BIOMETRIC GROWTH AND BEHAVIOR OF CALF-FED HOLSTEIN STEERS FED IN CONFINEMENT

By

Jacob A. Reed

B.S., Texas A&M University, 2012

A Thesis Submitted in Partial Fulfillment

of the Requirements for the Degree

MASTER OF SCIENCE

Major Subject: Animal Science

West Texas A&M University

Canyon, Texas

July 2015

ABSTRACT

The objective of this research was to determine the impact of zilpaterol hydrochloride (ZH) on movement behavior of calf-fed Holstein steers fed in confinement as well as understand the optimal slaughter end point for a calf-fed Holstein by use of biometric measurements. Calf-fed Holstein steers (n = 135) were randomized to 11 pre-assigned slaughter groups (254, 282, 310, 338, 366, 394, 422, 450, 478, 506, and 534 days on feed) consisting of 10 steers per group. Steers were assigned to one of three pens each containing a feed behavior and disappearance system (GrowSafe, Airdrie, AB Canada) which had four feed nodes per pen. A fourth terminal pen was divided in half with one side containing five steers fed a ration supplemented with ZH and the other half containing five steers fed a control ration without ZH supplementation. Steers placed in the fourth terminal pen were fed in 28 d feeding periods; d 1 to 5 included no ZH supplementation, d 6 to 25 included ZH (8.33 mg/kg dietary DM) supplementation, and steers were withdrawn from ZH during d 26 to 28. Objective movement behavior of each animal was monitored during the 28 d prior to harvest using an accelerometer (IceQube, IceRobotics, Edinburgh, Scotland, UK) attached to the left hind leg of each animal. The accelerometer recorded standing time (min), lying time (min), number of steps taken, and number of times lying down (lying bouts). These variables were accumulated in 15 min intervals. Data use began at 1200 h on d 1 to remove variation from movement caused by

handling the animals and ended on d 28 at 2400 h. Biometric measurements were takenon the same group of calf-fed Holsteins to allow for understanding of the maximal slaughter point based on hip height. Hip-height was measured every 28 d from 226 to 422 days on feed. Hip-height was a dependent variable modeled via linear regression procedures, utilizing days of age and live weight as independent variables. Additionally, logistic regression was used to estimate the probability of a steer exceeding a hip-height of 147.32 cm (58 inches) from independent variables of days of age and live weight. No ZH x slaughter group interaction ($P > 0.05$) was detected for any variable. No difference ($P > 0.05$) was observed between ZH supplementation treatment groups in the quantity of minutes spent standing (0 d ZH = 15,831; 20 d ZH = 15,470), minutes spent lying (0 d ZH = 23,769; 20 d ZH = 24,130), or number of steps taken per 28 d period (0 d ZH = 46,118; 20 d ZH = 46,914). The number of lying bouts tended to be different ($P = 0.09$) between treatment groups; cattle supplemented ZH exhibited 302 lying bouts whereas those not supplemented ZH had 326 bouts over the 28 d period. There was no day of period x ZH interaction ($P = 0.44$) for any of the behavior outcome variables. There was a difference ($P < 0.05$) between treatments in the amount of time spent standing (0d ZH = 571; 20d ZH = 541 min) and lying (0d ZH = 869; 20d ZH = 883 min) within day of a 28 d period. A difference ($P < 0.05$) occurred between treatments in numbers of lying bouts (0d ZH = 11.3; 20 ZH = 10.8) within day over the 28 d period. Interactions ($P < 0.01$) were observed for time x treatment for each one of the outcome variables when expressed in 15 min intervals during a 24 h period. The results indicated similar objective movement outcomes for calf-fed Holstein steers supplemented ZH when compared to those not supplemented ZH. The linear relationship of live weight to hip height had an R^2

value of 0.7116, and on average the calf-fed Holstein steers grew 1.0 cm per 16.9 kg of live weight gain during the finishing phase. The 10, 50, and 90% probability of a steer exceeding 147.32 cm (58 inches) of hip height was achieved at 563, 653, and 743 kg of live weight, respectively. The linear relationship of days of age to hip height had an R^2 value of 0.6691, and the calf-fed Holstein steers grew 1.0 cm for each 10.7 days of age during the finishing phase. The 10, 50, and 90% probability of a steer exceeding 147.32 cm (58 inches) of hip height was achieved at 408, 459, and 510 days of age, respectively.

ACKNOWLEGMENTS

I would like to thank Dr. Ty E. Lawrence for being my major professor during my time at West Texas A&M. I will forever be grateful for his mentoring and guidance, never giving up on me as student and as a person. He encouraged me to have attention to detail, work hard, put my heart into what I do, and reminded me that failure is not an option.

I would like to personally thank Dr. John Richeson and Dr. Jennie Hodgen for being on my thesis committee and using their valuable time to review my thesis and guide me in the corrections.

I would like to express gratitude to my parents, John and Karen Reed, my brother, Jon, and my sister, Jenny. Without their support, every step of the way, none of this would be possible. They have always been there, willing to push me when I was ready to give up. The countless phone calls and visits will not be forgotten.

I want to thank Trent McEvers, Lee-Anne Walter, Nathan May, DeMetris Reed, Carson Rogers, Remy Carmichael, Angie Schmitz, Jennifer Rowell, Kelly Lopez, Brian Blackburn, and John Mitchell, who made up the crew at the Beef Carcass Research Center. Their time, help, and support made this project worthwhile and possible. I could have not asked for a better group of people to work with. I want to thank John Hutcheson of Merck Animal Health for funding and allowing this project to occur. I would also like to thank Max Garrison for the use of his data collection system and continued support.

Marilyn Shepherd was always there for me. She supported me in my educational endeavors, encouraged me to get the best education possible and urged me to never give up on my goals. I would not be where I am today without the support and guidance she gave me during undergraduate and graduate work.

I have been fortunate to have great mentors during my education, especially Dr. David Lunt, Mr. Shelby Horn, and Mr. Zhan Aljoe. I would like to thank them for the guidance, and always expecting me to exceed my own expectations. They have impacted my life in a positive manner which has allowed me to reach this point in my education today.

DEDICATION

This thesis is dedicated to my brother Joshua Amos Reed who was an inspiration to all he knew and the many lives he touched during his life.

TABLE OF CONTENTS

\

LIST OF TABLES

Table
Page

LIST OF FIGURES

Figure
Page

CHAPTER I

INTRODUCTION

Understanding animal behavior and growth has become an increasingly contemporary issue as the feedlot industry works to improve the overall handling, well-being, and appropriate harvest point of each animal. Behavior monitoring may lead to better understanding, therefore improving animal welfare and the overall health status of the animal (Urton et al., 2005; Chapinal et al., 2007). The majority of cattle in feedlots today receive a beta-adrenergic agonist (BAA) for growth supplementation during the final 20 to 42 days on feed. The published literature regarding how BAA affect behavior in the feedlot is sparse.

Accelerometers have been used since the 1960's to quantify animal behavior in various research topics namely grazing patterns, estrus detection, castration, and research focused on general animal activity. Accelerometers allow researchers to objectively quantify activity with measurements such as: number of steps taken, the number of times an animal lies down (lying bouts), and the amount of time the animal spends in standing or lying positions. These devices have been attached to multiple body locations including: the lower front or rear pastern, neck collar, under the sternum, under the abdomen, and/or the axilla. Data from these devices are downloaded via radio transmission or manually downloaded after removal from the animal.

There is limited published knowledge of how BAA affect animal behavior during confined feeding. Anecdotal comments have suggested the BAA zilpaterol hydrochloride (ZH; Zilmax, Merck Animal Health) causes undue lameness and heat stress to cattle that are fed the growth promoting feed additive. Increasing the understanding of the effects of ZH will allow the industry to manage the use of BAA with greater precision and care. This research was designed to quantify the effects of supplementing ZH in the diet on animal movement behavior.

Biometric measurements are used to describe the dimensional measurements taken from designated anatomical points on an animal. In the cattle industry, biometric measurements have been used for non-invasive identification of characteristics including hip height, body depth, and frame size. These specific measurements have been used since the early 1950's to aid in prediction of dressed carcass yield percentages in beef cattle. Other measurement systems have been developed to build prediction equations to estimate criteria such as body volume, body area, dressed carcass yield, and pelvic size (Fisher, 1975; Comerford et al., 1987; De Paula et al., 2013). These measurements are generally taken manually or by a computerized measuring system and may consist of weight, wither height, heart girth, body length, hip height, width at rump, length of loin, and rib depth. Biometric measurements assist in determining optimal breeding capacity, meeting market end points, and allowing the producer to capture the highest financial gains.

Understanding the rate of growth and optimal slaughter point for calf-fed Holstein steers based on hip height has recently become important in the feedlot industry. The increase in carcass size of calf-fed and yearling-fed Holstein steers has outpaced the ability of some abattoirs to handle the larger animals. Moreover, some abattoirs have begun rejecting animals that exceed 147.32 cm (58 inches) at the hip, creating a challenge for many Holstein feeders. Analyzing growth curves for calf-fed Holstein steers is essential for predicting the necessary days on feed to reach the optimal harvest end point. Knowledge of calf-fed Holstein steer growth rates in relation to live weight and age may allow for refinement of sorting techniques to prevent oversized cattle arriving at the abattoir.

The objectives of this research were to understand the associated effects of ZH upon movement of calf-fed Holsteins, as well as the biometric growth patterns of these animals.

CHAPTER II

REVIEW OF LITERATURE

2.1 Mechanism of pedometer function

Pedometers are mechanical or electronic devices that record the number of steps of the subject being monitored. Pedometers were originally invented by Leonardo de Vinci for use in military applications (MacCurdy, 1938). The simple design of Leonardo de Vinci's mechanical pedometer, which was able to record number of steps, laid a foundation for the future of this technology. The mechanical style pedometer was patented in 1927 (Filed August 23, 1927: US 1685242 A). This basic mechanical pedometer was able to record steps of the subject using a mechanical pendulum swing-arm located inside the pedometer. When a subject had a step like movement the swing moved and made a connection to a post inside the pedometer. When this event occurred it counted as one step. This device was unable to define a step from other limb movements. In the 1960's health and fitness clubs began using the manpo-kei (meaning "10,000 steps meter") pedometer, and it became a huge success (Harvard Health publication, 2009). Since 1960's pedometers have been applied in animal research to increase understanding of movement and behavior. The use of pedometers in research has changed and evolved with the advancement of technology. They have continued to progress from the mechanical pendulum swing arm, into the electronic devices that are used today, allowing for real time pedometer data to be continuously logged. Current designs are electronic devices that record the standing or lying posture of the animal, as well as the number of steps taken. These behaviors are determined by the three plane axis found in the electronic chip located in the accelerometer. Accelerometers function using the piezoelectric effect, in which a microscopic crystal structure made of either quartz crystals or ceramics generates voltage when mechanically stressed from pressure or vibration. Once stressed, the microscopic crystal will send an electrical charge to a processor chip found on the accelerometer that will record a movement and/or a posture change in the three plane axis. Because the plane of the animal differs between standing and lying, the microscopic crystal will likewise be in a different position. This form of technology permits the pedometer to record the position of the animal at any given time during a known period. Accelerometers have gained acceptance in research as they allow for real time understanding of an animal's motion and behavior.

2.1.1 IceRobotics accelerometers in research

IceTag accelerometers (IceRobotics, Edinburgh, Scotland, UK) were designed specifically for research, and IceQube accelerometers (IceRobotics) were designed for either research or commercial monitoring of livestock. The company designed these accelerometers to be used in livestock production settings to record step count, quantity of time standing and lying, and number of lying bouts during a defined time period. These accelerometers are 95.0 x 82.3 x 31.5mm in size and weigh 130 g. They are encased in a plastic strap that is designed to be attached to the rear leg of the animal. The IceTag is also able to be attached to the neck to record grazing behavior of the animal. The IceTag data is exported by wireless transmission and may store up to 60 d of data.

The IceQube records movement behavior in summarized 15 minute intervals and is able to store collected data from 1 to 60 d, internally. IceQube data may be downloaded via an IceQube tag reader (IceRobotics) or an automated farm download system (IceRobotics). These products were introduced in 2005 and several research studies have been conducted to confirm the accuracy of the IceTag and IceQube as tools to monitor animal movement, behavior, and posture.

Endres and Bargerg (2007) evaluated different bed packing systems in dairy cattle production. They collected data on movement behavior from 147 cows at 12 different dairies in the state of Minnesota from June to September 2005. An IceTag accelerometer was used to monitor posture (lying or standing) and walking behavior of the animals. The IceTag was attached to the rear leg of approximately 15% of the dairy cow herd on each farm for one week. Cows were fed and milked twice daily and the relative humidity was recorded each day. They reported that peak hours of standing occurred from 1100 to 1900 h, with minimal activity from 2200 to 0400 h. The animals, on average, spent 9.3 ± 1.94 h lying with 11 ± 3.2 lying bouts during a day. They reported that at any given time 43% of all cows were lying down. They concluded that IceTags were an accurate tool to collect data on the standing and lying behavior of dairy cows.

Trénel et al. (2009) evaluated the use of the IceTag as an accelerometer to record an animal’s movement behavior. They attached the IceTag to the right hind leg of nine Holstein calves (3 males, 6 females) that were two months of age. Video data was recorded as well to validate the movement data that the IceTag collected. The data was evaluated by setting thresholds in a three step procedure to help eliminate false negatives and false positives. This system followed the standard for sorting animal movement data set by Dohoo et al. (2003). The first threshold was established by choosing a cutoff that maximized the sum of sensitivity and specificity. The second threshold was the lying period criterion, which was established empirically for the animal. The last threshold was an estimate of moving activity, conditional on the animal being in the upright position. Nine Holstein calves were observed in 12 h periods, and the data were analyzed using a 2 x 2 contingency table. Four calves were used to establish the lying period criterion, while five calves were used to validate this system. They reported the system to be highly accurate, at ≥ 90%, for capturing standing or lying behaviors of the animal. However, it was < 50% accurate at determining the gait of the movement behavior at any given time. They concluded the IceTag was not ideal for the monitoring of speed of movement behavior in the animal, as it was not able to distinguish between walking and running. In contrast, it was reported to be an accurate measure of standing and lying behavior of housed dairy cattle when the logged IceTag data were sorted via the three step system.

Nielsen et al. (2010) quantified walking and lying behavior of dairy cattle as a moving average based on accelerometer output activity. They evaluated if the IceTag was able to accurately log posture (standing or lying) and steps taken by the animals. Each hind leg had an IceTag attached to the lower limb in an effort to reduce false positives and improve the level of accuracy of data collected. These devices were attached to both hind legs of 10 lactating Holstein dairy cows from a group of 47 cows in a loose housing system. All cows were offered ad libitum feed and water from an Insentec feeding system (Insentec, Marknesse, The Netherlands), and each animal was milked automatically (DeLaval Milking Unit 2008, Delaval, Vejle, Denmark). Video recording was taken during the movement experiment in order to validate the data captured by the IceTag. Cows were walked down a designated alley by a technician and placed in a stall where the hind leg was touched by a technician to stimulate movement of the hind quarter. Nielsen reported that the number of steps recorded from video and logger data during a reviewed period were 11.5 and 7, respectively, and reported a difference of 2 to 5 steps. These scientists reported a possibility of false positives due to the IceTag not being strapped tightly to the leg, which in turn allowed it to move freely. Their conclusion was the IceTag was able to record animal movement behavior with some degree of accuracy.

The IceTag and IceQube accelerometers have been documented to be effective and accurate methods to monitor cattle in various production settings (Endres and Bargerg, 2007; Trénel et al., 2009; Nielsen et al., 2010). The use of these devices in research applications has gained popularity in recent years due to their ease of attachment with no apparent animal discomfort, no interference of animal behavior, reliable data capture, and ready access to stored or transmitted data.

Currently, there are several companies producing accelerometers for use in the bovine species. This type of technology will continue to advance, and the functions they are able to perform while on the animal will likely increase. Below is a list of the current manufacturers of bovine specific devices including the function they perform on the animal.

Brand	IceQube[u]	IceTag[v]	Pedometer Plus[w]	Alanya[x]	Cow Scout[y]	Track-a-cow[z]
Standing time (min)	Yes	Yes	Yes	Yes	No	Yes
Lying time (Min)	Yes	Yes	Yes	Yes	No	Yes
Steps	Yes	Yes	Yes	Yes	Yes	Yes
Lying bouts	Yes	Yes	Yes	Yes	No	Yes
Time at feed bunk	No	No	No	Yes	Yes	No
Leg mounted	Yes	Yes	Yes	Yes	Yes	Yes
Neck mounted	No	Yes	No	Yes	Yes	Yes

[u] IceRobotics, Edinburgh, Scotland, UK

[v] IceRobotics, Edinburgh, Scotland, UK

[w] Afimilk Ltd, Kibbutz Afikim, Israel

[x] Alanya Ltd, Cork, Ireland, UK

[y] GEA far, Technologies Inc. Naperville, IL

[z] Dairymac Limited. Swanmore, Southampton, England, UK

2.2 Monitoring of livestock by use of pedometer

Pedometers have been used to monitor livestock movement in pasture, after castration, during weaning stress, and during estrus. Initially, pedometers used a mechanical pendulum swing arm device that could only record the number of steps the animal took, and researchers were forced to use video recordings to know the animals standing and lying behavior during the day (Hurnik et al., 1975). As technological capabilities improved, pedometers began to log data electronically, continuously recording the quantity of steps the taken, as well as the standing and lying behavior of the animal, during a known period of time (White et al., 2008; Trénel et al., 2009; Gibbons et al., 2012). These devices could be attached to any limb of an animal and permitted researchers to objectively quantify movement in order to gain a greater understanding of elements influencing normal animal behavior.

2.2.1 Monitoring livestock grazing

Using a pedometer to monitor livestock grazing has been employed as a tool to better understand individual animal behavior and movement. Pedometers have been used to determine how different grazing systems, as well as differences in breed or gender, affected animal movement.

Powell (1968) monitored sheep with a pedometer system secured behind the left shoulder via an elastic belt encircling the chest of the animal. The pendulum swing arm style pedometer swung as the animal walked recording individual steps; however, this device required calibration to each individual animal. Unfortunately, normal animal movements including shaking, licking, or lying down, also caused the pedometer to record a false positive. Due to its design, this style of pedometer was not widely used in experiments. Powell (1968) concluded at that time, that reliability of data capture would need to improve for pedometers to be useful research tools.

Anderson and Kothmann (1977) determined grazing movement of animals was monitored effectively with the use of digital pedometers (Digi-Meter, Edge Mark, Japan). The pedometers measured vertical movement of the leg upon which they were placed. Pedometers were placed on the front left pastern of four heifers and calibrated to insure an accurate reading. Data were collected weekly during a 140 d study period on either continual grazing of a 20 ha area or short duration rotational grazing on 4 ha. Cattle grazing 20 ha paddocks traveled 36.1 km/week; whereas, cattle grazing in 4 ha paddocks traveled 25.0 km/week. Movement was similar among animals within a treatment group.

Walker et al. (1985) furthered the evaluation of grazing patterns in crossbred cows (Hereford x Angus and Hereford x Simmental) using Digi-Meter pedometers, which measured vertical movement of the front pastern. Ten animals were used, per treatment group, in two different experiments. Animals were placed on a continuous grazing system that consisted of 242 ha plots or a short duration grazing system, which consisted of two 30 ha and three 10 ha plots. Animals in the short duration grazing plots grazed for 6 or 9 d depending on the amount of forage available. Cattle movement for the two experiments was reported as 7.5 km and 6.2 km for continuous grazing and 10.1 km and 7.1 km for the short duration grazing. These results indicated no significant difference between breed groups when grazed in either system.

Funston et al. (1991) evaluated the differences in grazing patterns between Hereford, Hereford x Angus, Simmental x Hereford, and ¾ Simmental x ¼ Hereford breed combinations. Grazing patterns were observed using Digi-Meter pedometers which measured vertical movement of the front left pastern. Twenty four cows, comprised of six head of each breed type listed, were assigned to 276 ha fields. The mean distance traveled for each breed group was: Hereford (3.1 ± 0.2 km/d), Hereford x Angus (3.4 ± 0.2 km/d), ¾ Simmental x ¼ Hereford (2.8 ± .02 km/d), and Simmental x Hereford (4.0 ± 0.2 km/d). No differences in distance traveled during a day were reported among the various breed groups. Observations from this experiment agreed with Anderson and Kothmann (1977) and Walker et al. (1984) that pedometers were able to effectively monitor grazing livestock behavioral patterns.

2.2.2 Monitoring movement after castration

Castration is the removal of male reproductive organs of animals via surgical methods or by attaching a high tension latex band to interrupt blood circulation to the testicle resulting in necrosis. Castration results in a decrease in the aggressiveness of the animal and mounting activity in the feedlot pens and improves the meat flavor, texture, and overall palatability the meat, for consumer. Castration has become an area of awareness in the livestock industry, as consumers have become increasingly concerned about the occurrence of castration without pain mitigation strategies. Pedometers have been utilized in various experiments to gain a greater knowledge of the effect of castration on animal behavior.

White et al. (2008) evaluated movement using two-dimensional, commercially manufactured accelerometers (Crossbow Technology Inc., San Jose, California) as a behavioral indicator of pain in livestock animals following castration. The accelerometers were placed on the lateral aspect of the right hind limb, proximal to the metatarsophalangeal joint of 12 cattle. The amount of time spent lying down or standing up was recorded for each male and compared to intact bulls. Cattle were monitored 16 to18 h prior to castration and 20 to 25 h post-castration. There was a non-significant numerical difference in the quantity of time castrated males spent standing compared to intact males. Hours standing was not reported due to limited sample size. They concluded two-dimensional accelerometers can be used to gauge animal behavior;

however, a baseline was not established prior to trial initiation to standardize the movement of each treatment group, which could bias the results reported.

Currah et al. (2009) reported pedometers (Omron HJ-105 Pedometer, Omron Healthcare, Vernon Hills, IL) could be implemented as effective tools to indicate pain calves may experience after castration. The study consisted of 27 calves divided equally into three treatment groups: control castration, castration with lidocaine and epinephrine caudal epidural anesthesia, and castration with flunixin meglumine, lidocaine and epinephrine caudal epidural anesthesia. They evaluated the number of steps taken 24 h pre and post-castration. A significant reduction in number of steps taken was observed in the control castration group; whereas, no differences in steps taken were observed between the other treatment groups. Their results concluded that pedometers offer an effective means of measuring the change in animal behavior post-castration.

Devant et al. (2012) evaluated animal activity of Holsteins fed in confinement using pedometers (E.N.G.S system, Almagor, Israel). Pedometers were placed on the hind leg of 86 animals to determine activity pre and post-castration. Cattle were monitored for 65 to 69 d prior to castration and 70 to 79 d post-castration. The study consisted of 27 bulls, 29 steers (castrated at 3 months of age), and 30 bulls castrated at 8 months of age on d 69 of the study. Time spent lying down and number of steps were quantified. They reported a significant difference in the amount of time lying recently castrated bulls compared to steers until 5 d after the event. There was significant difference in the amount of activity between treatments, as the steers in the study were less active (48 ± 5.0 steps/h) compared to bulls (106 ± 5.0 steps/h). Pedometers were able to accurately document the change in behavior Holstein bulls exhibit after castration.

Pedometers have been illustrated as an invaluable tool to allow researchers a greater understanding of the effects castration has on the behavior of livestock (White et al., 2008; Currah et al., 2009; Devant et al., 2012). The use of pedometers will allow the industry to continue improving management practices during castration and reduce discomfort this practice may induce.

2.2.3 Monitoring weaning stress

Weaning is a stressful event that involves both physical and psychological separation of the offspring from its dam. Calf weaning commonly occurs at approximately 6 months after parturition, with calves being separated from the care of their dam. Weaning has the potential to change the weaned animal’s movement and behavior due to increased stress. Mitigating the inherent stress associated with weaning would likely decrease calf activity during the transition time from weaning.

Haley et al. (2005) evaluated calf behavior when utilizing various weaning management protocols. Anti-suckling devices (nose-flap) prevented calves from nursing four days prior to separation from their dam. Using 50 cow/calf pairs, calves were randomly selected for the two-stage treatment or a control group. Five randomly selected calves from each treatment group wore a pedometer (HJ-104, Omron Healthcare, Inc., Vernon Hills, IL) on their left front leg to quantify the amount of steps taken. Pedometers were attached four days prior to weaning and removed four days post weaning, with baseline data being collected for three days while the calves were nursing. Before weaning, the group with the anti-suckling devices in place took 2,019 more steps per day than the control group. Upon weaning, the control group took on average 8,887 more steps than calves weaned in two stages. The two-stage weaned calves took 4,084 fewer steps per day (2.7km/d distance) during the study period. These researchers concluded weaning in two stages helped mitigate stress on the animal weaned, because the two stages of weaning led to less steps taken after separation from their dam. This research demonstrated that pedometers were able to accurately log data from calves during weaning.

2.2.4 Lameness detection with pedometers

Lameness in the dairy industry is an area of concern due to the reduction in productivity and increased cost of caring for the animal (Mazrier et al., 2006). Although dairies often employ specially trained technicians to monitor for signs of lameness on each milking animal, there still remains an inability to diagnose all cases of lameness. Thus, many dairies have implemented the use of pedometers to improve the timeliness and frequency of detecting lameness for better diagnoses and treatment.

Mazrier et al. (2006) evaluated the ability of pedometers in detecting lameness in dairy cattle. They hypothesized that as cows became lame, they would exhibit a reduction in activity. Four-hundred Israeli-Holstein milking cows were used for this study and each wore a Pedometer Plus (AfiTag, Afikim Ltd, Kibbutz Afikim, Israel). Number of steps was retrieved from the pedometer, via a radio transmitter, during each milking in the parlor. The data were uploaded to a computer program that identified individual animals with reduction in steps taken. If individual cows had > 5% reduction in pedometer activity over the previous ten days, they were observed by a bovine specialist for clinical signs of lameness. The specialist evaluated the gait of the animal and palpated the suspected lame limb. Forty-six cows (11.5%) during the study had a reduction in pedometer activity. Twenty one (5.25%) of those cows developed clinical lameness, while the other 25 (54.3%) cows were deemed false positives. These scientists reported 92% of the lameness cases identified had a >15% reduction of pedometer activity. Therefore, to reduce the occurrence of false positives, they concluded it is unnecessary to establish a reporting threshold below 15%.

Higginson et al. (2010) conducted two studies to validate if Pedometers Plus could accurately record steps, standing time, lying time, and lying bouts (number of times lying down) of individual dairy cows. These studies utilized sixteen cows housed in maternity stalls. Study one had 11 cows with a pedometer placed on the hind leg and a previously validated IceTag accelerometer (IceRobotics, Edinburgh, Scotland, UK) on the opposite hind limb. Study two used five cows fitted with a Pedometer Plus on one hind limb and an IceTag on other hind limb. Both devices recorded length of time lying and standing, as well as number of steps taken. Correlation coefficients between the two devices were similar for number of steps taken in both study one ($r = 0.73$) and study two ($r = 0.82$). The amount of time lying was highly correlated in study one ($r = 0.98$) and study two ($r = 0.90$) for all cows. These authors concluded the Pedometers Plus device accurately monitored the activity of dairy cattle.

Alsaaod et al. (2012) evaluated the efficiency of the ALT-pedometer (ALT-Pedometers; ATB, Potsdam, Germany) to record activity, such as number of steps, time lying, and time standing, of the animal. They used 30 dairy cows that were selected based on their locomotion score (1 = sound, 5 = severely lame), with cows being required to score ≤ 2 to be enrolled in the study. Once per week, cow gaits were scored by visual observation while walking along a 16 m grooved concrete alley. A minimal locomotion score of 3 was required to be considered clinically lame in this study. The logged pedometer data indicated animals developing lameness tended to lay down for a greater amount of time.

Gibbons et al. (2012) studied the effects of the IceTag accelerometer device on the limb of the animal and possible effects to the cow's lying behavior. Forty lactating dairy cows were placed in eight groups and housed in sand-bedded free stalls with one cow per stall. Hobo pedometers (Pendant G data logger, Onset Computer Corporation, Pocasset, MA) were attached to all 40 cows with a side location (left or right hind leg) to have a baseline control of lying behavior in the animals. They used 16 of the 40 animals in a Latin square design to allow for comparison between the four treatments: no IceTag, IceTag on right hind limb, IceTag on left hind limb, IceTag on both hind limbs. Data were collected for 16 d on each treatment. The researchers quantified no significant differences among the treatments in number of steps, time spent lying or standing, or lying bouts. This research validated that IceTag accelerometers did not affect animal movement or behavior patterns when worn during a 16 d period.

The ability to detect lameness in lactating dairy cows is improved with the use of pedometers (Mazrier et al., 2000; Alsaaod et al., 2012). This technology allows dairy cows to be diagnosed earlier in comparison to conventional, visual evaluation methods used by dairy lameness technicians. Pedometers will continue to be used more widely on dairies to aid the prevention of severe lameness and improve early detection of clinical lameness in dairy cattle.

2.2.5 Estrus detection with pedometers

The ability to detect estrus in dairy cattle is one of the most critical aspects in maintaining cow productivity; ensuring cows are profitable and efficient. Knowing when an animal is exhibiting standing estrus is essential to timed artificial insemination, which has been problematic for some producers (Lewis and Newman, 1984). Typically, heat watches are done twice daily to observe for animals manifesting signs of estrus. Pedometers can aid in this process by allowing the producer to detect estrus earlier via behavioral changes in the animal. Earlier detection of the estrous cycle would allow for improved conception rates using artificial insemination.

Lewis and Newman (1984) used pedometers (K and R Instruments, Inc., Orlando, FL) to measure activity of 50 cows from 14 different dairy farms. Pedometers were attached to the rear leg of the animal and data were collected during each visit to the milking parlor. When an increase in the frequency of steps was noted in the pedometer data, activity three days before and three days after the increase was reviewed. Step activity on the day of estrus was 2.25% greater than the previous day activity. Physical activity was at maximal levels in 73% of the 55 estrus periods logged by the pedometer. They concluded pedometers were able to accurately predict estrus activity in dairy cattle, by effectively monitoring movement behavior.

Peter and Bosu (1986) continued to evaluate the efficacy of pedometers (Dairy Equipment International, Inc., Madison, WI) for estrus detection in an experiment that placed pedometers on the left front limb of 47 cows which were monitored from parturition until 60 d postpartum. Cows were in a management system that permitted pasture time during the day. Pedometers were checked twice daily in the milking parlor to detect any increase in physical activity in the animal's movement. Herdsmen also observed the cows twice daily for visual signs of estrus. During this time, there were 91 heat observations recorded in the herd; 76% were detected with the use of pedometers; whereas, only 35% were detected with visual observation. This experiment illustrated that use of pedometers can improve estrus detection in dairy cattle.

Roelofs et al. (2005) evaluated the use of pedometers for estrus detection and as predictors of the onset of ovulation in dairy cattle. Pedometers (NedapAgri B.V., Groenlo, The Netherlands) were attached to the front leg of 43 Holstein-Friesian cows. The devices were downloaded daily to a computer in the milking parlor to evaluate number of steps taken. The pedometers recorded steps in twelve 2 h time periods during a 24 h period. They reported that increased behavioral signs displayed during estrus (sniffing, mounting, chin resting) were detected with 87% accuracy when pedometers were used to log activity changes in the dairy cows.

The use of pedometers in dairies promotes the efficiency of estrus detection (Lewis and Newman, 1984; Peter and Bosu, 1986; Roelofs et al., 2005), which may allow for greater conception rates using timed artificial insemination. As pedometers become more economical, there will continue to be an increased number of dairies employing this technology for enhanced estrus detection. This trend will continue to increase as more research is conducted and reported.

2.3 Use of pedometers in other species

Pedometers have been used in other species of animal research including canine, equine, and caprine. Most pedometers that are used with these animals are made for use with humans; however, they have been modified to work in animal research. A limited number of studies have been performed evaluating movement behavior in other animal species.

2.3.1 Monitoring movement in canines

Chan et al. (2005) evaluated the number of steps taken by dogs recorded by pedometers and correlated the results to the activity of the pet owners themselves. Their assumption was that inactivity of human owners was possibly linked to inactivity and obesity in pets. Owners placed a pedometer (Optimal Health Products, San Antonio, TX) on their pet, and wore a pedometer (Yamax-200, New Lifestyles, Deep River, ON, Canada) themselves to evaluate the hypothesis. Owners were also provided a diary to record their physical activity and the activity of their pets during the day. When pedometer data was assessed, actual number of steps over a distance of 30 m was not significantly different from the number of steps recorded, regardless of gait. Furthermore, the number steps taken by the dog was positively correlated with the owner's activity level and inversely correlated with the body condition score of the dog. These findings indicate that pedometers were able to accurately record the number of steps taken by canines during a given period of time.

Hansen et al. (2007) measured the mobility of healthy dogs using accelerometers (Actical, Respironics Mini Mitter division, Bend, OR) to aid in the treatment of chronic pain. The compact accelerometers (28 x 27 x 10 mm) were attached at five of the eight various locations (top of collar, bottom of collar, lateral portion of the thorax, axilla, lateral portion of the humerus, antebrachium, under sternum, and under abdomen). Because only five accelerometers were available for use during the experiment, the locations of permanent accelerometer attachment (bottom of collar, lateral portion of the thorax, axilla, and under abdomen), and accelerometers on the other locations were rotated through for shorter periods of time. They subsequently placed the test subjects in a controlled area to correlate video recordings to accelerometer movement data. It was determined the collar was the ideal location to place the accelerometer because it was the most tolerated by the dogs and their owners. Video data helped explain the increase in activity at certain points; such as if the dog was vigorously wagging its tail. They concluded accelerometers were an effective tool for baseline experiments in canines experiencing chronic illness; however, more testing would be required to improve accuracy.

Warren et al. (2011) used pedometers (Accusplit AE120 with a Yamax digiwalker, Accusplit, Livermore, CA) to assess the relationship between the activity of dogs and their body condition score. During the validation stage of the experiment, 20 dogs were observed with weight ranges of 4.5 to 50 kg and body condition scores of five to seven on a nine-point body condition scale. Video recordings were taken while each dog wearing an accelerometer was walked a 25 m distance. This procedure was repeated six times for each animal. A significant inverse relationship existed between average daily steps and baseline body condition scores that were reported for each animal; as the body condition score increased the animal activity level decreased. However, it is not understood whether lack of physical activity leads to obesity or obesity leads to less physical activity in dogs. This experiment further documented accuracy of logged pedometer data in research.

2.3.2 Monitoring movement in equine

Holland et al. (1996) hypothesized dietary fats influenced the activity and reactivity of horses. They evaluated four fillies and four geldings randomly allotted to four diets in a replicated 4 x 4 Latin square design. Pedometers (Trial Tale Horse Pedometer, Kel Instruments, Wyckoff, NJ) were attached to the left front pastern to measure number of steps taken. Horses received one of four diets (control, corn oil, soy lecithin-corn oil, or soy lecithin-soy oil) during each three week test period. Spontaneous activity was evaluated by use of the pedometer during the last 5 d of the experiment. Reactivity was evaluated by the response to pressure or startling stimulus. The response to physical pressure was measured by an apple penetrometer (Effegi Fruit Tester, McCormick Fruit Tech, Yakima, WA) applied in front of the jaw and near the point of the hip on the flank until the horse moved away from the pressure being applied. This was performed on the last day of each period by the same technician. The startled reaction was elicited by visual or auditory stimuli. Visual stimulus was done by opening brightly colored umbrellas and the auditory stimulus was the rattle of coins in a metal can. Horses were walked 9.8 km on a designated path and time was recorded. Then the same horses were walked on the same designated path but the preselected stimuli were applied at the approximately half way distance, and time was recorded. They reported that horses in the control group exhibited a significantly slower response to spontaneous activity than horses consuming soy lecithin-corn oil, as the time to travel the 9.8 km increased. Reactivity measurements indicated less pressure was required on the flank to elicit a response when consuming control diet verse corn oil.

Warren-Smith and McGreevy (2010) evaluated the motor laterality, or preferences limb dominance, of forelegs in grazing horses. Six horses of varying ages (12.0 ± 2.4 years) were selected for the study. Each horse was fitted with a proprietary exercise boot (Sports medicine Boots, Professional's Choice Sports Medicine Products, Incorporated, El Cajon, CA) on each leg, and an accelerometer (designed for the study of human exercise; G-Sensor 2025 Accelerometer Million Step Pedometer, Pedometers Australia) was secured to the boot itself for five days, to avoid any signal day anomalies. They reported mean overall number of steps for left and right foreleg of 2829.7 and 2148.9, respectively. Over the 5 d recording period there was left leg movement bias in 4 of the 6 horses. This research illustrated the accelerometer was able to log data accurately and proved to be a useful resource to score motor laterality in horses.

2.3.3 Monitoring movement in caprine

Doherty et al. (1987) evaluated estrus detection in 26 dairy goats using pedometers. Pedometers (K+R Pedo Pedometer, Pedo-Company, Suffern, NY) were placed on neck tags and read twice daily at 0800 and 2000 h. Does were exposed to bucks in order to assess the estrus condition of does. If the doe stood to be mounted, it was recorded as standing estrus. A significant increase in activity over a 24 h period was observed when does were in estrus. In combination with previously mentioned work in in dairy cows (Peter and Bosu 1986; Roelofs et al., 2005), these data indicate that pedometers can aid in the detection of estrus in various species.

Pedometers have improved the understanding of movement behavior of canines (Chan et al., 2005; Warren et al., 2011), equine (Holland et al., 1996; Warren-Smith and McGreevy, 2010), and caprine (Doherty et al., 1987). Pedometers will have an increased presence in future research, as they aid in greater understanding of animal activity and behavior.

2.4 Methods to estimate live animal skeletal growth

Biometric measurements may be used to describe biological changes that occur over a period of time, and it offers opportunity for non-invasive assessment of physical characteristics in cattle. These measurements may consist of, but are not limited to: weight, wither height, heart girth, body length, hip height, width at rump, length of loin, and rib depth. These measurements may be taken manually or by a computerized measuring system and serve as an accurate and reliable method to predict body volume, body area, dressed carcass yield, and pelvic size.

2.4.1 Biometric evaluation of live animal growth

Cook et al. (1951) evaluated the relationship of body measurements to dressed carcass yield. Shorthorn steers (n = 62) were grown to an average weight of 226.8 kg, at which time they were placed on concentrate diet until a designated end point of 408.2 kg. Steers were then measured prior to harvest evaluating five different parameters on each steer (height at withers, height at chest floor, circumference of fore-flank, width at shoulder, and length of body). The relationship between the biometric measurements and slaughter grade, carcass grade and dressing percentage was then evaluated. Circumference at fore-flank was positively correlated (r = 0.43) with carcass dressing percentage, indicating the steers with wider fore flank expressed a greater probability of an increased dressing percentage. Height at withers was negatively correlated ($r = -0.19$) to slaughter grade, with shorter steers experiencing a higher slaughter grade. They concluded body measurements could be a potential resource to accurately predict dressed carcass yield.

Fisher (1975) evaluated the accuracy of biometric body measurements to predict carcass composition. They selected 25 of the most common body measurements recorded on live beef cattle to predict carcass composition. Purebred Hereford ($n = 15$) steers ranging in age from 529 to 885 d with body weights ranging from 379.5 to 476.5 kg were used. A technician recorded 25 measurements (circumference of cannon bone, height at withers, width of shoulders, circumference of heart girth, rear flank girth, width of ribs, width of paunch, length of loin, depth of rib point, depth of hooks, depth of patella from base of tail, circumference of hind leg, length of pelvic girdle, depth of patella from dorsal midline, length from patella to posterior mid line, width of rump, depth of rump, length of hindquarter, skinfold thickness at flank, and skinfold thickness at brisket) on the day of slaughter for each steer. These were repeated the same day with a sufficient lapse in time for the technician to forget the previous measurements of each animal. The reported data indicated that 22 (circumference of cannon bone, height at withers, width of shoulders, circumference of heart girth, rear flank girth, width of ribs, width of paunch, length of loin, depth of hooks, depth of patella from base of tail, length of pelvic girdle, depth of patella from dorsal mid line, width of rump, depth of rump, length of hindquarter, skinfold thickness at flank, and skinfold thickness at brisket) mean square variances were significant and concluded those measurements were sufficiently accurate to record the differences in body dimensions for the prediction of body composition.

Comerford et al. (1988) evaluated the performance characteristics of pre-weaning and post-weaning growth, hip height, and pelvic size over a five-year period. They evaluated 699 offspring over a 5 year period from Simmental, Limousin, polled Hereford, and Brahman breeds. Each group of progeny were evaluated for feedlot gain and carcass traits. Annual progeny groups during the first 3 years of the study were weighed every 14 d, and progeny groups during the last 2 years of the study were weighed every 28 d. Calves were placed in a feedlot on a high concentrate diet at a mean age of 217 d and randomly allotted into slaughter groups based on weight, mating type, and age. Biometric measurements (yearling weight, hip height, pelvic height, pelvic width, pelvic area) were recorded at a mean age of 379 d. They reported that weaning weight was highly correlated with yearling pelvic width ($r = 0.74$), yearling hip height ($r = 0.049$) and yearling pelvic area ($r = 0.085$). They concluded that biometric measurements could accurately estimate hip height of yearling calves of different breed types.

Heinrichs and Hargrove (1987) evaluated the standard weight and height for Holstein heifers to develop a prediction equation for dairy heifer growth at 24 months of age. They used biometric measurements of 5,723 heifers from 163 different herds throughout Pennsylvania. Herds were required to have a minimum number of heifers (ten $<$ 25 months of age, two $\leq$ 8 months of age, two $\geq$ 20 months of age). Biometric measurements included heart girth as an estimate of weight, height at withers, and date of birth. A prediction equation was developed using these biometric measurements to estimate weight and wither height for a 24 month old Holstein. They reported $r^2 > 0.99$

for both weight and wither height. These results indicated biometric measurement taken from dairy heifers ≤ 24 months of age were accurate at predicting weight and wither height at 24 months of age.

Heinrichs et al. (1992) evaluated equations for predicting body weight and wither height in Holstein heifers using biometric body measurements. Retrospective data from six separate studies (n = 2,625) were used with cattle ranging from 1 to 821 days of age. Measurements included: weight, wither height, heart girth circumference, body length, and hip width. A prediction equation was developed from the previously recorded body measurements to estimate body weight and hip height of Holsteins heifers based on days of age; they reported an r^2 of 0.997 and 0.999 for these measurements, respectively. These results indicated biometric measurements could accurately estimate body weight and hip height in Holstein heifers.

Fernandes et al. (2009) evaluated prediction equations for body area and volume of grazing crossbred bulls using body measurements. Crossbred bulls (n = 40) from different genetics, of at least 50% Nellore influence, with an initial age of 346 ± 30 d and body weight of 248 ± 40 kg were serially slaughtered in three groups (d 0, d 90, and d 220). Cattle were divided into four different nutrition supplementation groups and weighed every 28 d during the study period. The day prior to slaughter, cattle were weighed and biometric measurements recorded (hook width, pin width, pelvic girdle length, rump depth, rump height, abdomen width, body length, height at withers, rib depth, girth, and body diagonal length). A prediction equation was developed to estimate body area and body volume based on the measurements taken during the study. They reported $r^2 = 0.995$ and $r^2 = 0.999$ with RMSE of 0.307 and 0.005 for body area and body volume of the bulls respectively. They concluded that biometric measurements could predict body area and volume with a high degree of accuracy.

De Paula et al. (2013) evaluated the prediction of carcass composition using biometric measurements in beef cattle. They used 44 crossbred bulls of at least 50% Nellore genetics serially slaughtered in five groups (every 84 d) throughout a 310 d period. Cattle were divided into four different nutrition supplementation groups. The day before slaughter, cattle were weighed and measured (hook bone width, pin bone width, abdomen width, body length, rump height, height at withers, rib depth, girth circumference). A prediction equation was developed based on the measurements taken during this study to estimate total body surface and body volume; r^2 values were 0.908 and 0.997, respectively for total body surface and body volume prediction. They concluded that biometric measurement could aid in the prediction of carcass composition.

Biometric measurements have improved the ability to objectively assess a particular characteristic that is being evaluated; this has improved the livestock industry's ability to select for desired traits necessary to improve cattle growth and development. Understanding cattle growth better may allow for the feedlot industry to sort cattle more accurately which would result in improved efficiency in feedlots. This science will continue to be researched and developed to improve biometric measurements, allowing further understanding of compositional growth among different breeds, sexes, and ages of cattle. Further research will enable the individual animal units to be managed more effectively in the commercial production setting.

CHAPTER III

MOVEMENT AND ACTIVITY OF CALF-FED HOLSTEIN STEERS FED IN CONFINEMENT AND SUPPLEMENTED ZILPATEROL HYDROCHLORIDE

3.1. Abstract

Calf-fed Holstein steers (n = 135) were randomized to 11 pre-assigned slaughter groups (254, 282, 310, 338, 366, 394, 422, 450, 478, 506, and 534 days on feed) consisting of 10 steers per group. During the last 28d, steers were either fed a ration supplemented with zilpaterol hydrochloride (ZH) or a control ration without ZH supplementation. For steers fed ZH, d 1 to 5 included no ZH supplementation, d 6 to 25 included ZH (8.33 mg/kg dietary DM) supplementation, and d 26 to 28 allowed for withdrawal from ZH. Objective movement behavior of each animal was monitored during the 28 d prior to harvest using an IceQube (IceRobotics, Edinburgh, Scotland, UK) accelerometer attached to the left hind leg of each steer. The accelerometer recorded standing time (min), lying time (min), number of steps taken, and number of lying bouts. Data use began at 1200 h on d 1 to remove variation from movement from handling the animals and ended on d 28 at 2400 h. No ZH x slaughter group interaction ($P > 0.05$) was detected for any variable per 28 d period. No difference ($P > 0.05$) was observed between ZH supplementation treatment groups in the quantity of minutes spent standing (0 d ZH = 15,831; 20 d ZH = 15,470), minutes spent lying (0 d ZH = 23,769; 20 d ZH = 24,130), or number of steps taken per 28 d period (0 d ZH = 46,118; 20 d ZH = 46,914). The number of lying bouts tended to be different ($P = 0.09$) between treatment groups; cattle supplemented ZH exhibited 302 lying bouts whereas those not

supplemented ZH had 326 bouts over the 28 d period. No day of period x ZH interaction (P = 0.44) was observed for any of the outcome variables within day during a 28 d period. Differences (P < 0.05) were detected between treatments for the amount of time spent standing (0d ZH = 571 min; 20d ZH = 541 min), lying (0d ZH = 869 min; 20d ZH = 883 min), and number of lying bouts (0d ZH = 11.3; 20d ZH = 10.8) within a day during a 28 d period. Interactions (P < 0.01) were observed for time x treatment for each outcome variable except lying bouts when expressed in 15 min intervals during a 24 h period. Differences (P < 0.01) were detected in the number of steps taken (0d ZH = 16.4; 20d ZH = 17.6) and the number of lying bouts (0d ZH = 0.13; 20d ZH = 0.11) within 15 min intervals during a 24 h period however, no differences (P > 0.05) for time standing or time lying were observed.

3.2. Introduction

Supplementation of beta adrenergic agonists (BAA) such as zilpaterol hydrochloride (ZH) has become a contemporary practice in the U.S. cattle feeding industry. It is has been well documented that BAA are an efficient tool to increase the lean carcass weight up to 15 kg during the final 20 to 42 d of finishing (Montgomery et al., 2009; Robles et al., 2009; Rathmann et al., 2012). The practice of supplementing BAA has been challenged by animal welfare experts such as Grandin (2013) for possibly causing lameness and undue stress to the animal late in the feeding period. Minimal research has been published on the effects of animal movement behavior when supplemented ZH. Understanding the potential effects that ZH has upon animal behavior may allow for improvement in management practices when supplementing ZH during the finishing phase.

Pedometers permit evaluation of animal movements and behaviors; their accuracy has been documented by Anderson and Kothmann (1977), Roelofs et al. (2005), and Devant et al. (2012). Pedometers have been used to evaluate animal movement after castration (White et al., 2007; Currah et al., 2009), in the event of lameness (Mazrier et al., 2000; Higginson et al., 2010; Gibbons et al., 2012), and for estrus detection in dairy cattle (Lewis and Newman, 1984; Peter and Bosu, 1986). Pedometers use has not been limited to cattle. Previous literature includes canine (Chan et al., 2005; Hansen et al., 2007; Warren et al., 2011), caprine (Doherty et al. 1987), equine (Holland et al., 1996; Warren-Smith and McGreevy, 2000), and ovine (Powell, 1968). The objective of this research was to measure and objectively document the movement behavior and activity of calf-fed Holstein steers supplemented ZH during confinement in a feedlot environment.

3.3. Materials and methods

All experimental procedures followed the guidelines described in the guide for the care and use of Agriculture Animals in Agriculture Research and Teaching (FASS, Savory, IL) and were approved by the West Texas A&M University (WTAMU) Institutional Animal Care and Use Committee.

3.3.1. Cattle selection and randomization

Calf-fed Holstein steers (n = 135) were selected by weight from a larger cohort group of 320 steers located in a single pen at Quien Sabe Feeders (Happy, Texas) with steers being age and source verified via Select Sires (Plain City, Ohio). Selected cattle were moved to a private research feedlot facility in (AgriResearch, LLC) Canyon, TX 36 km from the origin feedlot. Steers were randomized into 11 pre-assigned slaughter groups consisting of 10 steers per group. Five steers were assigned to be used as a baseline for the study (d 0) and twenty steers were retained as alternates to replace any chronic, injured, or dead animals that might occur during the study. Steers were assigned to one of three pens that contained the GrowSafe feed disappearance monitoring system (Airdrie, AB Canada) which had 4 feed nodes per pen. A fourth pen was divided in half and contained two feed nodes per pen. Five steers were fed a ration supplemented with zilpaterol hydrochloride (ZH; 8.33 mg/kg dietary DM) for the last 20 d + 3 d withdrawal, and five steers were fed a control ration without ZH supplementation. Steers were fed in 28 d treatment periods; d 1 to 5 did not include ZH supplementation, d 5 to 25 included ZH supplementation, d 26-28 were ZH withdrawal days. Pen size was 215 m^2 and each pen had two GrowSafe nodes along the north pen edge. An automatic waterer was present in the middle of a dividing fence line to allow for equal access from the east for the control or west side for the ZH treatment; all animals had ad libitum access to water in each pen. Cattle were fed once daily at 0700 h during the entire project, and the final finishing ration remained the same throughout the project.

3.3.2. Animal movement monitoring

IceQube accelerometers (IceRobotics, Edinburgh, Scotland, UK) were used to monitor movement of the steers during each 28 d period for cattle in the control and ZH supplemented treatment terminal pens. IceRobtic (IceRobotics, Edinburgh, Scotland, UK) accelerometers were developed for the monitoring of the bovine species and several studies have documented that the IceTag and IceQube accurately monitor cattle movement, behavior, and posture (Endres and Bargerg, 2007; Trénel et al., 2009; Nielsen et al., 2010). An accelerometer was placed on the left hind limb of each animal (Figure 3.1) 28 d prior to harvest. Accelerometers were placed on the animals between 0500 and 0700 h; data use began at 1200 h on d 1 to remove variation from movement caused by handling the animals and ended on d 28 at 2400 h. The accelerometer continuously recorded standing time (mm:ss), lying time (mm:ss), number of steps taken, and the number of times the animal laid down (lying bouts) during the 28 d study period. Accelerometer data were downloaded using the IceReader (IceRobotics) with the use of the IceManager software (IceManager 2.014, IceRobotics). After the data were downloaded, the devices were reset and placed on the ten animals assigned to the subsequent slaughter groups.

3.4 Statistical analysis

This study was a completely randomized experimental design, with a 2 x 11 factorial treatment arrangement (0 or 20 d ZH supplementation by 11 slaughter dates). Individual animal was the experimental unit. Data were analyzed as three different time periods. The original 2 x 11 factorial design was analyzed as the summation of the total minutes spent standing or lying, the total number of steps taken, and the total number of times the animal lied down during the 28 d treatment period. These data were analyzed using ANOVA procedures with the fixed effects of ZH treatment and study period and the Kenward-Roger denominator degree of freedom method was used. Treatment means were generated using the LSMEANS option and separated when significant with the PDIFF option that was adjusted with the Bonferroni method to reduce the probability of a type-I error ($\alpha = 0.05$). A second analysis probed into the individual day effects prior to ZH inclusion in the diet, during the ZH treatment period, and during the withdrawal period. Those data were analyzed as repeated measures using a compound symmetry covariance structure via the GLIMMIX procedure of SAS. The tertiary analysis investigated the diurnal movement patterns of the cattle within a 24 h period. Pedometer data were recorded 96 times per day (compilation of 15 min increments) and were analyzed as repeated measures as previously described.

3.5 Results and discussion

Animal movement was collected during 11 periods from d 226 to d 533 of the study. No ZH x feeding period interaction ($P > 0.05$) was observed for standing time (Figure 3.2), lying time (Figure 3.3), or number of steps taken (Figure 3.4). An interaction tendency ($P = 0.06$) occurred for the number of lying bouts (Figure 3.5). This outcome is likely a result of small sample size per feeding period and is not likely biologically repeatable. The number of lying bouts tended ($P = 0.09$) to be different between treatment groups. Cattle supplemented ZH exhibited 302 lying bouts; whereas those not supplemented ZH had 326 bouts during the 28 d period. This is likely in part due to a reduction in a feed intake of ZH supplemented cattle, which consumed 0.57 kg less and attended the bunk for 11.3 fewer min per day as recorded by the GrowSafe system (Walter et al., 2015). A reduction feed intake was reported by Montgomery et al.

(2009) when cattle were supplemented ZH and many have speculated that maintenance energy requirements are reduced with ZH supplementation. If that is true, reduced feed intake would be a likely outcome due to a reduced demand for energy intake. Grandin (2013) proposed ZH may increase the incidence of lameness in cattle by 20 to 50 %; however, objective results reported here do not indicate that ZH fed cattle experience any differing standing time, lying time, or step count. No difference ($P > 0.05$) in ZH treatment was observed for the total minutes of standing (0d ZH = 15,831; 20d ZH = 15,470), total minutes of lying (0d ZH = 23,769; 20d ZH = 24,130), or number of steps taken (0d ZH = 46,118; 20d ZH = 46,914) during the 28 d periods (Table 3.1).

There was no day of period x ZH interaction ($P \geq 0.44$) observed for any of the behavior outcome variables (Table 3.2). Number of steps taken did not differ between treatments (0d ZH = 1616; 20d ZH = 1606). A reduction in steps occurred after d 23 of the treatment period and declined until d 28 (Figure 3.8). This is possibly due to physiological changes of the animal and the increased size and weight of the calf-fed Holsteins steers during the latter portion of the feeding periods. There was a difference ($P < 0.05$) between treatments in the amount of time spent standing (0d ZH = 571; 20d ZH = 541 min) and lying (0d ZH = 869; 20d ZH = 883 min) during the 24 h period. The 20d ZH supplemented cattle spent more time lying from the start of the 28 d period (Figure 3.7) compared to the control cattle over the same time period spent a greater amount time standing (Figure 3.6). A difference ($P < 0.05$) occurred between treatments in numbers of lying bouts (0d ZH = 11.3; 20ZH = 10.8) over the 28 d period. The greatest difference in lying bouts occurred between the treatments groups in the pre ZH period. One of the factors that could have influenced the increased lying time for the ZH treatment is that the ZH treatment pen only had cattle on one side of the pen whereas the control had cattle on both sides. This may have influenced how the cattle moved in each pen and is a possible explanation of the difference in the standing and lying behavior in the different treatment groups. Differences ($P < 0.05$) were also observed for day of the period for each of the behavior outcome variables. The variability in weather conditions during the 28 d periods is a possible explanation for the differences. Since each of the calf-fed Holstein steers are individual biological units, there will be changes in their behavior throughout a treatment period which is not be biologically repeatable.

A treatment x time interaction ($P < 0.0001$) was detected for each of the behavior outcome variables evaluated during 15 minute intervals (Table 3.3). However, there was no treatment effect ($P > 0.05$) for time standing, time lying or number of lying bouts during a 15 minute interval over a 24 h period. Within a 24 h period, movement was greatest during the hours 0700 to 0900 h and 1700 to 2300 h (Figure 3.10). Feed was delivered once daily at 0700 h, after feed delivery there was increased activity from 0700 to 0900 and the cattle competed for node space because only two of five animals were able to consume feed at a given time. The calf-fed Holstein steers spent the greatest amount of time lying from 0000 to 0630 h and 0930 to 1530 h during the day (Figure 3.11), this is also the time we observed an increase in lying bouts (Figure 3.13) for both treatment groups indicating the cattle were active in up and down movements. The 0930 to 1530 h occurred after the daily morning feed, which could explain the increased lying observed for this time period, as the animals would have been ruminating the feed consumed and preferred to be in sternal recumbency. During 1700 to 2300 h the least amount of time spent lying (Figure 3.11) and fewest lying bouts was observed, which is most likely due in part to the natural grazing pattern of bovine species. There was a difference (P <0.05) in ZH treatment for number of steps taken in 15 minute intervals within a 24 h period. Since the behavior variables were recorded in 15 min time intervals, it is likely to find statistical differences in the data since it is much more sensitive to detect difference in animal movement with very frequent data generating events. However, the differences that were found may not represent true biological difference between the treatments as individual animal variation would affect the differences reported.

The calf-fed Holstein steers movement behavior followed rhythmic movement patterns that have been previously reported in cattle that were monitored in a grazing pasture (Low et al., 1981; Erlinger et al., 1990; Taweel et al., 2004; Aharoni et al., 2009). This pattern of movement is characterized by an increase in activity from 0700 to 1000 h, a decrease in movement from late morning through the afternoon, followed by increased activity during the evening hours of 1700 to 2300. This pattern remains in the cattle entering confinement feeding situation. Therefore, we suggest that the calf-fed Holstein steers used in this study followed the natural grazing pattern of the bovine species throughout the duration of the study, lending to our observation of natural variability in behavior throughout a given day.

The current data were unable to demonstrate that increased lameness resulted from supplementation of ZH a beta-agonist in the diet. Five animals were removed from the study for laminitis at 506 DOF prior to being placed in the terminal feeding pens for assigned treatment. These individual steers most likely experienced lameness as a result of founder caused by the extended number of days on feed beyond what is typical for calf-fed Holstein steers which likely resulted in metabolic issues and greater than normal final body weights, 650kg.

Throughout the duration of this study, pen conditions remained firm, devoid of excessive mud accumulation, and no steer required treatments for clinical signs of foot rot. Supplementation with ZH currently displays no known mode of action for increasing the prevalence or severity of clinical foot rot in calf-fed Holsteins.

Extreme weather conditions are of concern for animals housed outside, because extreme heat or cold may influence their natural behavior. There have been anecdotal concerns that BAA may increase the incidence of heat stress in cattle during weather that is 35˚C (95˚F) or greater, causing cattle to be reluctant to move and to be sore footed Grandin (2013). Over the eleven 28 d treatment periods, cattle behavior was influenced by various weather conditions. During the 282 to 309 d period (August 2012: 23 months of age), the greatest number steps was observed to be 63,675. Movement behavior appeared to decrease during the winter months during 450 to 477 d, which coincided with the greatest amount of time lying (25,594 min). This may be due partially to a week of extreme cold weather (average ambient temperature = 5°C) and a snow accumulation (48.6 cm). The conditions were extreme for the Texas panhandle and likely affected movement of the steers, as the Holstein breed does not tolerate cold weather conditions well (Duff and McMurphy, 2007). Tucker et al. (2007) reported that Holstein dairy cows in extreme winter weather would position their neck and head to stay out of direct wind, and the calf-fed Holsteins steers in this study did not have any form of shelter during the winter storms. Lying times of cattle have been reported to increase during cold inclement weather; the increased lying posture of the calf-fed Holstein steers involved with this study, during the exceptionally cold period, would be consistent with these findings (Gonyou et al., 1979; Redbo et al., 2001; Zähner et al., 2004). This in part, could explain the tendencies (P = 0.09) reported between the slaughter groups over 11 periods in lying bouts, as they may have been reluctant to move during the cold windy months compared to greater activity in the warmer, arid months in the Texas panhandle. Moreover, there was not a difference between treatments in the amount of time spent lying during the inclement winter weather. These results demonstrate that ZH supplementation did not clearly have detrimental effects on calf-fed Holstein steers body posture or movement behavior in cold temperatures.

The steers used in this study were fed in small pens (215 m^2; 43 m^2 per animal). This may have affected the natural movement behavior because the animals were placed in 5 hd groups the day they entered the terminal sort pens. This may have impacted the social behavior and hierarchy of the calf-fed Holstein steers, influencing the movement during the 28 d ZH supplementation period. Movement behavior and body posture may be different in large pen settings where cattle have much greater area in which to move, as well as a greater number of animals to potentially interact with. There is no known documented research on the effects of pen size and calf-fed Holstein behavior. This area needs further research to understand the effects of the large group setting and how social hierarchy and movement behavior are affected.

Breed type, sex, weight, and temperament of individual animals influence movement behavior and posture (Keeling and Gonyou, 2001). Different breeds may exhibited more aggression and spontaneous behavior in a feedlot setting; whereas, others may display more docile and calm behavior, adapting more readily in confinement situations with less behavioral changes. Temperament of individual animals could also play a large role with movement behavior and social interaction with other animals in large or small pen settings. This presents an area that requires further research to understand how breed type, sex, and individual animal temperament influence movement behavior and posture of animals placed in large or small pen confinement feeding, and was beyond the scope of the data collected in this study.

3.6 Implications

Pedometers will continue to have an increased role in animal research to monitor movement behavior. Results of this study do not support detrimental effects or altered movement activity concurrent with ZH supplementation in the diet. The tendency for calf-fed Holsteins steers in the ZH treatment group to have fewer lying bouts warrants further research to understand confounders that could have influenced this finding. How breed type, sex, and animal temperament influences movement behavior and posture of animals placed in large or small pen confinement feeding is an area that needs further investigation to better understand these potential contributions on behavior and posture

CHAPTER IV

OBJECTIVE BIOMETRIC MEASUREMENTS OF CALF-FED HOLSTEIN STEERS FED IN CONFINEMENT

4.1. Abstract

Understanding the optimal slaughter point for calf-fed Holstein steers based on hip height has become a contemporary issue in the beef processing industry. Increased carcass size, in terms of both weight and length, has outpaced the ability of some abattoirs to handle the larger animals. Moreover, some abattoirs have begun rejecting animals that exceed 147.32 cm (58 inches) at the hip creating a challenge for various Holstein feeders. The objective of this study was to quantify the growth rate of calf-fed Holstein steers fed in confinement. Hip-height of calf-fed Holstein steers ($n \leq 135$) was measured every 28 d from 226 to 422 days on feed. To reduce measurement error, the same researcher performed the measurements each time the cattle were evaluated. Hip-height was a dependent variable modeled via linear regression procedures utilizing days of age and live weight as independent variables. Additionally, logistic regression was used to estimate the probability of a steer exceeding a hip-height of 147.32 cm (58 inches) from independent variables of days of age and live weight. The linear relationship of live weight to hip height had an R^2 value of 0.7116 {*Hip height, cm = (0.0593 x Live weight, kg) + 108.99; Figure 4.1*}, and on average the calf-fed Holstein

steers grew 1.0 cm per 16.9 kg of live weight gain during the finishing phase. The 10, 50, and 90% probability of a steer exceeding 147.32 cm (58 inches) of hip height was achieved at 563, 653, and 743 kg of live weight, respectively. The linear relationship of days of age to hip height had an R^2 value of 0.6691 {*Hip height, cm = (0.0937 x Days of age) + 104.4; Figure 4.3*}, and the calf-fed Holstein steers grew 1.0 cm for each 10.7 days of age during the finishing phase. The 10, 50, and 90% probability of a steer exceeding 147.32 cm (58 inches) of hip height was achieved at 408, 459, and 510 days of age, respectively. Knowledge of Holstein steer growth rate in relation to live weight and age may allow for more accurate sorting to prevent oversized cattle arriving at the abattoir, consequently receiving a discount or being rejected for slaughter.

4.2. Introduction

Holstein cows have historically been selected based primarily on milk yield and as a result, Holsteins have been increasing in size since the 1960's (Boettcher et al., 1993). Many producers believed that larger skeletal framed cows were able to consume greater quantities of feed, thus allowing them to produce a higher quantity of milk (Hansen et al., 1999). Holstein heifers at 24 months of age in the U.S. increased in skeletal height (131.3 to 134.6 cm) and weight (485.3 to 537 kg) in the period between 1934 and 1997 (Heinrichs and Losinger, 1998).

Hip height, and thereby carcass length and final body weight, of Holstein animals has increased, creating a challenge for some abattoirs to process the larger animals. Multiple abattoirs have been presented with food safety concerns due to longer animals touching the floor, because the shackle rails that hold the carcass during slaughter are not high enough to accommodate the increased length of the hanging carcasses. This may result in contamination of saleable meat (particularly tongue and lips), leading to food safety concerns. Thus, some abattoirs have implemented a size restriction at the hip height of 147.32 cm (58 inches), which in turn has created a unique challenge for feeders of Holstein steers to sufficiently finish those animals to industry expectations (i.e. USDA Choice or better) while not exceeding the hip height requirement.

Biometric measurement has been validated as a practical method for predicting weight and wither height (Heinrichs et al., 1992), hip width (Comerford et al., 1987), dressed carcass yield (Cook et al. 1950; Fisher, 1975), and for sorting groups of cattle to market (Koontz et al. 2008). The objectives of this research were to quantify hip height in relation to days of age and weight, and to develop prediction models useful for cattle feeders to manage optimal number of days on feed (DOF) without exceeding the 147.32 cm (58 inches) hip height rule.

4.3. Materials and methods

All experimental procedures followed the guidelines described in the guide for the care and use of Agriculture Animals in Agriculture Research and Teaching (FASS, Savory,IL) and were approved by the West Texas A&M University (WTAMU) Institutional Animal Care and Use Committee.

4.3.1 Biometric measurements

Biometric data were collected using a proprietary system from Performance Cattle Company, LLC (Amarillo, TX). The measuring device was attached to the working chute (L. Z. Equipment; Garden City, KS), and this device collected data on hip height.

The system was attached above the chute with two cable displacement transducers, one in the front area and one in the back area of the chute. The cables were linked together with a clevis that that was used as the measurement pointer. The clevis worked by touching a designated area of the animal, for this study the center of the hip of the calf-fed Holstein steers. The measurement system was calibrated by placing a calibration measuring rod 121.92cm on the floor in the middle of the working chute, then preceded by touching the working clevis on two predetermined height test spots at 15.24 cm and 106.26 cm, to simulate as if the animal were standing there, each morning prior to data collection. Once the system was calibrated to the correct height, calf-fed Holsteins were moved through the chute, and hip height measurement for each animal was recorded. This measurement was collected on each steer (n = 135) across eight 28 d periods. For consistency, the same researcher performed the measurements each time the cattle were evaluated. If the initial measurement recorded by the technician did not appear accurate for a particular animal, the animal was repositioned and measured a second time to confirm an accurate reading for the animal, at which time the animal was released. These measurements were collected on each animal unit until the designated harvest date or until the animals outgrew the measurement capabilities of the unit itself.

4.4 Statistical analysis

Hip-height, as a dependent variable, was modeled using the REG procedure of SAS (SAS Institute, Cary, NC) using days of age and live weight as independent variables. Additionally, the GLIMMIX procedure was used to estimate the probability of a steer exceeding a hip-height of 147.32 cm (58 inches) from independent variables of days of age and live weight.

4.5 Results and discussion

A linear relationship of live weight to hip height {*Hip height, cm = (0.0593 x Live weight, kg) + 108.99*; Figure 4.1} had an R^2 value of 0.7116, and on average the calf-fed Holstein steers grew 1.0 cm per 16.9 kg of live weight gain. The 10, 50, and 90% probability of a steer exceeding 147.32 cm (58 inches) of hip height was achieved at 563, 653, and 743 kg of live weight, respectively (Figure 4.2).

Calf-fed Holstein steers, typically, remain on feed for extended periods when compared to the traditional beef breeds placed in a confinement feeding system. The commercial calf-fed Holstein feeder is presented a challenge to allow the animal to reach an acceptable finishing weight required for sufficient fat to be deposited (Dolezal et al., 1995; Trenkle, 2001) while not exceeding 147.32 cm (58 inches) at the hip. Finding the correct production system based on weight will allow for the greatest profitability of the animal (Dolezal et al., 1995).

The calf-fed Holstein steers grew 1.0 cm for each 10.7 days of age {*Hip height, cm = (0.0937 x Days of age) + 104.4*; Figure 4.3}. The 10, 50, and 90% probability of a steer exceeding 147.32 cm (58 inches) of hip height was achieved at 408, 459, and 510 days of age, respectively (Figure 4.4). Knowing the growth rate based on age of calf-fed Holstein steers would allow less resorting of animals; however, there are practical limitations in the number of times and animal can be measured in sorting systems. The amount of times the animal is able to go through the chute system is limited due to increased rick of animal injury and labor requirements in the feedlots. This presents a challenge for marketers of the cattle to group cattle effectivity, because each animal will have a different rate of daily gain. Sorting cattle into refined slaughter groups based on weight and hip height would allow for improved uniformity in cattle which may result in greater production efficiency.

These data improve the understanding of the growth patterns of calf-fed Holstein steers and may aid producers in predicting the live weight or days on feed at which animals may exceed 147.32 cm (58 inches) of hip height. This may allow producers to manage feeding programs for calf-fed Holstein steers as well as marketing endpoints for individual animals. Furthermore, the ability to sort calf-fed Holstein steers based on hip height and weight may result in uniform grouping of cattle to allow for premiums when marketing the calf-fed Holstein steers on a value-based grid as documented with beef breeds (Trenkle, 1998; Adams et al., 2010). Accurate grouping of cattle will allow for more uniform carcasses, which would decrease the variation in hot carcass weight, therefore reducing the occurrence of heavy weight carcass discounts (Basarab et al., 1999; Pyatt et al., 2005). Challenges that sorting cattle presents include the increased labor required to move and sort cattle into marketing groups, the loss of performance associated with moving cattle from established pens, and stress and increased injury risk that might occur when regrouping cattle in new pens (Stanton, 1997).

During the current study, calf-fed Holstein steers began to exceed the 147.32 cm (58 inches) hip height after 375 days of age; the industry average for days of age on a Holstein is currently ≤ 500 days of age. This presents a challenge for large frame animals as they require more time to deposit back fat as compared to smaller framed animals

(Dolezal et al. 1995). Because large framed Holsteins will likely be marketed prior to achieving physiological maturity, they may have a greater likelihood of receiving discounts for inferior carcass quality, as cattle are commonly marketed on quality and yield grade. Sorting tools, such as the prediction equation developed from this study, will provide insight allowing the industry to be able to sort and group calf-fed Holstein steers more uniformly and allow for greater marketability.

There are Holstein genetic lines that possess smaller frame size, shorter than current Holsteins (Ragsdale, 1934; Boettcher et al., 1993; Heinrichs and Losinger, 1998) while still exhibiting efficient milk production compared to as the larger frame Holsteins. Adapting to using the genetic lines of the Holstein breed that produce shorter cattle would allow for a reduction in the overall size of the Holstein breed and greater marketability of the steers on a grid basis. Abattoirs would be more able to handle the smaller carcass size, and therefore would not deduct Holsteins to the same degree they currently do. Sorting cattle based on hip height and day of age will allow the marketer to more efficiently group cattle.

Cross breeding dairy Holstein dams with sire breeds such as Angus or Charolais has become more prevalent in the industry, as it leads to greater marketability of the offspring. The F1 offspring exhibit hybrid vigor, allowing for greater average daily gains and resulting in the producer of crossbred calf-fed Holstein to receive greater premiums for the animal once they reach abattoir. Bertreand et al. (1983) reported Dairy Holstein dams crossbred with Angus sires will produce heavier hot carcass weight and a higher marbling score. Crossbred calf-fed Holstein are more efficient when it comes to average daily gain (Gerhardy et al.1995), which will allow for fewer days on feed and reduced production cost of the animal. The dairy industry will continue to increase the amount of crossbred offspring produced as it looks for ways to increase the marketability of bull calf off spring.

4.6 Implications

Biometric measurements of calf-fed Holstein steers suggest hip height can be accurately estimated from live weight or days of age. This is of great importance to the industry because the size of calf-fed Holstein steers will continue to increase in stature and weight unless there is an abrupt change in the typical Holstein genetic selection criteria. This begs the question of when the industry will reach the tipping point on hip height and weight of calf-fed Holstein steers. Further research needs to be conducted to evaluate monetary value that could be added and how long the process would take be able to move toward a lower hip height in the Holstein breed to help reduce the incidence of calf-fed Holsteins steers exceeding slaughter hip height restrictions.

These data may allow producers to sort cattle more efficiently based on hip height and weight and prevent over-sized calf-fed Holstein steers from being rejected at the abattoir based on excessive hip height. Utilizing both the hip height measurement and days on feed could possibly be an effective sorting tool for calf-fed Holstein steers, as it would allow for the producer to sort cattle into uniform groups and allow for greater marketing opportunities.

CHAPTER V

LITERATURE CITED

Adams, D. R., T. J. Klopfenstien, G. E. Erickson, W. A. Griffin, M. K. Luebbe, M. A. Greenquist, and J. R. Benton. 2010. Effects of sorting steers by body weight in calf-fed, summer yearling, and fall yearling feeding systems. Prof. Anim. Sci. 26:587-594.

Aharoni, Y., Z. Henkin, A. Ezra, A. Dolev, A. Shabtay, A. Orlov, Y. Yehuda, and A. Brosh. 2009. Grazing behavior and energy cost of activity: A comparison between two types of cattle. J. Anim. Sci. 87:2719-2731.

Alsaaod, M., C. Römer, J. Kleinmanns, K. Hendriksen, S. Rose-Meierhöfer, L. Plümer, and W. Büscher. 2012. Electronic detection of lameness detection in dairy cows through measuring pedometric activity and lying behavior. Appl. Anim. Behav. Sci. 142:134-141.

Anderson, D. M. and M.M. Kothmann. 1977. Monitoring animals travel with digital pedometers. J. Range Mgmt. 30:316-317.

Basarab, J. A., J. R. Brethour, D. R. Zobell, and B. Graham. 1999. Sorting feeder cattle with a system that integrates ultrasound backfat and marbling estimates with a model that maximizes feedlot and profitability in value-based marketing. Can. J. Anim. Sci. 79: 327-334.

Bertrand, J.K., R. L. Willham, and P. J. Berger. 1983. Beef, dairy and beef x dairy carcass characteristics. J. Amin. Sci. 57: 1140-1448.

Boettcher, P.J., L.B. Hansen, H. Chester-Jones, and C.W. Young. 1993. Responses of yield and conformation to selection for milk in a designed experiment with a control population. J. Dairy Sci. 76:267-273.

Chan, C. B., M. Spierenburg, S.L. Ihle, and C. Tudor-Locke. 2005. Use of pedometers to measure physical activity in dogs. J. Amer. Vet. Med. Assoc. 226:2010-2015.

Chapinal, N., D. M. Veria, D. M. Weary, and M. A. G. von Keyserlingk. 2007. *Technical note*: Validation of a system for monitoring individual feeding and drinking behavior and intake in group housed cattle. J. Dairy Sci. 90:5732-5736.

Comerford, J.W., L.L. Benyshek, J.K. Bertrand, and M.H. Johnson. 1988. Evaluation of performance characteristics in a diallel among Simmental, Limousin, Polled Hereford and Brahman beef cattle. I. Growth, hip height and pelvic size. J. Anim. Sci. 66:293-305.

Cook, A.C., M.L. Kohli, and W.M. Dawson. 1951. Relationships of five body measurements to slaughter grade, and dressing percentage in milking shorthorn steers. J. Anim. Sci. 10: 386-393.

Currah J.M., S.H. Hendrick, and J.M. Stookey. 2009. The behavioral assessment and alleviation of pain associated with castration in beef calves treated with flunixin meglumine and caudal lidocaine epidural anesthesia with epinephrine. Can. Vet. J. 50:375-382.

De Paula, N.F., L.O. Tedeschi, M.F. Pualino, H.J. Fernandes, and M.A. Fonseca. 2013. Predicting carcass and body fat composition using biometric measurements of grazing beef cattle. J. Anim. Sci. 91:3341-3351.

Devant, M., S. Marti, and A. Bach. 2012. Effects of castration of eating pattern and physical activity of Holstein bulls fed high-concentrate rations under commercial conditions. J. Anim. Sci. 90:4505-4513.

Doherty, W.C., E.O. Price, and L.S. Katz. 1987. A note on activity monitoring as a supplement to estrus detection methods for dairy goats. Appl. Anim. Behav. Sci. 17:347-351.

Dohoo, I., W. Martin, and H. Stryhn. 2003. Veterinary Epidemiologic Research. AVC. Inc. Charlottetown, Canada.

Dolezal, H. G., J. D. Tatum, and F. L. Williams, Jr. 1993. Effects of feeder cattle frame size, muscle thickness, and age class on days of fed, weight, and carcass composition. J. Anim. Sci. 71:2975-2985.

Duff, G.C. and C. P. McMurphy. 2007. Feeding Holstein steers from start to finish. Vet Clin. Food Anim. 23:281-297.

Endres, M. I. and A. E. Barberg. 2007. Behavior of Dairy Cows in an Alternative Bedded-Pack Housing System. J. Dairy Sci. 90:4192-4200.

Erlinger, L. L., D. R. Tolleson, and C. J. Brown. 1990. Comparison of bite size, biting rate and grazing time of beef heifers from herds distinguished by mature size and rate maturity. J. Anim. Sci. 68:3578-3587.

Fernandes, H. J., L.O. Tedeschi, M.F. Paulino, and L.M. Paiva. 2010. Determination of carcass and body fat compositions of grazing crossbred bulls using body measurements. J. Anim. Sci. 88:1442-1453.

Fisher, A. V. 1975. The accuracy of some body measurements on live beef cattle. Live. Prod. Sci. 2:357-366.

Funston, R.N., D.D. Kress, K.M. Havstad, and D.M. Doornbos. 1991. Grazing behavior of rangeland beef cattle differing in biological type. J. Anim. Sci. 69:1435-1442.

Gerhardy. H., M. Kreuzer, H. J. Langholz. 1995. Experimental Evaluation of quality beef production systems of different fatting periods and intensities employing Holstein bulls. Zuchtungskunde. 67:117-131.

Gibbons, J., C. Medrano-Galarza, A. Marie de Passillé, and J. Rushen. 2012. Lying laterality and the effect of IceTag data loggers on lying behaviour of dairy cows. Appl. Anim. Behav. Sci. 136:104-107.

Gonyou, H. W., R.J. Christopherson, and B.A. Young. 1979. Effects of cold temperature and winter conditions on some aspects of behaviour of feedlot cattle. Appl. Anim. Ethol. 5:113–124.

Grandin, T. 2013. The effects of economics on the welfare of cattle, pigs, sheep, and poultry. Available at. Accessed Jun. 21, 2014

Haley, D.B., D.W. Bailey, and J.M. Stookey. 2005. The effects of weaning beef calves in two stage on their behavior and growth rate. J. Anim. Sci. 83:2205-2214.

Hansen, B.D., B.D.X. Lascelles, B.W. Keene, A.K. Adams, and A.E. Thomson. 2007. Evaluation of an accelerometer for at-home monitoring of spontaneous activity in dogs. Amer. J. Vet. Res. 68:468-475.

Hansen, L.B., J.B. Cole, G.D. Marx, and A.J. Seykora. 1999. Productive life reasons and disposal of Holstein cows selected for large versus small body size. J. Dairy. Sci. 82:795-801.

Harvard Health publication. 2009. Counting every step you take. Available at: http://www.health.harvard.edu/newsletters/Harvard_Health_Letter/2009/September/counting-every-step-you-take. Accessed Nov. 1, 2014.

Heinrichs, A. J. and G.L. Hargrove. 1987. Standards of weight and height for Holstein heifers. J. Dairy Sci. 70:653-660.

Heinrichs, A. J., G.W. Rogers, and J.B. Cooper. 1992. Predicting body weight and wither height in Holstein heifers using body measurements. J. Dairy Sci. 75:3576-3581.

Heinrichs, A.J. and W.C. Losinger. 1998. Growth of Holstein Dairy Heifers in the United States. J. Anim. Sci. 76:1254-1260.

Higginson, J.H., S.T. Millman, K.E. Leslie, and D.F. Kelton. 2010. Validation of a new pedometry system for use in behavioural research and lameness detection in dairy cattle. The First North American Conference on Precision Dairy Management, Toronto, ON, Canada. Progressive Dairy Operators, Elora, ON, Canada.

Holland, J. L., D. S. Kronfeld, T. N. Meacham. 1996. Behavior of horses is affected by soy lecithin and corn oil diet. J. Anim. Sci. 74:1252-1255.

Hurnik, J. F., G. J. King, and H. A. Robertson. 1975. Estrous and related behavior in postpartum Holstein cows. Appl. Anim. Ethol. 2:55-68.

Keeling, L. J. and H. W. Gonyou. 2001. Social Behaviour in Farm Animals. CABI Publishing, Oxforshire, UK. p. 120-135.

Koontz, S. R., D. L.Hoag, J. R. Brethour, and J. Walker. 2008. Production inefficiency in fed cattle marketing and the value of sorting pens into alternative marketing groups using ultrasound technology. J. Agri. Appl. Econ. 40:895-912.

Lewis, G.S. and S.K. Newman. 1984. Changes throughout estrous cycles of variables that might indicate estrus in dairy cows. J. Dairy Sci. 67:146-152.

Low, W. A., R. L. Tweedie, C. B.H. Edwards, R. M. Hodder, K. W. J. Malafant, and R. B. Cunningham. 1981. The influence of environment on daily maintenance behaviour of free-ranging shorthorn cows in central Australia. III. Detailed analysis of sequential behaviour patterns and integrated discussion. Appl. Anim. Etho. 7:39-56.

MacCurdy, E. (1938) The Notebooks of Leonardo Da Vinci. New York: Reynal & Hitchcock. p. 166.

Mazrier, H., S. Tal, E. Aizinbud, and U. Bargai. 2006. A field investigation of the use of the pedometer for the early detection of lameness in cattle. Can. Vet. J. 47:883-886.

Montgomery, J.L., C.R. Krehbiel, D.A. Cranston, D.A. Yates, J.P. Hutcheson, W.T. Nichols, M.N. Streeter, D.T. Bechtol, E. Johonson, T. TerHune, and T.H. Montgomery. 2009. Dietary zilpaterol hydrochloride. I. Feedlot performance and carcass traits of steers and heifers. J. Anim. Sci. 87:1374-1383.

Nielsen, L. R., A. R. Pedersen, M. S. Herskin, L. Munksgaard. 2010. Quantifying walking and standing behavior of dairy cows using a moving average based on output from an accelerometer. Appl. Anim. Behav. Sci. 127:12-19.

Peter, A.T. and W.T.K. Bosu. 1986. Postpartum ovarian activity in dairy cows: Correlation between behavioral estrus, pedometer measurements and ovulations. Therio. 26:111-115.

Powell, T. L. 1968. Pedometer measurement of the distance walked by grazing sheep in relation to weather. Grass. Forage. Sci. 23:98-102.

Pyatt, N. A., L. L. Berger, D. B. Faulkner, P. M. Walker, and S. L. Rodriguez-Zac. 2005. Factors affecting carcass value and profitability in early-weaned Simmental steers: II. Days on feed endpoints and sorting strategies. J. Anim. Sci. 86:2926-2937.

Ragsdale, A. C. 1934. Growth standards for dairy cattle. Univ. Missouri College of Agric. Exp. Stn. Publ. No. 336.

Rathmann, R. J., J. M. Mehaffey, T. J. Baxa, W. T. Nichols, D. A. Yates, J. P. Hutcheson, J. C. Brooks, B. J. Johnson, and M. F. Miller. 2009. Effects of duration of zilpaterol hydrochloride and days on the finishing diet on carcass cutability, composition, tenderness, and skeletal muscle gene expression in feedlot steers. J. Anim. Sci. 87:3686-3701.

Redbo, I., A. Ehrlemark, and P. Redbo-Torstensson. 2001. Behavioural responses to climate demands of dairy heifers housed outdoors. Can. J. Anim. Sci. 81:9-15.

Robles-Estrada, J. C., A. A. Arrizon, A. Barreras, J. F. Calderon, F. Figueroa-Saavedra, N. Torrentera, A. Plascencia and R. A. Zinn. 2009. Effects of preslaughter withdrawal period on response of feedlot heifers to zilpaterol. J. Anim. Sci. 87:1759-1763.

Roelofs, J.B., F.J.C.M. van Eerdenburg, N.M. Soede, and B. Kemp. 2005. Pedometer readings for estrous detection and as a predictor for time of ovulation in dairy cattle. Therio. 64:1690-1703.

Stanton, T. L. 1997. Cost of reworking cattle. Symposium: Impact of Implants on Performance and Carcass Value of Beef Cattle. Okla. Agri, Exp. Sta. Publ. P-957:95-99.

Taweel, H. Z., B. M. Tas, J. Dijkstra, and S. Tamminga. 2004. Intake regulation and grazing behavior of dairy cows under continuous stocking. J. Dairy. Sci. 87:3417-3427.

Trénel, P., M. B. Jensen, E. L. Decker, and F. Skjøth. 2009. *Technical note*: Quantifying and characterizing behavior in dairy calves using the IceTag automatic recording device. J. Dairy Sci. 92:3397-3401.

Tucker, C. B., A. R. Rogers, G. A. Verkerk, P. E. Kendall, J. R. Webster, and L. R. Matthews. 2007. Effects of shelter and body condition on the behavior and physiology of dairy cattle in winter. Appl. Anim. Behav. Sci. 105:1-13.

Trenkle, A. H. 2001. Effects of sorting steer calve on feedlot performance and carcass value. Iowa State Univ. Beef Research Report. A. S. Leaflet R1740.

Urton, G., M. A. G. von Keyserlingk, and D. M. Weary. 2005. Feeding behavior identifies dairy cows at risk for metritis. J. Dairy Sci. 88:2843-2849.

Walker, J.W., R.K. Heitschmidt, and S.L. Downhower. 1985. Evaluation of pedometers for measuring distance traveled by cattle on two grazing systems. J. Range. Manage. 38:90-93.

Walter, L. J., T. J. McEvers, N. D. May, J. A. Reed, J. P. Hutcheson, and T. E. Lawrence. 2013. The effect of zilpaterol supplementation and RFI on growth performance. J. Anim. Sci. 92 (Suppl. 2): 149. (Abstr.)

Warren, B.S, J.J. Wakshlag, M. Maley, T.J. Farrell, A.M. Struble, M.R. Panaseveich, and M.T. Wells. 2011. Use of pedometers to measure the relationship of dog walking to body condition score in obese and non-obese dogs. Brit. J. Nut. 106:S85-S89.

Warren-Smith, A. and P. McGreevy. 2010. The use of pedometers to estimate motor laterality in grazing horses. J.Vet. Behav. 5:177-179.

White, B.J., J.F. Coetzee, D.G. Renter, A.H. Babcock, D.U. Thomson, and D. Anderson. 2008. Evaluation of two-dimensional accelerometers to monitor behavior of beef calves after castration. Amer. J. Vet. Res. 69:1005-1012.

Zähner, M., L. Schrader, R. Hauser, M. Keck, W. Langhans, and B. Wechsler. 2004. The influence of climatic conditions on physiological and behavioural parameters in dairy cows kept in open stables. J. Anim. Sci. 78:139-147.

Figure 3.1 A calf-fed Holstein steer wearing pedometer on lower left rear limb.

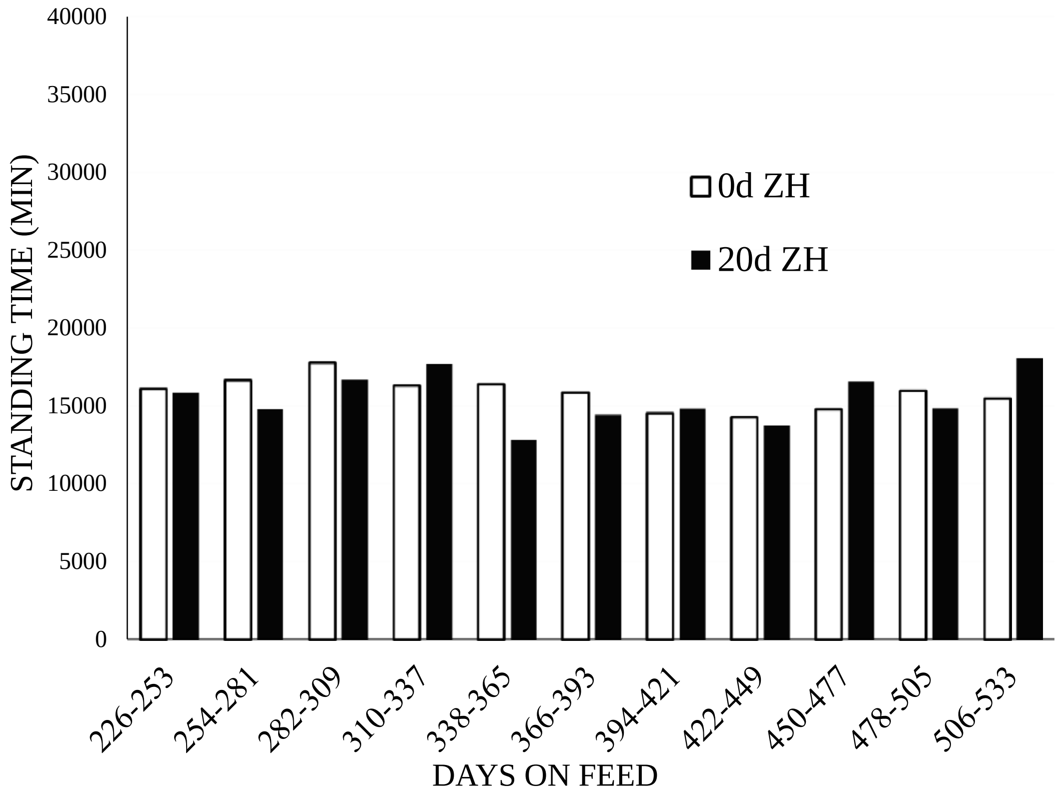

Figure 3.2. Total minutes of standing time during 28d treatment periods for calf-fed Holstein steers fed in confinement for 226-533 days on feed (DOF) and supplemented zilpaterol hydrochloride (ZH) for 0 or 20d. *P*-values: ZH = 0.45; DOF = 0.09; ZH x DOF = 0.26.

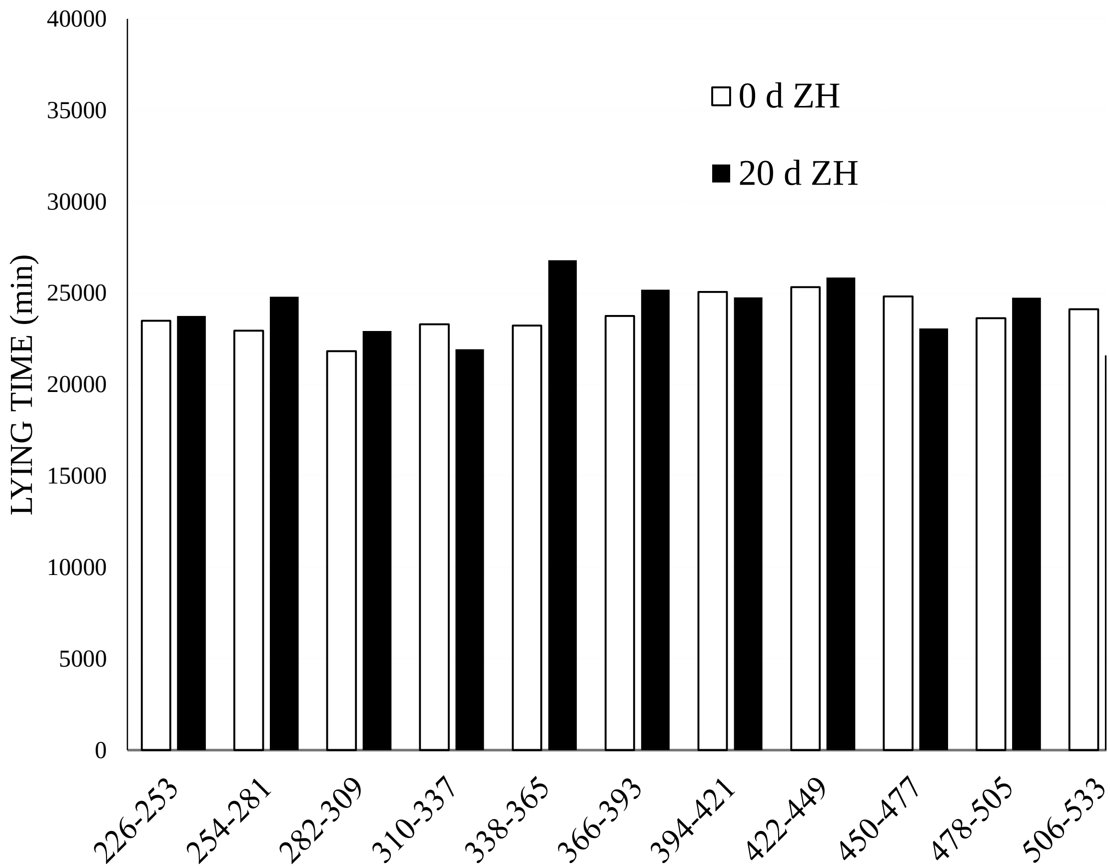

Figure 3.3. Total minutes of lying time during 28d treatment periods for calf-fed Holstein steers fed in confinement for 226-533 days on feed (DOF) and supplemented zilpaterol hydrochloride (ZH) for 0 or 20d. *P*-values: ZH = 0.45; DOF = 0.09; ZH x DOF = 0.26.

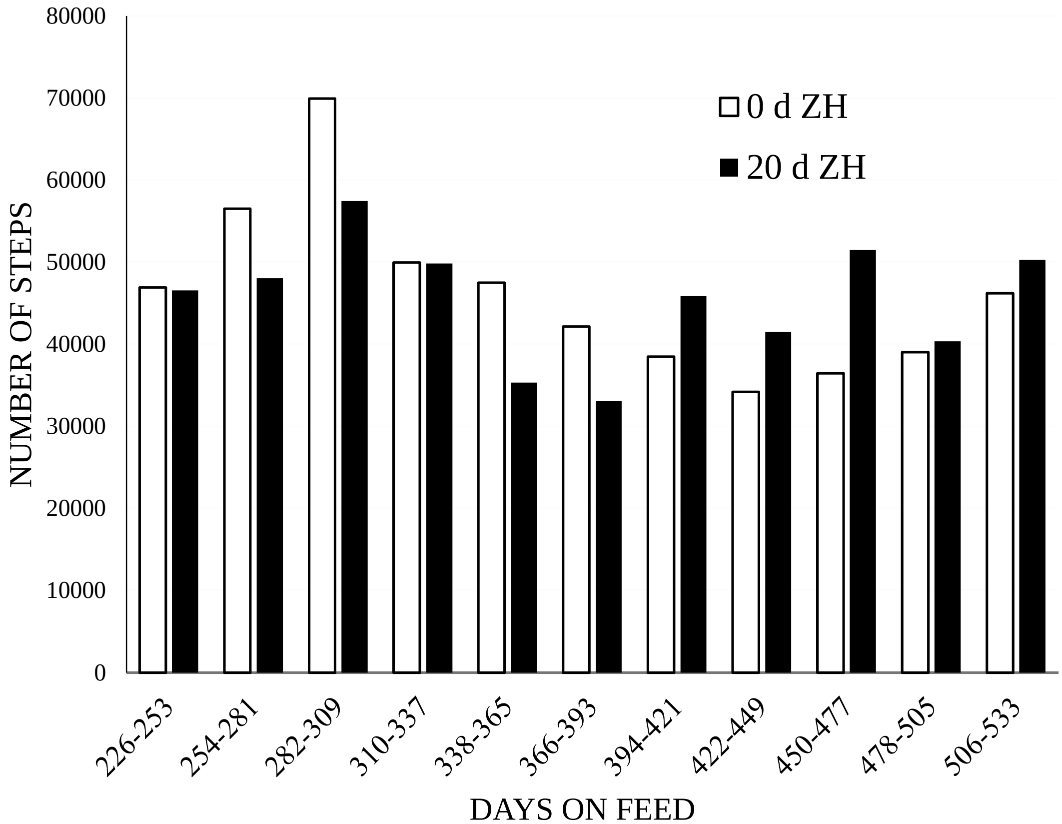

Figure 3.4. Total number of steps during 28d treatment periods for calf-fed Holstein steers fed in confinement for 226-533 days on feed (DOF) and supplemented zilpaterol hydrochloride (ZH) for 0 or 20d. *P*-values: ZH = 0.77; DOF < 0.01; ZH x DOF = 0.18.

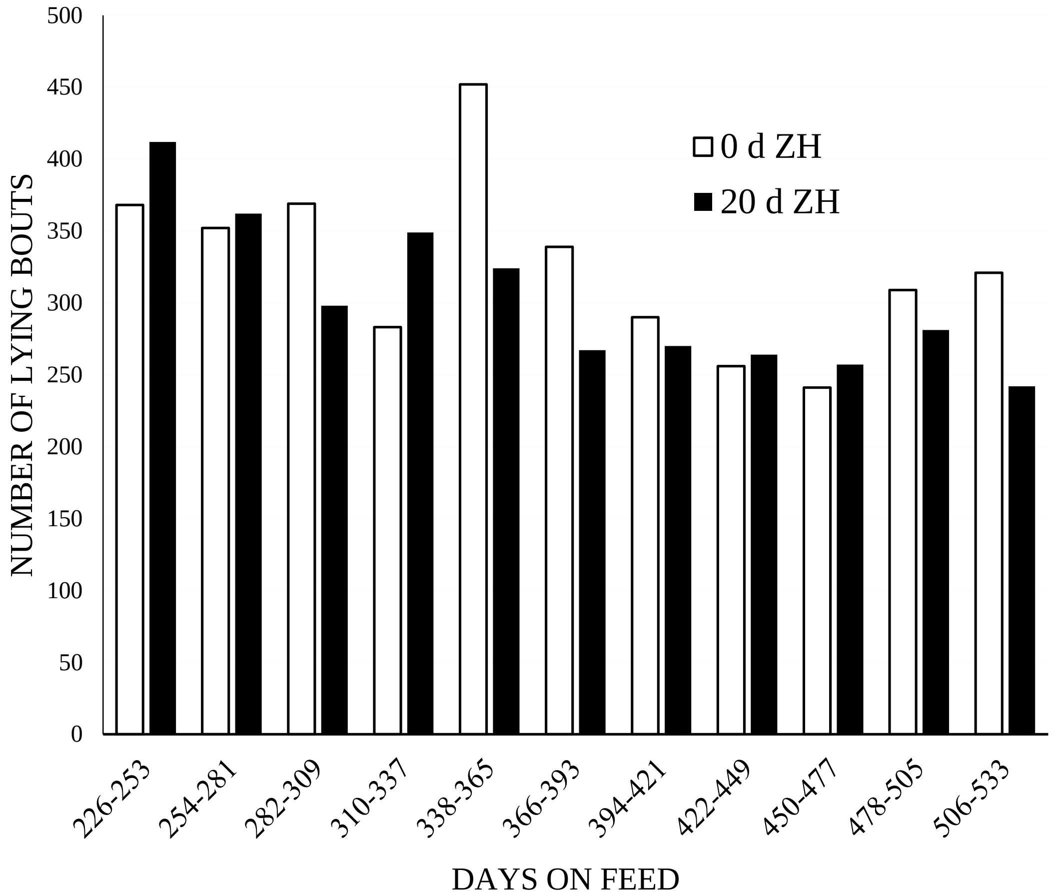

Figure 3.5. Total number of lying bouts during 28d treatment periods for calf-fed Holstein steers fed in confinement for 226-533 days on feed (DOF) and supplemented zilpaterol hydrochloride (ZH) for 0 or 20d. *P*-values: ZH = 0.09; DOF < 0.01; ZH x DOF = 0.06.

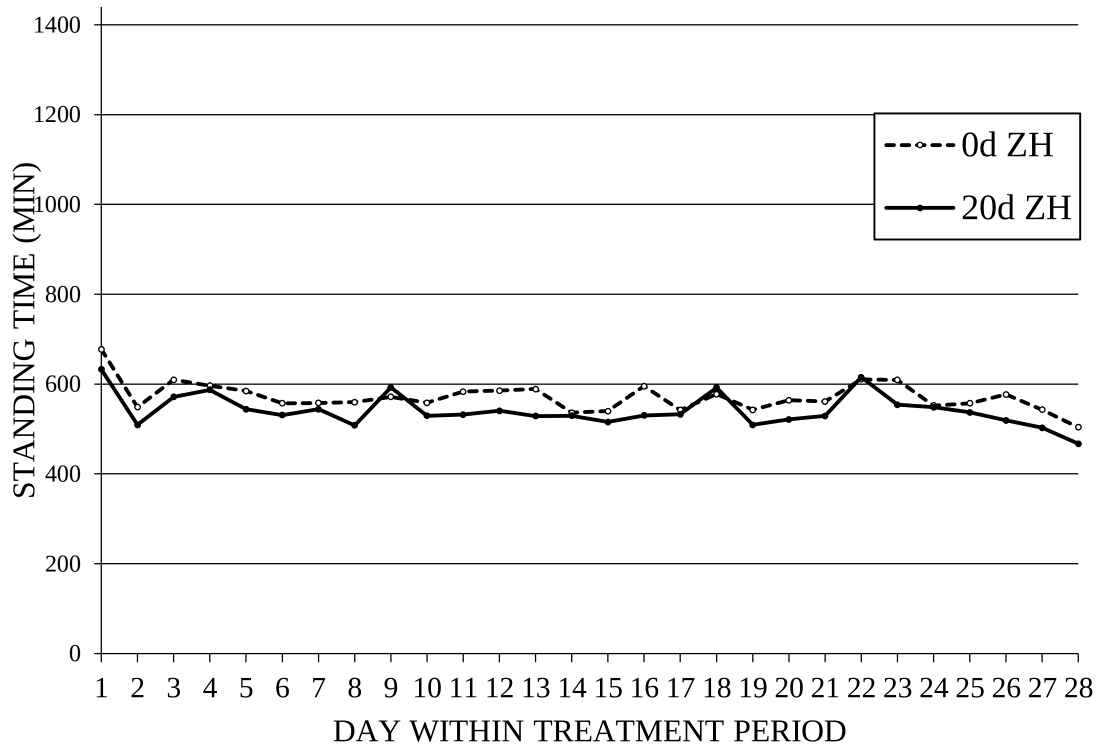

Figure 3.6. Average minutes of standing time during the 28d treatment period pooled across the 308d trial for calf-fed Holstein steers fed in confinement and supplemented zilpaterol hydrochloride (ZH) for 0 or 20d. Days 1 through 5 represented the pre-ZH period, days 6 through 25 represented the ZH feeding period, and days 26-28 represented the ZH withdrawal period. *P*-values: ZH = <0.01; Day = <0.01; ZH x DOF = 0.99.

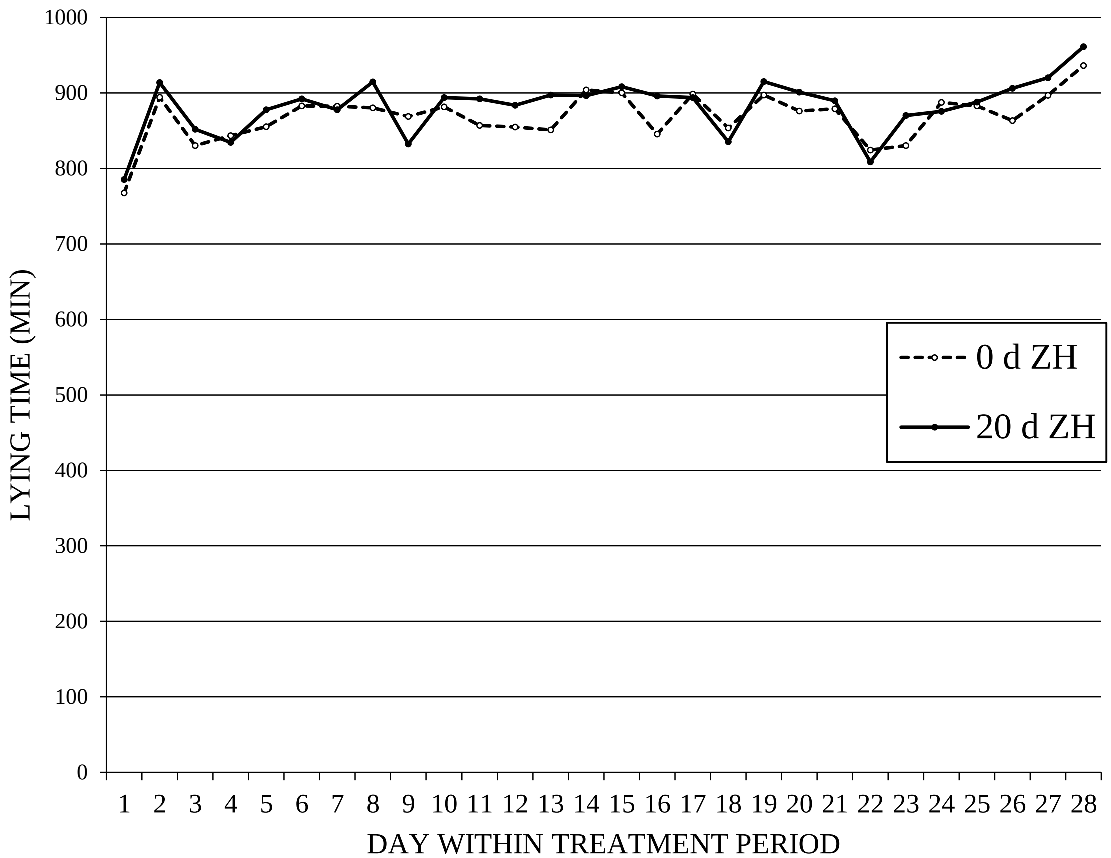

Figure 3.7. Average minutes of lying time during the 28d treatment period pooled across the 308d trial for calf-fed Holstein steers fed in confinement and supplemented zilpaterol hydrochloride (ZH) for 0 or 20d. Days 1 through 5 represented the pre-ZH period, days 6 through 25 represented the ZH feeding period, and days 26-28 represented the ZH withdrawal period. *P*-values: ZH = 0.02; Day = <0.01; ZH x DOF = 0.98.

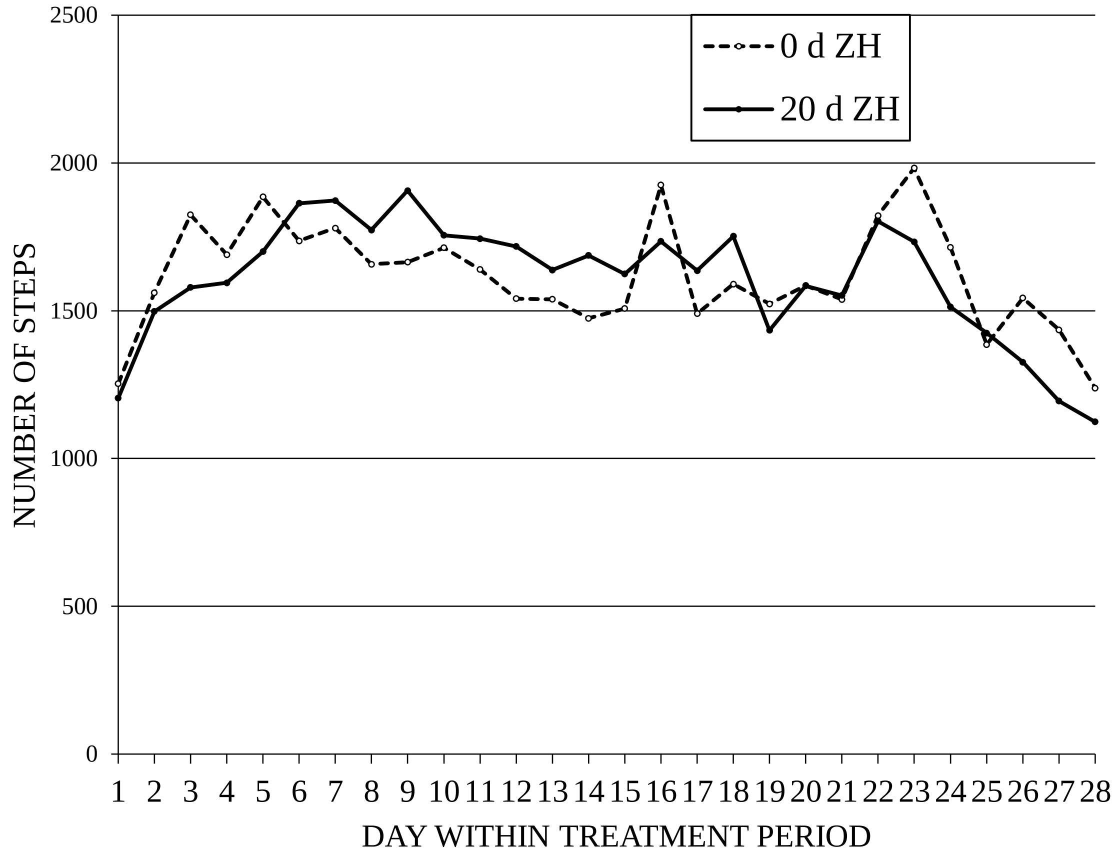

Figure 3.8. Average number of steps during the 28d treatment period pooled across the 308d trial for calf-fed Holstein steers fed in confinement and supplemented zilpaterol hydrochloride (ZH) for 0 or 20d. Days 1 through 5 represented the pre-ZH period, days 6 through 25 represented the ZH feeding period, and days 26-28 represented the ZH withdrawal period. *P*-values: ZH = 0.74; Day = <0.01; ZH x DOF = 0.44.

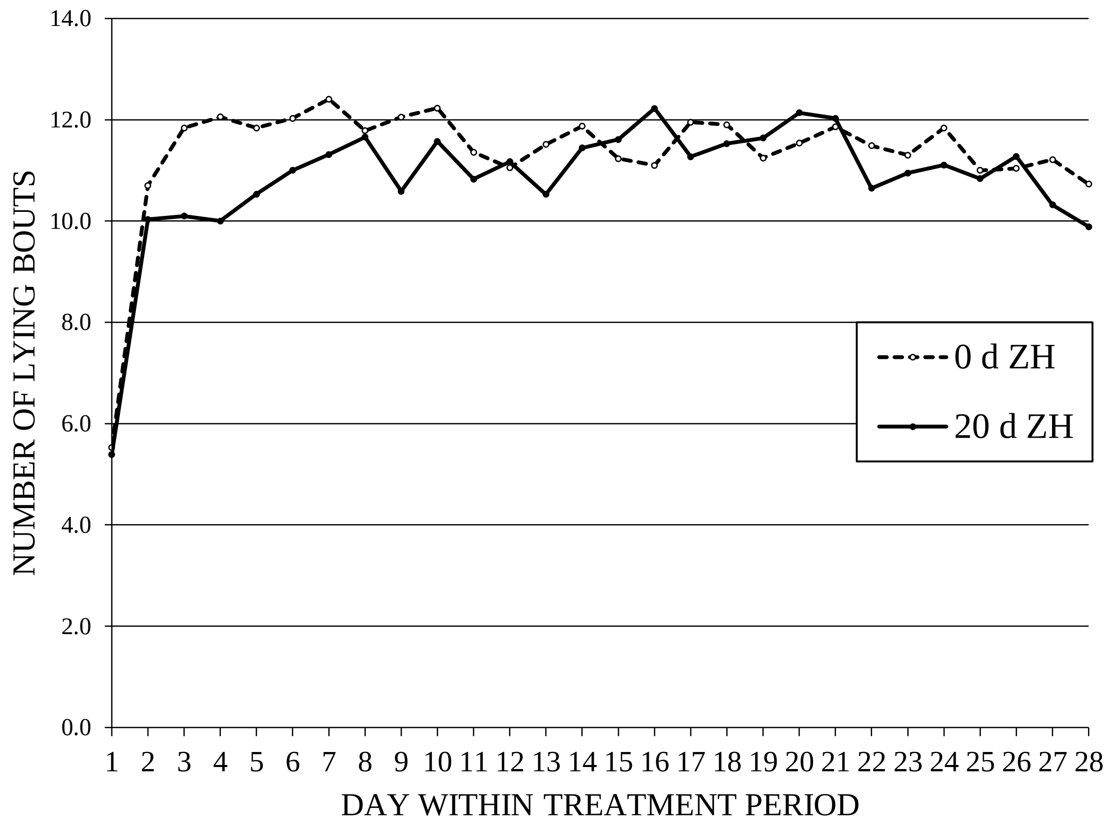

Figure 3.9. Average number of lying bouts during the 28d treatment period pooled across the 308d trial for calf-fed Holstein steers fed in confinement and supplemented zilpaterol hydrochloride (ZH) for 0 or 20d. Days 1 through 5 represented the pre-ZH period, days 6 through 25 represented the ZH feeding period, and days 26-28 represented the ZH withdrawal period. *P*-values: ZH < 0.01; Day = <0.01; ZH x DOF = 0.96.

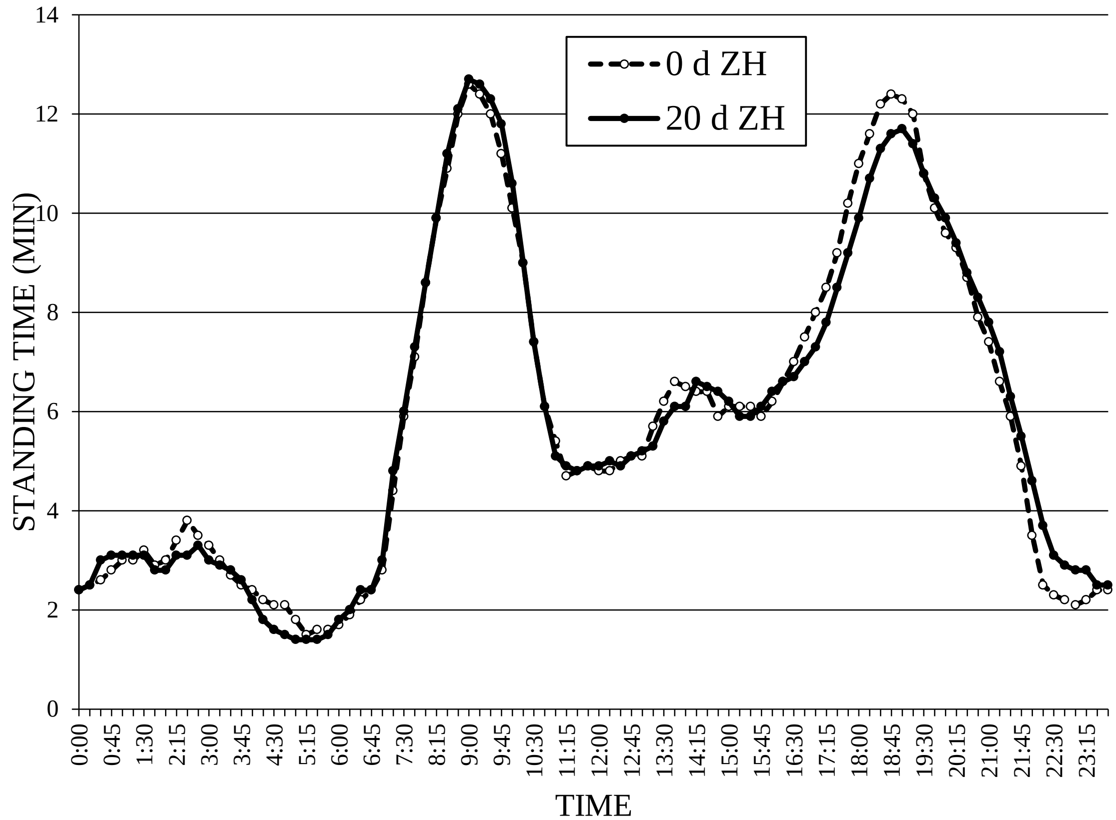

Figure 3.10. Average minutes of time standing during 15 minute intervals over a 24 h d pooled across the 308d trial for calf-fed Holstein steers fed in confinement and supplemented zilpaterol hydrochloride (ZH) for 0 or 20d. *P*-values: ZH = 0.87; Time = <0.01; ZH x Time = < 0.01.

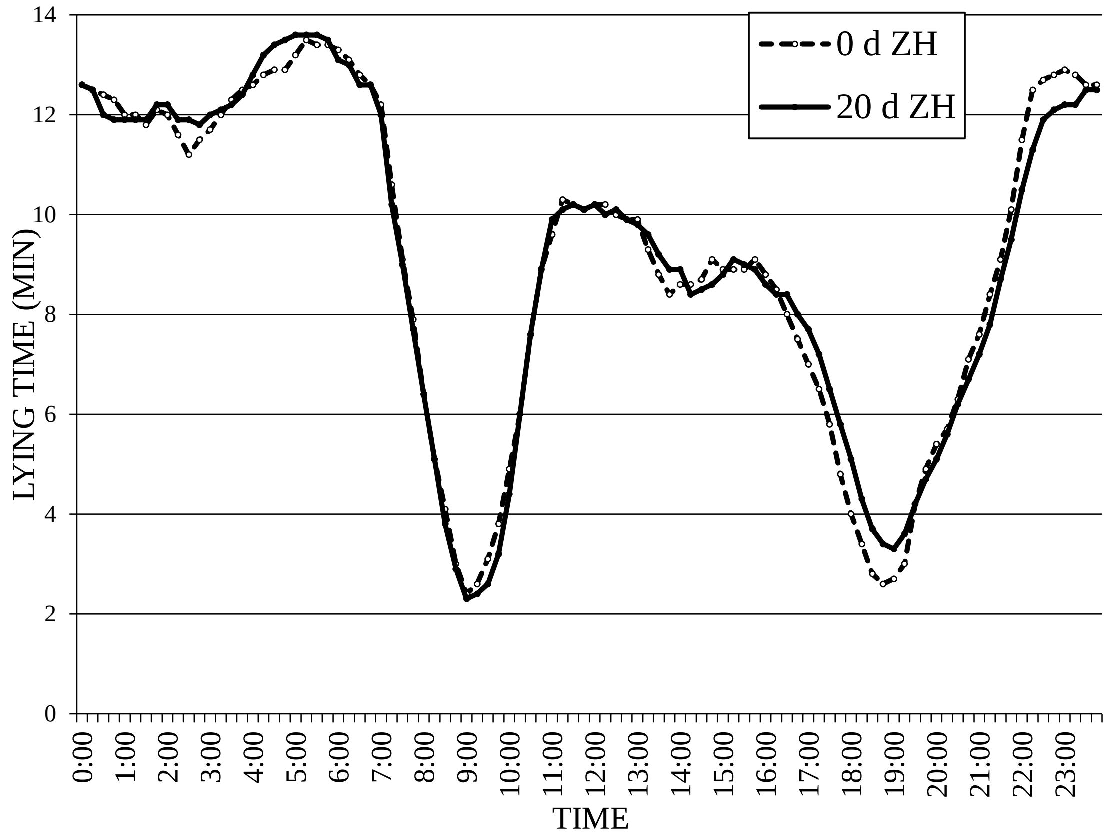

Figure 3.11. Average minutes of time lying during 15 minute intervals over a 24 h d pooled across the 308d trial for calf-fed Holstein steers fed in confinement and supplemented zilpaterol hydrochloride (ZH) for 0 or 20d. *P*-values: ZH = 0.88; Time = <0.01; ZH x Time = <0.01.

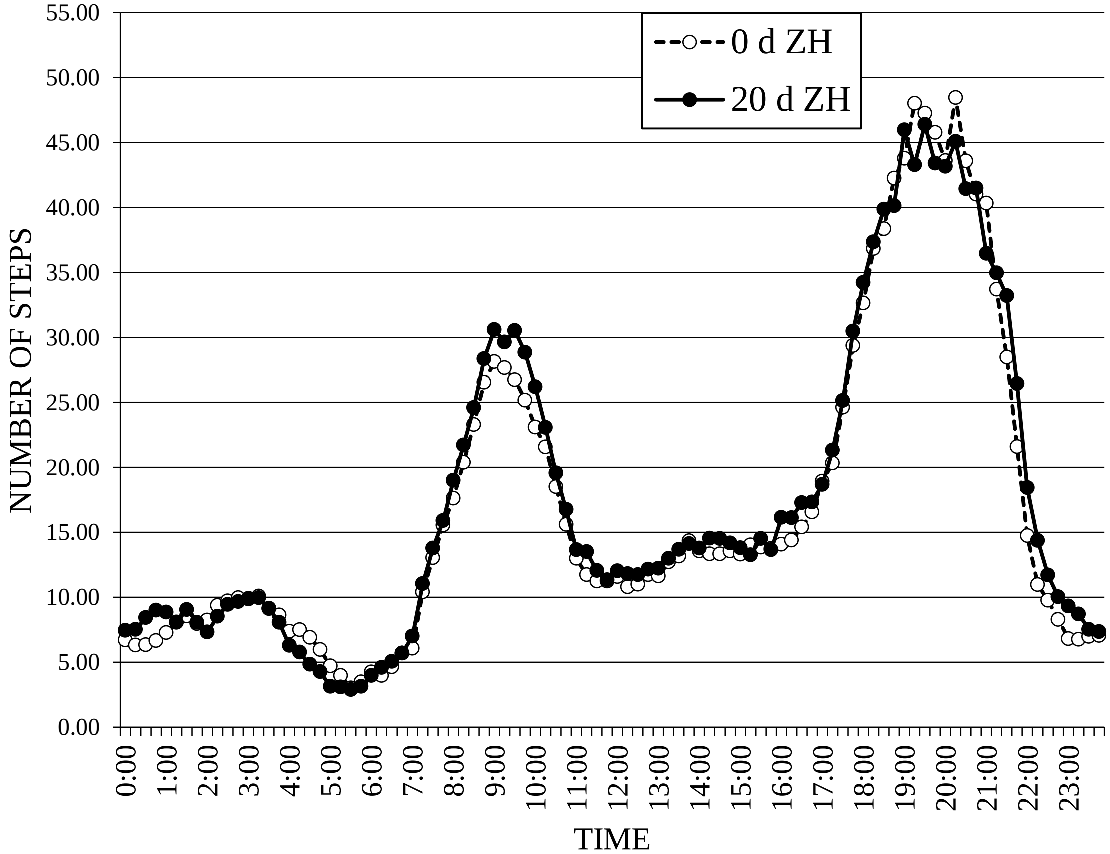

Figure 3.12. Average number of steps during the 15 minute treatment period over a 24 h d pooled across the 308d trial for calf-fed Holstein steers fed in confinement and supplemented zilpaterol hydrochloride (ZH) for 0 or 20d. *P*-values: ZH <0.01; Time = <0.01; ZH x Time = <0.01.

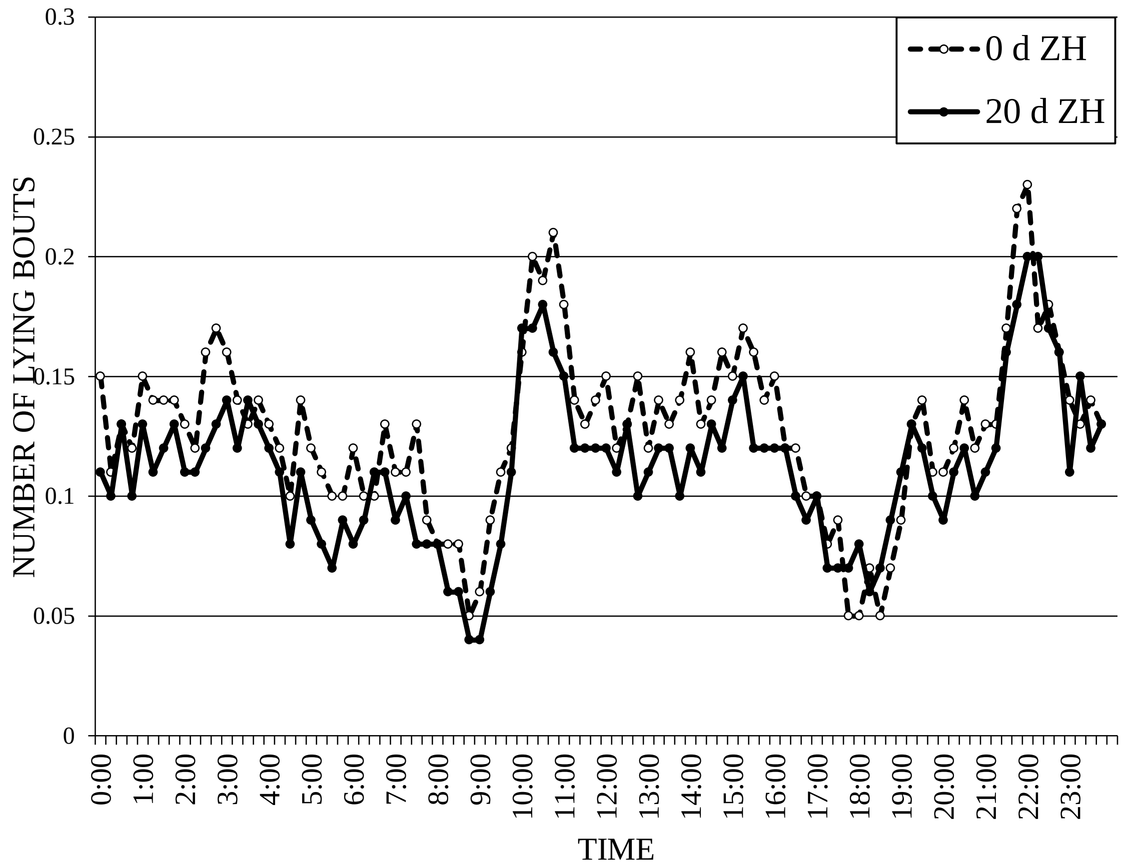

Figure 3.13. Average number of lying bouts during the 15 minute treatment period over a 24 h d pooled across the 308d trial for calf-fed Holstein steers fed in confinement and supplemented zilpaterol hydrochloride (ZH) for 0 or 20d. *P*-values: ZH = <0.01; Time = <0.01; ZH x Time = 0.07.

Table 3.1. Movement parameters for calf-fed Holstein steers fed in confinement from 226 to 533 days on feed (DOF) and fed zilpaterol hydrochloride (ZH) for 0 or 20d.

DOF	Standing time (min)	Lying time (min)	Steps	Lying bouts
226-253	15,977	23,623	46,740^{yz}	390^{y}
254-281	15,727	23,873	52,277^{yz}	357^{yz}
282-309	17,225	22,375	63,675^{y}	333^{yz}
310-337	16,990	22,610	49,886^{yz}	316^{yz}
338-365	14,598	25,002	41,423^{z}	388^{y}
366-393	15,133	24,467	37,611^{z}	303^{yz}
394-421	14,687	24,913	42,170^{z}	280^{z}
422-449	14,006	25,594	37,837^{z}	260^{z}
450-477	15,654	23,946	43,963^{z}	249^{z}
478-505	15,412	24,188	39,702^{z}	295^{yz}
506-533	16,750	22,850	48,245^{yz}	282^{z}
SEM	796	796	3807	22.0
P-value	0.0882	0.0882	0.0002	<0.0001
ZH treatment				
0d	15,831	23,769	46,118	326
20d	15,470	24,130	46,914	302
SEM	340	340	1626	9.4
P-value	0.4547	0.4547	0.7666	0.0850
DOF x ZH *P*-value	0.2556	0.2556	0.1799	0.0622

^{yz} Within a movement parameter, means without a common superscript letter differ ($P < 0.05$).

Table 3.2. Movement parameters by day within each 28d period for calf-fed Holstein steers fed in confinement from 226 to 533 days on feed (DOF) and fed zilpaterol hydrochloride (ZH) for 0 or 20d.

Day of period	Standing time (min)	Lying time (min)	Steps	Lying bouts
1	655^{w}	776^{z}	1229^{yz}	5.5^{z}
2	529^{xyz}	904^{wx}	1529^{uvwxyz}	10.4^{y}
3	591^{wxy}	841^{xyz}	1702^{uvwx}	11.0^{y}
4	592^{wxy}	839^{xyz}	1642^{uvwxy}	11.0^{y}
5	564^{wxyz}	867^{xy}	1792^{uvw}	11.2^{y}
6	544^{xyz}	887^{wxy}	1800^{uvw}	11.5^{y}
7	551^{xyz}	880^{wxy}	1826^{uv}	11.9^{y}
8	534^{xyz}	897^{wxy}	1715^{uvwx}	11.7^{y}
9	582^{wxy}	851^{xyz}	1786^{uvw}	11.3^{y}
10	544^{xyz}	888^{wxy}	1734^{uvw}	11.9^{y}
11	558^{xyz}	875^{wxy}	1692^{uvwx}	11.1^{y}
12	563^{wxyz}	869^{xy}	1629^{uvwxy}	11.1^{y}
13	559^{xyz}	874^{xy}	1588^{uvwxy}	11.0^{y}
14	533^{xyz}	900^{wx}	1581^{uvwxy}	11.7^{y}
15	528^{xyz}	904^{wx}	1566^{uvwxyz}	11.4^{y}
16	563^{wxyz}	871^{xy}	1830^{uv}	11.7^{y}
17	537^{xyz}	896^{wxy}	1563^{uvwxyz}	11.6^{y}
18	585^{wxy}	845^{xyz}	1671^{uvwx}	11.7^{y}
19	526^{xyz}	906^{wx}	1478^{vwxyz}	11.4^{y}
20	543^{xyz}	888^{wxy}	1585^{uvwxy}	11.8^{y}
21	545^{xyz}	884^{wxy}	1545^{uvwxyz}	11.9^{y}
22	613^{wx}	817^{yz}	1812^{uv}	11.1^{y}
23	582^{wxy}	850^{xyz}	1858^{u}	11.1^{y}
24	550^{xyz}	882^{wxy}	1614^{uvwxy}	11.5^{y}
25	547^{xyz}	885^{wxy}	1405^{wxyz}	10.9^{y}
26	548^{xyz}	885^{wxy}	1434^{vwxyz}	11.2^{y}
27	523^{yz}	909^{wx}	1315^{xyz}	10.8^{y}
28	485^{z}	949^{w}	1181^{z}	10.3^{y}

Table 3.2. Continued

SEM	16.8	15.2	76.6	0.47
P-value	<0.0001	<0.0001	<0.0001	<0.0001
ZH treatment				
0d	571	869	1616	11.3
20d	541	883	1606	10.8
SEM	4.5	4.1	20.5	0.13
P-value	<0.0001	0.02	0.7399	0.0052
Day of period x ZH *P*-value	0.9931	0.9843	0.4358	0.9647

[uvwxyz] Within a movement parameter, means without a common superscript letter differ ($P < 0.05$).

Table 3.3. Movement parameters during the daily 24 h period for calf-fed Holstein steers fed in confinement from 226 to 533 days on feed and fed zilpaterol hydrochloride for 0 or 20d.

	Days fed zilpaterol hydrochloride							
	0	20	0	20	0	20	0	20
Time	Standing time (min)		Lying time (min)		Steps		Lying bouts	
0000	2.4	2.4	12.6	12.6	5.9	6.9	0.15	0.11
0015	2.5	2.5	12.5	12.5	5.7	7.0	0.11	0.10
0030	2.6	3.0	12.4	12.0	5.9	8.3	0.13	0.13
0045	2.8	3.1	12.3	11.9	6.5	8.9	0.12	0.10
0100	3.0	3.1	12.0	11.9	7.6	8.7	0.15	0.13
0115	3.0	3.1	12.0	11.9	7.4	8.0	0.14	0.11
0130	3.2	3.1	11.8	11.9	7.9	9.2	0.14	0.12
0145	2.9	2.8	12.1	12.2	7.2	8.2	0.14	0.13
0200	3.0	2.8	12.0	12.2	7.4	7.4	0.13	0.11
0215	3.4	3.1	11.6	11.9	9.0	8.7	0.12	0.11
0230	3.8	3.1	11.2	11.9	9.4	9.4	0.16	0.12
0245	3.5	3.3	11.5	11.8	9.4	9.5	0.17	0.13
0300	3.3	3.0	11.7	12.0	9.1	9.7	0.16	0.14
0315	3.0	2.9	12.0	12.1	9.4	9.7	0.14	0.12
0330	2.7	2.8	12.3	12.2	8.4	9.3	0.13	0.14
0345	2.5	2.6	12.5	12.4	7.9	8.4	0.14	0.13
0400	2.4	2.2	12.6	12.8	6.9	6.2	0.13	0.12
0415	2.2	1.8	12.8	13.2	6.8	5.5	0.12	0.11
0430	2.1	1.6	12.9	13.4	6.2	4.4	0.1	0.08
0445	2.1	1.5	12.9	13.5	5.4	3.9	0.14	0.11
0500	1.8	1.4	13.2	13.6	4.7	3.1	0.12	0.09
0515	1.5	1.4	13.5	13.6	4.1	3.0	0.11	0.08
0530	1.6	1.4	13.4	13.6	2.9	3.1	0.10	0.07
0545	1.6	1.5	13.4	13.5	3.1	3.4	0.10	0.09
0600	1.7	1.8	13.3	13.1	3.7	4.3	0.12	0.08
0615	1.9	2.0	13.1	13.0	3.7	5.0	0.10	0.09
0630	2.2	2.4	12.8	12.6	4.0	5.4	0.10	0.11
0645	2.4	2.4	12.6	12.6	5.3	6.1	0.13	0.11
0700	2.8	3.0	12.2	12.0	5.2	7.0	0.11	0.09
0715	4.4	4.8	10.6	10.2	9.3	11.1	0.11	0.10
0730	5.9	6.0	9.1	9.0	12.1	13.8	0.13	0.08
0745	7.1	7.3	7.9	7.7	14.6	16.2	0.09	0.08

Table. 3.3. Continued.

	Days fed zilpaterol hydrochloride							
	0	20	0	20	0	20	0	20
Time	Standing time (min)		Lying time (min)		Steps		Lying bouts	
0800	8.6	8.6	6.4	6.4	17.2	19.9	0.08	0.08
0815	9.9	9.9	5.1	5.1	20.3	22.8	0.08	0.06
0830	10.9	11.2	4.1	3.8	23.1	25.8	0.08	0.06
0845	12	12.1	3.0	2.9	25.7	29.6	0.05	0.04
0900	12.6	12.7	2.4	2.3	27.2	31.1	0.06	0.04
0915	12.4	12.6	2.6	2.4	26.6	30.0	0.09	0.06
0930	12	12.3	3.1	2.6	26.2	31.0	0.11	0.08
0945	11.2	11.8	3.8	3.2	24.9	29.1	0.12	0.11
1000	10.1	10.6	4.9	4.4	22.3	26.3	0.16	0.17
1015	9.0	9.0	6.0	6.0	20.5	23.1	0.20	0.17
1030	7.4	7.4	7.6	7.6	17.2	19.0	0.19	0.18
1045	6.1	6.1	8.9	8.9	14.0	15.7	0.21	0.16
1100	5.4	5.1	9.6	9.9	12.1	12.8	0.18	0.15
1115	4.7	4.9	10.3	10.1	11.1	13.0	0.14	0.12
1130	4.8	4.8	10.2	10.2	10.6	11.7	0.13	0.12
1145	4.9	4.9	10.1	10.1	10.8	11.4	0.14	0.12
1200	4.8	4.9	10.2	10.2	10.5	12.2	0.15	0.12
1215	4.8	5.0	10.2	10.0	9.5	11.6	0.12	0.11
1230	5.0	4.9	10.0	10.1	10.1	11.5	0.13	0.13
1245	5.1	5.1	9.9	9.9	11.3	12.0	0.15	0.10
1300	5.1	5.2	9.9	9.8	11.1	11.7	0.12	0.11
1315	5.7	5.3	9.3	9.6	12.3	12.2	0.14	0.12
1330	6.2	5.8	8.8	9.2	12.8	13.8	0.13	0.12
1345	6.6	6.1	8.4	8.9	14.2	13.9	0.14	0.10
1400	6.5	6.1	8.6	8.9	13.7	13.7	0.16	0.12
1415	6.4	6.6	8.6	8.4	13.4	14.9	0.13	0.11
1430	6.4	6.5	8.7	8.5	13.5	14.6	0.14	0.13
1445	5.9	6.4	9.1	8.6	13.4	14.4	0.16	0.12
1500	6.1	6.2	8.9	8.8	13.3	14.3	0.15	0.14
1515	6.1	5.9	8.9	9.1	14.3	14.7	0.17	0.15
1530	6.1	5.9	8.9	9.0	13.2	14.5	0.16	0.12
1545	5.9	6.1	9.1	8.9	13.2	13.7	0.14	0.12
1600	6.2	6.4	8.8	8.6	14.3	15.5	0.15	0.12
1615	6.6	6.6	8.5	8.4	14.4	15.2	0.12	0.12
1630	7.0	6.7	8.0	8.4	15.3	16.3	0.12	0.10
1645	7.5	7.0	7.5	8.0	16.6	16.6	0.10	0.09

Table. 3.3. Continued.

	Days fed zilpaterol hydrochloride							
	0	20	0	20	0	20	0	20
Time	Standing time (min)		Lying time (min)		Steps		Lying bouts	
1700	8.0	7.3	7.0	7.7	18.7	17.8	0.10	0.10
1715	8.5	7.8	6.5	7.2	20.2	20.7	0.08	0.07
1730	9.2	8.5	5.8	6.5	24.7	24.2	0.09	0.07
1745	10.2	9.2	4.8	5.8	30.0	29.4	0.05	0.07
1800	11.0	9.9	4.0	5.1	33.4	33.3	0.05	0.08
1815	11.6	10.7	3.4	4.3	36.7	36.7	0.07	0.06
1830	12.2	11.3	2.8	3.7	39.0	40.4	0.05	0.07
1845	12.4	11.6	2.6	3.4	42.2	41.1	0.07	0.09
1900	12.3	11.7	2.7	3.3	43.4	46.7	0.09	0.11
1915	12.0	11.4	3.0	3.6	48.0	44.3	0.13	0.13
1930	10.8	10.8	4.2	4.2	47.3	47.6	0.14	0.12
1945	10.1	10.3	4.9	4.7	47.3	44.8	0.11	0.10
2000	9.6	9.9	5.4	5.1	43.9	44.5	0.11	0.09
2015	9.3	9.4	5.7	5.6	49.3	47.3	0.12	0.11
2030	8.7	8.8	6.3	6.2	45.7	45.2	0.14	0.12
2045	7.9	8.3	7.1	6.7	43.6	44.3	0.12	0.10
2100	7.4	7.8	7.6	7.2	40.3	37.4	0.13	0.11
2115	6.6	7.2	8.4	7.8	32.5	34.9	0.13	0.12
2130	5.9	6.3	9.1	8.7	26.1	33.2	0.17	0.16
2145	4.9	5.5	10.1	9.5	18.7	25.1	0.22	0.18
2200	3.5	4.6	11.5	10.5	11.4	17.5	0.23	0.20
2215	2.5	3.7	12.5	11.3	7.8	12.8	0.17	0.20
2230	2.3	3.1	12.7	11.9	6.6	9.6	0.18	0.17
2245	2.2	2.9	12.8	12.1	6.2	9.2	0.16	0.16
2300	2.1	2.8	12.9	12.2	5.3	8.4	0.14	0.11
2315	2.2	2.8	12.8	12.2	5.6	8.3	0.13	0.15
2330	2.4	2.5	12.6	12.5	5.8	7.0	0.14	0.12
2345	2.4	2.5	12.6	12.5	6.0	6.7	0.13	0.13

Table. 3.3. Continued.

SEM	0.19	0.19	0.9	0.002
ZH *P*-value	0.8709	0.8762	0.0004	<0.0001
Time *P*-value	<0.0001	<0.0001	<0.0001	<0.0001
Time x ZH *P*-value	<0.0001	<0.0001	<0.0001	0.07

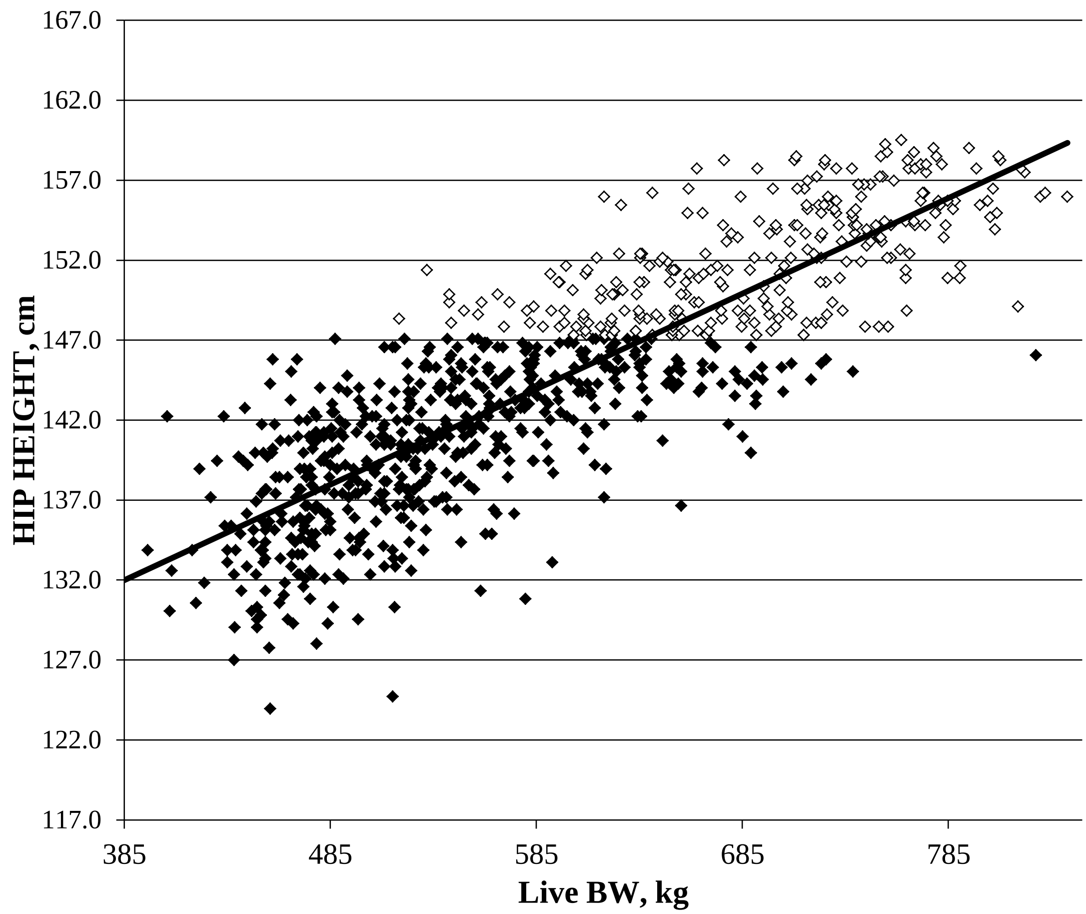

Figure 4.1. Relationship of live BW to hip height for calf-fed Holstein steers. The hollow diamonds outlined in black represented steers that exceed the hip height threshold of 147.32 cm (58 inches).

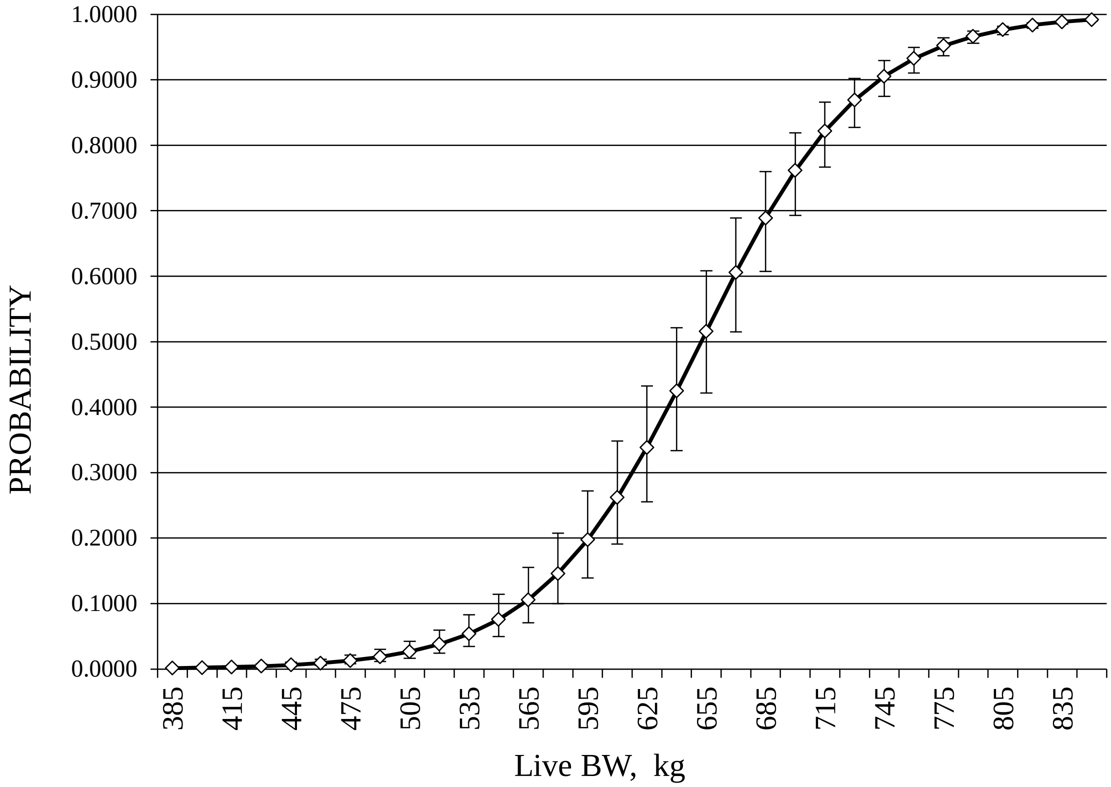

Figure 4.2. Probability ± 95% CI of a calf-fed Holstein steer with a hip height of 147.32 cm (58 inches) or greater as a function of live weight.

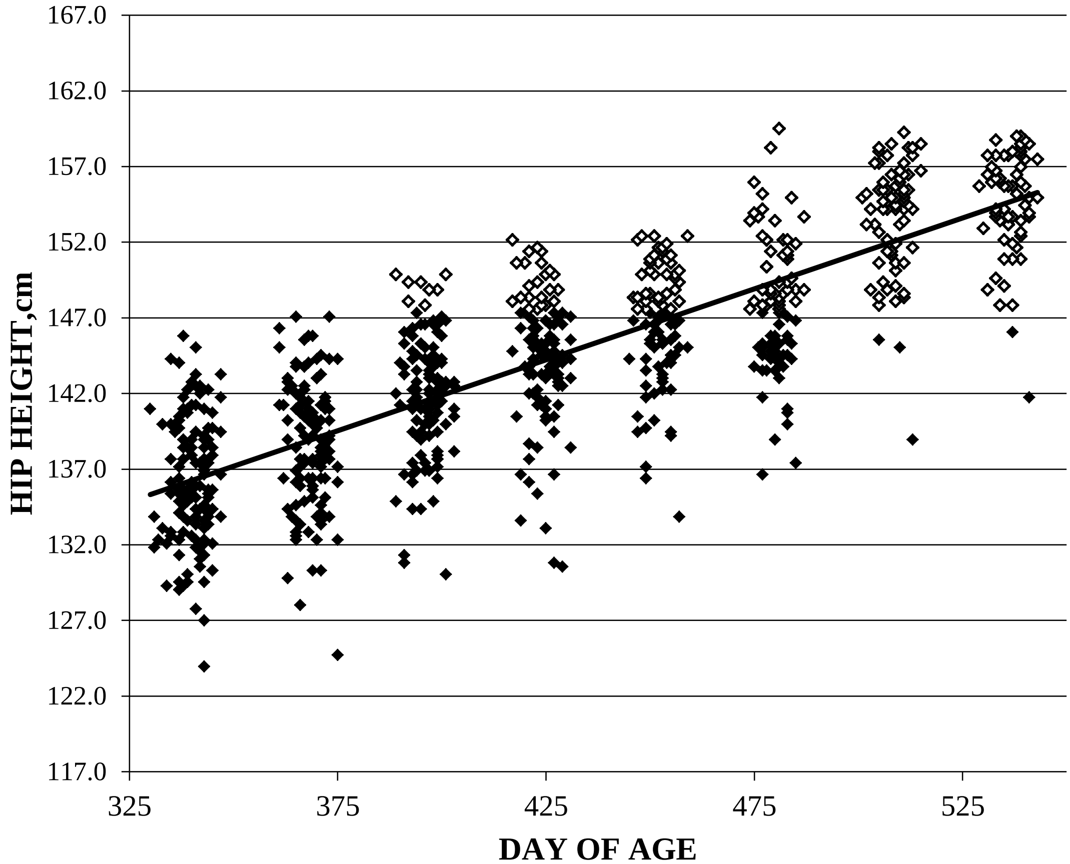

Figure 4.3. Linear relationship of days of age to hip height. The hollow diamonds outlined in black represented steers that exceed the hip height threshold of 147.32 cm (58 inches).

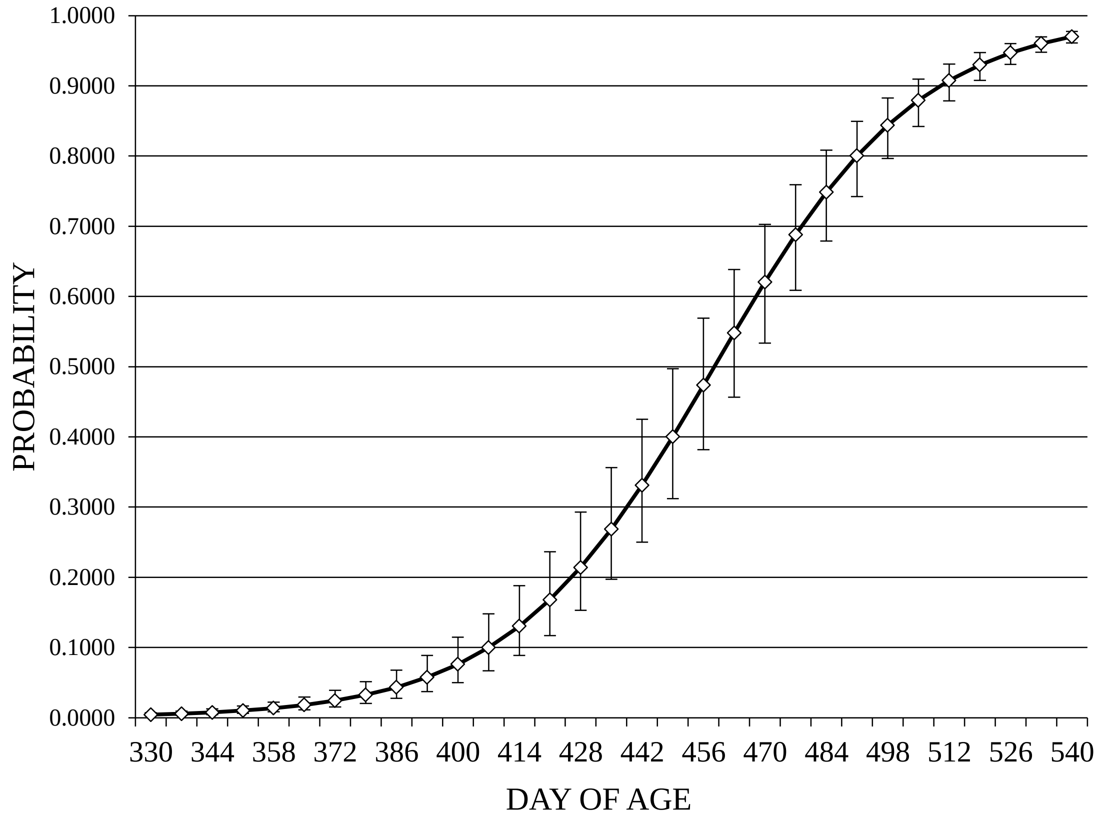

Figure 4.4. Probability ± 95% CI of calf-fed Holstein steers with a hip height of 147.32 cm (58 inches) or greater as a function of day of age.