Unbridled Insights: Exploring Equine Behavior Through GPS Tracking and Analysis

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UNBRIDLED INSIGHTS: EXPLORING EQUINE BEHAVIOR THROUGH GPS TRACKING AND ANALYSIS

By

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A Thesis

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Horse behavior in pasture and grazing environments remains understudied, despite the substantial domestic horse population in the United States. This paper explores the utilization of Global Positioning System (GPS) technology to detect equine behavior, specifically focusing on grazing behaviors. By analyzing GPS data from (n=9) Standardbred horses, this study aims to establish the capabilities and accuracy of the Columbus P-1 data logger as a low-cost GPS unit for equine research, without the use of accelerometers. Through the data provided by the GPS unit, a model to distinguish grazing, resting, drinking, walking, trotting, and running was developed with satisfactory detection rates. The model is developed using a series of parameters, including speed, distance traveled, distance to water and shade, and heading changes. The model achieved the highest detection rates for resting (104.4%) and grazing (100.1%). Limitations of the model include difficulties in detecting rolling, grooming, and drinking behaviors, these behaviors are limited to due not using an accelerometer. Future research could further refine the model, validate it under different conditions, and investigate the impact of seasonal weather on equine behavior. Implications of this research include the potential improvement of equine health monitoring and pasture management. This study advances the ability to leverage GPS technology to enhance our
understanding of equine behavior in pasture, which would benefit the welfare and management of domestic horses
DEDICATION

I would like to dedicate this manuscript to my son Lorenzo. I did not know it at the time I started this journey, but I did this all for you.
ACKNOWLEDGEMENTS

I would like to try and thank Dr. Colt W. Knight for taking me on as his first master of science student. Where he does not hold a faculty obligation to the University of Maine School of Food and Agriculture, he really did not have to take me on as a graduate student. I would like to thank him for all the time and effort he has put not only into my projects, but into my career development and helping me discover a professional purpose. He has pushed me to become a better person, educator, and academic. He has supported me through many life and academic trials, never letting me lose sight of my goals and aspirations. Goals and aspirations that he helped inspire and instill in me. He has pushed me to no longer be terrified of public speaking and taught me what it means to be a part of Cooperative Extension and its value to the community and education system. He truly has had an influential impact on my life, and I am grateful to call him my advisor. In addition, I would like to extend my gratitude to the Oscar Turner Scholarship Fund for their scholarship that funded the first year of my degree. Without this scholarship I would not have had the opportunity to pursue this degree.
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CHAPTER 1: LITERATURE REVIEW

1.1 HISTORY OF GLOBAL POSITIONING SYSTEM

A review of the history of the global positioning system (GPS), conducted by Getting in 1993 cited GPS was first developed and utilized for matters of national security through the military and was officially used in 1991, at the start of the Persian Gulf War. Even though the global positioning system was not fully operational yet. The GPS system was developed based off radio wave and inertial navigation systems that were adapted during World War II, however the inertial navigation system had issues with positional error over time and were not able to be refined within 1-2 km when flying (1993).

In his review, Getting cited that radio wave systems were first put into practice in nautical applications in the early 1910’s. This system utilized two receivers that were set up within a known proximity of each other than two pulses were sent out at the same time, when they were received the position of an object could be mapped. Spurring the creation of the Loran navigation system (Long Range Navigation). This was the first time that positioning technology was used and the starting point for what would later turn into the development of the GPS system (1993). Over the next several decades, the system was refined and utilized by military forces.

However, in the 1960’s, a need for a more refined system was identified when missile navigation became more complicated, leading to the development of satellites. When combined with the already in place radiotechnology allowed for the development and launch of the GPS system (Getting, 1993). The GPS system was the first system that allowed for 3-D placement of a tracked object. The early GPS system was able to determine the placement of an object through radiofrequencies that were bounced off 4 satellites to give a 3-dimensional, accurate placement of the object getting within 15 m and 100 Ns of the actual object placement (Getting, 1993).
1.1.2 HISTORY OF GLOBAL POSITIONING SYSTEM RESEARCH WITH ANIMALS

Global positioning system research has been increasingly utilized to monitor both livestock and wildlife since as early as 1990’s and by 2013 at least 99 studies had been published utilizing GPS collars on cattle since the first study performed in 1997 (Anderson et al., 2013). According to Anderson et al. in 2012, GPS systems are advantageous to animal monitoring as it allows for animal behavior and movement to be tracked without human interference influencing behavior. Methods utilized before the deployment of GPS collars included: parked vehicle observation, video recording, binocular observation, horseback tracking and observation, or platform observations (Anderson et al., 2012). While all these methods can have their own benefit to a study; it is hard to ignore that all can introduce human bias or influence on a study. Therefore, the development of GPS collars and developing protocols to process and understand this data is huge in increasing our understanding of animal behavior when there is not human influence. This is important because even a domesticated animal on pasture has the potential to be influenced by the presence of a human, overall, potentially skewing the data collected (Anderson et al., 2012).

1.1.3 GLOBAL POSITIONING SYSTEM RESEARCH WITH WILDLIFE

Wildlife research has widely utilized GPS systems in its research since GPS became available for public use. Global positioning systems have been cited as especially useful by researchers as it allows for observation and tracking of the animals without human inferences, as wild animals are especially influenced by human presence (Recio et al., 2011; Stabach et al., 2020; Van De Bunte et al., 2021; Wall et al., 2021). Remote GPS tracking has been used on animals from the size of elephants (Wall et al., 2021) to hummingbirds (Williamson and Witt, 2021), and even for marine life such as whales (Meynecke and Liebsch, 2021), manatees (Castelblanco-Martínez et al., 2015), and sea turtles (Schofield et al., 2007). One limitation often brought up in wildlife
applications is the longevity and accuracy of the GPS unit in long term monitoring of wildlife (D’Eon et al., 2002; Pépin et al., 2004; Buerkert and Schlecht, 2009).

A research study conducted by Dr. Strauss and Hoven on Nile crocodiles in South Africa, looked at this issue and how to attach GPS units and VHF monitors in a way that did not negatively impact the animals’ life. However, in Strauss study 40% of the VHF and GPS units mechanically failed in some way. Having many of the units fail resulted in mass amount of data loss, highlighting a need to determine why the units failed and identify better ways to attach units to wildlife without impacting day to day quality of life (2008).

In the Strauss Nile crocodile study, the VHF monitors used had a higher expected battery life than predicted but 80% of the monitors were broken off throughout the duration of the study. While the two GPS units that were utilized in this study stayed attached to the crocodile, they both failed before the study was over, citing battery failure as the reason for function loss (2008). This study really highlighted a main component issue with GPS monitoring of wildlife which is unit failure, damage, and battery life. Making it harder to retrieve the units from the animal and causing data loss that the researcher would not know about until the unit was retrieved.

A shared and warranted concern amongst researchers and wildlife advocates with GPS collars and wildlife, are the effects the collars have on the animals’ health, activity, and behavior during their deployment (Stabach et al., 2020; Van De Bunte et al., 2021). This concern has sparked an interest in looking at physiological stress indicators present in animals before, during, and after short-term GPS collar deployments. Until recently this had not been evaluated in domestic or wildlife species, however in recent years researchers have started to evaluate this potential effect on the wildlife they aim to track (Stabach et al., 2020).
Scimitar-horned oryx are an endangered type of antelope found in the grasslands of North Africa. The Stabach et al., team investigated if GPS collars had adverse health or behavioral effects on the Oryx. The study specifically looked at Oryx because every Oryx that is reintroduced into the wild is fitted with a GPS collar to track its success in reintroduction. The research team achieved this by visual monitoring the behavior of the animals before, after and during collar placement. Additionally, fecal samples were collected to assess the fecal glucocorticoid metabolites, a stress indicator expressed in fecal matter of the oryx. These observations were then compared to normal activity observations. Gender directly determined the procedure for how the collars were fitted and deployed, as it was done during normal reproductive procedures. The behavior and stress metabolites of the Oryx were then monitored over a couple of weeks post collar deployment. While there was an uptake in irritated behavior and stress metabolites in the first three days after collar deployment, the assessment showed there was not a long-term effect on the animal as undesirable effects peaked and receded after the initial expected adjustment period (2020). This study is influential in wildlife GPS utilization research as it shows that wild Bovidae species are not adversely affected by GPS collars and can be used even in at risk or endangered species monitoring without long-term health effects.

1.1.4 GLOBAL POSITION SYSTEM RESEARCH WITH LIVESTOCK

Global Positioning system tracking of livestock started in the 1990’s (Bailey et al., 2018). However, during that time, collars were cost prohibitive and lacked accuracy due to the U.S government implementing selective availability into the NAVSTAR system (Witte and Wilson, 2004). Selective availability was a security measure of error, up to 100 m, built into civilian GPS receivers enforced by the United States Department of Defense (D’Eon et al., 2002; Witte and Wilson, 2004).
Initially, collars were used to track grazing beef cattle (Bailey et al., 2018). Later this research expanded to goats (Buerkert and Schlecht, 2009; Chebli et al., 2022), sheep (Rutter et al., 1997; McGranahan et al., 2018), dairy cattle (Williams et al., 2016) and horses (Curtis et al., 1997). The need for this research is attributed to the fact that livestock grazing and general behavior, directly affects the food supply chain. This makes it important for livestock managers to understand their influence, not only on their animals, but also on the environment (Acciaro et al., 2022). Grazing behavior research allows for the evolution of grazing practices to make sure that both the producer and environment are benefiting from the management of the available forages (Bailey et al., 2018).

1.2 CATTLE

As of May 2023, the USDA estimates that the average American will consume 52.8 pounds of beef annually. While beef is not the most heavily consumed meat source, it is in the top three, second to chicken and nearly tied with pork (Knight, 2023). Since beef is significant in the American diet it is crucial for the producer to understand cattle behavior and how behavior can affect the profitability of a herd.

While numerous factors influence having a profitable head of cattle, including reproductive factors, illnesses, hoof health, and more, two primary influences on profitability are feed cost and weight management (Knight et al., 2015; Bailey et al., 2018). The necessity for understanding grazing behavior and its influence on profit has directly influenced the research being conducted in this area. Gaining insights on how cattle graze allows researchers to develop and improve grazing practices to ensure both the producer and environment benefit from the management of the available forage (Cline et al., 2006).
1.2.1 GLOBAL POSITION SYSTEM GRAZING BEHAVIOR AND CATTLE

While many behavior factors go into having healthy profitable cattle, how cattle grazing is managed can have a huge influence on the longevity and profitability of those cows (Acciaro et al., 2022). To gain insights into grazing behavior, GPS protocols have been developed to effectively track cattle behavior (Augustine and Derner, 2013). These protocols evaluated numerous factors to determine their influence on grazing behavior including distance to water, elevation, short-term and long-term distances traveled, time spent with head down, lying time, and more (Augustine and Derner, 2013; Bailey et al., 2018; Brennan et al., 2019).

Early distribution studies conducted on rangeland cattle aimed to document overall grazing patterns, behaviors, and tendencies. A notable study conducted by Ganskopp and Bohnert in 2006, utilized cattle GPS data to analyze grazing velocity trends and pasture utilization patterns. Ganskopp and Bohnert, found that grazing preference is habitual in cattle. Even when high-quality grazing areas are far apart and consist of small areas, cattle will prioritize grazing these patches before compromising quality forage for quantity of forage (2006).

While many cattle distribution studies have been conducted with GPS collars, fewer studies have been done on quantifying livestock grazing behavior. Knight et al, utilized GPS collars to track activity in cows that were detected as having high residual feed intake and low intake in diverse types of rangelands. Ultimately, showing how grazing behavior changed between the groups of cattle based on elevation and overall distance traveled changed depending on rangeland forage availability. The study showed that low intake cows are more likely to travel longer to graze and at higher elevations than higher intake cows (2018). This is practical management data that can then be utilized by ranchers to select cattle for their herds that will utilize the terrain they have most efficiently.
Since Knight et al.’s, work with GPS collars, further studies have been conducted to see if GPS data coupled with low-cost accelerometer data can be classified by an algorithm into grazing and non-grazing that can then be used as a prediction model for future grazing behavior (Brennan et al., 2019). Brennan and his team developed an algorithm for classifying behavior in python validated by pairing the data with direct observation data. The prediction model developed by Brennan et al was developed off data collected over a 3-year period and while it had a lower calculated accuracy rate than previous short-term studies, the model developed was able to show grazing behavior that aligned with what would be expected for hours or activity (2021). However, this grazing behavior prediction model has only been validated in beef cattle and further research is needed before it can be determined if this model can be modified to fit for other classes of animals. While ongoing GPS grazing behavior studies are essential, the current understanding obtained from these studies has given cattle producers data to push for change in management practices, in turn increasing profitability of their cattle and optimizing the use of land available to them.

1.3 EQUINE

Horses and humans have had a codependent relationship for centuries, it is this relationship that has influenced humans’ interest in equine behavior. Through observations of natural equine behavior, humans have developed their current understanding of equine behavior (Carson and Wood-Gush, 1983). However, most of the research done on equine behavior tends to be human influenced equine behavior: such as therapy behavior (Arrazola and Merkies, 2020), racing (Mactaggart and Phillips, 2023), handling and groundwork (Fenner et al., 2016; Gronqvist et al., 2017), or general riding relationships (Romness et al., 2020). While a general understanding of grazing behavior is understood as important to horse health, there has not been a lot of work done
on grazing behavior when humans and their influence is taken completely out of the equation (B. Hampson et al., 2010).

1.3.1 EQUINE BEHAVIOR

Horses are typically social animals and prefer to live in a herd, as they are animals of prey (Pacheco and Herrera, 1997). Horses, despite having a diet consisting mostly of forages, are non-ruminant animals and instead use hindgut fermentation in the caecum to break down and process the cellulose found in forages (MacNicol et al., 2023). Since they are non-ruminants, and do not undergo regurgitation and mastication of their cud (Shingu et al., 2010) as ruminants do, horses have a different eating pattern than ruminant livestock animals, and they are classified as continual grazers (Carson and Wood-Gush, 1983). Horses consume around 2 to 2.5 percent of their body weight in feed a day (Houpt, 1990), typically grazing anywhere between 10-17 hours a day (Bott et al., 2013). This means when given the chance horses spend most of their day eating or looking for palatable feed (Houpt, 1990). Horses are selective or spot grazers and typically like to consume short-stemmed forages or the leaves from shrubbery and brush (Bott et al., 2013). In captivity they will aggressively graze areas with palatable forage to the ground (Carson and Wood-Gush, 1983), and if not involved in rotational grazing will continue to aggressively graze these favored areas as new regrowth occurs (Shingu et al., 2010).

In his analysis of horse behavior, Dr. Carson and Wood-Gush cite that horses have both internal and external factors that affect their grazing behavior and preferences. Internal factors that affect horses’ grazing behavior include workload, age, nutritional requirements, feed preference, and bite size. These factors are horse dependent and vary between individual horses, even if housed in the same herd. External factors that affect grazing include weather, seasonality, management,
palatability of available forage, social structure, and interactions (among both horses and horses with humans), water availability and pasture size to name a few (1982).

These types of influences on behavior are important to understand, as they play a key role in the management of horses and making economical and practical management decisions (Sato et al., 2017). For example, when horses are kept in a single small paddock, they will graze down the pasture into short, overgrazed areas and leave areas of taller less palatable grasses (Bott et al., 2013). Horses have also been documented to choose excrement areas and will not graze near them (Carson and Wood-Gush, 1983). This is an instinct for parasite prevention, as they do not want to eat forage contaminated by feces.

When managing equine facilities, utilizing information on horse behavior is beneficial as it allows for informed land management. The information we have on horse behavior has been instrumental in implementing rotational grazing protocols for both large- and small-scale facilities. Rotational grazing is the practice of systematically moving livestock to different sections of pasture or range to allow the recovery and regrowth of plants after grazing (Bailey and Brown, 2011). Understanding a facilities specific horses grazing behavior offers advantages as it allows for a custom rotational grazing protocol to be developed for the facility.

To further understand horse behavior, it is essential to understand their normal movement patterns. A typical horse exhibits 4 different movement patterns also known as gaits (Hildebrand, 1965). These gaits from slowest gait to fastest are walk, trot, canter, and gallop (B. Hampson et al., 2010). Standardbred horses also have a 5th movement pattern known as the pace, which is between a trot and canter in speed (Hildebrand, 1965). According to Montana State Equine Extension page on locomotion, the walk is a four-beat gate slow gate that ranges from 5.6 to 8 kph. The trot is a two-beat diagonal gate that averages 11-16 kph but when in an extended trot the horse
can reach 16-48 kph (2023). The pace is a two-beat lateral gate that is faster than the trot and can reach speeds over 48 kph (Hildebrand, 1965). The canter is a three-beat gate that ranges from 19-32 kph and finally the gallop is the fastest gate where the horse travels between 40-56 kph (MSU Extension Animal and Range Science, 2023). The gallop is a four-beat gate similar in pattern to the walk but much faster. These are all typical types of movement that can be observed at any given time, and it is important to understand them when looking at tracking movement (Hildebrand, 1965).

According to Gustafson, horses and humans have coevolved over thousands of years, their behavior and how they interact with humans is well understood from this coevolution. The earliest evidence suggests that horses and humans have had a relationship since at least 5500 years ago. This relationship is thought to have developed in tandem and not necessarily from forced domestication, as it is thought that both horses and humans discovered they could fill niche roles in day-to-day life (2022). Today horse behavior is less innately understood and much of our knowledge of horse behavior comes from research than daily dependent interactions.

Today it is understood that horses are social creatures, that can even form bonds with the humans that work with them (Arrazola and Merkies, 2020). Horses that are socialized and have a herd to fall back on have been observed to have a greater willingness to work and exhibit higher levels of trainability (Gustafson, 2022). The American Association of Equine Practitioners documents that trainability seems to be influenced by both pasturing type and husbandry interactions this claim is backed by the research of Dr. Gustafson. He claims that having healthy productive horses requires friends, forage, and locomotion are the key to having healthy behaviors and keep away unfavorable behavior (2022).
In their study on welfare assessments of horses, Lesimple and Hausberger, define unfavorable or abnormal behaviors in horses citing these behaviors as indicators of the horse’s overall health. While certain unfavorable behaviors are innate and unavoidable, understanding these behaviors and how the horse’s environment influences them is influential in curbing them. Commonly observed unfavorable behaviors typically include mild wood chewing, cribbing, stall kicking, weaving, striking out and box walking (2014). Understanding these behaviors and why they occur is especially important because horses are one of the most dangerous livestock animals (Gronqvist et al., 2017).

While there is a solid understanding of horse behavior under human influence and observation, there is a lack of understanding of their behavior without human influence (B. Hampson et al., 2010). Understanding behavior without the influence of humans could potentially help determine why these behaviors manifest. Thus, potentially allowing targeted interventions to be developed to help minimize these undesirable behaviors (Romness et al., 2020).

1.3.2 EQUINE BEHAVIOR AND EQUINE RESEARCH UTILIZING GLOBAL POSITIONING SYSTEMS

Equine behavior has not been studied extensively utilizing GPS. There are few published studies discussing the use of GPS to understand horse behavior (B. Hampson et al., 2010; Hildebrandt et al., 2020), and most GPS work with horses has been dedicated to the racetrack and utilizing it to track horse speeds or in other athletic events (Kingston et al., 2006; Morrice-West et al., 2021). However, in recent years GPS has sparked an interest in being utilized to classify horse behavior (Hildebrandt et al., 2020; Hildebrandt et al., 2021).

In 2010, Hampson et al., explored the use of GPS collars to track horse behaviors assessing horse and foal movement in various paddock sizes and fence designs. To be cost effective a
modified personal or vehicle Wintec G-Rays GPS unit was used to create a low-cost tracking headcollar. This involved modifying the unit to add a circuit board and battery pack resulting in a collar capable of obtaining a fix every 5 seconds for 6.5 days. Horse behavior was tracked throughout several days in unique style paddocks ranging from open space to tight spiral pattern paddocks. The movement data was compared to an earlier study that studied wild horse movement over an extended period. Ultimately Hampson et al., showed that an open large paddock should be utilized for higher horse distance traveled in a day, and that a horse kept in a small or complex fenced paddock will move significantly less than both its domesticated and feral counterparts. Higher movement was shown to lead to increased grazing behavior (2010).

Recently in 2020, a study conducted by Dr. Hildebrant and his team, looked at how daily traveled distances changed depending on if a horse was long established in the herd or new to the herd in an open stable environment through the utilization of a Qstarz GPS unit duct-taped to a breakaway nylon collar. Multiple instances of damage or collar loss over the 9-month study period were reported. The usable data did show interesting insight into herd behavior during herd transition periods. It was found that the introduction of a horse to the herd will cause the new horse to have increased activity for the first 9 days after introduction (2020).

In 1996, Dr. Kingston and his team conducted a physiological study to assess the workload in racehorses. The study utilized the NAVSTAR system, heart rate monitoring and a treadmill system. Nineteen 3-year-old horses were included in the study, and readings were taken daily during training sessions. The NAVSTAR system was able to accurately detect the speed of the horses during their training sessions which was later confirmed by comparing to times cited by their trainers. On average, the GPS showed a maximum speed that was 1.5 kilometers per hour faster than the calculated speed of the trainer. The GPS took readings every 5 seconds, and then
the speed was able to be calculated between fixes. This allowed for a greater insight at the peak work speeds that a horse can exhibit in a work session than just the time and distance calculated average workout speeds. Up until this point there had not been a way to track how speed changed throughout a workout. Overall, the study concluded that in a monitored workout GPS and heart rate monitors are a reliable means to measure the speed and workload of the horse in the training session (Kingston et al, 2006).

In more recent years, accelerometers and global positioning systems have been used to examine horse stride in thoroughbreds on the racetrack (Morrice-West et al., 2021). An accelerometer is a device that can detect gravitational forces in 1, 2 or 3 axes, allowing detection of behavior such as head movement for grazing or movement during exercise (Bailey et al., 2018). In other studies, GPS and inertial sensors were utilized to examine stride characteristics of horses on the track (Davíðsson et al., 2023). Morrice-West et al’s study had the goal of also incorporating accelerometers into monitoring to further understand stride parameters and how it relates to speed, as this approach was shown to be successful in human athletic training programs. Morrice-West and his team hypothesized that speed is dependent on stride length, count and duration and that parameters on the horse and race level influence stride. This had been shown in a smaller scale study (Fonseca et al., 2010), so the goal was to validate the data on a larger pool of participants utilizing Stridemaster equipped with a GPS and a 3-axis accelerometer capable of taking 5 recordings per second with an accuracy within 10 cm of the actual position. Overall, it was determined that stride parameters are both horse dependent, as well as race dependent and that further studies are needed to understand how much these parameters influence stride (2020).

Other behavior research utilizing GPS collars includes a study conducted by Sato et. al, that looked at how distances between Thoroughbred dams and their foals changed throughout the
first year of the foal’s life then characterizing this behavior based on both GPS data and visual observations. The objective was to evaluate the accuracy of the distances observed between two Thoroughbreds on pasture, and then how those distances change from birth to weaning in foal and dam pairs. A commercial GPS logger (Trip Recorder 747Pro) was attached to a head halter by placing the unit in a plastic bag and duct taping it to the halter, the unit was then deployed once a month for 24-hour collection periods. The GPS data distances were evaluated in excel using Hubeny’s distance formula. The accuracy of the GPS data calculated distances was determined to be less than 3.0 m from actual distance. Sato et al, concluded that dam foal distance increases up to 9 weeks (about 2 months), plateaus until 22 weeks (about 5 months) and then increases again as the foal approaches weaning or has weaned. The research team suggests that further behavior analysis should be conducted using gravitational force data loggers in accompaniment of the GPS collar. The gravitation logger and GPS unit combination allows for standing and lying behaviors to be paired with the GPS data and gives a more in-depth behavior analysis of the horse and foal on pasture (2017).

1.4 GLOBAL POSITION COLLARS

In the past couple of decades, the Global Positioning System has become extremely accessible to the public. Most people carry around a GPS in their pocket every day, as most modern-day smartphones come equipped with a GPS chip. This is because the United state requires that all mobile phones be able to be located in case of emergency (Tomkiewicz et al., 2010). With the strides that GPS has made in the last few decades, it has made GPS a regular tool in research and wildlife conservation (Tomkiewicz et al., 2010; Collins et al., 2014; Van De Bunte et al., 2021). There are many options when looking for a GPS collar and the collars are often tailored to fit specific needs for researcher or consumers, however, this can also come at a cost. This increased
price associated with commercial GPS collars is what has sparked interest in creating low-cost alternatives for when a research question does not require additional parameters or for when cost is influencing the population and type of data that is being collected (Bailey et al, 2018).

1.4.1 COMMERCIAL GPS COLLARS

Commercial GPS collars have been available for the last few decades. They have been utilized in many studies and are convenient for researchers as they usually do not require modifications to meet the needs of the researcher (Hebblewhite and Haydon, 2010). However, this comes at a cost. A commercial GPS collar can be anywhere from a few hundred dollars to over $1,000 USD per unit depending on the type of unit selected and additional features it may contain (Abdulai et al., 2022). Popular commercial units often come equipped with additional features such as accelerometers (Bailey et al., 2018), temperature sensors, the ability to download data remotely (Bailey et al., 2021) or even geofencing capabilities (Muminov et al., 2019; Bailey et al., 2021). Depending on the researcher’s needs and question, these features can be advantageous in answering the research question, but these are not always needed to answer the researcher’s question.

With the development of GPS collars has come the need to fit an extensive range of animal sizes and statures. In New Zealand, Recio and his team looked to assess that accuracy of five lightweight GPS tags (Sirtrack) attached to lightweight collars. These units are meant for medium to small stature animals. The tags performance was then assessed against a commercially available collar under a variety of New Zealand ecosystems from grassland to forest. This was a stationary study to test the collar and tags under different controlled areas to assess how environmental factors may affect the accuracy of the fixes for the GPS unit. Recio et al hypothesized that vegetation and terrain would affect the GPS accuracy. The investigation explored how vegetation affected the
accuracy in both open sky areas and areas that had a partial to full canopy. While the collar was not attached to an animal during this study and was evaluated using fixed points, it was also tested under movement by being moved to simulate the way a cat moves through different terrains and vegetations. Interestingly, the data showed there was a 10% decrease in fix rate between motion and static testing no matter the terrain and cover. The data even supported the FSR (fix success rate) shown for this collar was within the same ranges as larger commercial collars used on larger animals (2011).

1.4.2 LOW-COST GPS COLLARS

In the past decade or so, there has been a notable decrease in the cost of GPS collars per unit, however, the cost can still be a challenge for researchers looking to utilize multiple units (Knight et al., 2018a). Consequently, the search for a suitable low-cost GPS collar has been sought after by researchers. Commercially available GPS units and collars’ price points vary greatly and run anywhere between $600 USD to $3000 or more USD per unit, making it not always realistic to obtain enough collars at this price point (Abdulai et al., 2022). These high price points have driven researchers to develop an alternative budget-friendly option that is customizable depending on the study’s scope and needs (Knight et al., 2018a). Economical consumer grade GPS units are defined as units that cost under $500 developed for recreational or personal use, the horizontal accuracy of these units must be between 5-10 m depending on the GPS unit (Abdulai et al., 2022).

One affordable option for GPS collars, which was directly compared to a commercial collar, is the Knight GPS tracking collar for cattle and small ruminants. In a study conducted by Knight et al., the Knight GPS collar was compared to a commercially available LOTECK collar. Knight GPS collars were found to have a statistically significantly lower fix success rate than the LOTECK collar when utilizing a budget friendly igotU GT-120 GPS unit when both units were
placed in power saving mode. This resulted in a lower overall distance traveled per day when utilizing the budget unit. The researcher identified that while the affordable GPS unit option may not be suitable for all research questions, it can serve the needs of some questions relating to distance and location traveled (2018).

The igotU GT-120 GPS unit (recently discontinued) has been popular in animal research and has been cited for use in many low-cost collar models from large mammals (cattle) to birds to even grey squirrels (Morris and Conner, 2017). However, despite its popularity the potential error with fixes had not been evaluated in this unit for research application. This gap in information drove the investigation into the accuracy and limitations of this GPS unit. Morris conducted a series of stationary trials utilizing the igotU GT-120 both under optimal conditions and covered trials. The study found that this GPS tracker had a location error of 9.2 m in optimal conditions and the average location error of all cover types was still under 10 m. These rates were found to be the same or better than previous tests done in other studies. The fix success rate for this tracker was found to be almost 100% whether under cover or not (Morris and Conner, 2017). This data further supports that budget GPS trackers can be beneficial to wildlife and livestock research for researchers with a restrictive budget.

A large limitation of economical collars, cited in several cattle behavior studies (Cline et al., 2006; Bailey et al., 2018; Knight et al., 2018a), is that these types of collars often are not equipped with accelerometers or other motion detection to build behavior models from the data that a commercial collar provides (Brennan et al., 2019). Brennan and his research team attempted to bridge this gap by equipping low-cost GPS collars with accelerometers and aimed to keep the cost under 230 USD per unit. The team then developed an algorithm, that built off the earlier work of David Augustine and Justin Derner, to detect and classify grazing versus non-grazing behavior
and then assessed the accuracy of this model through error rates and expected observation behavior (2020). Augustine and Derner laid the foundation for Brennan et al. in 2013, when they developed a binary classification system tree to sort GPS data into behavior categories through a 9-split model. The model allowed for data to be sorted into grazing or not grazing from the movement and sensor data collected with 87.1% accuracy. Augustine and Derner, then took the model a step further and thought a 10 split model were able to create a four-category tree able to classify data into resting, grazing, traveling, or mixed behavior with a minimum misclassification of 16.4%. This model had a higher misclassification rate that varied among categories, as it did not always correctly differentiate grazing from true traveling behavior (2013).

Brennan et al, used the same igotU GT-120 GPS logger that the formerly mentioned Knight et al (2018) study utilized. In contrast to the Knight et al study, Brennan and his team added the component of a 3-axis mini-accelerometer made by GULF Coast Concepts (2019). The collars were then put onto a beef herd and data collected. This data was paired with direct visual observations, which is common in GPS behavior studies, so that the GPS data can be paired with what the trained observer was witnessing at that moment. Forty-five beef steers were used over a three-year period to form the data set used. Overall, Brennan et al. was able to show that a low-cost GPS collar and accelerometer can monitor and predict seasonal cattle grazing behavior. However, Brennan et al cited that further research and application is needed of his prediction model before it can be said if this model is suitable for other classes of animals (2019).

1.4.3 PROCESSING GPS DATA TO CLASSIFY BEHAVIOR

A large issue with utilizing GPS data is the processing of the data. Methods for processing GPS data typically vary depending on the researcher and their own preference for protocols (Augustine and Derner, 2013; Brennan et al., 2019). Brennan et al, cited a need for streamlining
GPS data processing as it is a process that can turn into thousands of steps just to see the coordinates on the map, making it time consuming, inefficient, and depending on the protocol used prone to human error. Brennan et al, were able to develop a GPS data processing protocol in the statistical analysis program R, which is opensource and free to all users, that can streamline the processing process and limit human error.

The protocol is then able to read the input file, clean points out of error range, convert the data, standardize it to 5-minute intervals regardless of fix rate and then calculate the duration, distances and bearings between the successful points, its final step can classify the behavior as grazing or nongrazing based on the time fixes and distances between points (Brennan et al., 2019). This is an important development in this type of coding as it allows for data and behavior to be classified without additional observation or human influence on the data. Brennan et al, cites that the protocol takes 30+ minutes of processing with an established protocol of one collar’s data to a matter of seconds, and limits human error in the cleaning process, as the computer program does the sorting and entering off all data (2019).
CHAPTER 2

2.1 INTRODUCTION

The American Veterinary Medical Association estimates the domestic horse population to be approximately 1.9 million in the United States (2018). However, despite the population size, little research has been conducted on horse behavior in the pasture and grazing. While GPS has been utilized to understand both livestock and wildlife behavior since the late 1990’s (Buerkert and Schlecht, 2009; Bailey et al., 2018; Meynecke and Liebsch, 2021; Van De Bunte et al., 2021; Acciaro et al., 2022) little work has been done utilizing horses (Kingston et al., 2006; B. Hampson et al., 2010) and, more specifically horse grazing behavior.

Understanding horse grazing behavior can allow for refined management plans that can better fit a facility's needs. Increased understanding of horse grazing behavior allows for horses to potentially be utilized in multi-specie rotational grazing systems to maximize the forage availability for a given farm (Catorci et al., 2012). Horses are selective grazers (Shingu et al., 2010) and can be detrimental to a pasture if not involved in a rotational system (Carson and Wood-Gush, 1983). The anatomy of the horse’s mouth allows for the horse to graze as close to the ground as rabbits. This advantage in the ability to graze makes the horse less selective in its grazing when placed on an overgrazed patch of land (Catorci et al., 2012) and increases the potential for irreparable damage to the forage system.

Previous research conducted utilizing GPS on both wildlife and livestock species has paved the way for the principles and practices developed to be applied and adapted to horses. Most notably, the work conducted by Augustine and Derner laid the foundation of GPS behavior classification work. Augustine and Derner developed a binary classification process through a 9-step model that sorted GPS data into grazing and non-grazing behavior (2013). This work was
later expanded upon when it was shown that low-cost GPS units can be adapted and used for livestock tracking and behavior classification with similar success to Augustine and Derner who utilized a commercial GPS tracking collar (Bailey et al., 2018; Knight et al., 2018a; Brennan et al., 2019; Brennan et al., 2021). Tracking of beef cattle on rangeland has been shown to be advantageous as it allows for forage management of desert conditions (Bailey et al., 2018). Understanding cattle behavior in relation to water availability and shade allows for managers to manipulate grazing areas to encourage grazing in unfavorable conditions (Bailey, 2004). Applying this knowledge of water and shade manipulation and seeing if the same principles can apply to horse management remains to be explored, as a baseline for horse behavior characteristics under GPS monitoring has yet to be established.

The lack of this baseline has driven the need for development of this study. The objective of this study is to establish the testing capabilities and accuracy of the Columbus P-1 data logger as a low-cost GPS unit in research for horses; by testing its ability to classify and detect differences in equine behavior without the use of an accelerometer. The use of an accelerometer creates a more intensive data set that requires more time, knowledge, and effort to process. The skillsets required to process accelerometer data are specialized, where GPS data can be processed utilizing basic software such as excel.

2.2 METHODS:

2.2.1 ETHICS STATEMENT:

This study was conducted in accordance with the protocol approved by the University of Maine Institutional Animal Care and Use Committee utilizing the University owned herd of standardbred horses. (Protocol number: A2023-06-01)
2.2.2 STUDY AREA/SUBJECTS:

The research was conducted at the J.F Witter Teaching and Research center, located at 160 University Farm Road, Old Town, Maine. The center is a part of the Maine Agricultural and Forest Experiment Stations which are involved in research across all 16 counties in the state of Maine. The J.F Witter center is composed of two farms; the crops farm (Rogers Farm) and Witter farm, the livestock facility. The facility is located approximately 2 miles from the University campus and serves as the large animal research station. The center is home of the University of Maine’s Standardbred horses and Holstein dairy herd, both of which are utilized for teaching and research by the animal science students and faculty. The J.F. Witter center consists of approximately 300 acres used for animal housing, pasture, crops, and forage production. Of the acreage utilized by the facility, approximately 5 acres are fenced in for horses, with an additional 50 acres utilized for hay production.

The Witter center Standardbred herd is composed of eight mares and one stallion. All the horses housed at the center are donated former harness racers involved in the Maine Standardbred harness racing circuit and have been repurposed. They are all trained for mounted riding, used in research, and for teaching students basic equine care. For this study, all nine Standardbred horses were used. All the standardbred horses’ range in age from 6-25 years of age at the time of the study. The Standardbred mares are handled daily for training, turn-in and turn-out. The stallion is utilized for reproduction demonstrations and to teach safety in stallion handling.

The horses are pastured from 8 am (EST) daily until between 5 and 7 pm (EST), depending on seasonality and weather conditions. During the study period, rainfall average for the month was 3.0 in, with an average temperature of 77.8°F and 88% humidity. The Standardbreds remain on pasture unless extreme inclement weather is predicted or for short training periods throughout the
day. Since the center has limited pasture available, the mares receive a supplemental supply of hay twice a day (at turnout and mid-day) to complement the pasture. Supplemental forage is provided in a sacrificial area that also contains their water. Horses are pastured either singly or in pairs, based on temperament and health conditions as determined by the equine manager.

The horses are housed in seven different paddocks. Since paddocks potentially have variability in environment, they were compared for similarities in elevation and slope utilization. While the paddocks' forage composition was not examined, the fields at the center are mostly composed of timothy grass.

2.2.3 GLOBAL POSITION SYSTEM COLLAR:

The Knight collars utilized in this study were made and developed by Knight GPS collars in the Maine Grazing Behavior lab located at the University of Maine (See Figure 1). These collars were created by modifying cattle collars. Instead of the traditional buckles used to secure collars on cattle, the collars were modified to utilize industrial Velcro to create a breakaway collar (See Figure 2). The collar was also made to be 56 cm rather than the 61cm cattle collar length to accommodate the narrower neck of the horses. The GPS unit was attached to the collar by sewing a leather pouch to the collar (See Figure 3). The GPS unit was then accessible by a Velcro closure allowing the GPS unit to be removed for data retrieval or charging. (See Figure 4)

The GPS unit utilized in this study was the Columbus p-1 professional GPS logger. The GPS battery was not modified to improve performance because the collars were only deployed for short intervals. The GPS unit was configured to take readings in 1s intervals. The unit comes with its own mapping software that is compatible with both Mac and Windows software (TimeAlbum Pro).
Figure 1: GPS collar

Figure 2: Velcro Collar attachment
2.2.4 GPS ACCURACY TESTING:

The Columbus p-1 professional logger was subjected to a series of preliminary tests before deployment to assess its accuracy in both practical and stationary use. The unit is configured at a 1Hz collection interval, recording data points once per second. This configuration allows for a smaller differential correction within the GPS software. The unit was evaluated for accuracy in frequency and precision of the GPS fixes, and overall duration testing. Stationary testing was conducted to determine its accuracy over a 24-hour period in an open field at the J.F. Witter center.
Motion testing involved walking or driving a known route and comparing the data to known distances.

2.2.5 GPS COLLAR DATA COLLECTION AND ANALYSIS:

Collars were deployed on (n=9) Standardbred horses over the trial period. The collars were fitted prior to observation and promptly removed afterward (Figure 5&6). Observation intervals consisted of one-hour time increments for five sessions for each individual horse. The observations occurred at 8:00-9:00, 10:00-11:00, 13:00-14:00, 15:30-16:30, 17:30-18:30 hrs. A trained observer was tasked with identifying several types of behavior. The observer recorded the time of the behavior, what behavior was observed, how long the behavior lasted, and any outside stimuli that may have influenced the behavior. Behaviors were classified as grazing, resting, traveling, rolling, and drinking. Traveling was noted as walking, trotting, or running (canter, gallop, pace) (Table 1). The GPS data was then paired with the observation data for analysis.

Data collected and extracted from the raw GPS files included slope, elevation, distance between points, time of fix and heading. Data categories calculated from the raw data included distance to water and shade, distance traveled between points, distance changed (the difference between two distance traveled points), average distance changed (10s average), velocity (m/s and km/h), change in heading, and average change in heading (10s average).

Data was extracted from the GPS unit and cleaned and formatted in Microsoft Excel utilizing the principles outlined in the manual “Data Analysis for Knight GPS collars & Mobile Action i-gotU GPS Units, Version 2” (Knight & Bailey, 2019). The GPS units were already calibrated to be in the correct time zone. The GPS data was initially converted from longitude and latitude coordinates to Universal Transverse Mercator (UTM) system coordinates. Once converted to UTM, distance to water and shade were calculated (eq.1) from the known UTM
coordinates for each water trough and shelter. This same protocol was used to calculate distance traveled between data points. Velocity was calculated from the distance between points data. Slope and elevation were extracted for each data point utilizing the software ArcGIS PRO.

Temperature and humidity conditions for all observations were used to calculate the temperature humidity index (THI) for each observation period. The THI is used to measure the potential of heat stress (eq. 2), where Ambient temperature (AT) in Celsius, and relative humidity (RH) were obtained from local weather station data.

An algorithm was developed using common data ranges in each category to classify data points into behaviors based on several parameters built into the equation. The equation was then compared to the known observations done by trained observers to assess its accuracy to identify grazing behaviors.

*Figure 5: Horse Fitted with GPS Collar Under Observation.*
Figure 6: Horse Fitted with GPS Collar Under Observation

Equation 1: Distance Formula

\[ \text{distance} = \sqrt{(N2 - N1)^2 + (E2 - E1)^2} \]

*Northing 1 = "N1", Northing 2 = "N2", Easting 1 = "E1", Easting 2 = "E2"

Equation 2: THI calculation equation from (Arias et al., 2018)

\[ \text{THI} = 0.8 \times AT + ((RH/100) \times (AT - 14.4)) + 46.4 \]
Table 1: Ethogram of Horse Behavior Classification System

<table>
<thead>
<tr>
<th>Activity Scale</th>
<th>Classification</th>
<th>Behavior</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Inactivity</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Resting</td>
<td>Sleeping</td>
<td>Horse head down, eyes closed. No reaction to surroundings. Can be standing or lying</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Dozing</td>
<td>Horse eyes half-closed, head up or down. Opens eyes in response to surroundings. Can be standing or lying</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Attentive</td>
<td>Horse looking around, lying, or standing still, head up</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Urination/defecation</td>
<td>Horse Actively urinating or defecating</td>
</tr>
<tr>
<td></td>
<td>Moderate activity</td>
<td>Grooming</td>
<td>Horse uses tongue and teeth to clean itself or another animal</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Drinking</td>
<td>Actively drinking from water tub</td>
</tr>
<tr>
<td></td>
<td></td>
<td>rolling</td>
<td>Horse on back rolling on ground, all weight on body feet may be in air or various stages of touching ground</td>
</tr>
<tr>
<td></td>
<td></td>
<td>grazing</td>
<td>collecting, chewing, and swallowing vegetation or hay from the ground, can involve walking while head down actively collecting forages</td>
</tr>
<tr>
<td></td>
<td>Traveling</td>
<td>walking</td>
<td>4 beat gait where 2 to 3 feet remain in contact with the ground, 1-2-3-4 rhythm, slowest movement</td>
</tr>
<tr>
<td></td>
<td></td>
<td>trotting</td>
<td>2 beat diagonal gait, follows a 1-2 rhythm, Left hind moves with right front (diagonal)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Run</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Canter</td>
<td>3 beat, follows 1,2,3 rhythm, Diagonal to triangular to single leg support, Faster than trot, moment of suspension!</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Gallop</td>
<td>4 Beat gate, fastest gate, 1-2-3-4 rhythm, Diagonal to triangular to single leg support, Moment of suspension!</td>
</tr>
</tbody>
</table>

2.2.6 STATISTICAL ANALYSIS:

Data were analyzed using the statistical software SAS (v. 9.4 SAS inst. Inc., Cary, NY), and Microsoft office 365 Excel. The horse will serve as the experimental unit. The model followed that of a completely random design.
2.3 RESULTS/DISCUSSION:

2.3.1 PADDOCK COMPARISON

Slope utilization for all horses throughout the day did not differ (P=0.97). This suggests that the paddock conditions were similar for all horses. Similar statistical results were obtained for elevation (P=0.88), further supporting that the paddocks are similar. Therefore, all data can be used to compare grazing behaviors amongst the horses without introducing an environmental effect.

However, when paddocks are examined on a horse-by-horse basis, there are statistical differences detected between horses, even amongst ones that share a paddock (Table 1). This can be explained by horses in the same paddock not always occupying the same areas and potentially utilized areas of the paddock with varying slope or elevation compared to their pasture mate.

Table 2: Paddock Comparison: Comparison of the elevation and slope that each horse utilized in their paddock.

<table>
<thead>
<tr>
<th>Horse</th>
<th>Elevation Mean</th>
<th>Elevation Std Dev</th>
<th>Slope Mean</th>
<th>Slope Std Dev</th>
</tr>
</thead>
<tbody>
<tr>
<td>Blisstex</td>
<td>52.48&lt;sup&gt;ABC&lt;/sup&gt;</td>
<td>0.76</td>
<td>3.72&lt;sup&gt;A&lt;/sup&gt;</td>
<td>0.47</td>
</tr>
<tr>
<td>Diva*</td>
<td>51.76&lt;sup&gt;C&lt;/sup&gt;</td>
<td>0.86</td>
<td>7.58&lt;sup&gt;C&lt;/sup&gt;</td>
<td>0.80</td>
</tr>
<tr>
<td>Dixie**</td>
<td>51.44&lt;sup&gt;C&lt;/sup&gt;</td>
<td>0.23</td>
<td>3.76&lt;sup&gt;AB&lt;/sup&gt;</td>
<td>0.61</td>
</tr>
<tr>
<td>Gina</td>
<td>51.24&lt;sup&gt;C&lt;/sup&gt;</td>
<td>1.07</td>
<td>4.66&lt;sup&gt;AB&lt;/sup&gt;</td>
<td>1.17</td>
</tr>
<tr>
<td>Laney*</td>
<td>51.34&lt;sup&gt;C&lt;/sup&gt;</td>
<td>0.59</td>
<td>7.34&lt;sup&gt;C&lt;/sup&gt;</td>
<td>0.37</td>
</tr>
<tr>
<td>Roadshow</td>
<td>53.80&lt;sup&gt;B&lt;/sup&gt;</td>
<td>0.34</td>
<td>4.92&lt;sup&gt;AB&lt;/sup&gt;</td>
<td>0.42</td>
</tr>
<tr>
<td>Sara**</td>
<td>51.26&lt;sup&gt;C&lt;/sup&gt;</td>
<td>0.21</td>
<td>3.62&lt;sup&gt;AB&lt;/sup&gt;</td>
<td>0.55</td>
</tr>
<tr>
<td>Suzie</td>
<td>52.40&lt;sup&gt;AC&lt;/sup&gt;</td>
<td>0.42</td>
<td>4.50&lt;sup&gt;AB&lt;/sup&gt;</td>
<td>0.45</td>
</tr>
<tr>
<td>Whiteout</td>
<td>53.16&lt;sup&gt;AB&lt;/sup&gt;</td>
<td>0.75</td>
<td>5.02&lt;sup&gt;B&lt;/sup&gt;</td>
<td>0.66</td>
</tr>
</tbody>
</table>

* Indicates horses that share a paddock means with different superscripts are considered significantly different (P≤0.05) Slope is reported in percent rise
2.3.2 HORSE HERD COMPARISON

This study included all horses housed at the Witter center and did not exclude horses due to differences such as sex, age, or injury. The herd had an average age of 17.73 ± 5.54 years old, with ages ranging from 6 to 25 years. One of the horses, named Whiteout, sustained a stifle injury to her rear left leg that ended her racing career. Although she was included in this study, it is important to note this injury and its potential influence on her behavioral data. Whiteout can move through her paddock but has difficulty maintaining higher speeds of travel for more than a few seconds. She was seen favoring the injured leg, which may have affected how often she traveled during observation periods.

Another limitation of this study was the ability to detect differences in behavior based on sex. Differences between the sexes were not examined as there are eight mares and only one stallion. Further research is needed to investigate the differences in behaviors amongst the sexes and between gelded horses and stallions.

2.3.3 WEATHER:

When comparing humidity among observation collection intervals, it was found that the humidity (p=0.002) and temperature (p=0.001) significantly changed as the days progressed (Table 3). This is expected, as the humidity and temperature can vary throughout the Maine summers. The data collection spanned several days, but each observation period occurred at the same intervals allowing for comparisons across the data set. When assessing the significance of the THI changing over time, it was found that there was statistical significance in the change of THI (p=0.0002). This means that the THI can vary from time intervals and days in the summer. Understanding how THI influences behavior offers insight to how heat stress affects horses in the paddock.
Differences in temperature (p=0.025) and humidity (p=0.010) were also found when comparing individual horse observations. This aligns with expectations, as not all the horses were observed on the same day, leading to variations in temperature and humidity based on the specific day of observation. However, when examining individual horse observations, a statistical difference in THI was not detected (p=0.064). This suggests that there was not a difference in risk of heat stress throughout the week that the horses were observed, and it can be assumed that all horses were susceptible to heat stress at any given point. The mean THI was calculated to be 74.08, indicating that the horses were potentially experiencing mild to moderate heat stress at any given point during data collection period (Eirich and Woolsoncroft, 2018).

Table 3: Weather Comparison of temperature, humidity, and THI. Data is organized by observation interval and is the average of multiple days.

<table>
<thead>
<tr>
<th>Time</th>
<th>Temp (°C) Mean</th>
<th>Temp (°C) Std Dev</th>
<th>Humidity Mean</th>
<th>Humidity Std Dev</th>
<th>THI Mean</th>
<th>THI Std Dev</th>
</tr>
</thead>
<tbody>
<tr>
<td>afternoon</td>
<td>27.1B</td>
<td>3.2</td>
<td>66.9A</td>
<td>14.6</td>
<td>76.1B</td>
<td>3.0</td>
</tr>
<tr>
<td>mid-day</td>
<td>27.2B</td>
<td>4.0</td>
<td>70.1A</td>
<td>14.8</td>
<td>76.6B</td>
<td>4.1</td>
</tr>
<tr>
<td>mid-morning</td>
<td>24.0AB</td>
<td>2.8</td>
<td>80.2AB</td>
<td>9.1</td>
<td>73.1AB</td>
<td>3.4</td>
</tr>
<tr>
<td>morning</td>
<td>21.3A</td>
<td>2.4</td>
<td>88.2B</td>
<td>6.3</td>
<td>69.5A</td>
<td>3.5</td>
</tr>
<tr>
<td>night</td>
<td>25.2AB</td>
<td>1.3</td>
<td>75.3AB</td>
<td>8.8</td>
<td>74.6B</td>
<td>1.3</td>
</tr>
</tbody>
</table>

Means with a different superscript are considered significantly different (p ≤0.05)

2.3.4. OBSERVED BEHAVIORS:

2.3.4.1 DISTANCE TO WATER:

When assessing the difference in the distance that all the horses traveled from water by time interval, a significant difference was not detected (p=0.501). However, a noticeable trend was detected indicating that the distance to water varied greatly in the morning and at night. The data revealed that some horses stayed close to their water in the mornings and evenings, while others traveled farther away. This trend may be attributed to the fact that hay is fed to the horses.
in the same area as the water source in the morning, potentially influencing some horses to stay nearby to consume the provided hay. Also, a few horses receive hay supplementation in the afternoon due to low forage availability in the paddock. This potentially influences the horses to return to the water area again before the end of the day to consume the forage.

When examining the distance to water on the individual horse level, a statistical difference was observed among the horses (p=0.001). While some of the variability in water preference can be explained, further investigation would be required before definitive conclusions can be drawn. For instance, in the case of Gina, the pasture is a walk down a single lane that then loops around a private resident and along the forest line, while the water source is located up at the paddock gate. This unique pasture configuration may have contributed to her staying the furthest from her water source (>50 m).

2.3.4.2 DISTANCE TO SHADE:

Differences in time spent near shade were not detected (p=0.203). Out of the mares the horse named Whiteout had the smallest range of distance from shelter (Table 4), likely attributed to her injury limiting her travel throughout the pasture to graze. She primarily stayed near the upper paddock, where her shelter, water, and hay were located. The stallion, Roadshow, spent most of his time near his shelter, often resting and grazing inside it during various observation periods. His tendency to stay near shelter can be attributed to feeding pattern, as supplemental hay supplied provided directly outside the shelter opening and on the backside of the shelter.

When comparing distance from shade based on the observation period, it was observed that there was a wider range of distances from shelter during the mid-morning (10-11 am) observation period, ranging from under 10m to over 50 m. However, overall distance to shelter
throughout the different observation periods was found to be statistically insignificant (p=0.587), suggesting that horses do not appear to prefer staying near shade as the day and risk of heat stress progresses.

Table 4: Average Distance to Water and Shade by Horse (m)

<table>
<thead>
<tr>
<th>Horse</th>
<th>Average of Distance to water</th>
<th>Std Dev of Distance to water</th>
<th>Average of Distance to shade</th>
<th>Std Dev of Distance to Shade</th>
</tr>
</thead>
<tbody>
<tr>
<td>Blisstex</td>
<td>38.9^B</td>
<td>19.6</td>
<td>27.1^B</td>
<td>18.0</td>
</tr>
<tr>
<td>Diva</td>
<td>33.7^{AB}</td>
<td>21.0</td>
<td>24.7^B</td>
<td>11.6</td>
</tr>
<tr>
<td>Dixie</td>
<td>18.5^A</td>
<td>16.6</td>
<td>20.6^{AB}</td>
<td>18.2</td>
</tr>
<tr>
<td>Gina</td>
<td>61.0^D</td>
<td>22.7</td>
<td>29.1^B</td>
<td>20.8</td>
</tr>
<tr>
<td>Laney</td>
<td>36.2^B</td>
<td>19.7</td>
<td>26.6^B</td>
<td>10.1</td>
</tr>
<tr>
<td>Roadshow</td>
<td>19.8^{AC}</td>
<td>8.2</td>
<td>11.5^A</td>
<td>6.5</td>
</tr>
<tr>
<td>Sara</td>
<td>15.9^C</td>
<td>17.5</td>
<td>22.4^{AB}</td>
<td>17.4</td>
</tr>
<tr>
<td>Suzie</td>
<td>38.0^B</td>
<td>10.1</td>
<td>25.8^B</td>
<td>13.1</td>
</tr>
<tr>
<td>Whiteout</td>
<td>26.5^{ABC}</td>
<td>16.1</td>
<td>17.5^{AB}</td>
<td>7.2</td>
</tr>
</tbody>
</table>

*Means with a different subscript are considered significantly different (P=0.05)

2.3.4.3 DISTANCE TRAVELED:

Overall distance that the horse traveled across all observation periods was compared and a statistical difference between the distance traveled by horse was found (p=0.0004). This difference in daily distance traveled is noteworthy because, even though there were differences between the horses in terms of distance traveled, their behaviors were not statistically different from each other (Table 5). This indicates that while one horse may move more than another, they still exhibit the same behavior patterns as horses that tend to be more stationary.
2.3.5 BEHAVIOR PREDICTIONS:

2.3.5.1 EQUATION DEVELOPMENT:

Data were collected and analyzed at 1 s intervals to develop the behavior detection model. When the data was examined in 5 s, 10 s, 15 s, 30 s and 1 min intervals a prediction model that was able to detect the quick changes in motion and behavior that horses exhibit could not be developed. When examined at one min intervals distinguishing between resting, grazing, and walking was nearly impossible. This was because much of the movement data was excluded between these long interval points. Additionally, behaviors such as trotting and running could not be detected. This is because the horses in the study rarely exhibited these behaviors for over a few seconds, confounding the behavioral data into the other behaviors displayed for longer intervals. As the separation intervals between points were decreased, more behaviors were differentiated, but with lower accuracy rates than the final model. Through this trial process, it was determined that maintaining the data at 1 s intervals, despite the potential for higher GPS
error, provided the best chance of effectively differentiating the most behaviors exhibited by horses on pasture.

The development of an equation capable of differentiating behaviors such as grazing and resting from each other required breaking the data into numerous parameters to try and extract as differential data from GPS points as possible. These parameters were then assigned a value if true and each parameter added together. This resulting value was then matched to a range assigned to the behaviors being identified and compared against the known behavior recorded by the observer.

The final model consists of 12 differential equations used to distinguish between behaviors. Classification parameters used include speed, distance traveled between points, distance to shade and water, distance changed between points, the average of distance changed between a series of 10 points, heading, difference in heading and average change in heading. Using multiple combinations of these classifiers allowed the parameter equations to be developed (Appendix A).

2.3.5.2 LIMITATIONS:

The model could not be adjusted to detect all the observed behaviors using GPS data alone. The data gathered by the GPS did not allow the detection and differentiation of rolling or grooming behaviors from other data points. To isolate and develop a model capable of detecting these behaviors, an accelerometer or other motion detection device would be necessary to capture head movement and the GPS data. These behavior patterns involve motion that is difficult to differentiate from grazing or resting, as both exhibit minimal horizontal movement that a GPS unit can detect.
Another limitation of this model was the ability to differentiate drinking behavior from grazing or resting behavior. While the model could be adjusted to detect some instances of drinking behavior, it only achieved a 35.7% detection rate (table 6). Multiple factors were manipulated to improve this detection rate, but it could not be refined further because the parameters to detect resting and grazing often overlapped with drinking, leading the model to assign one of the other behaviors other than drinking. However, it is possible that using an accelerometer and adjusting the model could lead to a higher detection rate for drinking compared to this study. The ability to detect head motion would allow for the side-to-side motion of grazing to be differentiated from the steady drinking bobbing motion or resting head movement.

This model also displayed some misclassifications of data points. While the overall classification aligned with the observed behavior, it was not always accurately classified. Under the created model, drinking was incorrectly identified 64.3% of the time assigning either grazing or resting instead. Grazing had an over classification rate of 100.1%, meaning it had instances of misidentifying other behaviors as grazing instead of what happened. Similarly resting and walking exhibited overclassification, with accuracy rates of 104.4% and 102%, respectively. Running was only correctly identified 55.4% of the time, while trotting was classified 155.4% of the time.

There is the potential for improvement by calibrating the model to individual horse averages, as this model used standard accepted velocities for each gait. An examination of the data revealed that points identified as running during observation were often misclassified as trotting in the algorithm. However, this error might also stem from observation issues, as the horses’ velocities were not recorded, potentially leading to visual misclassification by the
observer. Combining running and trotting into a single category labeled “traveling” improved the model accuracy to 97.66%. This is a way to mitigate the model's limitations if traveling velocity is not crucial for the intended application.

To provide further insight into the model’s classification, detection rate by horse was evaluated (table 7). Evaluating the data and classification accuracy on a per-horse basis allowed for the model accuracy to be assessed in a refined manner. This approach can help identify parameters that may affect the model’s accuracy and guide adjustments. However, some overclassification of the model by horse is expected, as there were horses that displayed behaviors the model could not classify. This could explain the inflated detection rates for certain parameters in some horses.

A statistical difference between horses and the behaviors they showed was not observed for most behaviors. The lack in statistical differences aligns with what would be expected, as it was assumed that horse behavior would not differ significantly amongst experimental units when building the prediction model for behavior. The only statistically significant difference in behavior was for ‘grooming’ (p=0.045). However, it is important to note that grooming was not a behavior that could be determined by GPS data alone, so it did not affect the outcome of the prediction model.

A trend in behavior differences was also observed for ‘trotting’ (p=0.095) and ‘rolling’ (p=0.0611). However, this trend could potentially be explained by not having enough observation data available, and further research will be needed to see if these behaviors are profoundly different amongst horses or if they occur less frequently due to sample size limitations (table 7).
Table 6: All horses behavior observation versus predicted with detection rate.

<table>
<thead>
<tr>
<th>All Horse Behavior</th>
<th>Predictions (n)</th>
<th>Observed Behavior (n)</th>
<th>Detection Rate (%)</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>drinking</td>
<td>181</td>
<td>507</td>
<td>35.70</td>
<td>0.10</td>
</tr>
<tr>
<td>grazing</td>
<td>144338</td>
<td>144246</td>
<td>100.06</td>
<td>0.98</td>
</tr>
<tr>
<td>resting</td>
<td>13991</td>
<td>13402</td>
<td>104.39</td>
<td>0.82</td>
</tr>
<tr>
<td>running</td>
<td>93</td>
<td>177</td>
<td>52.54</td>
<td>0.22</td>
</tr>
<tr>
<td>trotting</td>
<td>249</td>
<td>157</td>
<td>158.60</td>
<td>0.10</td>
</tr>
<tr>
<td>walking</td>
<td>2067</td>
<td>2028</td>
<td>101.92</td>
<td>0.90</td>
</tr>
</tbody>
</table>

Table 7: Detection Rate of Behavior by Horse

<table>
<thead>
<tr>
<th>Blisstex</th>
<th>Diva</th>
<th>Dixie</th>
<th>Gina</th>
<th>Laney</th>
<th>Roadshow</th>
<th>Sara</th>
<th>Suzie</th>
<th>Whiteout</th>
</tr>
</thead>
<tbody>
<tr>
<td>% Detection Rate</td>
<td>% Detection Rate</td>
<td>% Detection Rate</td>
<td>% Detection Rate</td>
<td>% Detection Rate</td>
<td>% Detection Rate</td>
<td>% Detection Rate</td>
<td>% Detection Rate</td>
<td>% Detection Rate</td>
</tr>
<tr>
<td>drinking</td>
<td>N/A</td>
<td>0</td>
<td>7.2</td>
<td>0</td>
<td>N/A</td>
<td>6.5</td>
<td>95.4</td>
<td>0</td>
</tr>
<tr>
<td>grazing</td>
<td>88.4</td>
<td>94.7</td>
<td>107.5</td>
<td>100.0</td>
<td>103.6</td>
<td>89.0</td>
<td>108.5</td>
<td>97.1</td>
</tr>
<tr>
<td>resting</td>
<td>235.1</td>
<td>273.0</td>
<td>45.9</td>
<td>119.8</td>
<td>36.6</td>
<td>153.9</td>
<td>31.4</td>
<td>209.9</td>
</tr>
<tr>
<td>running</td>
<td>66.7</td>
<td>31.3</td>
<td>92.3</td>
<td>87.5</td>
<td>51.0</td>
<td>N/A</td>
<td>N/A</td>
<td>0.0</td>
</tr>
<tr>
<td>trotting</td>
<td>100.0</td>
<td>132.4</td>
<td>102.8</td>
<td>133.3</td>
<td>158.5</td>
<td>300.0</td>
<td>N/A</td>
<td>50.9</td>
</tr>
<tr>
<td>walking</td>
<td>80.6</td>
<td>143.3</td>
<td>114.9</td>
<td>94.3</td>
<td>119.2</td>
<td>114.4</td>
<td>57.5</td>
<td>105.5</td>
</tr>
</tbody>
</table>

*N/A indicates that this behavior was not observed for this animal

Equation 3: Detection Rate

\[
\text{Detection Rate} = \frac{\text{Total True Predictions}}{\text{Total number of times activity was observed}} \times 100
\]
2.3.5.3 FUTURE:

The model developed in this trial should be validated under further studies. With increased data points for the test subjects, it would validate that the behaviors observed were in line with “normal” behavior for a horse on pasture. Having further data to differentiate if behavior trends change as the day progresses would give key insight to grazing behavior of a pastured horse that is turned in and out daily. Expanding this research to cover multiple seasons and months would allow for behavior changes by seasonality to be detected. Testing this model under multiple seasons could potentially show how heat stress influences grazing behavior in horses. Further trials would also open the potential to see if different precipitation and weather trends influence grazing behavior.

2.3.6 REFLECTION:

While this study's findings are promising for both low-cost animal research GPS technology and the equine industry, it is important to acknowledge that the classification system developed still has limitations in its ability to detect horse behaviors. The system developed in this study could be paired with already utilized technology to increase its detection rate and validate the detection algorithm. This study utilized human detection for paired behavior observation. This makes for subjective behavior classifications since the observer is the one making the classifications. This subjectivity in model validation efforts, while the standard in similar studies, is not necessarily the best validation method since more technology has become available and validated.

Additional technology that could be used to improve this GPS sensor and detection algorithm and to validate behavior detection includes systems such as Equiwatch (Weinert et. al. 2020), RFID sensors, microphones, and scales. The system Equiwatch is a continuous
monitoring system that was validated for grazing detection in horses in 2019. It functions similarly to the Rumniwatch system used for cattle grazing detection and was originally validated using stall observation of feeding behavior (Werner et al. 2016). This type of system takes the guess work out of grazing versus not grazing and eliminates the human perception error. The system functions as a halter with a noseband attachment and could easily be used with the GPS collar.

Implementing the use of RFID sensors, scales, game cameras or microphones offers the potential to improve drinking detection in the behavior detection algorithm. These systems would need to be used with the collar even after validation. Setting up an RFID scanner near the water station would allow for animal detection and identification at the water tub, pairing this then with a scale system for the water tub would then allow for water consumption to be tracked. A cheaper alternative could be fitting the collar to have a microphone that could detect the gulping of water and pairing it with a game camera that would show you when a horse was at the water tub. These are theories for model improvement and would need to be tested and validated before commenting further on this application.

This behavior detection model was derived and implemented using Excel. The overall process was labor intensive and not intuitive, making it a considerable feat to extract the data. The next step for this detection model would be to try and apply it to a data system that could automate some of the processes in R or SAS. These systems, with the right coding, could automate this process and make data extraction easier. While in other cattle studies these systems have already been used to process data, these studies had lower detection rates than exhibited in this study.
2.4 IMPLICATIONS:

There has been limited research utilizing GPS technology to detect behavior with horses, this study demonstrates the feasibility of extracting grazing behavior information from GPS data. This research serves as a foundational step toward potentially integrating equine GPS behavior detection into management protocols. The implications of these findings for behavior management and remote monitoring are particularly promising when thinking about applying it for health monitoring and pasture management.

The integration of GPS technology in equine management offers the potential to enhance horse health by deepening our understanding of equine behavior, allowing for the development of tailored care and management practices. Remotely tracking and analyzing behavior patterns could allow for horse owners and caretakers to gain valuable insight into their animals’ health status and wellbeing. Early detection of irregular behaviors would enable earlier interventions, potentially preventing health issues from escalating.

Additionally, applying GPS technology in behavior monitoring is promising for optimizing pasture management and tailoring it to specific facilities. Equipped with personalized data on the grazing patterns and movements of the facility’s own animals, horse owners and facility managers could potentially develop more efficient and sustainable grazing strategies tailored to their current pasture setups. This could lead to improved pasture utilization, reduced overgrazing, and a more sustainable environment.

As this technology evolves and more data is collected, it may reveal previously unnoticed behavioral patterns that, when identified, contribute to a more comprehensive understanding of equine well-being and behavior. The true impact of this study is yet to be determined but offers
potential in advancing the equine industry as a deeper understanding of grazing behavior emerges.

2.6 CONCLUSION:

The Columbus P-1 data logger is a suitable low-cost GPS unit that can be used for research in horses. It has the ability to collect data that can be classified to detect differences in equine behavior without the use of an accelerometer. Further research and validation studies needed to determine if this GPS unit and classification system are suitable for research with other horse herds.
LITERATURE CITATIONS:


Knight, C. W. 2016. Intake, Reproductive, and Grazing Activity Characteristics of Range Cattle on Semi-arid Rangelands. Available from: https://repository.arizona.edu/handle/10150/612879


APPENDICES

APPENDIX A: EXCEL FORMULAS TO BUILD PREDICTION PARAMETERS

These equations were constructed using the IF function in Excel, following the format: value of interest, value if true, value if false.

*Equation 1: Resting Qualifier 1*

“Resting” = if(change in heading =0,1,0)

*Equation 2: Resting Qualifier 2*

“Resting” = if(and(speed km ≤ 0.1, Distance Traveled= 0, Average of distance changed =0, distance to water >5),1,0)

*Equation 3: Drinking Qualifier*

“Drinking” = if(and(speed km < 0.1, distance traveled=0, Distance changed=0, average distance change =0, Distance to water < 1.25m),100,0)

*Equation 4: Grazing Qualifier 1*

“Grazing” = if(distance to shade >13m),1,0
Equation 5: Grazing Qualifier 2

“Grazing” = if(and(distance to water > 1.25 m, distance to water < 10 m)), 1, 0

Equation 6: Grazing Qualifier 3

“Grazing” = if(change in heading > 0, 1, 0)

Equation 7: Grazing Qualifier 4

“Grazing” = if(and(speed km > 0.1, speed km < 4.0, distance traveled > 0, distance traveled < 2)), 2, 0

Equation 8: Grazing Qualifier 5

“Grazing” = if(average distance changed > 0, 3, 0)

Equation 9: Grazing Qualifier 6

“Grazing” = if(distance changed > 0, 3, 0)
Equation 10: Walking Qualifier

“walking” = if(and(speed km > 4, speed km < 8.6, distance traveled > 1.5, distance traveled < 3.6)), 20, 0

Equation 11: Trotting Qualifier

“trotting” = if(and(speed km > 8.6, speed km < 16.09, distance traveled > 2)), 30, 0

Equation 12: Running Qualifier

“running” = if(speed km > 15.0, 40, 0)

Equation 13: Prediction Algorithm

=IFS(sum of equations ≤ 2, resting, (AND(sum of equations ≥ 3, sum of equations < 20)), grazing, (AND( sum of equations ≥ 20, sum of equations < 30)), walking, ((sum of equations ≥ 30, sum of equations < 40)), trotting, (AND( sum of equations ≥ 40, sum of equations < 100, running, sum of equations ≥ 100, drinking))
APPENDIX B: MAP OF WITTER CENTER PADDOCK AND PADDOCK UTILIZATION

Figure 7: Witter Center Pasture Map

Figure 8: Witter Center Pasture Utilization Heat Map
BIOGRAPHY OF THE AUTHOR

She was born and raised in Maine, having spent most of her childhood growing up on the coast of Maine in Searsport. She later moved to Old Town, ME in 2017 when she entered the Animal and Veterinary Science program at the University of Maine. She received her Bachelor of Science in Animal and Veterinary science with a pre-veterinary concentration and equine science minor in May 2021. She is now looking to pursue a career in Cooperative Extension as an Animal Science Educator. Madison Philbrick is a candidate for the Master of Science degree in Animal Science from the University of Maine in December 2023.