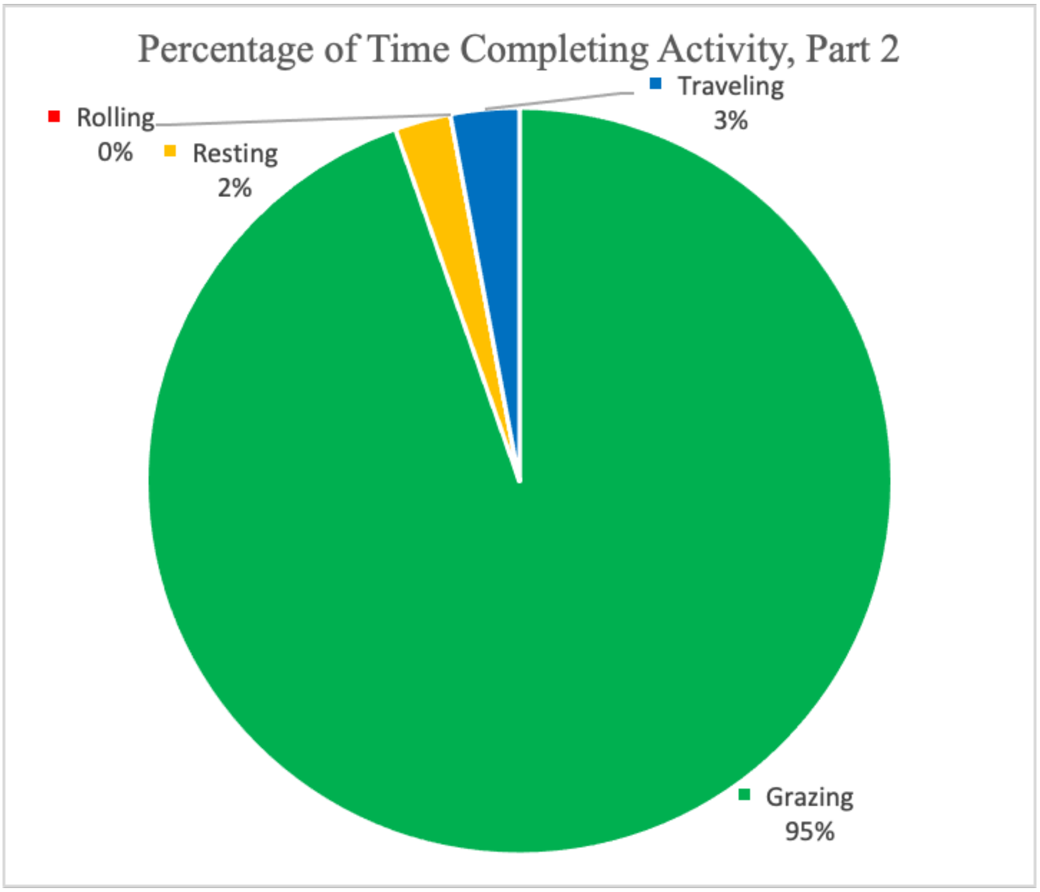

Figure 15. Comparison of time spent in study 2 doing each activity with all 4 mare's added together

By utilizing velocity, distance traveled, and spatial location of the animal, we were able to tell when the animal was traveling because they had a velocity of >3 m/s. However the horses did not move often while grazing, so differentiating resting and grazing behavior was impossible using GPS data alone. Our predictions based on GPS data were able to accurately characterize 97.6% of behavior in relation to grazing and traveling.

Figure 16 shows each pasture at the J. Franklin Witter Teaching and Research Center and the corresponding data points from each horse. These data points correspond to movements made by each mare as they moved around their pastures over the course of their time wearing the GPS halter. In Figure 17 a heat map is shown which indicates which part of each pasture is being used the most by the mare associated with that pasture area.

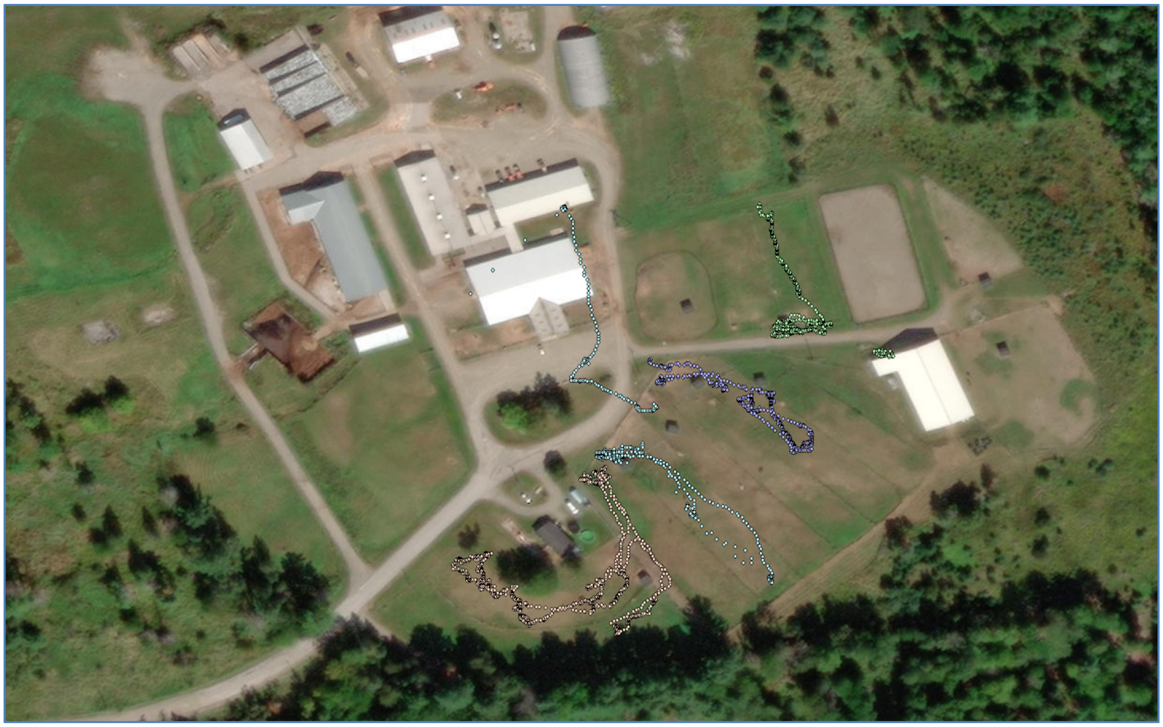

Figure 16. An aerial view of the J. Franklin Witter Teaching and Research Center with data points indicating horse pasture usage. The tan color is Gina, blue is Suzie, purple is Bliss, and green is Diva.

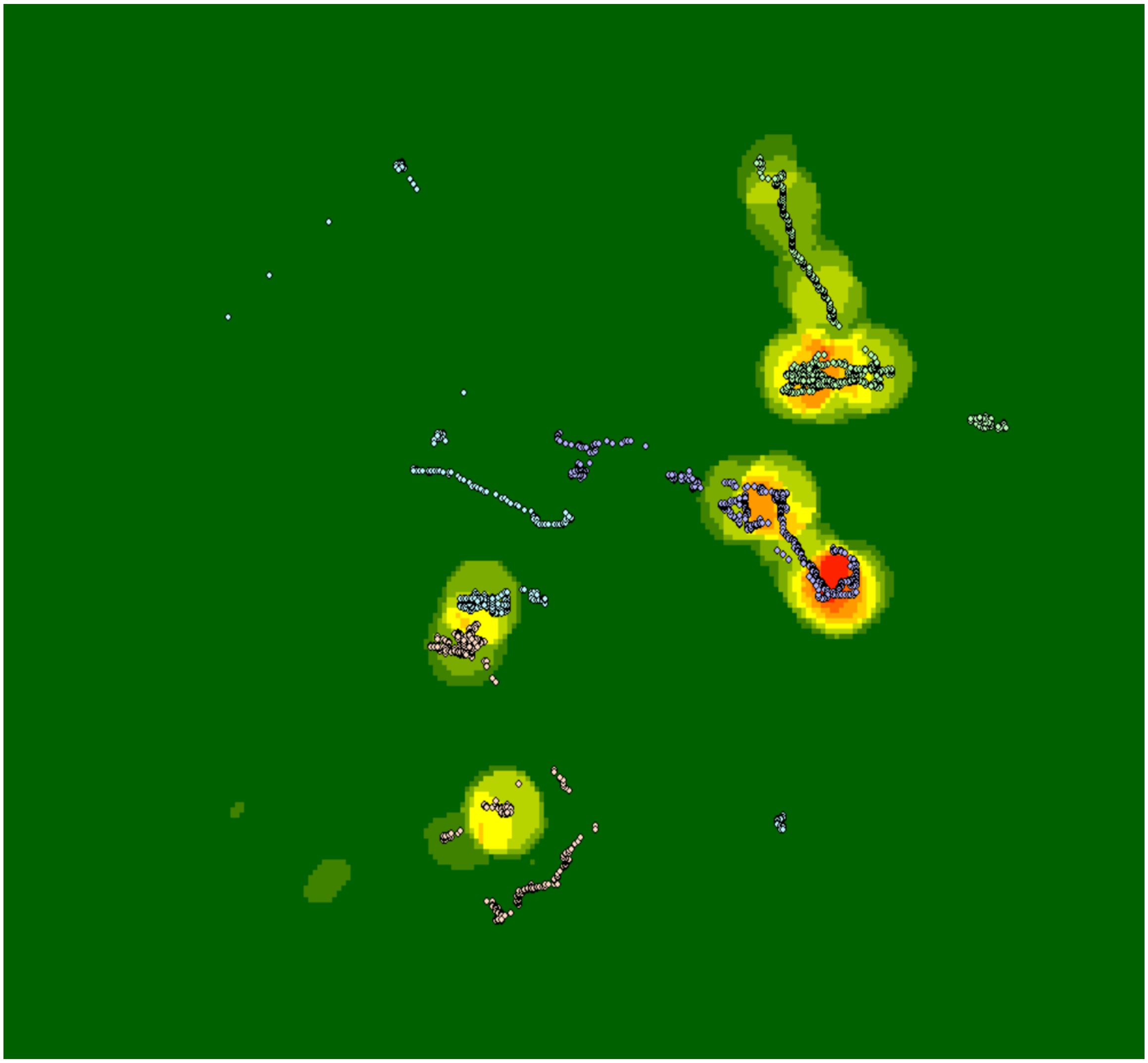

Figure 17. A heat map based off of Figure 16 data indicating where each mare spends the most time in their pasture. The tan color is Gina, blue is Suzie, purple is Bliss, and Green is Diva.

DISCUSSION

The aim of this study was to determine if equine behavior could be detected by using a GPS system to find correlations between movement and that subsequent behavior. Though this was a pilot study that was conducted on a limited sample due to the availability of equines, there were still several notable findings. The first being that 97.9% of the time the mares spent out on the pasture was spent grazing, thus falling in line with previous research that had been conducted which found that horses typically spend anywhere from 13-18 hours grazing in their pasture. With this information we could view horses' eating habits in real time to see whether their eating habits have changed over time depending on weather, terrain, or even potential ailments they may be having.

As shown in each of the graphs there is no data collection for 2 m/s, which matches previously conducted studies showing that the slowest pace a horse moves at is a walk, which falls between 3.5-5 m/s. The changes in velocity in Figure 9 show movement from 0-26 m/s, but there is potential to break up the traveling into walking, trotting, cantering, or galloping since, as was stated earlier, each gait type is broken up into different speeds. There is some overlap between each gait though, which is why for the sake of this research instead of distinguishing between each gate type, all of the movement was considered traveling so show that there is a difference between grazing and traveling which is well showcased.

Since Suzie was the only mare to showcase rolling there was not enough data to distinguish a roll from traveling since there was an overlap between 0 m/s to 8 m/s. Future studies may be able to collect more data on rolling which could allow researchers to find a distinction between that and traveling if enough data points were obtained. At this point it is only speculation based on a singular occurrence.

Initially it was hypothesized that the GPS monitors would be able to detect small movements which would indicate horses' position in their pasture, or grazing, and also detect movements that are outside of each horse's normal movements which may indicate some kind of illness or issue in their pasture.

In part, the GPS did signal movements which correlated to grazing, though it is not possible at this time to distinguish between resting and grazing since they're both typically marked at 0.0 m/s. There is potential for future researchers to differentiate between resting and grazing if they utilized a 3-axis accelerometer. This accelerometer would be able to measure up and down, side to side, as well as back and forth movements of the head which would emphasize when the animal was actually grazing or resting. There is also another possibility to differentiate between resting and grazing if researchers set GPS data collection points to summarize at 5 or 10 minute intervals by using velocity combined with their distance traveled. Since the mares used for this data were located on small pastures for short periods of time, they did not move around as much but there is the indication that these parameters work with this research.

Further research would need to be conducted to better document each mare's individual typical behavior to see changes in it over time, but with this preliminary data we can see that the four mares examined show cased typical equine behavior. Grazing for extended periods of time is normal in equines, usually lasting anywhere from 13-18 hours. Changes in eating habits, or a decrease in movement in the pasture could signal some kind of illness with the horse, but with the available information at hand there is no way to confirm that currently since this study only collected two sets of data and that information would require much more in depth study. Future studies should look into using a GPS as well as a device to monitor neck movement, such as the accelerometer mentioned earlier, which would help distinguish between resting and grazing. With the constant advancement in technology, there is the potential to make a real time GPS or accelerometer that could transfer data collected directly to a cell phone app which could alert managers to changes in behavior to indicate problems such as illness or lameness, or even alert them in real time if a horse got out of their pasture which would ensure the safety of all horses wearing this kind of device.

Diva was the only mare in this study that was paired with another mare when out in the pasture. As shown in the data, there was no considerable difference in her movements from the other mares, all of which were pastured alone. The biggest change in movement actually came from Suzie who is one of the middle aged mares included in the study. This may indicate that age and time spent being handled by students at the Witter Center does not have a significant impact on their overall behavior and their actions are really dependent upon their own natural behavior.

As shown in Figure 16, we can see that each horse uses a large portion of their pastures but as we can see in Figure 17 each horse has particular places that they tend to stick to based on the heat index which indicates the most popular spots in each mare's pasture. In a discussion with Dr.Causey, it was mentioned that Diva and her companion Laney may be moved to a different pasture area to preserve their pastures. Both of these figures show pasture usage and degree of which they're being used, which is a useful tool in pasture management for horse owners to indicate when they should move horses to new pastures. Another useful aspect to both Figure 16 and Figure 17 is that this also indicates which areas in their pastures are not being used, which could be helpful to horse owners so they can find whether the horse is avoiding those areas for a particular reason like lack of grazing material or if they just have a preference for a certain area in their pasture.

CONCLUSION

Now that this research has been conducted in the equine industry as it had been done previously in the cattle industry, we can see that horses do have different grazing habits and vary in their typical pasture use from horse to horse. The possibilities created by this research are boundless as it showed behavior changes which have the potential to detect abnormal behavior that could indicate illness, pasture area problems, or other unknown issues that have not yet to be considered. Continuation of behavioral research in the equine field is an important stepping stone in coming to understand these creatures better and providing them with the best life we can. Animals don't have the ability to verbally let their caretakers know immediately when something starts to feel off, but by reading their behavior with GPS, and/or other devices such as accelerometers, at every point throughout their day we can identify issues earlier than ever before.

This research was in part successful in indicating the differences in grazing behavior to traveling behavior, but was unable to detect differences in grazing behavior to resting behavior due to the overlap in velocity with both behaviors being detected at 0 m/s. From these findings future researchers should be able to further the research by adding an accelerometer which would detect movement in the horse's neck, enabling them to distinguish between resting movements to grazing movements.

Though in this research there was no observation of weaving or circling, data collection does indicate that this may be a possibility in future studies with a more sensitive GPS as well as a sensor which would indicate head movement. With a sensor that detects minute movement in the neck this may also give horse owners the ability to detect cribbing, wood chewing, stall kicking, as well as weaving and circling. The GPS would be able to indicate precise location in the pasture, or potentially within their stalls and the sensor would collect data if the horses neck stopped moving in a particular position to alert to abnormal behavior such as cribbing or wood chewing.

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