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IDENTIFYING EARLY-LIFE BEHAVIOR TO PREDICT MOTHERING ABILITY IN  
SWINE UTILIZING NUTRACK SYSTEM

By

Savannah Gabrielle Millburn

A THESIS

Presented to the Faculty of  
The Graduate College at the University of Nebraska  
In Partial Fulfillment of Requirements  
For the Degree of Master of Science

Major: Animal Science

Under the Supervision of Professor Benny Mote

Lincoln, Nebraska

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# IDENTIFYING EARLY-LIFE BEHAVIOR TO PREDICT MOTHERING ABILITY IN SWINE UTILIZING NUTRACK SYSTEM

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University of Nebraska, 2022

Advisor: Benny Mote

Early recognition of indicator traits for swine reproduction and longevity supports economical selection decision making. Gilt activity is a key variable impacting a sow's herd life and productivity. The purpose of this study was to examine early-life behaviors contributing to farrowing traits including gestation length (GL), number born alive (NBA), number weaned (NW), and herd life (HL). Herd life was a binary trait representing if a gilt was culled after one parity. Beginning at approximately 20 weeks of age, video recordings were taken on 480 gilts for 7 consecutive days and processed using the NUtrack system. Activity traits include angle rotated (degree), average speed (m/s), distance travelled (m), time spent eating (s), lying lateral (s), lying sternal (s), standing (s), and sitting (s). Final daily activity values were averaged across the period under cameras. Parity one data was collected for all gilts considered. Data were analyzed using linear regression models and odds ratios (R version 4.0.2). GL was significantly impacted by angle rotated ( $p = 0.03$ ), average speed ( $p = 0.07$ ), distance travelled ( $p = 0.05$ ), time spent lying lateral ( $p = 0.003$ ), and lying sternal ( $0.02$ ). NBA was significantly impacted by time spent lying lateral ( $p = 0.01$ ), lying sternal ( $p = 0.07$ ), and time spent sitting ( $p = 0.08$ ). NW was significantly impacted by time spent eating ( $p = 0.09$ ), time spent lying lateral ( $p = 0.04$ ), and time spent sitting ( $p = 0.007$ ). Estimated odds ratios showed gilts traveling below average speeds and spending below average

time lying sternal were positively associated with below average GL. Gilts spending below average time lying lateral are associated with below average NW. Gilts spending below average time sitting were negatively associated with below average NW. Gilts spending below average time lying sternal were negatively associated with below average HL. This analysis suggests early-life gilt behavior is associated with sow productivity traits of importance. Further examination of the link between behavior and reproductive traits is necessitated. Utilization of the NUtrack video monitoring system to isolate behavioral differences offers potential to aide in selection decisions.

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*Galatians 6:9 – And let us not grow weary of doing good, for in due season we will reap,  
if we do not give up.*

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## **1. CHAPTER 1: LITERATURE REVIEW**

### **1.1 Introduction**

Maintaining a healthy, productive sow herd is of key importance to maximizing the financial viability of a commercial hog production system. Even so, high sow culling rates have historically limited a farms ability to regain the initial investment cost of breeding females and capitalize on their most productive parities (Stalder, Kenneth J. et al., 2003). The number born alive, number weaned, and litter weaning weight throughout a sow's lifetime all contribute to a sow's financial return to an operation. In addition to traditional production measures, both agonistic and maternal behavior influence a sow's utility within the breeding herd. Unfortunately, objective quantification of animal behavior has long been an obstacle facing this field.

In addition, current legislation regarding group housing of livestock has created the need to identify animals that can coexist in new, group-housed systems. However, identification of behavioral traits in swine requires additional labor inputs and costs that are not presently feasible for industry-wide use. Moreover, traditional quantification methods have required subjective scoring and human annotation which cause increased variability, potentially diminishing the value of behavioral measures. Therefore, it is of paramount importance to determine a non-labor intensive, objective method to quantify sow behavior on a large scale. By gaining a better understanding of how female behavior influences production traits of economic importance, producers may develop more holistic breeding programs. Thus, the identification of methods to isolate various behavioral traits correlated to maternal behavior or sow lifetime production in a low-cost,

non-invasive manner will be key to the inclusion of such traits into future selection indices to maximize welfare and productivity.

## **1.2 Sow Productivity Traits**

The genetics of sow productivity have been extensively studied because of the economic importance of performance in the farrowing house. Due to high sow replacement costs, sow productivity and retention are of critical financial importance to commercial swine entities. As of 2020, the average sow culling rate is approximately 48% (PigChamp benchmark.2020). Historically, a cascade of reproductive inadequacies have been the cause for early culling. Failure to breed, lameness, and poor performance at farrowing have been primary reasons cited for culling (Dagorn and Aumaitre, 1979).

Traditionally, sow productivity has been measured through counts taken soon after farrowing. In most systems, these performance records generally include number born alive, number weaned, and litter weaning weight/21-day litter weight (Bereskin, 1984). Another important trait to consider related to reproductive fitness is gestation length. A study focusing on the key differences between high and low performing herds found that the high productivity herds recorded higher number of pigs born alive and lower preweaning mortality, further emphasizing the importance of these key traits (Stein et al., 1990). These traits have been used to quantify sow productivity due to their critical impact on long-term profitability and sow longevity.

### ***1.2.1 Gestation Length***

Gestation length is the number of days a sow is pregnant. It is recorded as the length of time between breeding and when a sow farrows. Generally, gestation length in swine ranges from approximately 111 days to 120 days, with an average gestation length

of approximately 114 days. However, in recent years data obtained and analyzed by Swine Management Systems has shown an increase in the average gestation length from approximately 114.9 day in 2013 to 115.8 days in 2017 (Ketcham et al., 2017). A study looking at the relationship between gestation length, log odds of stillbirths, and piglet viability scores in 98 farrowing events found that shorter gestation lengths were significantly associated with increased log odds of stillbirths as well as decreased average piglet viability scores (Zaleski and Hacker, 1993). A foundational study using 301 sows and 391 gilts showed that gestation length was significantly positively correlated with piglet birth weight (0.12) but negatively correlated with pigs farrowed per litter (-0.16) and litter birth weight (-0.12) (Omtvedt et al., 1965). Similar results were found in a larger, more recent study using 66,254 farrowing records collected on 94 farms in 1999. Sasaki and Koketsu (2007) found that gestation length showed a repeatability of 0.50. In addition to being repeatable across parities, the authors also found that shorter gestation lengths were associated with higher total number born and dead piglets, as well as sows with intermediate gestation lengths (between 113 to 116 days) farrowing a higher number born alive than sows with gestation lengths outside of that range (Sasaki and Koketsu, 2007). Finally, a genome-wide association study looking at gestation length across a range of parities discovered discrepancies between QTL's shared between different parities, concluding that gestation length is likely polygenic in nature (See et al., 2019).

It has been recognized in both research settings and commercial farms that gestation length is a key reproductive measure that impacts litter traits, and thus culling rates and ultimately financial return. However, as noted in the literature above the effects of gestation length on number born alive and piglet birth weight and vitality are complex.

Further, selection for intermediate gestation lengths could prove challenging without further research into the traits that exert influence on different parities. Therefore, gestation length is an intricate trait that warrants further investigation to determine best practices for selection and management to maximize both piglet success and sow longevity.

### ***1.2.2 Number Born Alive***

Number born alive is a count measurement of the litter size for a given farrowing. Number born alive (NBA) is a reproductive trait of economic importance for multiple reasons. Prolific sows that produce a high number of pigs during their lifetime have a greater opportunity to create a financial return on their original retainment investment cost (Stalder, K. J. et al., 2004). Furthermore, a high first litter NBA can reduce early culling pressure and decrease costs associated with high replacement rates (Gruhot et al., 2017). In addition to the role of genetics, management style and group behavior of sows can influence stress levels and impact NBA in the sow. In an array of studies focused on the impact of stressors on swine reproduction, it has been shown that elevated levels of cortisol can result in decreased reproductive success in females (Turner, A. I. et al., 2005). Other research has demonstrated that sows housed in groups have higher rebreeding rates than those in individual housing, indicating the potential for social stressors to impact NBA and sow reproductive success (Munsterhjelm et al., 2008).

Considerable ranges in heritability estimates have been reported for reproductive traits in swine. Heritability measures the portion of variation in performance that can be attributed to underlying genetic variation (Falconer and Mackay, 1996) (Rothschild, 1996). Reported heritability estimates for NBA have a wide range, but have averaged

around 0.07 (Rothschild, 1996). The low heritability of NBA means that direct genetic selection will likely not yield a large increase in the number of live piglets born per litter. However, given the considerable improvements in NBA reported between 2015 and 1960 (13.5 vs. 10), improvement for this trait has been realized likely through selection on multiple reproductive measures (Putman et al., 2018)

Negative environmental correlations could be partially responsible for the low heritability of NBA. Sows from highly prolific lines have been shown to sometimes be outperformed by sows from lower performing dams (Revelle and Robison, 1973). This negative environmental relationship could be due to the added competition for resources that gilts face when raised in larger litters (Yen et al., 1987). In a highly competitive environment, gilts are unable to express their genetic potential due to slowed physiological maturity (Revelle and Robison, 1973). However, later research focused on sow lifetime productivity of Yorkshire females has shown that sows from small litters farrow for the first time at a more advanced age, were culled earliest, and gave birth to fewer piglets and litters than gilts that were farrowed in large litters during their productive lifetime (Warda et al., 2021). Further studies have shown a significant association between selection for increased litter size and resulting low individual birthweight phenotypes (Patterson et al., 2020). These dissonant findings suggest that litter of origin is an important predictor for future performance and a complex trait that influences multiple lifetime reproductive outcomes.

Further research has found that parity one NBA can be a strong indicator of lifetime performance, especially for the most prolific sows that produce greater than 14 pigs in their first farrowing (Iida et al., 2015) (Koketsu and Iida, 2020). However, other



studies suggest viewing parity one as a non-repeatable genetic trait due to low correlations ( $<0.62$ ) with future parity measures (Hermesch et al., 2000). These findings further reiterate the complicated genetic nature of reproductive traits.

### ***1.2.3 Number Weaned***

Like NBA, number weaned (NW) is an economically important reproduction trait. When the number of weaned pigs increases, the profit potential for a swine operation will increase as well (Gruhot et al., 2017). Laid on piglets, starvation, and gastrointestinal disease are common causes of preweaning mortality (Lay Jr. et al., 2002). Maternal behavior of the sow in the farrowing crate has been found to be closely related to incidence of laid on piglets (Lay Jr. et al., 2002). Sow movements, including the method of laying down (flopping straight down, lying down vertically) have been shown to impact the danger of piglets being crushed (Wechsler and Hegglin, 1997). In a study aimed to quantify sow behavioral differences using postural changes in both free farrowing pens and crates, it was shown that sows in pens exhibited greater postural changes ( $P = 0.04$ ) and had higher occurrences of piglet trapping ( $P=0.07$ ) than females in crates (Melišová et al., 2014). However, behavioral differences observed between the two farrowing systems did not result in a difference in piglet mortality ( $P=0.38$ ) (Melišová et al., 2014). The authors theorize that this was due to differences in piglet body condition between the two farrowing systems, however the study was limited by the small number of sows ( $n=38$ ).

Sows' responsiveness to her litters' distress calls has also been shown to have an influence on preweaning mortality, with more responsive sows crushing fewer piglets (Wechsler and Hegglin, 1997). However, others have found that a large proportion of

sows are unresponsive to piglet vocalizations (Lay Jr. et al., 2002). It's been shown that sows farrowing in pens have a greater response to playbacks of piglet distress calls than sows farrowing in crates ( $P=0.04$ ) (Melišová et al., 2014). However, the same study found that farrowing system (pen vs. crate) did not have a statistically significant impact on sow response to true piglet distress calls (Melišová et al., 2014). Lay Jr. et al. (2002) theorize that unresponsiveness could be due to the proximity of adjacent litters, potentially desensitizing sows to piglet distress sounds. When analyzing the difference between Meishan and Yorkshire sows' response to piglet distress calls, there was no significant breed effect (Farmer et al., 2001)

Savaging is another negative maternal behavior post-farrowing that can influence piglet mortality and number weaned. In a study classifying sow behavior for the 8 hours directly after parturition, it was observed that 4 out of 19 gilts were categorized as savagers based on aggression and postural changes towards their litters (Ahlström et al., 2002). Sows categorized as savagers spent a greater amount of time investigating their litters and had higher responsiveness to litters, particularly during the first two hours post-partum (Ahlström et al., 2002). However, the authors believe that savaging is a result of an abnormal coping style to being restricted in farrowing crates during parturition. Given the small sample size considered ( $n=19$ ), further analysis of farrowing behavior and savaging incidence is necessitated to build a more substantial body of evidence for this theory. In a larger study ( $n=226$ ) analyzing savaging differences between farms, it was again shown that aggressive sows were more restless and responsive during the immediate time frame following farrowing (Chen et al., 2008). After categorizing aggressive sows, this entire population was genotyped and a whole

genome linkage analysis was conducted (Chen et al., 2009). Chen et al (2009) reports finding seven regions that were linked with maternal infanticide and QTL's that could lead to the identification of candidate genes to select on for aggressive maternal behavior. However, direct extrapolation of results to commercial production in the United States is somewhat limited due to the use of farrowing pens and nesting straw.

Presently, Precision Animal Management (PAM) technologies are being developed to minimize laid on piglet losses that occur because of sow behavior. Smartguard (SwineTech) is a PAM technology developed to reduce laid on losses. Smartguard uses voice recognition to identify piglet distress calls and subsequently deliver a vibration to sows to stimulate them to stand up (Mumm et al., 2020). If piglet distress calls continue to be recognized, Smartguard delivers an electrical impulse to encourage sows to stand. It has been shown that relative to conventional human interaction, sows stimulated with Smartguard technology show minimal disruption to normal coping and nursing behavior (Mumm et al., 2020). In place of constant human observation, PAM technologies create potential for decreased labor needs and human intervention.

In parallel to NBA, number weaned is a lowly heritable trait (Mote and Rothschild, 2020). Rothschild (1996) summarized past heritability research and suggested that the average heritability for NW is approximately 0.06. Research performed on NW in the first parity found a similar but slightly higher estimated heritability of 0.09 when analyzing 11,222 sow records (Serenius et al., 2008).

#### ***1.2.4 Litter Weaning Weight***

An additional sow productivity trait of economic importance is litter weaning weight (LWW). This is a measure of how much a litter weighs at the time of weaning. The time of measurement for this trait is variable depending on production scheme but is traditionally obtained at approximately 21 days of age. Historically, heritability estimates for LWW have been relatively low ( $<.20$ ), following the same trend as NBA (Bereskin, 1984). However, reported heritability measurements for LWW have ranged from  $.07$  to  $.372$  in the literature reviewed, indicating that an array of factors may contribute to inconsistent values (Bereskin, 1984) (Blunn and Baker, 1949) (Hermesch et al., 2000).

Historically, the link between direct maternal behavior and litter weaning weight has not been thoroughly explored. However, differences in breed and production scheme that contribute to maternal behavior and piglet performance have been examined. When looking at differences between Meishan and Yorkshire sows during the lactation period, it has been observed that Meishan sows have greater daily milk yield corrected for suckling interval at day 22 of lactation ( $P=0.003$ ) and wean heavier litters ( $P=0.00001$ ) (Farmer et al., 2001). However, when observing postural differences across the length of lactation, no traits approached statistical significance. Given the high prolificacy and number born alive associated with Meishan sows, it is not surprising that they weaned heavier litters. In addition to breed effects, management systems have been evaluated for their impact on litter weaning weight. When comparing farrowing pens with temporary crating to farrowing crates, regardless of sow posturing differences piglet performance was unimpacted ( $P>0.05$ ) by pen system (Goumon et al., 2018). Likewise, in a study analyzing the effect of indoor versus outdoor management, piglet and sow production parameters were unaffected by location ( $P>0.05$ ). Given the differences in sow

posturing reported across studies, these results suggest that variation in sow behavior may impact piglet behavior or survivability but only influence litter weaning weights peripherally through piglet mortality due to sow crushing and savaging.

From a profit standpoint, high number born alive, consistent number weaned, and heavy litter weaning weights should yield optimal results. However, as previously stated, large litter sizes have been shown to create additional competition after farrowing (Yen et al., 1987). Negative correlations between high number born alive and the maternal environment have been shown to negatively affect piglet development (Revelle and Robison, 1973). This slowed development can result in larger litters that have lowered gain during lactation, negatively impacting LWW (Yen et al., 1987). Additionally, gilts raised in larger litters have been shown to have slowed growth curves, which can result in delayed puberty (Revelle and Robison, 1973). Finding an optimal target for litter size could help maximize survivability and litter weaning weight (Andersen et al., 2011).

### **1.3 Sow Longevity**

Sow longevity is generally defined as the length of time that a sow is a productive member of a breeding herd. However, longevity can also be measured as the length of productive life, number of parities retained within the herd, culling rate, or replacement rate (Stalder et al., 2004). Sow longevity is highly important to commercial swine production due to the impact that female retention has on the economic viability of an operation. In addition to the economic importance of longevity, retention rates can also influence biosecurity and even the productivity of the progeny.

#### ***1.3.1 Length of Productive Life***

Length of productive life (LPL) in swine is the number of parities that a sow remains in the breeding herd. LPL is a complex trait because it includes aspects of longevity as well as reproductive performance and the ability of the breeding technician (Mote et al., 2009). From a genetic standpoint, survival analyses have shown that there are molecular markers associated with factors contributing to sow productive life (Mote et al., 2009). These markers could be useful to include when creating selection indices, due to the favorable economic impact of increasing sow longevity. Candidate genes associated with LPL include insulin-like growth factor binding protein 1 (IGFBP1), insulin-like growth factor binding protein 3 (IGFBP3), carnitine O-palmitoyltransferase I (CPT1A), and organic cation/carnitine transporter 2 (SLC22AF) (Mote et al., 2006). However, these genes differ in their association with longevity, number born alive, and parity favored for these traits. In the population examined, sows with favorable IGFBP1 genotypes had a greater probability of LPL meeting 5 parities as well as producing 1.5 greater pigs than contemporaries (Mote et al., 2006). As discussed by Mote et al. (2006), the CPT1A gene differed, being positively associated with NBA past parity 3 as well as exhibiting a favorable association for LPL through parity 5. Isolation of candidate genes and regions creates opportunity for marker-assisted selection programs to maximize time and cost efficiency in selection for LPL.

Other studies have assessed the associations between length of productive life and age at first farrowing, number of piglets weaned, and wean to insemination interval. Age at puberty in gilts has been shown to be associated with stayability in swine. Using six genetic lines primarily composed of Yorkshire and Landrace crossed females, it was shown using a logistic regression model that stayability to four parities was significantly

influenced by age at first farrowing (Knauer et al., 2010). When age at first farrowing was omitted from the model, age at puberty was shown to have a comparably significant influence on stayability through four parities (Knauer et al., 2010). In both cases, Knauer et al. (2010) found younger ages at first puberty and farrowing were associated with positive reproductive outcomes in relation to sow longevity through four parities. In a study analyzing genetic variants in a population of 1,644 gilts, it was shown that age at puberty explained the largest phenotypic variation (27.3%) for a sow's ability to produce at least three parities (Wijesena et al., 2017). From a dataset including 11,222 Finnish Landrace sows, the estimated heritability for length of productive life was reported as 0.22 (Serenius et al., 2008). The same study found a moderately favorable correlation between LPL and number weaned/age at first farrowing (Serenius et al., 2008). Given that sows weaning larger litters earlier tend to be viewed more favorably from a productivity standpoint, it follows that there would likely be a favorable association between these traits.

Another important factor to consider when evaluating sow productive life is reproductive performance per parity. Analyses of sow productivity by breed and litter have shown that sows tend to produce their most prolific litters between parities three and six (Ehlers et al., 2005). In a study analyzing ten different culling strategies, it was shown that an optimized parity distribution occurs when sows are culled at later parities (eight/nine), resulting in an average herd parity of approximately 3.5 (Dhuyvetter, 2000). Further work looking at cross fostered piglet performance based on litter nursed in indicates that multiparous sows raise litters that are weaned at heavier weights and consume greater creep feed, compared to litters raised on gilts and second parity sows

(Huting et al., 2019) . However, Huting et al. (2019) also reported that multiparous sows have more heavy piglets removed preweaning, indicating that the best time to cull sows is a multifaceted issue, impacted by many factors. Overall, these studies further reemphasizes the importance of maintaining sows within the herd until at least parity three to maximize productivity.

### ***1.3.2 Culling and Financial Impact***

Culling rate and parity distribution are key factors affecting the profitability of commercial hog producers (Gruhot et al., 2017) There are many reasons that sows are culled from breeding herds in the United States. Main reasons that females are removed include reproductive failures, poor performance in the farrowing crate, age, soundness issues, and disease problems (Stalder et al., 2004). Among these traits, the factors that impact culling the greatest are reproductive failure and structural soundness concerns (Mote et al., 2008). Culling rates in the United States historically have hovered around approximately 50% (Stalder et al., 2004) (Engblom et al., 2016). High replacement rates have resulted in animals that are unable to pay for their initial investment cost (Stalder et al., 2003). Due to the financial impact of culling, many studies have sought to model swine herds to determine economic return and the optimal parity to remove a female from the breeding herd.

Depending on the production system, sows may be voluntarily culled based on breeding programs or involuntarily culled due to unforeseen circumstance. In a net present value analysis that modelled sow culling, it was found that sows do not reach a positive net present value until their third parity (Stalder et al., 2003). Economic models focusing on the production of weaned pigs found that costs were minimized when a sow



was between parities five through nine (Gruhot et al., 2017). Further models have analyzed how economic conditions (revenue per piglet, salvage values, replacement costs) and replacement rates interact to determine the optimal parity to cull in breed to wean systems (Rodriguez-Zas et al., 2006). It is important to consider the costs that contribute to maintaining a sow in a breeding herd. Costs considered by Rodriguez-Zas et al. (2006) include a base annual sow cost, revenue generated per weaned pig, replacement cost, salvage values, equipment cost per sow, and interest on buildings that housed females. When including these sow costs, Rodriguez-Zas et al. (2006) found that the optimal parity to cull changed based upon economic variables. Economic variables that most heavily influenced optimal culling parity included replacement cost and salvage value (Rodriguez-Zas et al., 2006). However, they reported that for the models base economic and biological variables, culling is financially optimized at four to five parities (Rodriguez-Zas et al., 2006). These conclusions mirror those found in earlier research by Stalder et al. (2003).

When analyzing the economics of sow culling, it is evident that sows that remain in the breeding herd for a greater number of parities tend to financially optimize production due to their ability to produce a greater number of piglets (Stalder et al., 2003). However, it has been previously stated that the average culling rate in the United States has historically hovered around 50%, indicating that many herds likely face challenges with optimal parity distribution and the recovery of initial investment costs.

#### **1.4 Quantifying Behavior**

Swine behavior is characterized by a complex interplay of genetic, environmental, and physiological factors. Due to the confinement and group aspects of commercial

swine production, behavior has an impact not only on profitability, but also on welfare and consumer acceptance (Rydhmer, 2021). Historically, behavior has not been included in large-scale swine selection programs (Rydhmer, 2021). This is likely due to the heavy emphasis placed on reproductive and production traits, as well as the subjectivity and labor-intensive nature of behavioral trait observation. In past research, selection for behavioral improvement has been evaluated on the individual level through direct and indirect genetic effects (Angarita et al., 2019) (Camerlink et al., 2013) (Hessing et al., 1994) (Hong et al., 2017). Other work has focused on group selection to improve welfare and overall group performance (Gunsett, 2005) (Rodenburg et al., 2010). Presently, most of the research done on individual and group behavior has focused on terminally driven production traits. However, sow behavior is of high importance due to the effect that the maternal environment exerts on piglet survivability (Andersen et al., 2005) (Lay Jr. et al., 2002). Current legislation and consumer welfare concerns related to gestation crates necessitate the understanding of hierarchal behavior of group housed sows (Rydhmer, 2021). By quantifying the relationship between behavior, welfare, and economically relevant production traits, selection programs could be developed to maximize consumer acceptance without sacrificing financial efficiency.

#### ***1.4.1 Back Test***

In research settings, backtests are used to quantify animal behavior and coping style. Backtests are used to categorize pigs as proactive or reactive in their stress response style (Spake et al., 2012). Backtests are generally performed during the first 21 days of life prior to weaning. Individual animals are restrained in a supine position for approximately 60 seconds (Spake et al., 2012). In most test settings, an animal is

released after 60 seconds or once they have stopped struggling/returned to a calm state (Spake et al., 2012) (Rohrer et al., 2013) At the conclusion of the 60 seconds, animals are classified as highly or lowly responsive, based upon the number and length of struggle attempts (Spake et al., 2012). Additional traits that can be analyzed in a backtest include latency time, number of struggle events, as well as the total duration of struggle events (Rohrer et al., 2013).

One study utilized backtests to categorize preweaning pigs into resistant, non-resistant, and doubtful groups based upon how many escape attempts were made during the 60 second test (Hessing et al., 1994). Once the animals were 9 weeks old, they were assigned to groups based upon their classification. There were multiple pens of entirely resistant, entirely non-resistant, and mixed animals. The researchers found that agonistic behaviors post-mixing were the greatest in pens of entirely resistant classified animals (Hessing et al., 1994). At the conclusion of the study, Hessing et al. (1994) found that the mixed pens exhibited the highest rate of gain (ADWG), carcass weight ( $P < 0.05$ ), meat percentage ( $< 0.10$ ), and positive carcass classification ( $P < 0.05$ ). In addition to positive ADWG, this study also found the least ADWG variability within mixed pens (Hessing et al., 1994). As well as the positive outcomes associated with mixed pens, Hessing et al. (1994) also saw unfavorable outcomes from purely non-resistant pens. From this, it can be speculated that certain social structures/hierarchies related to passive and active coping styles can be beneficial when mixed in the same setting. The purpose of this study was to relate social behavior to financial benefit gained across pens at harvest. However, due to the increased performance consistency and decreased post-mixing aggression, it is

likely safe to assume that similar benefit could be realized in the growing stage of breeding females.

A comparable study by Rohrer et al. (2013) looked at latency time, time spent struggling, and the number of struggling events on backtests of weaned piglets at 24 days of age. Heritabilities generated in a single trait analysis for backtest traits were significant ( $P < 0.05$ ) and 0.159, 0.148, and 0.157, respectively (Rohrer et al., 2013). This study found genetic correlations exhibiting animals with a higher latency to struggle period ate a greater number of meals per day (0.599,  $P < 0.05$ ), spent more total time at the feeder per day (0.772,  $P < 0.001$ ), and had shorter average meal lengths (-0.460,  $P < 0.05$ ) (Rohrer et al., 2013). The pigs with higher struggle times and struggle events had increased average mealtimes (0.451,  $P < 0.05$ , 0.509,  $P < 0.05$ ). However, pigs with higher struggle times also had decreased total mealtimes per day (-0.960,  $P < 0.01$ ) (Rohrer et al., 2013). No backtest traits were found to be significantly correlated ( $P < 0.05$ ) to backfat values at 154 days of age (Rohrer et al., 2013). However, no backtest traits were significantly correlated with 154-day weight (Rohrer et al., 2013). As might be expected, weight at 154 days of age was positively genetically correlated with average mealtime and total daily mealtime (0.356,  $P < 0.001$ , 0.339,  $P < 0.01$ ) (Rohrer et al., 2013).

When utilizing two separate backtests, it has been shown that behavior is inconsistent between test one and test two (Scheffler et al., 2014). Additionally, high correlations between duration of escape attempts/struggle, latency to escape, and number of escapes have been found (Scheffler et al., 2014). This indicates that recording only number of escapes or latency to escape/struggle could be sufficient to adequately capture coping style with lessened labor requirements. In addition to these correlations, Scheffler

et al. (2014) also found that animals with heavier birthweights tended to have fewer escape attempts with shorter durations. Since piglets were tested preweaning, this indicates that there is potential for birthweight to be an indicator for stress coping style.

Backtest traits tend to illustrate coping behavior that may impact how animals behave when housed in mixed groups (Hessing et al., 1994). However, backtest procedures are labor intensive and require additional handling of individual animals. Additionally, scoring systems that rely on human observation are subjective and utilize non-standard scoring procedures across studies. Because of this, use of backtests to quantify animal coping style results in limitations that may restrict practical use in commercial practice.

#### ***1.4.2 Resident-Intruder Test***

Resident-intruder (RI) tests have been used to measure social, defensive, and aggressive behavior in animals. Traditionally, RI tests have been performed in laboratory research settings utilizing rats or mice. However, since RI tests can measure defensive and offensive aggression these tests have been used in studies of swine behavior as well. RI tests are performed by housing one animal, the resident, independently and then introducing another smaller or younger intruder animal (Koolhaas et al., 2013). In laboratory settings, RI tests tend to last approximately 15 minutes. In swine studies, tests typically measure “latency to first attack” and range from approximately three and a half to five minutes. Due to welfare implications, tests are terminated once an attack is initiated. Unlike backtests, which attempt to capture individual stress coping style, resident-intruder tests are believed to measure specific aggression towards unfamiliar animals (Cassady, 2007) (Spake et al., 2012).

In swine, RI tests have shown that aggressive, early-life behavior is consistent for individual resident animals (Erhard and Mendl, 1997). Erhard and Mendl (1997) found that pigs housed exclusively with their own litter showed consistent aggression in RI tests performed at 7 and 11 weeks of age. These results were independent of the age, sex, or weight of resident animals, suggesting that aggressive behavior is not entirely influenced by dominance rank within litter or physical characteristics.

Pigs tested at 46, 80, and 113 days of age exhibited aggressive behavior more stable than expected by random chance ( $P < .026$ ), supporting the theory that behavioral characteristics are consistent within individuals across time (D'Eath, 2004). However, across longer time periods females were more frequently recorded to show aggressive behaviors, indicating that sex may play a role in long-term aggression ( $P < .007$ ) (D'Eath, 2004). Additionally, pigs that were only housed within their litter showed less aggressive behavior than pigs that had been mixed after weaning ( $P < .05$ ) (D'Eath, 2004). Moreover, mixed groups with a greater number of pigs deemed aggressive by RI tests have been shown to have more lesions, indicating potential welfare concerns associated with consistent aggressive behavior (D'Eath, 2002).

### ***1.4.3 Alternative Approaches***

Many different tests have been implemented to quantify animal behavior. The two afore mentioned measures, back tests, and resident-intruder tests, are widely accepted for their ability to capture differences in behavior. However, due to the invasive nature of these tests, they require additional inputs of time and labor. To circumvent these obstacles, a scale activity score (AS) was developed as an adaptation of cattle chute

scores (Holl et al., 2010). AS is a categorical measure ranging from 1 to 5, with 1 being the calmest and 5 the most responsive/excitable (Holl et al., 2010).

Initially, AS was used in conjunction with ultrasound backfat measurements to examine the potential relationship between behavior and production traits (Holl et al., 2010). Utilizing a linear model, Holl et al. (2010) found that AS had a heritability of 0.23 and exhibited negative genetic correlations with body weight (-0.38), first rib back fat (-0.11), last rib back fat (-0.12), and lumbar vertebrae back fat (-0.16) (Holl et al., 2010). From these correlations, the authors concluded that selecting for increased docility (as characterized by scale scores) should result in animals with increased backfat values and body weights (Holl et al., 2010).

In an expansion of the AS dataset used by Holl et al. (2010), Schneider et al. (2011) investigated the genetic link between early-life behavior and reproductive behavior and performance. In addition to the scale score, a farrowing score (FS) was recorded approximately 24 hours post-farrowing (Schneider et al., 2011). FS was evaluated during piglet handling and assigned on a scale ranging from 1 to 3. Additionally, scores were impacted by whether the sow had laid on any piglets prior to handling (Schneider et al., 2011). A score of 1 indicated that the sow was calm and cautious with her piglets, 2 indicated she was nervous and had laid on piglets, and 3 meant the sow was visually distressed and had engaged in aggressive behavior towards her litter (Schneider et al., 2011).

In this larger dataset, Schneider et al. (2011) found a lower heritability of 0.15 ( $P < .0001$ ) for AS and a marginally significant heritability of 0.06 ( $P < .054$ ) for FS. The authors evaluated 15 reproductive traits, and of these traits found 7 that were statistically

significant and of a large enough magnitude to potentially be included in future genetic indices or selection programs (Schneider et al., 2011). Of these, the four that were favorable included correlations between AS and NBA (-0.53,  $P < .01$ ), AS and number weaned (-0.38,  $P < .10$ ), FD and NBA (0.51,  $P < .10$ ), and FD and litter birth weight (-0.64,  $P < .05$ ) (Schneider et al., 2011). The remaining three correlations indicated unfavorable changes in reproductive trait values when behavior scores increased. The unfavorable correlations were between AS and wean to estrous interval (-0.79,  $P < .05$ ), AS and average piglet birth weight (0.53,  $P < .001$ ), and AS and litter weaning weight (0.33,  $P < .10$ ) (Schneider et al., 2011). While these findings do support a connection between behavior and reproductive performance, the mix of favorable and unfavorable AS correlations reinforces the idea that behavior needs to be more thoroughly quantified before commercial incorporation is seen on the large scale.

The behavior of the sow after farrowing has implications for piglet survival (Lay Jr. et al., 2002). In a system utilizing a family pen system, behavior was found to have an impact on the number of piglets that were crushed and in danger of being crushed (Wechsler and Hegglin, 1997). Wechsler and Hegglin (1997) utilized continuous video recordings during farrowing and 10 days post farrowing to score sows based on their movements. Movements included in the final behavioral score included the average frequency of when the sows lied down and rolled, as well as if they lied down by “flopping straight down”, when they lied down in an area with the majority of the piglets present, and the average percentage of her litter that was present during laying down events (Wechsler and Hegglin, 1997). Ranking of behavior was done by assigning values according to the number of described behaviors exhibited that were associated with risk



of crushing. Once sows were ranked for these behaviors, a composite rank was determined for each sow and used to describe the quality of mothering behavior. Additionally, the researchers analyzed the sow's physical response to playbacks of piglet distress calls and control recordings of bird calls (Wechsler and Hegglin, 1997). The authors found that the sows behavior score was significantly correlated to the number of piglets where crushing was the cause of death in litters recorded between June 1991 to July 1993 ( $P < .05$ ) (Wechsler and Hegglin, 1997). Further, they reported that 63.6% of the sows altered their posture in the majority of the piglet distress playback events, but the overall sow behavioral score was not correlated with posture changes (Wechsler and Hegglin, 1997) These results led the authors to believe that differences in behavior explained a large portion of the variation in the number of piglets crushed by individual sows (Wechsler and Hegglin, 1997). However, it is important to note that sows in this study were loose housed in farrowing pens with straw bedding. This production system is not reflective of traditional, commercial farrowing crates that are current with United States industry standards.

Another similar study on maternal behavior categorized sows into groups of "crushers" or "non-crushers", dependent on if they had crushed any piglets by four days post-farrowing (Andersen et al., 2005). Sows were under continuous video-monitoring for two days pre-farrowing until four days post-farrowing, with nesting, suckling, nursing, and posture change behavior being analyzed (Andersen et al., 2005). Additionally, piglet distress sound tests and separation/reunion tests as well as post-weaning sow mixing behavior was investigated (Andersen et al., 2005). Crusher sows were found to have significantly larger litter sizes in this sample group ( $P < .01$ )

(Andersen et al., 2005) However, non-crusher sows were found to perform more nest building activity six to eight hours prior to farrowing ( $P < .05$ ) in addition to being more responsive to piglet distress calls ( $P < .06$ ) and showing avoidant behavior during post-weaning mixing with other sows (Andersen et al., 2005). These findings support that there are measurable differences in maternal behavior of the domestic pig. Even so, small sample sizes and human observation are limiting factors in previous studies attempting to quantify behavioral differences.

#### ***1.4.4 Feeder Behavior***

Behavior at the feeder is another important time point for animal observation in addition to post-mixing and post-farrowing observations. In the past, feeding behavior was limited to observational recordings and feed intake data (Brown-Brandl and Eigenberg, 2011). Like previously discussed behavior measures, feeding behavior historically has required individual or small groups of animals to be used. However, current research has focused on adaptation of systems to track feeding behavior in a manner that better mirrors industry conditions.

Radio frequency identification (RFID) is currently being used to overcome past limitations associated with collecting feeding behavior information. In a system used at the United States Meat Animal Research Center (USMARC), antennas that register energy from RFID tags are attached to swine feeders. Once the antenna has recognized an animal during a feeding event, information is sent to a host computer to be processed by software (Brown-Brandl and Eigenberg, 2011). In early verification trials, this monitoring system was found to have at least a 97.9% agreement to independent video

monitoring equipment when used continuously in a pen holding 40 barrows (Brown-Brandl and Eigenberg, 2011).

Further research at USMARC analyzed feeding behavior of group housed finishing pigs using the RFID feed system (Brown-Brandl et al., 2013). Brown-Brandl et al. (2013) collected information on 960 barrows and gilts during the finishing period for approximately 60 days. They found that time spent feeding was variable between barrows and gilts and plateaued after the animals had been in the finishing facility for approximately 6 weeks (Brown-Brandl et al., 2013). Moreover, animals classified as high gaining spent the most time at the feeder and reached market weight the earliest. Once high gaining animals were removed, the slower gaining animals spent a greater amount of time at the feeder which could show a competition/social interaction among animals that differed considerably in terms of gain (Brown-Brandl et al., 2013). During the study, a pneumonia break occurred. Animals that had to be treated for pneumonia during the observation period were found to spend less time engaging in feeding events (Brown-Brandl et al., 2013). While antagonistic behaviors at the feeder were not quantified in this study, the patterns of behavior that surfaced show potential for feeding systems to enlighten management and welfare decisions.

In addition to the system used by USMARC, individual animal feeders have been employed to identify feeding behavior in pigs. One study analyzed feeding differences between Yorkshire, Landrace, and Duroc pigs depending on the time of day and season of year. Xin et al. (2016) used individual FIRE feeders to track feeding lengths. In this system, the feeder registers the RFID tag to track the amount of feed and length of time that an animal spends at the feeder (Xin et al., 2016). From this, Xin et al. (2016) found

that feeding behavior peaked at two daily time points and was consistent across breed and season. Peak feeding times were discovered to be consistent among breeds and fall between 8:00-9:00am and 2:00-3:00pm (Xin et al., 2016). As may be expected, Xin et al (2016) note that pigs consistently have lower daily feed intake during the winter and spring relative to autumn months, regardless of breed composition. However, group behavior and social interactions during feeding were inherently excluded from this analysis due to the individualized nature of the FIRE feeders.

#### ***1.4.5 Observational Systems***

In livestock production, activity and behavior have impacts on management, productivity, and economic efficiency. In the past, behavioral observations have been limited by human labor and technological constraints. However, systems focusing on visual identification and deep-learning networks have opened the door to more accurate, less time intensive behavioral records.

In commercial swine, group aggression poses problems in the form of animal welfare concerns and economic loss. Considerable efforts have been put forth to identify aggressive animals and interaction within group-housed systems. In one study, pigs were visually recorded for 24 hours and 3-second-long instances were human annotated as aggressive or non-aggressive interactions (Steibel, 2020). An algorithm was developed to delineate between interaction type and tested based on 1,666 video segments. When tested, the algorithm exhibited an accuracy rate of 97.5% correct detection of aggressive interactions. While these results show that the system can accurately detect aggressive interactions, these instances are not categorized as reciprocal or unilateral which may limit their use in selection.

In poultry, feeding behavior and appropriate floor distribution of animals are highly important from a flock health and management standpoint. One method to quantify feeding and social behavior in poultry is a machine, vision-based system. This system divides the broiler floor into sections based on their purpose (exercise area, feeder, waterer) and processed images using a neural network to identify animals (Guo et al., 2020). Guo et al. (2020) found their system to report accuracies of 0.9419 for birds in drinking areas and 0.9544 in feeding areas.

Utilizing electronic sow feeders (ESF) and Smartbow tags and positioning software provides an alternative to video recording mechanisms. In a study focused on social interactions between sows after reintroduction from farrowing, ESF's and Smartbow tags were used to analyze social hierarchy and group interactions. ESF's used RFID tags to determine what order sows enter the feeder. To determine location within a pen, Smartbow ear tags transmit information to antennas that use triangulation to approximate an animal's orientation (Perisho and Hajnal, 2021). In addition to positioning, Smartbow tags also collected acceleration data via an internal accelerometer mechanism. Using results from a principal component analysis to create a regression model, Perisho and Hajnal (2021) found that high levels of activity were predictors of reproductive success. Further, the authors observed an association between low social standing and engagement in aggressive events as predictors for low average piglet birth weight. Compared to visual methods, one limitation of the Smartbow and ESF method is that aggressive events were unable to be classified as reciprocal or unilateral (Perisho and Hajnal, 2021). Without classifying who the aggressive actor in an interaction is, connections between personality type and value in production are unable to be drawn.

Further, Smartbow tags had to be attached to the back of sows, and any female that lost their tag during the reintroduction period had to be removed from the statistical analysis.

Given the previously discussed limitations of human observation in research and industry settings, much work has been focused on machine learning and the use of neural networks to identify and track individual animals. One system using a fully convolutional neural network identifies individual pigs' location and orientation in group settings with a precision rate greater than 99% on previously seen environments (Psota et al., 2019). The neural network connects body parts of individual animals via association vectors to determine orientation within a pen (Psota et al., 2019). Measures that can be obtained from this system include the time spent laying, distance travelled, time standing, angle rotated, time at the feeder/waterer, distance from other animals within the pen, and various orientation measures. Early swine research using this system has drawn positive correlations between instances laying down and weight, as well as negative correlations between weight and distance travelled and time spent standing (Ostrand et al., 2020). Moreover, differences in the behavior of nursery pigs after an immune challenge have been discerned using this monitoring system (Holliday et al., 2021). Results from these studies have shown the potential for non-invasive tracking systems to capture behaviors that go unnoticed by daily handlers in a commercial setting.

#### ***1.4.6 Behavior in Selection Programs***

Due to the complexities related to identifying and interpreting behavioral traits in livestock species, animal behavior traits have not traditionally been included in selection programs. For a trait to be included in a selection index, a few requirements must first be satisfied. One of the key requirements is that behavior traits need to be measured on

many individual pedigreed animals so that there are sufficient records to calculate heritability (Turner, S. P. et al., 2011). In the past, this has been a limiting factor for behavior traits due to the labor-intensive nature of measurements.

Currently, behavioral traits like temperament are being recorded and used for selection in cattle. An example of this is the docility EPD used by the American Angus Association (EPD and \$Value Definitions.). The docility EPD for Angus cattle can be used to improve both within herd temperament for ease of handling and rate of gain (Church, 2011). Although temperament EPD's are widely available through cattle breed associations, they have not been included in selection indices. As illustrated by Turner et al. (2011), this is likely because selection indices require that genetic correlation estimates exist among traits. Further, economic selection indices also necessitate that each trait has an associated economic value. For various behavior related traits, this can be a challenge due to the complicated nature of associating temperament with quantifiable economic outcomes (Turner et al., 2011).

In addition to improving production outcomes from an economic standpoint, the inclusion of behavioral traits into selection indices also offers the potential for improving overall welfare. By using precision livestock technology, behavioral traits and phenotypes can be recorded on a greater number of individual animals. Current research has focused on how welfare can be improved through the inclusion of these traits (Brito et al., 2020). However, determining which traits are most relevant for inclusion in selection and economic selection indices and determining appropriate economic weights will be key for widespread use of these traits across species.

#### ***1.4.7 Multilevel Selection***

The multilevel selection model rests on the assumption that interactions between individuals within groups influence phenotypic or survival outcomes (Bijma et al., 2007). In multilevel selection, an animal's total breeding value consists of direct breeding value and social/indirect breeding value (Bijma et al., 2007). The direct effect is how individuals' own genes affect their phenotype (Bijma et al., 2007). Indirect genetic effects (IGEs) are characterized as the heritable effect of an animal on the expressed traits of other members of a common group (Canario et al., 2017). The difference between the classic quantitative genetic model and the multilevel selection model is that the multilevel model accounts for how IGEs influence expressed phenotypes (Bijma et al., 2007). Under this model's parameters, it is therefore possible to make greater genetic improvement when selecting on both direct and indirect genetic effects (Bijma et al., 2007).

Proponents of the multilevel selection model argue that adding IGEs to selection indices will increase genetic progress while benefiting animal welfare (Muir, William M., 2005). The reviewed multilevel selection experiments and case study involve laying hens, Japanese quail, and swine populations (Muir, W. M., 1996) (Muir, 2005) (Gunsett, 2005).

A form of multilevel selection known as group selection was used in White Leghorn chickens to examine mortality and egg production traits in group housed hens that did not have their beaks trimmed (Muir, 1996). A control line was kept in single housed cages and maintained for six generations (Muir, 1996). Only hens in generation 1 had their beaks trimmed, which excludes generation one from direct comparison to later generations that were not beak trimmed (Muir, 1996). Muir (1996) housed the selected lines in groups of 9 or 12 depending on generation. Entire cages composed of hens from



sire family groups were selected or rejected based initially on an egg mass index, but in later generations on days survived and indices including both survivability and production traits (Muir, 1996). At the conclusion of the experiment, Muir (1996) reported a 59.2% reduction in mortality from generation 2 to generation 6 using this selection method. The mortality rate of the selected hens in generation 6 (8.8%) was comparable to that of the individually housed control line (9.1%) (Muir, 1996). Due to the high mortality and stocking density, the welfare and experimental design of this experiment have been brought into question (Rodenburg et al., 2010). Nonetheless, results from this study have served as foundational verification for the efficacy of group selection methods in biological settings.

Later work on multilevel selection has focused on quantifying and selecting on associative effects that individuals exert on groupmates (Muir, 2005). One such validation study utilized Japanese quail. In population of quail, two lines were selected for 6-week weight (Muir, 2005). One line of quail was selected utilizing best linear unbiased prediction (BLUP) for direct effects, while the other line was selected using BLUP methods with a combination of direct and indirect genetic effects (Muir, 2005). In Muir's (2005) experiment, the line selected on a combination of direct/indirect effects had a significant, positive response to 6-week weight selection. The line selected only based on direct effects had a negative response to selection that was not significant (Muir, 2005). Muir (2005) theorized that the difference in response was due to the addition of indirect genetic effects.

To date, a case study at Newsham Hybrids is the longest and most comprehensive documented commercial use of group selection in swine. Newsham Hybrids implemented

group selection after noticing that genetic improvement at the nucleus level was not being realized in commercial production (Gunsett, 2005). Newsham Hybrids designed a complex group selection model where sires were evaluated based on an index value calculated for groups of their progeny (Gunsett, 2005). The goal was to “rear individuals in half-sib groups and choose the best performing individuals within the group” (Gunsett, 2005). Under this selection scheme, one boar and two randomly selected gilts were chosen from the highest performing sires, which resulted in a high nucleus herd replacement rate and relatively inefficient allocation of breeding stock (Gunsett, 2005). The program at Newsham Hybrids ran from 1996 to 2002 but was subsequently discontinued when the company was acquired by Seghers Genetics (Gunsett, 2005). Fields Gunsett summarized the anecdotal results of the experiment in a swine case study, reporting favorable 150- and 160-day weight increases in response to the change in selection method. However, Gunsett admits that the selection program was complex and required drastic changes at the expense of increased inbreeding and decreased selection intensity relative to traditional selection methods.

#### ***1.4.8 Social Genetic and Early-Life Social Effects***

Social behavior of swine holds a high degree of importance to the industry from an animal welfare and public perception standpoint. Traditional methods to decrease negative social interactions between animals (tail docking, individual gestation housing) have recently been subject to public scrutiny (Rydhmer, 2021). Because of this, there has been a recent push to quantify social behavior and select animals that are more adaptable to varying social situations. One method to quantify social behavior has been to analyze

group interactions of growing pigs and sows through the lens of social and indirect genetic effects as well as early-life social effects.

Social genetic effects (SGEs) and early-life social effects (ELSEs) have been analyzed in addition to indirect genetic effects (IGEs). Social genetic effects are comparable to IGEs in the sense that they attempt to quantify the effect that an animal's genotype exerts on the performance of groupmates (Angarita et al., 2019). On the other hand, an early-life social effect (ELSE) captures the effect that an individual has on the performance of group mates that shared the same early-life environment (Canario et al., 2017). SGEs and ELSEs have been a focal point for recent behavioral research due to their ability to account for potential differences in the genetic effects and social behavior.

One study utilized records from 1,827 static gestation groups to estimate social genetic effects and their importance relative to total number born, number born alive, and gestation length (Bunter et al., 2015). Group sizes ranged between two to ten sows per pen. The statistical model used a custom dilution factor that was determined based on the number of sows per pen relative to the maximum number of sows per pen (Bunter et al., 2015). When estimating heritabilities for the reproductive traits in the model, Bunter et al. (2015) found that genetic models were significantly ( $P < 0.05$ ) improved through the addition of SGEs. Bunter et al. (2015) found that the influence of SGEs was reduced when there more space per individual sow, regardless of the maximum number of sows per pen. Additionally, the optimized model resulted in no correlation that was significant between the additive direct genetic effect and the SGE (Bunter et al., 2015). The lack of correlation between these effects further supports the idea that social genetic effects describe a phenotype that is not accounted for in traditional genetic models.

One confounding problem with the estimation of IGEs and SGEs is the dilution factor. Dilution factor is the adjustment made during the estimation of an IGE/SGE based upon the group size that is being analyzed (Heidaritabar et al., 2019). A data simulation performed by Heidaritabar et al. (2019) looked at how differing group compositions and sizes affected the precision of IGE dilution factor. Group sizes in swine can differ considerably over time due to mortality and morbidity, therefore recognizing how this variation impacts genetic effects is important from a modelling standpoint. Additionally, Heidaritabar et al. (2019) analyzed groups composed of random individuals as well as those comprised of animals from two families. This study found dilution to be estimable and tended to be more precise when variation in group size was increased (Heidaritabar et al., 2019). Further, Heidaritabar et al. (2019) found that groups that were made up of two families performed better when estimating dilution factors.

Social behavior has implications for growing pigs in addition to group housed females. It has been estimated that in growing pigs, the social interactions among group mates may account for up to 70% of the variation in feed intake and growth rate (Bergsma et al., 2008). One of the key time points for aggression in swine is post-mixing, prior to the establishment of a social hierarchy. To estimate associations between behavior and social effects of growth rate, Canario et al. (2012) observed behavior 24 hours and three weeks post mixing. Animals were recorded for a 24-hour period at both time points and human annotation was used to record incidence of reciprocal fighting, bullying, receipt of bullying, and number of times observed lying. In addition to behavior records, number of new anterior and posterior skin lesions were counted before and after mixing at two separate time points (Canario et al., 2012). Canario et al. (2012) found that

in a population exhibiting genetic mutualism for growth rate, pigs with the highest total breeding values tended to engage in bullying behavior post-mixing and had fewer lying down incidence at the second time point. This suggests that animals with the highest total breeding value (combined social and direct breeding values) were most aggressive directly post-mixing. However, once hierarchical groups were established, animals tended to be more active but less willing to engage in fighting behavior (Canario et al., 2012). The quantification of behavioral tendencies post mixing and after group dynamics are established holds value when trying to select for animals that perform better in group settings. However, human observation and annotation of video recordings and live animals is a recurring, substantial limitation from a labor and cost perspective.

Further studies have utilized SGEs and skin lesion counts to model direct genetic additive models, traditional social genetic effect models, and intensity-based social genetic effect models. To model intensity-based social genetic effects, post-mixing videos were annotated for the type of interaction (reciprocal fighting/unilateral attack) and intensity of interaction between animals (Angarita et al., 2019). From this, Angarita et al. (2019) found that the intensity-based social genetic effect model resulted in the highest direct genetic variance as well as the highest estimated heritabilities for estimated traits ( $P < 0.01$ ). Because of this, the intensity-based model allowed for the estimation of both direct genetic effects and SGEs. Parsing out a greater amount of variation allows for selection to reduce aggressive interactions between animals in new group settings. However, in addition to the afore mentioned labor and financial limitations of observation, the intensity-based model also requires the human annotation of all interactions between groupmates.

In addition to IGE/SGEs, ELSEs also look at the way that social interaction impacts the performance of livestock animals. However, ELSEs focus on how animals reared in the same environment non-genetically affect their groupmates later in life (Canario et al., 2017). In a study focusing on growth rate in swine, Canario et al. (2017) found that littermates yield a similar social effect on their eventual groupmates. Further, the effect that early-life environment had on an individual animal was not correlated to the ELSE that was expressed on groupmates, suggesting that pigs can positively contribute to their groupmates growth without negatively impacting their own performance (Canario et al., 2017). From a model estimation standpoint, Canario et al. (2017) found that the exclusion of ELSEs resulted in inflated IGE values. This suggests that group dynamics impact performance on both a social and genetic level, and thus accounting for non-genetic effects is integral in creating a robust model.

## **1.5 Conclusion**

There are many factors that impact sow utility and the economics of commercial swine production. A thorough understanding of the driving factors of sow productivity and longevity is necessary. The number born alive, number weaned, and 21-day litter weight all impact a sow's probability of being retained in the breeding herd. In addition to the genetic and environmental components of these traits, they are also influenced by female behavior. Further, on-farm animal handling and individual stockmanship of personnel impact longevity outcomes in commercial settings.

Animal behavior is a complex topic that requires an interdisciplinary approach to partition. Genetics, nutrition, welfare, legislation, and economic considerations must be made when assessing behavioral traits. While there are currently methods to measure the

productivity and longevity of females within breeding herds, the impact of behavior on culling and on-farm economic feasibility has been overshadowed by more readily obtainable measures. This is due to the labor-intensive nature of measuring behavior traits. For behavioral traits to be included in future selection indices and breeding programs, a few requirements must be met. Firstly, behavioral traits must be measured on many individual animals in a low-cost manner that requires little additional labor. Moreover, traits must be objectively scored to reduce human error and variability. In addition to the collection of behavioral traits, understanding how to model them in the framework of quantitative genetics requires further research. Recognizing how behavior affects the individual as well as group mates will be key when determining which models best capture genetic variation. Using a data collection system that can capture unbiased measurements on individual animals in group settings is key to determining the effect that female behavior has on sow productivity and longevity. An objective, continuous monitoring system would satisfy these requirements and generate enough data to thoroughly analyze the impact of behavior on commercial swine production.

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## **2. CHAPTER II: IDENTIFYING EARLY-LIFE BEHAVIOR TO PREDICT MOTHERING ABILITY IN SWINE UTILIZING NUTRACK SYSTEM**

### **2.1 Introduction**

Selection of replacement females is a critical decision for commercial producers sometimes based on little known information outside of pedigrees and physical conformation. From an economic standpoint, maintaining a productive, healthy sow herd while placing emphasis on female longevity is of high importance. However, sow longevity and productivity can be ambiguously defined terms across different production systems. Further, these traits are not observed until advanced stages of life, increasing investment costs in replacement gilts. Breeding failures, lameness, and poor performance in the farrowing crate have historically been cited as reasons for early culling (Dagorn and Aumaitre, 1979). Determining a connection between early-life, observable activities and reproductive traits could give commercial producers the ability to improve sow herds in a more rapid and cost-effective manner.

Gestation length (GL) measures the amount of time between when a sow is bred and when she farrows. Shorter gestation lengths have been shown to be significantly associated with increased log odds of stillbirths in addition to decreased piglet viability (Zaleski and Hacker, 1993). Conversely, increased GL is positively correlated with piglet birth weight but negatively correlated with pigs farrowed per litter as well as total litter birth weight (Omtvedt et al., 1965). Moreover, a genome-wide association study assessing gestation length across a range of parities discovered differences between QTL's shared between different parities, adding to the complexities of this trait (See et al., 2019). Thus, breeding goals related to GL must be defined within the framework of

production goals specific to operation. Similarly, past research on number born alive (NBA) provides mixed results, with certain studies suggesting gilts raised in larger litters endure lasting negative environmental effects while other studies show that females from small litters of origin were culled earliest and produced small litters (Foxcroft et al., 2006) (Revelle and Robison, 1973) (Warda et al., 2021). Moreover, preweaning mortality may result from negative maternal behaviors such as impartiality to piglet distress calls, method of laying down, and savaging, negatively impacting total number weaned (NW) (Ahlström et al., 2002) (Lay Jr. et al., 2002) (Wechsler and Hegglin, 1997). Additionally, poor NW can be the outcome of management failures or environmental conditions unrelated to the sow herself. In addition to the complex associations above, NBA and NW are lowly heritable traits, with reported average heritabilities of 0.07 and 0.06, respectively (Rothschild, 1996). Gestation length has been shown to be moderately heritable, at 0.29 when estimated for a Landrace population and 0.34 in a Yorkshire population (Ogawa et al., 2019).

Past research in swine has failed to quantify activity and behavioral traits consistently and objectively. Methods used to categorize animal behavior and response type include back and resident-intruder tests, scale activity scores, and post-farrowing postural scoring. Both back test outcomes and scale activity scores have been shown to be heritable traits (Rohrer et al., 2013)(Holl et al., 2010). However, inconsistencies in repeated back tests call into question the stability of behavioral differences across time (Scheffler et al., 2014). Sow postural scoring studies have shown litter size differences between sows categorized as “crushers” vs. “non-crushers” (Andersen et al., 2005). However, underlying physiological or genetic differences between these sows have not

been examined. Thus, behavioral studies have been limited by subjectivity, sample size, and the time and labor involved in data collection.

Presently, little data exists examining the impact of behavior during the gilt growing phase on later observed reproductive traits such as GL, NBA, and NW. The objective of this study was to determine if there is a relationship between activity traits expressed early in life and reproductive traits measured during the first farrowing event. Further, the goal was to verify the NUtrack system's ability to objectively measure gilt activity traits in a group-housed environment. We hypothesized that active and passive behaviors displayed during the gilt growing phase may be indicators of parity one performance.

## **2.2 Materials and Methods**

### **Animals:**

All procedures involving the use of animals were approved by the University of Nebraska Institutional Animal Care and Use Committee protocol number 2089. The group-housed replacement gilts (n = 2,859) used in this dataset were housed at the United States Meat Animal Research Center (USMARC) in Clay Center, NE. Replacement gilts were all produced on-site and with breed compositions of Yorkshire by Landrace. The USMARC swine resource population is managed as a rotational crossbreeding herd alternating use between Yorkshire and Landrace semen. All semen is sourced from four separate commercial genetics suppliers. Replacement gilts are managed in facilities reflective of commercial production with newly constructed breed, group-housed gestation, and farrowing barns. Replacement gilts are kept in groups of 12-16 animals in finishing barn pens that are 2.438x7.01 meters. Gilts were observed and kept for use as

replacements or culled from the herd by an experienced caretaker on the primary basis of conformation.

#### Data Collection:

Video recording of gilts began at approximately 20 weeks of age. Animals were under cameras for nine consecutive days. Only full 24-hour cycles were considered for analysis, resulting in 2,859 individual animals with observation lengths ranging from six to eight full days under cameras. Any gilts that were removed due to illness or death during the trial period were consequently dropped from analysis. The age of gilts was chosen due to the timing of replacement and culling decisions in typical commercial swine operations. Cameras at USMARC were procured and installed by University of Nebraska-Lincoln researchers. Video output was managed and analyzed at UNL. Using NUtrack, the proprietary data analysis systems developed at UNL, observations on individual pigs in a group-housed setting included the following data:

1. Seconds/day spent walking, standing, sitting, at the feeder, and lying (lateral + sternal)
2. Distance walked/day and average speed
3. Angle rotated/day
4. Continuous head and tail coordinates within pen

NUtrack is a computer-vision monitoring system used for continuous observation in this study. NUtrack is a deep-learning based multi-object tracking system that can achieve >95% precision and recall tracking the long-term location and identity of individual pigs in group-housed settings (Psota et al., 2019). FLIR/Lorex 4k Ultra HD NVR System with added infrared capability was used to record video at 5 frames per

second. These cameras are cost-effective and were used for their ability to withstand severe environments. Video from the cameras was sent to a Dell-Alienware GPU with NVIVIA Graphics System for processing. It requires approximately 1 terabyte of memory to store 7 days of data from 12 cameras. Cameras are positioned downward facing on the ceiling in the center of a pen with care to avoid feed lines and piping that may downgrade images of animals in pens.

For a thorough description of the NUtrack system, reference Psota et al. (2019). In brief, NUtrack takes frame by frame movement probabilities to utilize Bayesian multi-object tracking. Points of reference on individual pigs are each ear, the shoulder, and tail. NUtrack individually identifies animal probabilities using deep network classification. To verify identities of individuals in each pen, 16 unique Allflex ear tags were assigned per pen for this study. Tags used were non-barcoded and non-radio frequency identification (RFID). Ear tag color and alphanumeric tags were generated for this study to maximize tag identification probability.

NUtrack has capabilities to continuously track a range of social and normative behaviors and activities. For the purposes of this study, the recorded activities include angle rotated (radians), average speed (meters/second), distance travelled (meters), time spent eating (seconds), time spent lying lateral (seconds), time spent lying sternal (seconds), time spent sitting (seconds), and time spent standing (seconds). Angle rotated represents the degrees of rotation an individual pig makes per day. In addition to individual activities, location within pen and proximity to pen mates (meters) were recorded. In this study, angle rotated, average speed, distance travelled, time spent eating,

and time spent standing were considered “active” traits. Time spent lying lateral, time spent lying sternal, and time spent sitting were categorized as “passive traits”.

In addition to NUtrack, outdoor air temperature was obtained for analysis. Temperatures were acquired from the Department of Natural Resources at the University of Nebraska-Lincoln through the Nebraska Mesonet network. The weather station where data were collected is located on site at USMARC. Air temperatures were automatically taken once per minute and averaged to generate a 24-hour average temperature. Average temperatures for each day on test as well as 3 days prior to test were included in analysis. Outside air temperature was chosen for analysis since finishing units at USMARC do not have cooling cells and are maintained at minimum temperatures during cold weather. The set barn temperature at USMARC is approximately 18 degrees Celsius. All outside air temperatures below 18 degrees Celsius in the dataset were set equal to the barn set point for analysis. The dataset includes one spring, two summers, two falls, and two winters.

Farrowing records were collected at USMARC on a subset of gilts that were retained following observation under NUtrack cameras. Normal farrowing assistance was provided in accordance with USMARC standard procedures during working hours (06:00am – 15:00pm). In total, 480 females were considered after censoring of farrowing records. Two gilts were removed from the dataset for failure to wean any live pigs in their first farrowing event. All litters born after January 1<sup>st</sup>, 2022, were dropped from analysis due to changes in farm health status. Traits reported for each parity include gestation length (days), number born alive, litter birth weight (kg), mean birth weight (kg), number weaned, litter weaning weight (kg), and mean litter weaning age. Herd life was also considered and calculated as the number of parities a female was present in the

breeding herd, ranging from one to three in the censored dataset. Gilts retained for 3 or more parities within the USMARC herd were assigned a herd life of 3 for the intent of this analysis.

Odds ratios (OR) were calculated for farrowing traits including herd life, gestation length, number born alive, and number weaned. For OR calculation, gilts remaining in the herd for greater than one parity were assigned a value of 2. Gilts that were culled after parity one were assigned a value of 1. The other farrowing traits (GL, NBA, NW) were transformed to binary based on if gilts had observations below (1) or above (2) the population average for each individual trait. Similarly, activity traits were dichotomized based on if observations were below the average or above the average for each trait. For individual activity traits, gilts were assigned a value of 1 (below the population average) or 2 (above the population average). For each pair of activity and reproductive trait, 2x2 contingency tables were created to generate odds ratios.

### **Statistical Analysis**

Data were analyzed using linear regression models (R version 4.0.2). Non-linear trends were not seen in the data and reproductive and activity variables were left untransformed for analysis. All NUtrack activity traits were averaged across days to represent one 24-hour period for each individual animal. Linear regressions were initially fit for all seven reproductive traits in the dataset. Variable selection was performed based upon linear regression models generated using the `lm()` function in R that were significant. Reproductive traits selected for in-depth analysis include gestation length (GL), number born alive (NBA), and number weaned (NW). For linear regression, p-values  $\leq 0.10$  were considered significant. For odd ratios, p-values  $\leq 0.05$  were

considered significant. Correlations were calculated using the `cor()` function. Odds ratios were calculated using the `twoby2()` function in the `epitools` package in R. Confidence intervals for odds ratios were calculated using the `twoby2()` function which utilizes method 10 discussed by Newcombe (Newcombe, 1998). Figures were generated in R using `ggplot2` and `forestploter` packages.

## **2.3 Results**

### **Summary Statistics**

Summary statistics were calculated for each farrowing trait considered in the analysis as well as the activity traits. Parity one gestation length had a mean of 115.2 days, standard deviation of 1.5 and median value of 115 days. Number born alive resulted in a mean of 11.7 piglets per sow, standard deviation of 3.33 and median value of 12 piglets. The number of piglets weaned in parity one had a mean value of 10.34 piglets, standard deviation of 3.24 and median of 11 piglets. See Figures 2.1, 2.2, and 2.3 for histograms of GL, NBA, and NW, respectively. For full summary statistics of reproductive traits, consult table 2.2. For histograms representing the distribution of all NUtrack traits, consult figures 2.4 – 2.11. Consult table 2.1 for full summary statistics for activity traits. Correlations between all activity traits were calculated and can be found on table 2.4. For a plot representing the correlation between time spent lying lateral and time spent lying sternal, see figure 2.12.

### **Regression Estimates**

Simple linear regression models were estimated individually regressing all eight activity traits (angle =  $\beta_1$ , average speed =  $\beta_2$ , distance travelled =  $\beta_3$ , eat =  $\beta_4$ , lie lateral =  $\beta_5$ , lie sternal =  $\beta_6$ , sit =  $\beta_7$ , stand =  $\beta_8$ ) on gestation length, number born alive, and



number weaned. All linear regression estimates, standard errors, and respective statistical significance can be found in Table 2.3. For gestation length, angle rotated, average speed, distance travelled, time spent lying lateral, and time spent lying sternal were found to be statistically significant. Time spent lying lateral, time spent lying sternal, and time spent sitting were statistically significant with respect to number born alive. Time spent eating, time spent lying lateral, and time spent sitting were statistically significant in regression models for number of piglets weaned.

Of the eight separate models fitted for gestation length, the following five traits were found to be statistically significant: angle rotated, average speed, distance travelled, and time spent laying lateral and sternal. It was determined that angle rotated was a marginally significant predictor of gestation length ( $r^2 = 0.009$ ,  $\beta_1 = 0.000396$ ,  $p = 0.038$ ). Average speed travelled was a marginally significant predictor of gestation length ( $r^2 = 0.007$ ,  $\beta_2 = 9.988$ ,  $p = 0.065$ ). Distance travelled was marginally significant in predicting gestation length ( $r^2 = 0.008$ ,  $\beta_3 = 0.000563$ ,  $p = 0.051$ ). Time spent lying lateral significantly predicted gestation length ( $r^2 = 0.019$ ,  $\beta_5 = -0.0000449$ ,  $p = 0.002$ ). Finally, time spent lying sternal significantly predicted gestation length ( $r^2 = 0.012$ ,  $\beta_6 = 0.00003723$ ,  $p = 0.016$ ).

Simple linear regression showed that time spent lying lateral, lying sternal, and sitting were significant predictors of number born alive in parity one. Time spent lying lateral significantly predicted number born alive ( $r^2 = 0.014$ ,  $\beta_5 = 0.0000858$ ,  $p = 0.01$ ). Time spent lying sternal was a marginally significant predictor of number born alive ( $r^2 = 0.007$ ,  $\beta_6 = -0.0000613$ ,  $p = 0.07$ ). Time spent sitting was a marginally significant predictor of number born alive ( $r^2 = 0.006$ ,  $\beta_7 = -0.000368$ ,  $p = 0.08$ ).

Finally, simple linear regression models were generated for parity one number weaned. Activity traits that were significant predictors of number weaned include time spent eating, lying lateral, and sitting. Time spent at the feeder was a marginally significant predictor of number weaned ( $r^2 = 0.006$ ,  $\beta_4 = -0.000175$ ,  $p = 0.09$ ). Time spent lying lateral was a marginally significant predictor of number weaned ( $r^2 = 0.009$ ,  $\beta_5 = 0.0000684$ ,  $P = 0.03$ ). Finally, time spent sitting significantly predicted number weaned ( $r^2 = 0.015$ ,  $\beta_7 = -0.000557$ ,  $p = 0.006$ ).

### **Odds Ratios**

Odds ratios were calculated for herd life, gestation length, number born alive, and number weaned. Corresponding activity traits were chosen based upon what was shown to be significant in the simple linear regression models. ORs were calculated for GL and angle, distance, speed, time spent lying lateral, lying sternal. For NBA, lie lateral, lie sternal, and sit were examined. Odds ratios for time spent eating, lying lateral, and sitting were calculated for number weaned. Finally, herd life and angle, speed, distance, time spent eating, lying lateral, lying sternal and sitting were examined. For full OR results, consult figures 2.13 and 2.14 as well as table 2.5.

For gestation length, ORs for speed and lying sternal were statistically significant. The estimated odds of a gilt having a below average gestation length are 1.43 times as large for gilts travelling below average speeds than for gilts travelling at above average speeds ( $P \leq 0.05$ ). The estimated odds of a gilt having a below average gestation length are 1.55 times as large for gilts spending below average time lying sternal than for gilts spending above average time lying sternal ( $P \leq 0.05$ ).

For number born alive there were no ORs significant at the 0.05 level. However, time spent lying sternal was marginally significant ( $P \leq 0.10$ ). The estimated odds of a gilt farrowing below average number born alive was 0.73 times as large for gilts who spent below average time lying sternal than for gilts who spent greater than average time lying sternal.

Time spent lying lateral and time spent sitting were significant ORs with number weaned. The estimated odds of a gilt having below average number weaned was 1.51 times larger for gilts spending below average time lying lateral than for gilts spending greater than average time lying lateral. The estimated odds of a gilt weaning fewer than average piglets was 0.66 times as large for gilts who spent below average time sitting than for gilts who spent greater than average time sitting.

The only significant OR for herd life was time spent lying sternal. The estimated odds of a gilt being culled after parity one were 0.67 times as large for gilts who spent less than average time lying sternal than for gilts who spent above average time lying sternal.

## **2.4 Discussion**

The results of this analysis indicate potential for early-life activity traits to serve as indicators of parity one reproductive performance. Moreover, activity trait distribution and statistical significance validate the consistency of NUtrack as a continuous monitoring system for group-housed livestock. For parity one gestation length, three active behavior traits (angle rotated, average speed, distance travelled) were individually shown to be significant predictors of length of gestation. Further, two passive traits (time

spent lying lateral, lying sternal) were significant predictors of gestation length. Three passive NUtrack traits (time spent lying lateral, lying sternal, sitting) were significant predictors of parity one number born alive. Additionally, one active trait (time spent eating) and two passive traits (time spent lying lateral, sitting) were significant predictors of parity one number weaned. These results suggest that there is a link between early-life behavior and parity one reproductive traits.

Gestation length was the only parity one reproductive trait shown to be significantly predicted by more than one active NUtrack trait (angle rotated, average speed, distance travelled). All three NUtrack traits were individually shown to have a positive impact on parity one gestation length. To the author's knowledge, no prior research has analyzed the link between early life "active" behaviors and parity one farrowing records. The results of the simple regression models suggest that more active gilts tend to have longer parity one gestation lengths. Moderate heritabilities ( $h^2=0.29$ ) for gestation length have been reported in the literature (Ogawa et al., 2019). Similarly, heritabilities calculated from NUtrack activity data for angle rotated, average speed, and distance travelled have been reported as 0.13, 0.13, and 0.31, respectively (Ostrand, in preparation). The moderate heritabilities reported for activity traits imply there is potential for gestation length to be altered by selection on NUtrack activity traits.

In addition, gestation length, number born alive, and number weaned were shown to independently be significantly predicted by multiple "passive" NUtrack traits. Time spent lying lateral had a negative impact on the prediction of length of gestation while time spent lying sternal had a positive impact on the prediction of gestation length. It is

important to note that based on these results, a model combining lying lateral and lying sternal into one lie trait would be counter-productive due to the divergent signs on the regression coefficients. Time spent lying lateral (+), lying sternal (-), and sitting (-), were shown to have a significant impact on the prediction of number born alive. Further, time spent eating (-), lying lateral (+), and sitting (-) were modeled having a significant impact on the prediction of number weaned.

Across the simple regression models, time spent lying lateral has a consistent, statistically significant impact on GL, NBA, and NW. The impact that lying lateral exerts on NBA and NW is consistent and positive, indicating that gilts who spend a greater amount of time lying laterally during the growing phase farrowed and weaned a greater number of pigs in their first farrowing event. When viewing decreased GL favorably given the negative correlations between GL and piglets farrowed per litter, time spent lying lateral is favorably related to parity one production. The consistency of time spent lying lateral across GL, NBA, and NW indicates that gilts who spend a greater amount of time lying lateral at an early age are more productive mothers or have more favorable outcomes in their first parity.

Conversely, time spent lying sternal was unfavorably associated with reproductive traits. Further, time spent lying sternal and time spent lying lateral were consistently antagonistic in their effect on the three reproductive traits examined. The correlation between lying lateral and lying sternal was strong and negative ( $r = -0.80$ ). Past NUtrack analysis has viewed total time lying as a function of time spent lying lateral and time spent lying sternal. The consistent opposite effect of these traits paired with the strong

negative correlation suggests lying lateral and lying sternal should be viewed as separate traits and not components of total time lying. Calculated heritabilities for total lying time (0.21), lying lateral (0.32) and lying sternal (0.30) further support the theory that lateral lying and sternal lying should be viewed as separate activity traits (Ostrand, in preparation). Determining potential underlying mechanisms that explain differences in time allocation and preference of lying lateral and lying sternal should be explored. Moreover, additional research into the genetic, environmental, and management components related to the reproductive and activity traits is required.

In commercial settings, phenotypically or genetically “above average” animals are selected. The purpose of dichotomizing activity and reproductive traits into above and below average groups was to mirror this selection practice in the dataset. Calculated ORs represented the odds that a gilt is below average for reproductive traits (GL, NBA, NW) or was culled after parity one (HL). Interpreting the significant results for gestation length indicates that a gilt has higher odds of below average GL when travelling at below average speeds and spending less than the average amount of time lying sternal. These ORs mirror what was seen in the simple regressions, where speed and time spent lying sternal both had a positive effect on gestation length. These results further support the impact that speed and time spent lying sternal have on gestation length. Therefore, average speed and time spent lying sternal are strong candidate traits for further examination and potential inclusion in selection programs and decisions.

There were no ORs that were statistically significant for number born alive. For number weaned, time spent lying lateral and time spent sitting were statistically

significant. Below average time spent lying lateral was associated with increased odds of below average number weaned. This result supports what was seen in the simple regression model, where time spent lying lateral was positively associated with number of piglets weaned. When rescaling the odds ratio, below average time spent sitting was related to greater odds of above average number weaned (1.52). This value follows what was shown in the simple regression model, where an increase in time spent sitting was associated with a decrease in number of piglets weaned. Time spent lying lateral is consistently associated with favorable number weaned results. Further, time spent sitting is consistently associated with unfavorable reproductive outcomes. However, time spent sitting should be considered with caution given that sitting is viewed as a transitional state between standing behaviors and lying behaviors. Moreover, the range of time spent sitting in this dataset is relatively small (1.5 minutes per day – 88.5 minutes per day). Additionally, the mean time spent sitting is ~17 minutes with a standard deviation of ~12 minutes. Therefore, time spent sitting and statistically significant outcomes should be considered with caution. Dissimilarly, time spent lying lateral is approximately normally distributed and consistent in regression and OR outcomes. Thus, time spent lying lateral should offer more value for potential inclusion in selection indices and breeding decisions based upon the results of this analysis.

The only activity trait that had a statistically significant OR with herd life was time spent lying sternal. The results of the OR calculation show that gilts with below average time spent lying sternal had lower odds of being culled after parity one. The effect of time spent lying sternal is consistent across all simple regression models and odds ratios. It follows that time spent lying sternal has a negative impact on reproductive

traits and longevity. The consistent results shown in this analysis suggest that time spent lying sternal may be one of the most influential negative activity traits on reproductive outcomes. However, in this dataset herd life should be considered with caution due to the small range (1 – 3 parities) and the mandatory culling after parity 3.

Although not a direct parallel, it has been shown that sows exhibiting restless behavior following farrowing were more often categorized as savagers and aggressive towards their litters (Ahlström et al., 2002) (Chen et al., 2008). In many sow behavior studies, postural changes are used to categorize risk to piglets. If gilts who spend a greater amount of time lying lateral also exhibit fewer postural changes in the crate, time spent lying lateral could serve as an indicator trait for post-farrowing behavior. Similarly, if time spent lying sternal is shown to be an indicator of more alert or restless “personalities”, this trait could be used to select for females that will be more docile during their lifetime. Future research should examine farrowing behavior and postural changes in gilts who spend a significant time lying lateral or lying sternal. Determining a potential link between postural changes (lying lateral, lying sternal) during the growing phase and the propensity to frequently change postures or exhibit aggressive behavior in the farrowing crate could demonstrate a stability in behavior or personality type in swine. A better understanding of the genetic and behavioral components associated with savaging and agonistic mothering behavior would result.

Reported raw regression coefficients for the activity traits listed in table 2.3 were relatively low. Noting unit of measurement for each trait can assist in more practical interpretation of regression results. Angle rotated is measured in radians and average



speed was represented as meters per second. Distance travelled was reported as the number of meters travelled, on average, per day of observation. Given the diminutive size of units and nature of 24-hour observation, scaling of regression coefficients for interpretation is relevant. Interpretation of the lateral-sternal complex is pertinent when rescaling coefficients to an hourly basis. A one-hour increase in daily time spent lying lateral during the growing phase resulted in a 3.88 hour decrease in gestation length. Conversely, a one hour increase in time spent lying sternal results in a 3.21 hour increase in gestation length. Similar results can be seen for both NBA and NW. A one-hour daily increase in time spent lying lateral during the growing phase resulted in 0.31 more piglets born alive in the first farrowing event. Again, the same increase in time spent lying sternal resulted in an average decrease of 0.21 piglets born alive. Finally, a one hour increase in time spent lying lateral resulted in an average increase of 0.25 piglets weaned. A one hour increase in time spent lying sternal resulted in 0.11 fewer piglets weaned. Across all three reproductive variables included in the analysis, lying lateral and lying sternal have a similar magnitude but antagonistic effect on outcomes. Recognizing the relationship between these two activity traits is the most striking outcome of this analysis. These results indicate that passive NUtrack lying traits offer insight into differences in reproductive traits.

An important limitation to note is that gestation length was measured on a discrete basis during the hours that farm staff was present in facilities. The discrete nature of this variable is a limitation when examining the impact of NUtrack activity traits (measured in seconds) on parity 1 gestation length. While the gestation length observations are

relatively precise by day, continuous hourly observation of farrowing events would yield a more accurate dependent variable to model.

Research has shown that highly productive sow herds record high number born alive and low preweaning mortality rates (Stein et al., 1990). Further studies have reported a negative correlation between gestation length and NBA/NW, but positive correlations between GL and piglet birth weight (Omtvedt et al., 1965) (Sasaki and Koketsu, 2007). Clearly, the genetic and environment elements contributing to reproductive traits are intricate. It follows that improvement in farrowing traits will likely be the result of incremental changes to breeding programs and selection decisions. The simple linear regressions generated in this analysis resulted in low  $r^2$  values, ranging from 0.006 to 0.019 across significant models. Although the explanatory power of NUtrack traits in these models was relatively low, the traits considered must be contextualized within the larger framework of swine breeding systems. In theory, explaining 1% of a lowly heritable reproductive trait with moderately heritable, novel activity traits observed early in life ( $\leq 150$  days) offers potential to make earlier selection decisions and breeding programs more robust. However, in future research it is important to quantify a genetic link between behavior traits and farrowing traits.

## **2.5 Conclusion**

The results of this analysis showed a connection between NUtrack activity traits collected during the growing phase and parity one gestation length, number born alive, and number weaned. Further, these results validate the NUtrack systems ability to detect and continuously monitor group-housed livestock activity. The regression models in this

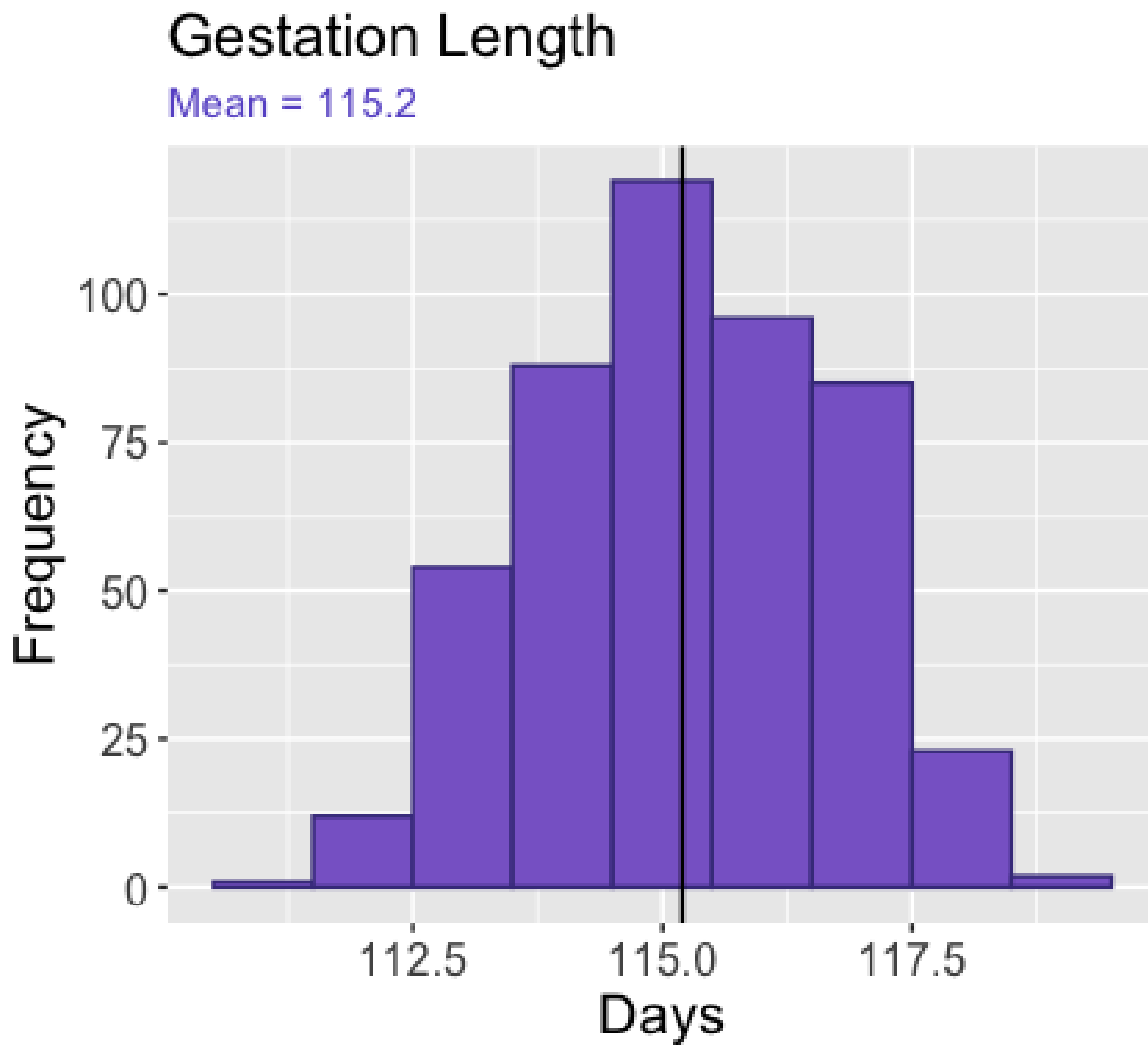
study show a significant linear relationship between the activity traits and parity one farrowing records, suggesting potential for early-life activity to serve as an indicator for parity one farrowing performance. In addition, odds ratios were calculated based upon the results of the simple regression models. The resulting ORs mirrored what was found in the simple regression models. Overall, time spent lying lateral had a consistent, favorable effect on reproductive outcomes. In addition, time spent lying sternal had a stable, negative impact on reproductive outcomes and longevity. These results suggest that time spent lying lateral and time spent lying sternal could serve as important early-life behavioral indicator of mothering ability. Further studies utilizing increased sample size and hourly gestation length records should be conducted to increase accuracy of gestation length models. Moreover, additional research is needed to determine whether the relationships established in this study are genetic or environmental in nature.

## 2.6 Literature Cited

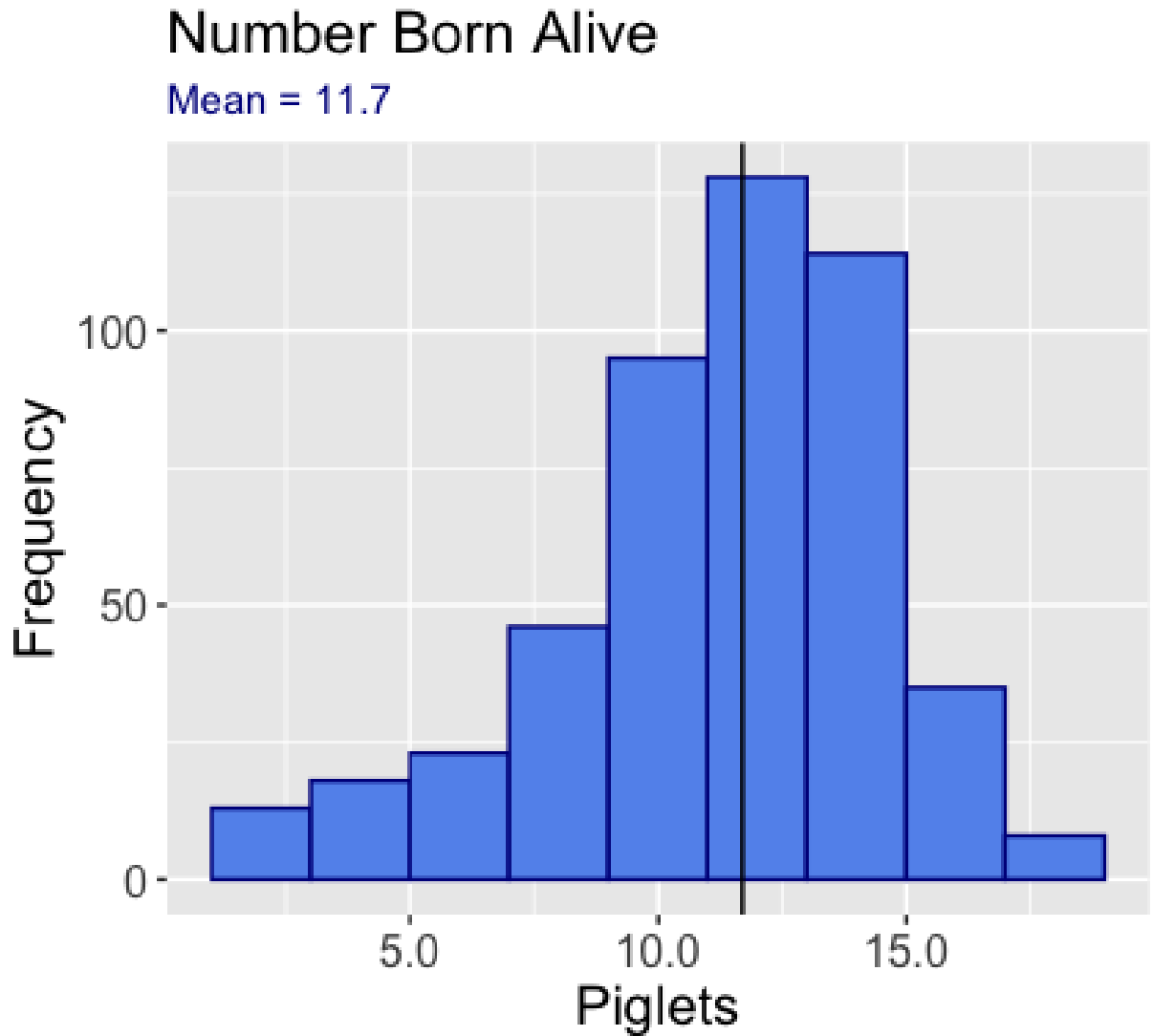
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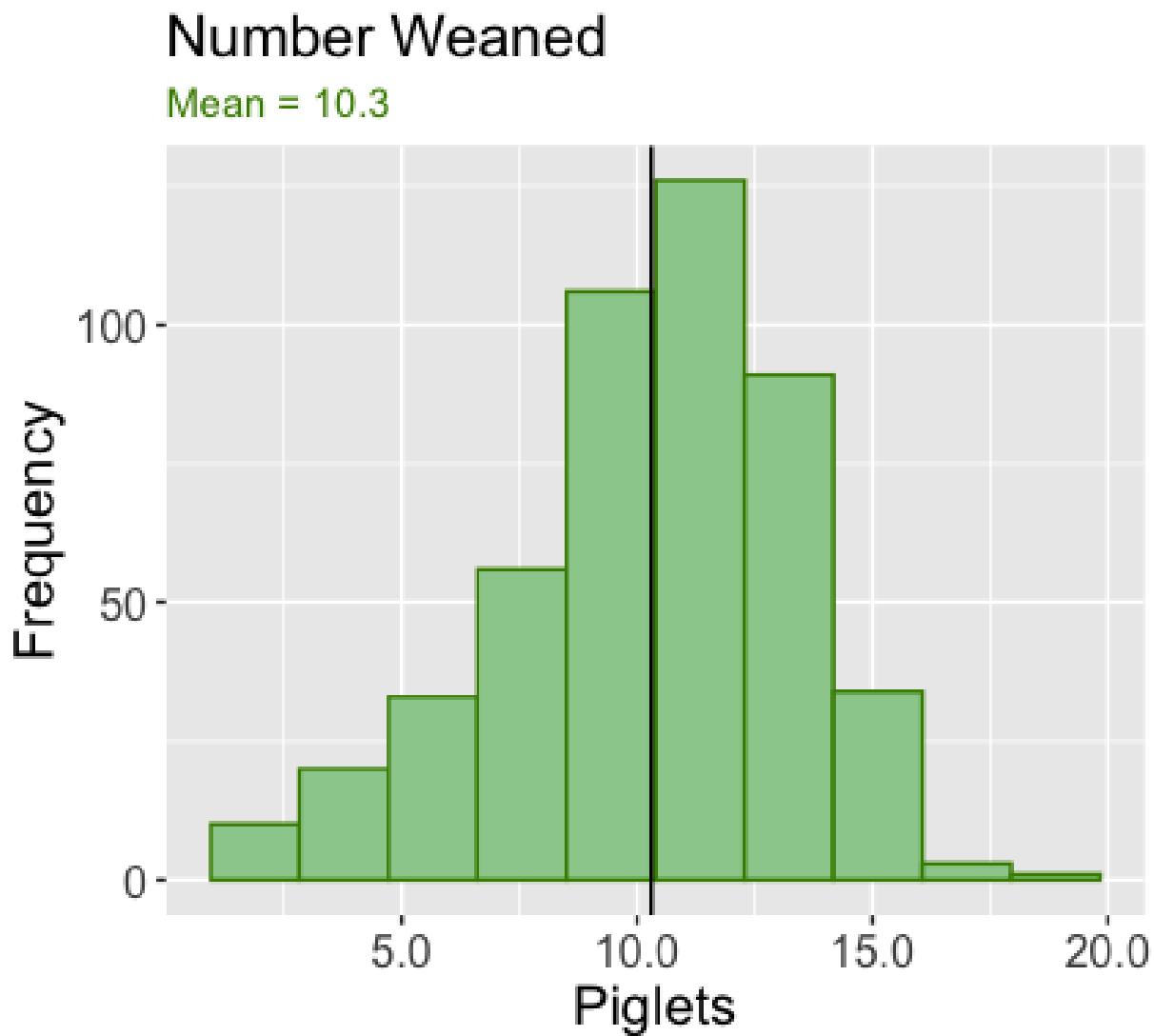
## Figures



**Figure 2.1.** Histogram representing the distribution of gestation length across the sample. Sample mean is represented by black line.

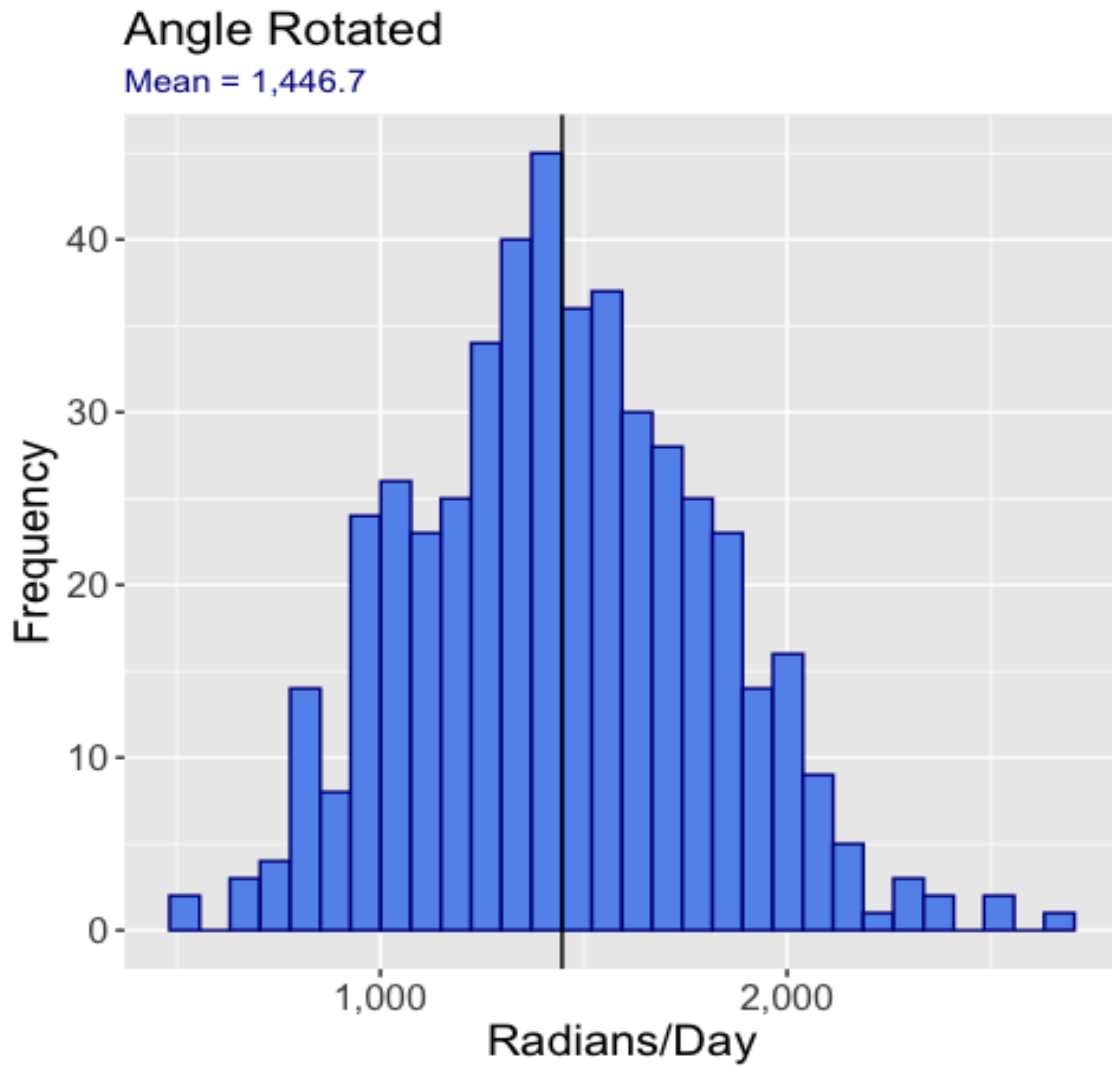


**Figure 2.2.** Histogram representing the distribution of number born alive across the sample. Sample mean is represented by black line.

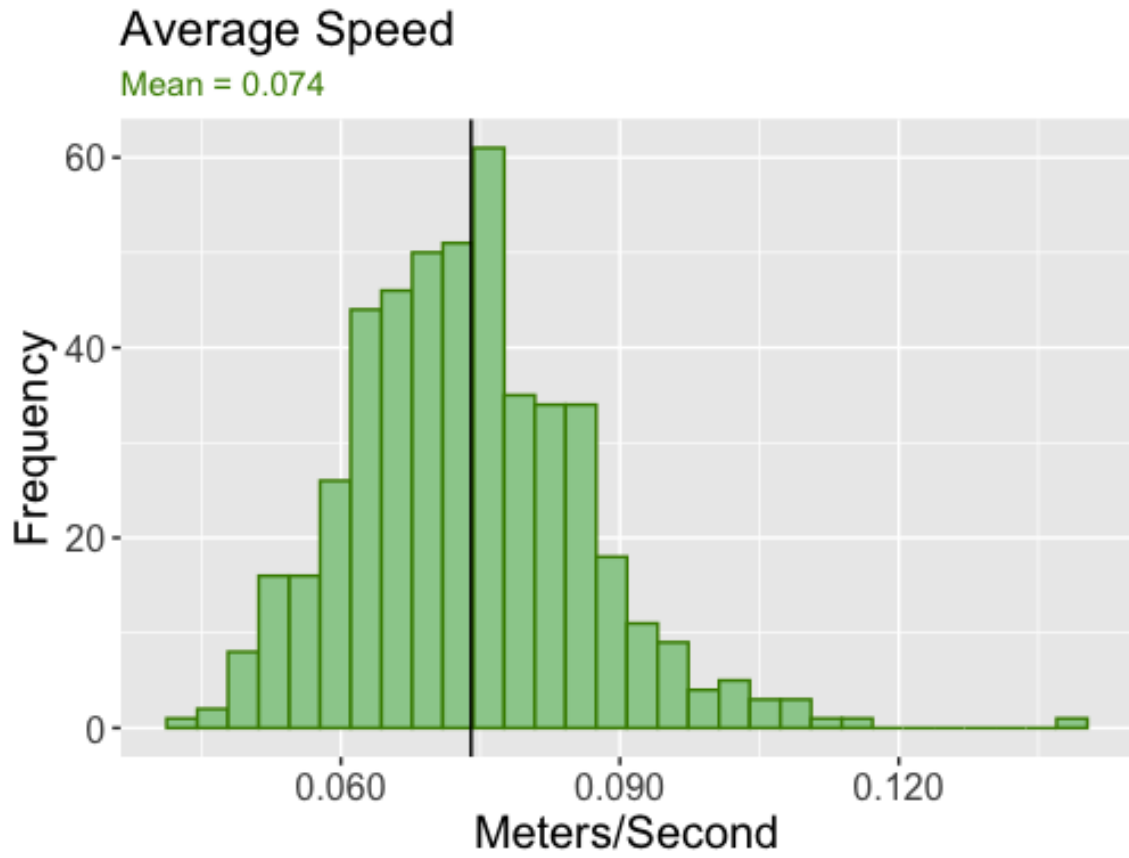


**Figure 2.3.** Histogram representing the distribution of number weaned across the sample. Sample mean is represented by black line.

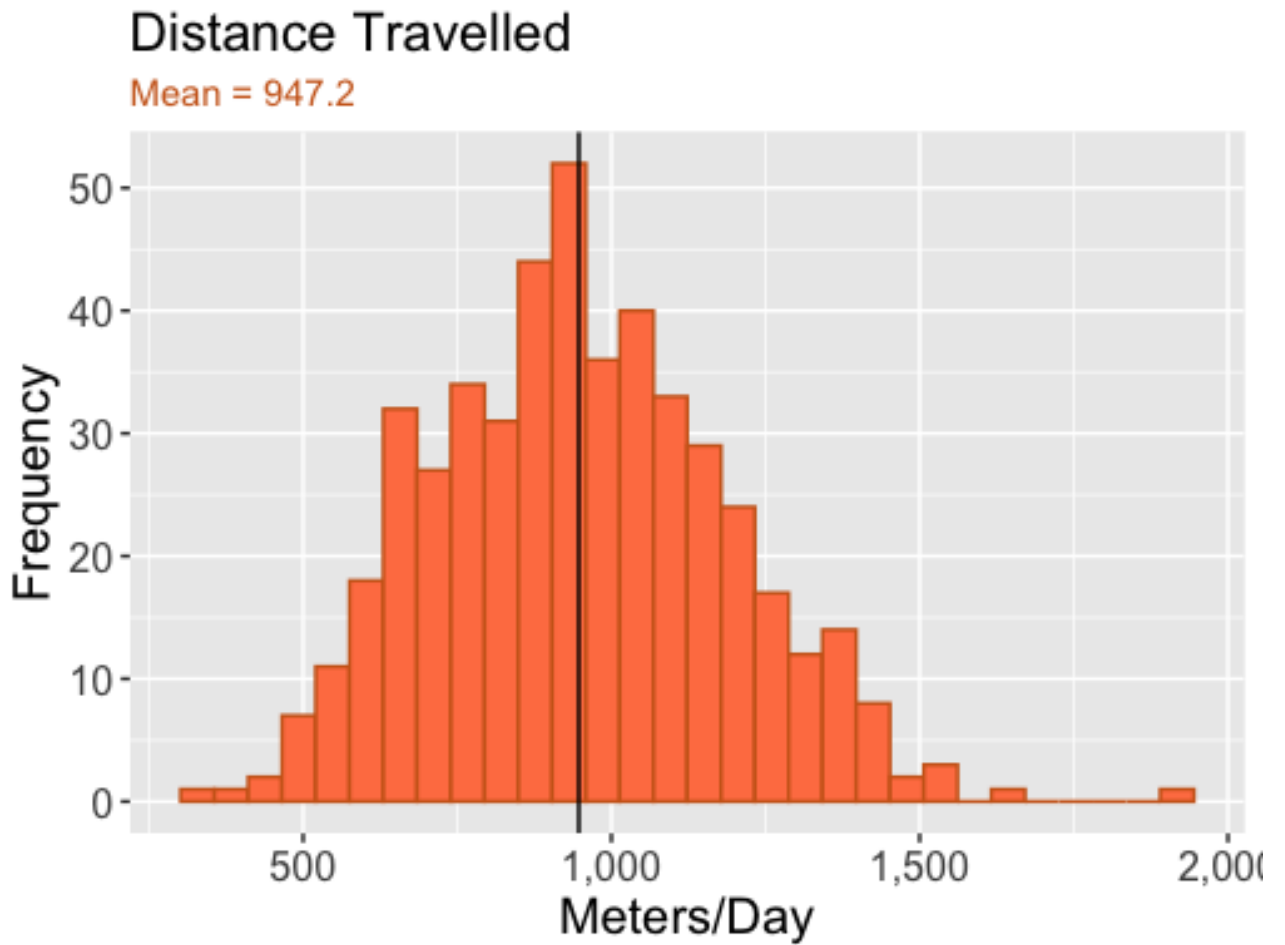




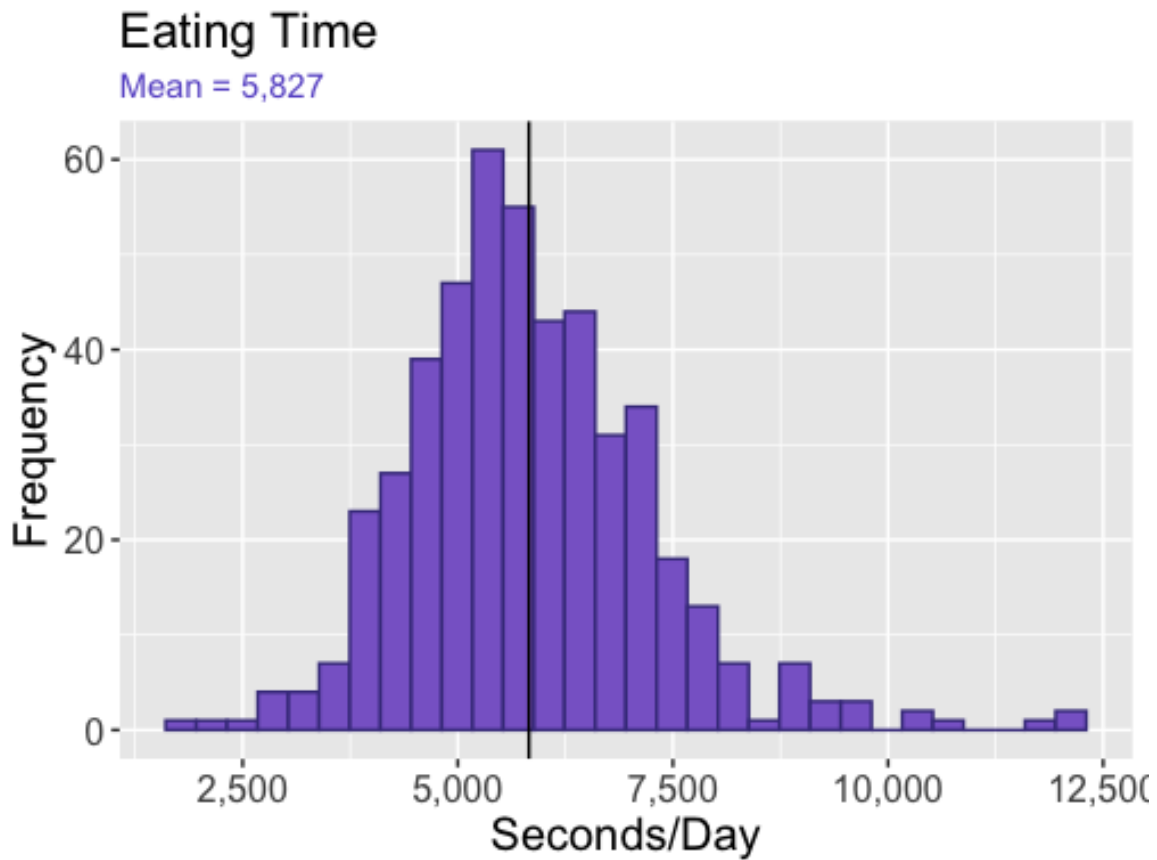
**Figure 2.4.** Histogram representing the average daily angle rotated. Sample mean is represented by black line.



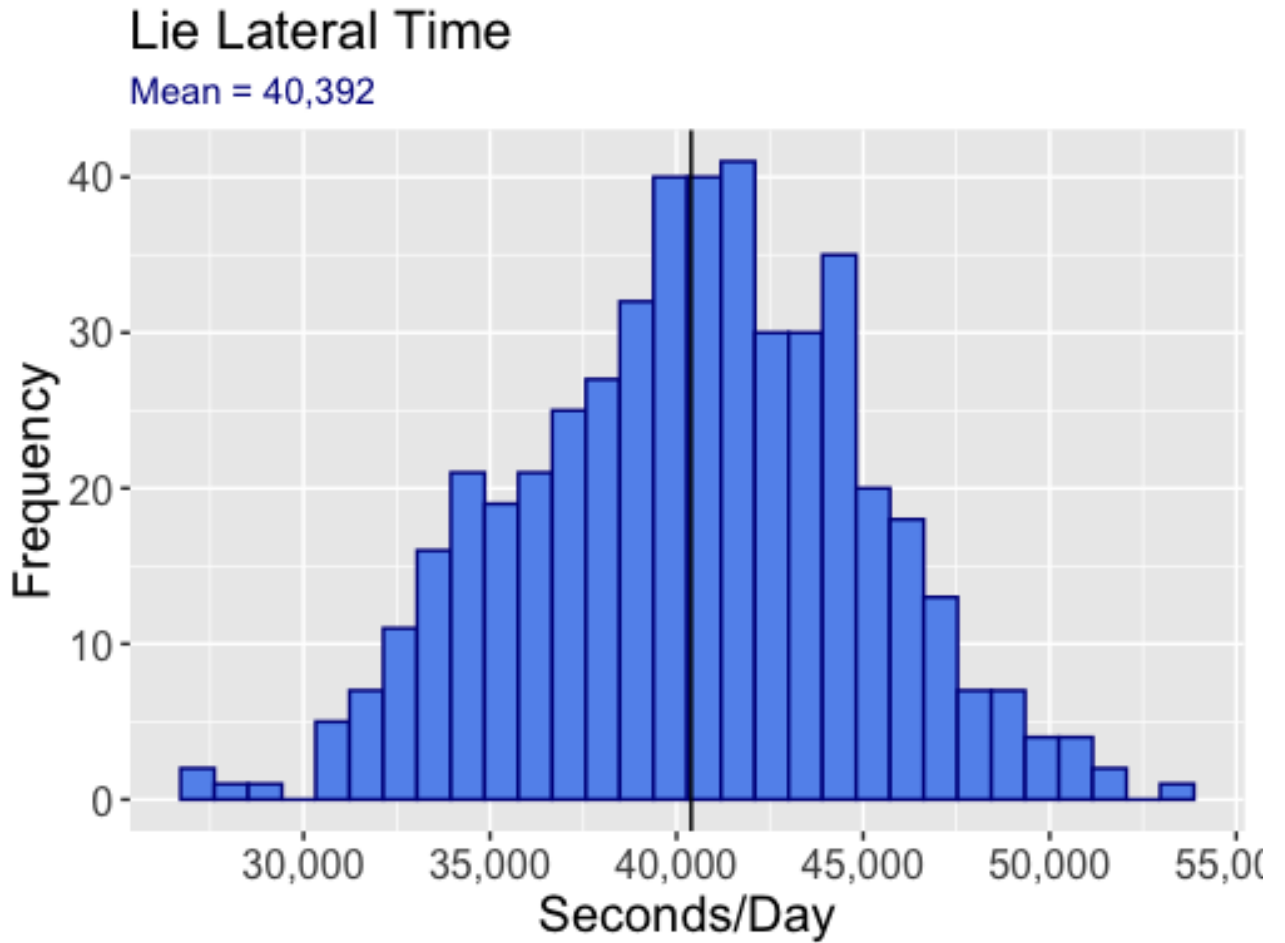
**Figure 2.5.** Histogram representing the average daily speed travelled. Sample mean is represented by the black line.



**Figure 2.6.** Histogram representing the average distance travelled. Sample mean is represented by the black line.



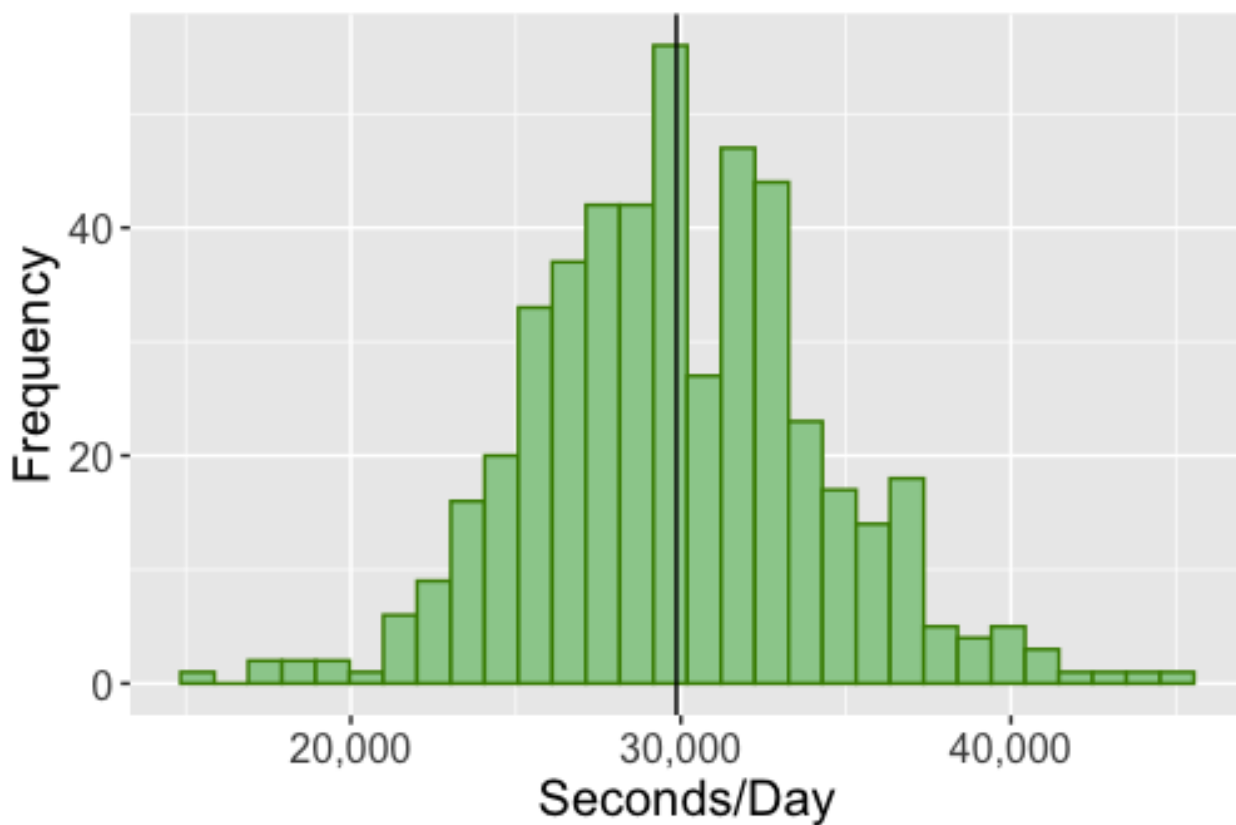
**Figure 2.7.** Histogram representing the distribution of average time spent eating per day. Sample mean is represented by black line.



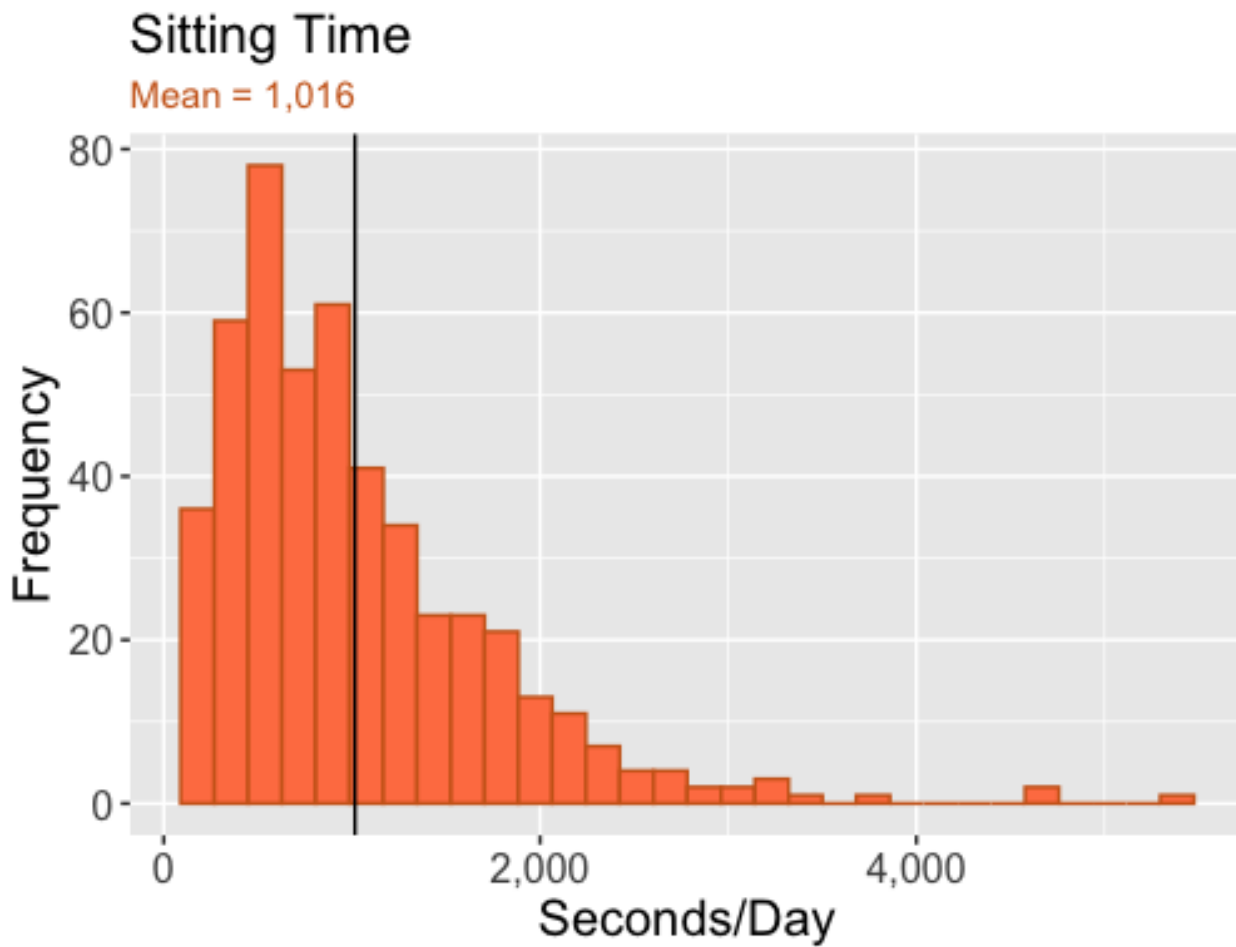
**Figure 2.8.** Histogram representing the distribution of time spent lying lateral per day. Sample mean is represented by black line.

## Lie Sternal Time

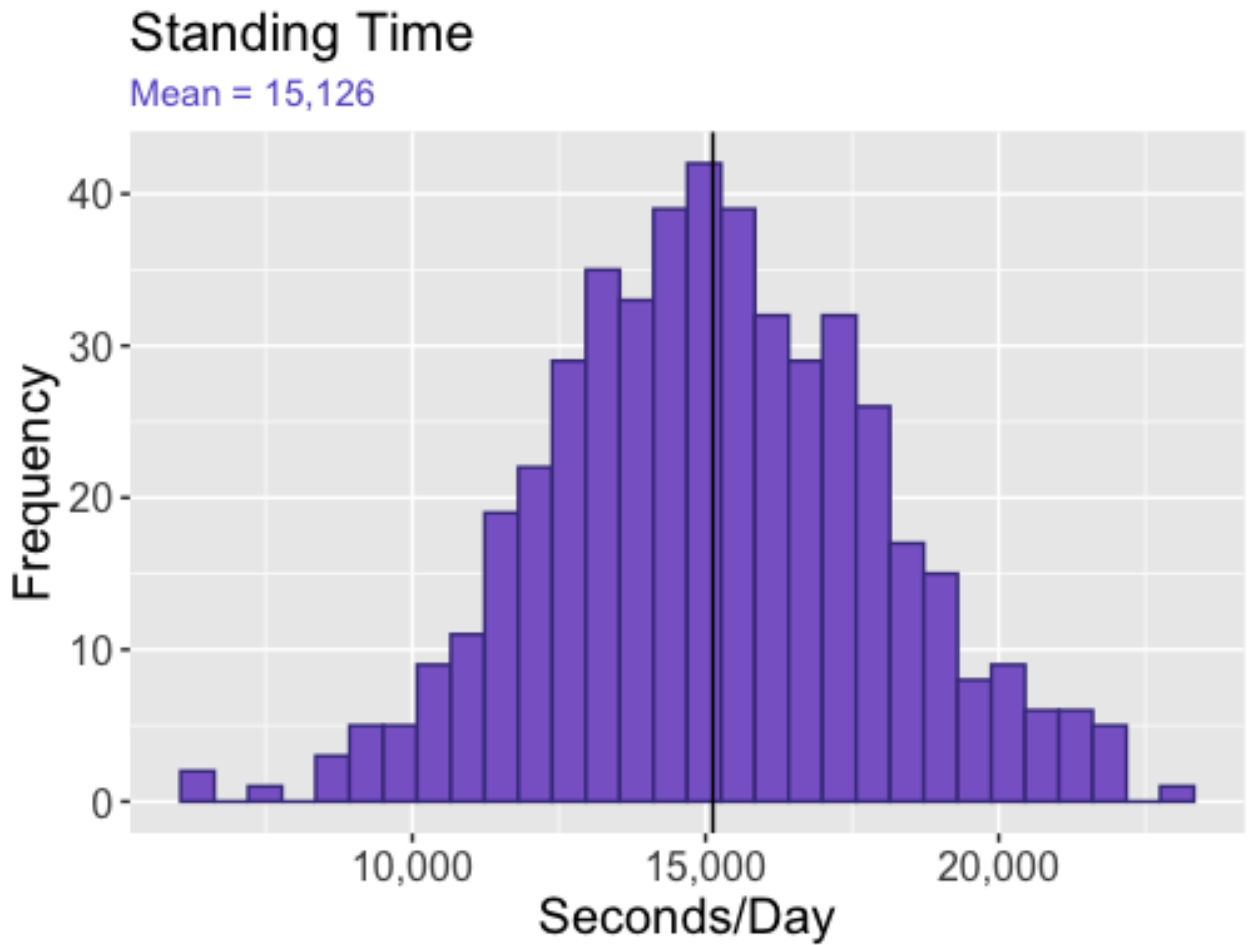
Mean = 29,866



**Figure 2.9.** Histogram representing the distribution of time spent lying sternal per day. Sample mean is represented by black line.

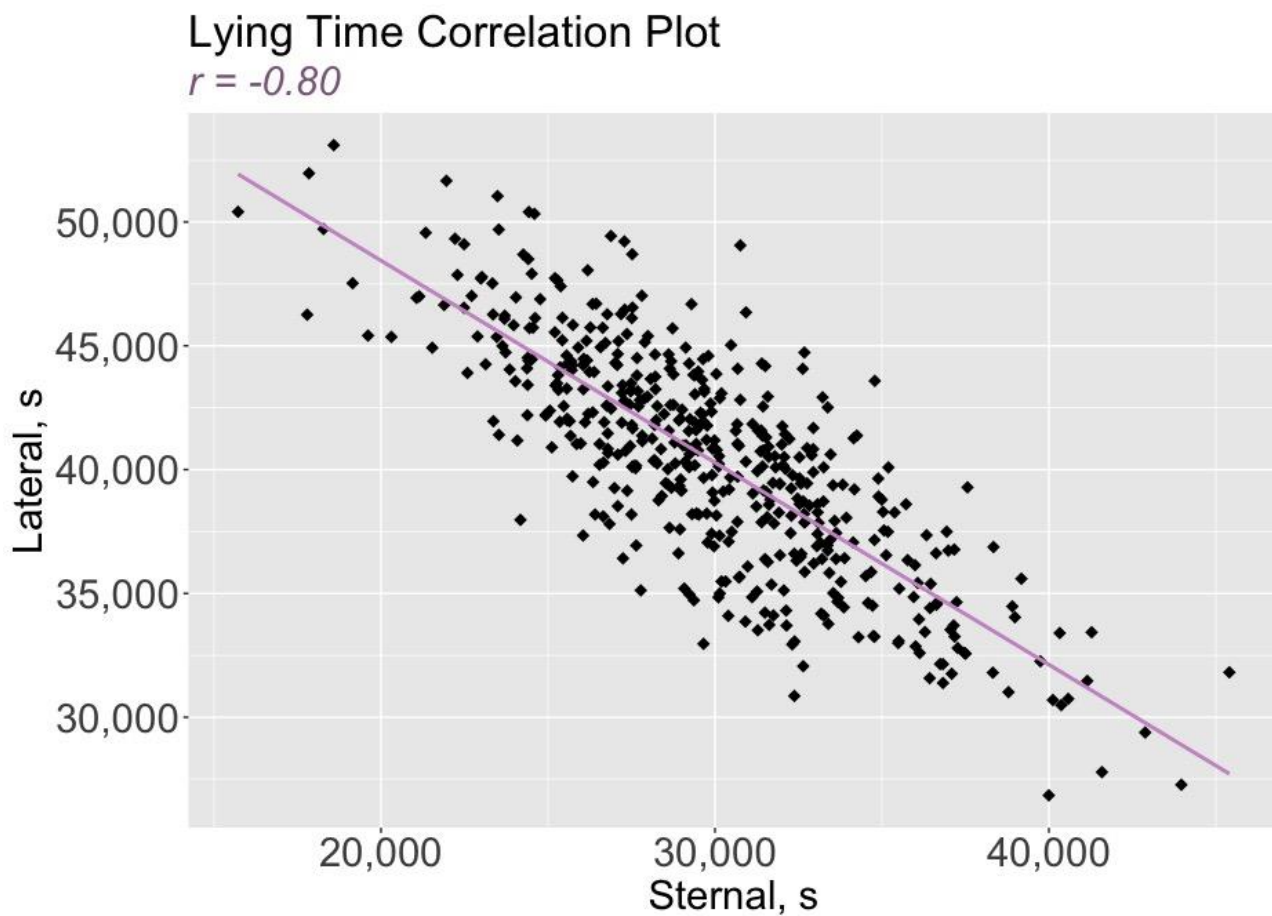


**Figure 2.10.** Histogram representing the distribution of time spent sitting per day. Sample mean is represented by black line.



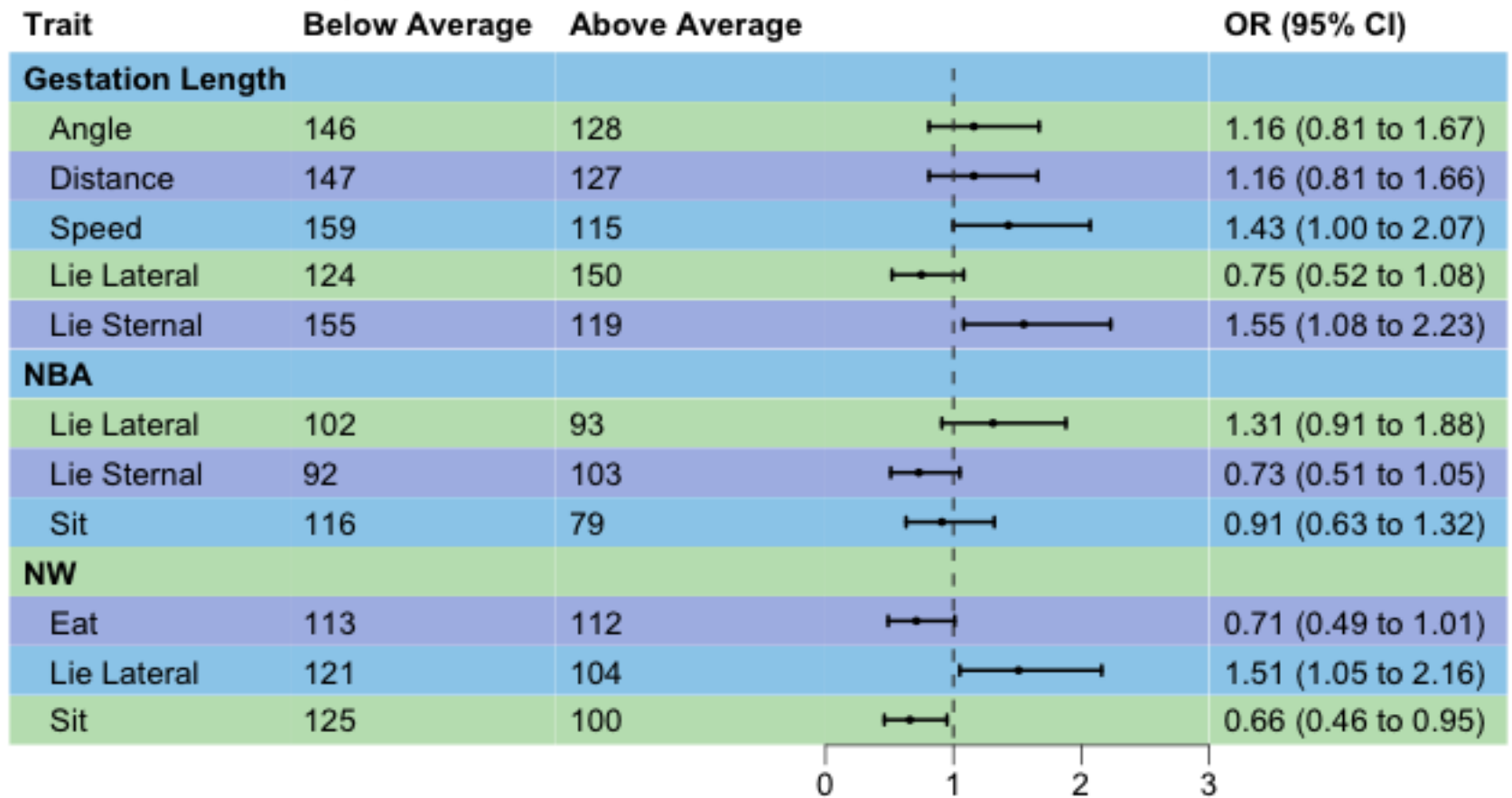
**Figure 2.11.** Histogram representing the distribution of time spent standing per day. Sample mean is represented by black line.





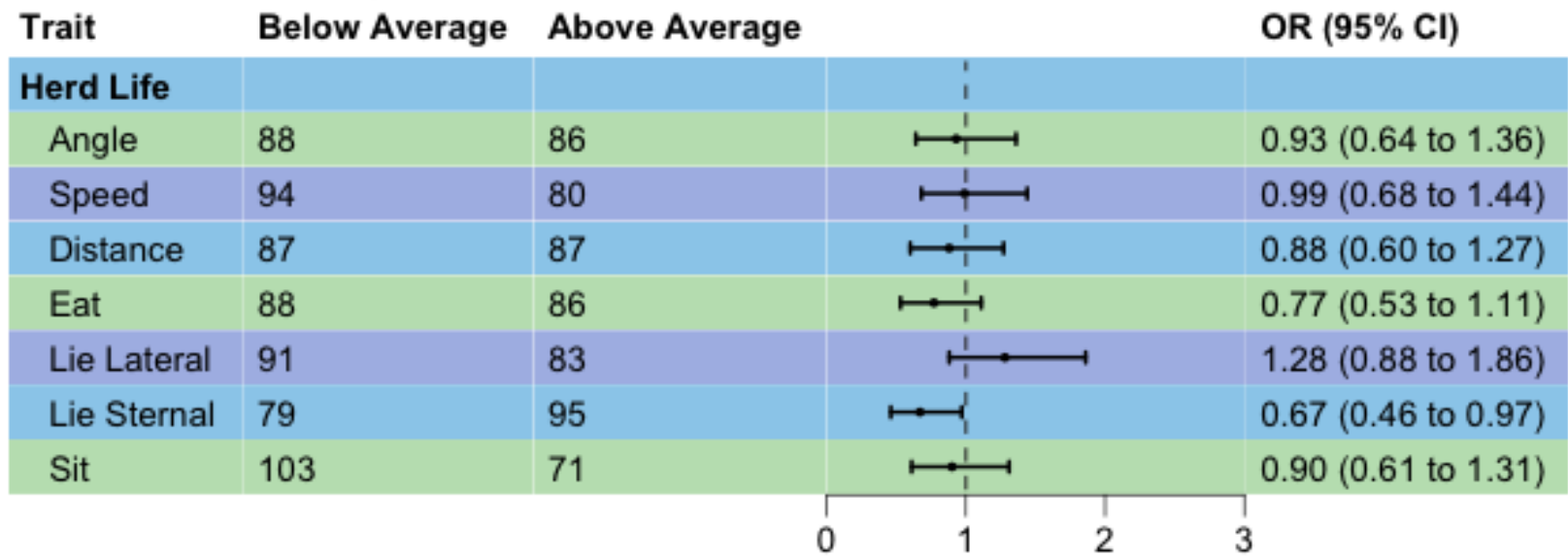
**Figure 2.12.** Scatterplot representing the correlation between time spent lying sternal and time spent lying lateral.

## NUtrack Activity and Production Trait ORs



**Figure 2.13.** Forest plot representing odds ratios relating production traits and NUtrack activity traits. ORs for GL, NBA, and NW represent the number of below average GL/NBA/NW gilts who are above or below average for each corresponding activity trait.

## NUtrack Activity Trait and Herd Life ORs



**Figure 2.14.** Forest plot representing odds ratios relating herd life and NUtrack activity traits. Herd life ORs represent gilts who were culled after parity one and above or below average for each activity trait.

**Tables****Table 2.1.** Summary statistics for parity one gilts (n = 480) activity traits. All values for traits measured in seconds are rounded to the nearest second.

| <b>Trait</b>           | <b>Mean</b> | <b>Standard Deviation</b> | <b>Minimum</b> | <b>Maximum</b> |
|------------------------|-------------|---------------------------|----------------|----------------|
| <b>Angle (rad)</b>     | 1,446.7     | 357.4                     | 489.3          | 2,639.5        |
| <b>Speed (m/s)</b>     | 0.074       | 0.0126                    | 0.041          | 0.137          |
| <b>Distance (m)</b>    | 947.2       | 237.4                     | 335.1          | 1923.9         |
| <b>Eat (s)</b>         | 5,827       | 1,415                     | 1,886          | 12,229         |
| <b>Lie Lateral (s)</b> | 40,392      | 4,546                     | 26,848         | 53,103         |
| <b>Lie Sternal (s)</b> | 29,866      | 4,441                     | 15,719         | 45,403         |
| <b>Sit (s)</b>         | 1,016       | 717                       | 102            | 5,308          |
| <b>Stand (s)</b>       | 15,126      | 2,825                     | 6,186          | 22,891         |

**Table 2.2** Summary statistics for parity one gilts (n = 480) reproductive traits

| <b>Trait</b>             | <b>Mean</b> | <b>Standard Deviation</b> | <b>Minimum</b> | <b>Maximum</b> |
|--------------------------|-------------|---------------------------|----------------|----------------|
| <b>Gestation Length</b>  | 115.2       | 1.50                      | 111            | 119            |
| <b>Number Born Alive</b> | 11.7        | 3.33                      | 1              | 19             |
| <b>Number Weaned</b>     | 10.34       | 3.24                      | 1              | 18             |
| <b>Herd Life</b>         | 2           | 0.85                      | 1              | 3              |

**Table 2.3.** Regression estimates of reproductive traits with angle rotated, average speed travelled, distance travelled, time spent eating, laying lateral, laying sternal, sitting, and standing.

| <b>Parity 1</b>                 |                           |                          |                          |
|---------------------------------|---------------------------|--------------------------|--------------------------|
| <b>Activity Trait</b>           | <b>Gestation Length</b>   | <b>Number Born Alive</b> | <b>Number Weaned</b>     |
| <b>Regression Estimate ± SE</b> |                           |                          |                          |
| <b>Angle (rad)</b>              | 0.000396 ± 0.0001912 **   | -0.000546 ± 0.000426     | -0.000496 ± 0.000414     |
| <b>Speed (m/s)</b>              | 9.988 ± 5.41 *            | 2.823 ± 12.05            | 12.528 ± 11.71           |
| <b>Distance (m)</b>             | 0.000563 ± 0.000289 **    | -0.000292 ± 0.000642     | -0.000195 ± 0.000625     |
| <b>Eat (s)</b>                  | -0.00000581 ± 0.0000485   | -0.000169 ± 0.00012      | -0.000175 ± 0.0001 *     |
| <b>Lie Lateral (s)</b>          | -0.0000449 ± 0.000015 *** | 0.0000858 ± 0.000033 *** | 0.0000685 ± 0.0000325 ** |
| <b>Lie Sternal (s)</b>          | 0.0000372 ± 0.0000154 *** | -0.0000613 ± 0.0000342 * | -0.0000308 ± 0.0000334   |
| <b>Sit (s)</b>                  | -0.0000258 ± 0.0000958    | -0.000368 ± 0.000212 *   | -0.000557 ± 0.000205 *** |
| <b>Stand (s)</b>                | 0.0000261 ± 0.0000243     | -0.000047 ± 0.0000539    | 0.0000655 ± 0.00005242   |

\* P≤0.10; \*\* P≤0.05; \*\*\* P≤0.01

**Table 2.4.** Correlations (n = 480) between NUtrack activity traits.

| Trait           | Angle | Speed  | Dist. | Eat   | Lat.  | Stern. | Lie Total | Sit   | Stand |
|-----------------|-------|--------|-------|-------|-------|--------|-----------|-------|-------|
| Angle           | 1     |        |       |       |       |        |           |       |       |
| Speed           | 0.59  | 1      |       |       |       |        |           |       |       |
| Distance        | 0.97  | 0.65   | 1     |       |       |        |           |       |       |
| Eat             | 0.28  | 0.12   | 0.29  | 1     |       |        |           |       |       |
| Lie Lateral (s) | -0.26 | -0.005 | -0.24 | -0.29 | 1     |        |           |       |       |
| Lie Sternal (s) | -0.22 | -0.05  | -0.22 | -0.08 | -0.80 | 1      |           |       |       |
| Lie Total       | -0.75 | -0.08  | -0.72 | -0.58 | 0.35  | 0.29   | 1         |       |       |
| Sit             | 0.16  | 0.10   | 0.10  | 0.02  | -0.11 | -0.002 | -0.18     | 1     |       |
| Stand           | 0.72  | 0.05   | 0.71  | 0.58  | -0.33 | -0.29  | -0.97     | -0.07 | 1     |

**Table 2.5.** Odds ratio estimates, 95% confidence intervals, and associated p-values for OR estimates for gestation length, number born alive, number weaned, and herd life.

| Trait                    | Estimate | Lower Bound | Upper Bound | p-value |
|--------------------------|----------|-------------|-------------|---------|
| <b>Gestation Length</b>  |          |             |             |         |
| Angle                    | 1.16     | 0.81        | 1.67        | 0.47    |
| Distance                 | 1.16     | 0.81        | 1.66        | 0.46    |
| Speed                    | 1.43     | 1.00        | 2.07        | 0.05    |
| Lie Lateral              | 0.75     | 0.52        | 1.08        | 0.14    |
| Lie Sternal              | 1.55     | 1.08        | 2.23        | 0.02    |
| <b>Number Born Alive</b> |          |             |             |         |
| Lie Lateral              | 1.31     | 0.91        | 1.88        | 0.16    |
| Lie Sternal              | 0.73     | 0.51        | 1.05        | 0.09    |
| Sit                      | 0.91     | 0.63        | 1.32        | 0.63    |
| <b>Number Weaned</b>     |          |             |             |         |
| Eat                      | 0.71     | 0.49        | 1.01        | 0.07    |
| Lie Lateral              | 1.51     | 1.05        | 2.16        | 0.03    |
| Sit                      | 0.66     | 0.46        | 0.95        | 0.03    |
| <b>Herd Life</b>         |          |             |             |         |
| Angle                    | 0.93     | 0.64        | 1.36        | 0.78    |
| Speed                    | 0.99     | 0.68        | 1.44        | 1       |
| Distance                 | 0.88     | 0.60        | 1.27        | 0.51    |
| Eat                      | 0.77     | 0.53        | 1.11        | 0.18    |
| Lie Lateral              | 1.28     | 0.88        | 1.86        | 0.22    |
| Lie Sternal              | 0.67     | 0.46        | 0.97        | 0.04    |
| Sit                      | 0.90     | 0.61        | 1.31        | 0.63    |



### **3. CHAPTER III: CONCLUSION**

#### **3.1 Introduction**

Sow productivity and longevity are two of the most influential factors contributing to the financial stability of a commercial hog operation. The underlying genetic and environmental components impacting these traits are complex and often challenging to estimate. Reproductive traits contributing to economic return are typically expressed late in life and lowly heritable. In addition to challenges associated with improving sow longevity, pending legislation regarding swine housing necessitates a better understanding of group-housed animal management for optimized performance.

Developing phenotypes to represent activities of both group and individually housed swine offers potential to eliminate subjectivity in quantifying these traits. Further, automation of phenotyping should decrease labor requirements as well as offering the potential for early recognition of abnormal biological state. Thus, quantification of animal activity offers potential to generate incremental improvement in sow longevity traits of importance.

#### **3.2 Major Findings**

Associations between early-life activity and parity one reproductive traits were established and statistically significant. Gestation length was significantly impacted by multiple active traits (angle rotated, average speed travelled, distance travelled). Additionally, gestation length was impacted by time spent lying both laterally and sternally. Number born alive was impacted by three passive traits; time spent lying lateral, time spent lying sternal, and time spent sitting. Number weaned was significantly impacted by time spent eating, time spent lying lateral, and time spent sitting. These

results indicate that there is a measurable association between active phenotypes displayed early in life ( $\leq 150$  days of age) and reproductive traits expressed in the first farrowing event.

In addition to the associations seen in linear regression, a relationship between early-life phenotypes and parity one reproductive traits was also exhibited using odds ratios. Odds ratios were calculated by dichotomizing activity and reproductive traits into “below average” and “above average” categories. The decision to model these traits in a binary format was made based upon the practice of animal breeders to select above or below average animals based upon subjective phenotypes. By assigning gilts to a more general category, statistical variation was lost. However, the practical implications of this decision outweigh the statistical drawbacks. In the OR calculations, gestation length was impacted by average distance travelled and time spent lying sternally. Number weaned was related to time spent lying laterally and time spent sitting. Herd life was statistically significantly impacted by time spent lying sternal. Fewer activity traits were statistically significant in their association with the reproductive traits using this method. However, this was expected due to the loss of variation incurred by dichotomizing traits.

Upon completion of the linear regression and odds ratio analyses, correlations between activity traits were examined. The initial analysis suggested that time spent lying lateral and time spent lying sternal were significant predictors of parity one reproductive performance. These traits were also antagonistic in their impact on reproductive performance. In general, time spent lying lateral had a favorable impact on reproduction. Dissimilarly, time spent lying sternal was unfavorable in its impact on reproductive traits. A strong negative relationship was observed and verified by a correlation coefficient of -

0.80. This relationship indicates that total time lying should be viewed as two separate traits (lateral, sternal). Preliminary research utilizing NUtrack tended to view total time lying as a singular trait comprised of lying lateral and lying sternal. Initial heritability calculations (Ostrand et al., in preparation) showed that time spent lying lateral and time spent lying sternal were more highly heritable than total time spent lying. The results of both the heritability estimations and this analysis support the theory that total time lying does not represent a singular phenotype or activity. Therefore, the delineation between lying lateral and lying sternal is a significant outcome of this study.

The verification of NUtrack's ability to subjectively capture activity phenotypes and their association with parity one performance are primary outcomes of this analysis. The establishment of a difference between the lying lateral and lying sternal phenotypes is a tertiary, but significant result of this study. Paired, these results indicate the potential for early-life activity phenotypes to serve as indicator traits for parity one reproductive performance.

### **3.3 Personal Implications**

This project has generated a significant amount of personal growth from the standpoint of scientific writing, comprehension of prior research, data editing and management, statistical analysis, and result synthesis. Writing a comprehensive literature review enhanced my ability to interpret and describe research independently. The task of combing through past literature on sometimes sparsely researched topics was challenging but ultimately rewarding. Further, developing my lexicon and sharpening my technical writing skills were key outcomes from this process.

Working with a raw NUtrack dataset was a complex process that required analytical problem-solving skills. Animals in this analysis were under cameras for approximately 7 days. The decision was made to average activity traits across the 7-day span to represent one 24-hour period. This choice maximized efficiency and was sufficient for the purpose of examining the association between activity traits and reproductive traits. However, differences for individual gilts that occurred on a day-to-day basis were lost by managing the data in this manner.

Gilts were observed at USMARC across all four environmental seasons. Because of this, it was of interest to examine activity differences between gilts that were under observation in different seasons. Average daily temperature values were obtained for this purpose. However, since gilts segregated by barn, sire lines, and breeds, differences between seasons were non-significant and confounded. Further, these confounded variables limited the use of multiple linear regression. Therefore, multiple linear regression methods were not described in the full thesis.

Initially, one of the primary goals of this analysis was to examine differences in “socialability” of gilts. Our goal was to use proximity data from NUtrack. Proximity data describes the average distance that individual gilts within pens were from each other during the data collection period. Unfortunately, due to system complications with obtaining this data, we were unable to analyze these differences for the purpose of this thesis.

The process of managing and editing data illuminated to me the challenges of observational studies utilizing animals. Having an increased ability to manage and standardize genetic factors (sire, line, breed) as well as environmental differences

(season, barn, pen) should lead to a greater ability to discern true phenotypic differences between animals.

### **3.4 Future Research**

The association between early-life activity-based phenotypes and parity one reproductive traits was shown in this analysis. However, while these results indicate a relationship, further research is necessitated to isolate causation. Given NUtrack's proven ability to capture activity phenotypes, future work should focus on what these differences describe.

Moreover, the lie lateral, lie sternal complex should be thoroughly investigated. Suggested research includes analyzing underlying mechanisms contributing to differences between gilts who display preference for lying lateral versus lying sternal. Additionally, these preferences should be observed in individual gestation stalls and farrowing crate environments. Past research has shown that gilts who exhibit frequent postural changes in the farrowing crate pose greater risk to piglet survivability. Identifying an association between lying preference and the propensity to engage in frequent postural change could result in decreased piglet mortality, improving both profitability and animal welfare. Finally, utilization of activity phenotypes should result in decreased subjectivity as well as a more holistic view of the factors contributing to sow longevity and productivity as a whole.