December 9, 1960

To the Graduate Council:

I am submitting herewith a thesis written by Chekkera.N. Ganapathy entitled "Evaluation of Factors Affecting Heart Rates of Dairy Cows." I recommend that it be accepted for nine quarter hours of credit in partial fulfillment of the requirements for the degree of Master of Science, with a major in Dairying.

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EVALUATION OF FACTORS AFFECTING HEART RATES OF DAIRY COWS

A Thesis

Presented to

The Graduate Council of

The University of Tennessee

In Partial Fulfillment

of the Requirements for the Degree

Master of Science

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by

Chekkera.N. Ganapathy

December 1960

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CHAPTER I

INTRODUCTION

A dairy cow can produce her maximum only when her physiological and environmental conditions are optimum. To determine the normal physiological condition of a cow or any other animal, it is necessary to study the heart rate, respiration rate and body temperature. The rate, rhythm and amplitude of the heart beat give an index of normal health, and by constant study it is possible to recognize the normal and abnormal heart responses.

The normal physiological processes such as gestation, lactation and aging, and environmental factors such as temperature, humidity and the level of feeding may produce changes in heart rates. Variations in heart rates may also be due to size, age and factors like excitement, exercise, fever and cardiac diseases. All studies of physiological processes form steps in the process of applying fundamental knowledge to practical problems in breeding and management. The physiological responses of different pure breeds of cattle and of cross breeds of cattle to variations in temperature, humidity and solar radiation may aid in determining the degree of adaptability of these animals to different climates.

This study was made primarily to determine the importance of several factors which might affect heart rate of Jersey and Holstein dairy cattle in the University of Tennessee dairy herd. It was

conducted during the summer and early fall months with cattle representing different age groups, different stages of lactation and gestation, and different levels of nutrition. A secondary objective was to develop some heart rate standards for use in future studies in which heart rates may be important criteria of experimental effects.

CHAPTER II

REVIEW OF LITERATURE

General physiological studies on heart rates. Fuller (17) observed that heart rates of dairy cows ranged from 38 to 96 beats per minute. These variations applied to the heart rates of a group of healthy dairy cows. It was observed that the initial heart rate was high compared to the subsequent readings. The first half minute was 72 beats per minute and the subsequent reading gave an average of 67 beats per minute, indicating excitement of the cow during the first half minute. He noticed a drop of 5 to 7 beats per minute when the animal was lying down. Rumination caused a small accelerating effect on heart rate, amounting to approximately 2 beats per minute. He also noted a continuous decline in the heart rate during the night of 1 beat per minute per hour, which resulted in the minimum heart rate occurring in the early hours of the morning.

Kibler and Brody (28) observed that pulse rate curves were similar to heat production curves in dairy cows under different environments. Factors such as endocrine stimulation, muscular activity, tension of muscles, exercise, shivering, feed, and productive processes such as gestation and lactation contributed to the changes in pulse rate.

The electrocardiographic studies of Alfredson and Sykes (1) on dairy cows showed that the mean heart rate for dairy cattle was

71.6 beats per minute and the standard error of the mean was 1.22 beats per minute. The average rate was 82.5 per minute up to 18 months of age and 67.8 for animals above this age. Blaxter (8) observed that cows showed an increase of 5 to 7 beats per minute while standing instead of lying. There was a slight increase while ruminating, and eating caused a definite increase in the heart rate.

Ashiya and Hiroba (2) investigated the changes of pulse rate under a series of sensory and emotional stimuli and found positive reactions under psychic tension conditions in man. While males showed a tendency toward slowing, the females showed a tendency toward hastening. Calculation caused a fast pulse but photic stimulation produced a slow pulse.

Hamilton and Remington (22) stated that rate of the heart was kept reflexly adjusted to the rate of venous flow into the right auricle. The chemoreceptors caused reflex regulation of circulation. Carbon dioxide exhibited a stimulating effect upon the heart, increasing both the force and frequency of the beat.

Britton (10) found a reciprocal relationship between heart rate and carotid arterial pressure in experimental animals. Craig (12) noticed in man significantly high correlations between heart rate and work load. Bond (9) observed that sympathetic nerve stimulation in dogs increased the heart rate by several beats which were followed by a straight fall and then a gradual rise. A change in respiration would cause a faster pulse and also a change in the rhythm of the

heart beat. Herman and Arthur (24) found that heart rate increased progressively with altitude. It was higher during the first ten minutes at elevated altitude and there was a progressive fall later.

Gonsago and Rubic (19) found that pulse rates, respiration rates and body temperatures were higher in younger than in older pigs and in female than in male pigs. Sellers et al. (54) found that cases of postparturient paralysis of cows failing to respond to calcium therapy, not due to conditions such as ketosis, were found to have a fast weak pulse, low arterial pressure, auricular fibrillation, decreased renal and other changes. Goetz (18) observed that even slight changes in posture in man showed a marked effect on the plethysmograph, affecting both the height and pulse rate. Vanremoorteve (61) observed that a fall in heart rate accompanied deep expiration and noticed a rise during deep inspiration. Malamo and Shagass (37) observed that heart rate variability under stress appeared to decrease linearly with age, which might be explained in terms of diminished nervous system influences, both vagal and sympathetic, with increasing age.

Effect of temperature. Blaxter (5) studied frequency distributions of heart rates, respiratory rates, and body temperatures in cows both in mornings and evenings and found large variations. He found that differences in heart rates between mornings and evenings in winter and summer were but slightly affected by the season of the year. The heart rates in the afternoon were 6.22 beats higher than the morning rates in winter and 5.34 beats higher in summer. He reported that the

coefficients of variation for heart rates, respiration rates and body temperatures were 12.8, 21.5 and 0.42, respectively. Blaxter (6) also observed low respiration rates of 15 to 20 during the cold month of January compared to 40 and 50 during summer months. He noticed a significant effect of environmental temperature on the respiration rate. Higher temperature caused a slightly higher heart rate.

Mullick and Kehar (42) reported that Indian crossbred and Hariyana cows showed positive relations in heart rates with an increase in atmospheric temperature. Kleitman and Ramaswaroop (32) found parallelism in women between the mouth temperature and heart fluctuations. A rise of $1^{o}F$ in mouth temperature caused an increase of 10 to 20 beats per minute. There were deviations from this parallelism during the post-ovulatory phase in menstrual cycle as well as in pregnancy and lactation.

Regan and Richardson (46) observed in their experimental animals that heart rates declined with increasing environmental temperature. There was an increase in the rectal temperature when the environmental temperature was $70^{o}F$. It was thought that the large variation in respiration rate compared to heart rate was due to environmental temperature.

Regan and Richardson (46) studied the physiological reactions of high producing cows under controlled conditions of temperature, humidity and air movement. They observed that as the room temperature increased, there was a rise in respiration rate and a fall in the

pulse rate. There was a change in the amount of milk production, and in its physical and chemical characteristics. There was a decrease in milk flow and the percentage of solids-not-fat and protein. As the cow does not sweat, her dry skin in a hot environment may actually acquire a temperature above that of the body, in which case increasing the rate of circulation would tend to place an added burden upon the heat dissipative mechanism, while a slowing of the heart rate would be actually beneficial.

Landsteiner and Hayes (35) found that with an increase or decrease of temperature the heart rate of man also increased or decreased correspondingly. Knowton and Starling (33) in their pioneer work on the heart-lung preparation found a linear relationship between body temperature and heart rate. Rodbard and Tolpin (52) reported that body temperature was an important variable in determining heart rate and the high rate in birds was in part related to their high body temperature. They found an increase of 2 to 3 beats for a 10 degree rise in temperature and the rate of increase was found to be logarithmic in nature.

Kibler and Brody (29) observed the pulse rate of cattle, like heat production, decreased with rising chamber temperature; but an increase of temperature to abnormal levels of 106° to 108°F caused an increase of pulse rate. On lowering the chamber temperature to 40°F, the pulse rate, like heat production, was low at first but gradually increased to normal levels. The pulse rate curves of heifers differed

from those of cows. As the temperature increased from 40° to 100°F, the pulse rate decreased in all heifers, although heat production was constant. This fall in pulse rate was due to a decrease in pulse frequency with increasing age and body weight in growing animals. In lactating Jersey and Holstein cows, Kibler and Brody (30) found the limiting temperatures for minimal heart rate marked the boundaries of the zone of thermoneutrality. There was a slight increase in the pulse rates, from 60° to 70°F, but there was a rapid fall at chamber temperatures above 70°F. The rise of approximately 8 per cent in pulse rates below 40°F chamber temperature was associated with increased heat production and moderately increased feed consumption.

Brody and Worstell (31) reported that in Jerseys and Holsteins at 95°F the rectal temperatures rose from the original 101°F to 106°F and 108°F, respectively, and the respiration rate increased from 300 to 400 per cent in Holsteins and over 500 per cent in Jerseys. The pulse rate in Holsteins declined as chamber temperatures were increased from 80° to 95°F and rose thereafter. In Jerseys it declined at temperatures from 80° to 105°F. The heat production also declined with increasing temperature beginning at 80°F, and milk production and feed consumption began to decline at this temperature. With the increase of temperature, there was increased difficulty in heat elimination. The pulse rate rose as the rectal temperature reached 107° to 108°F.

Kibler and Brody (28) observed the influence of increasing temperature from 50°F to 105°F and of decreasing temperature from 50°F

down to 9°F on heat production and cardio and respiratory activities in Brahman, Jersey and Holstein cows. The critical temperature level of Indian evolved Brahman cows was observed to be between 90° to 95°F. The lower heat production of Brahman cows, associated perhaps with their lower milk production and feed consumption and possibly with an inherently lower metabolism, might be a factor in their greater heat tolerance.

Robinson et al. (50) observed the effect of environment on men in relation to their activity and clothing and found the heart rates under these conditions were significantly variable. Landsteiner and Hayes (35) observed that when the temperature of blood lay between 26°C and 40°C, the pulse rate varied from 63 to 165 and there was a linear relationship to the temperature. The heart rate decreased when the temperature of the blood exceeded 43°C. Gosselin (21) observed close relationship between heart rate and colonic temperature during cooling between 35°C and 23°C. There was a fall of 17.5 beats per minute for each lowering of 1°C.

Cooper (11) observed, when large areas of skin were warmed by radiation, the heart rate increased a few seconds before the onset of peripheral vasodilatation. Douglas and Phillips (15) observed that the temperature of the blood showed a direct effect on the heart itself which would be slowed down by cold and accelerated by heat. The cardiomotor centers in the hind brain which controlled the heart rate would be affected by this and the heat regulating centers would further enhance these effects.

Exercise. Hamilton et al. (22) observed the effects of muscular exercise which increased the output of the heart at each beat. The increased tension on the venous side, caused reflex acceleration of heart rhythm by inhibiting the vagus and by stimulating the accelerator nerves. There would be a corresponding change in the rhythm of the heart and this resulted in an increase of pulse rate. He also observed that the output of the heart was remarkably constant for each individual under conditions of complete physical and mental rest during basal metabolic periods. They observed a reduction in the cardiac output from the recumbent to the standing position, and found that muscular exercise caused the greatest increase in heart rate.

Wyndam et al. (63) in their experiment found that there was maximum oxygen intake and maximum heart rate during strenuous work. Craig (12) observed the heart rates of a submaximal exercising group of men were 130 per minute and those of a maximal exercising group were 198 beats per minute. Robinson and co-workers (51) observed that the heart rates of workers before acclimatization were 186 beats per minute and after acclimatization were 164 beats per minute. Erickson and co-workers (16) observed a close correlation between pulse rate and oxygen consumption during a constant state of training. Dawson (14) observed that the effect of practice and training increased the pulse rate in man due to exercise. Exercise during acute infection would cause a greater increase in pulse rate than in the normal subject. Knox (34) noticed that the common feature was a delayed acceleration commencing

about 12 seconds after the exercise started. Digitalis reduced but did not eliminate the very marked tachycardia following exercise. Malinow et al. (38) observed that simple exertion caused first an increase and later a decrease in systolic and diastolic pressure and noticed also an increase in the heart rate. Herxheimer (25) noticed tachycardia after severe exercise and tachycardia was found to persist longer, due to persisting peripheral vaso-dilatation. Knowlton and Starling (33) observed that cardiac increase during muscular exercise in the human is proportionate to degree of muscular contraction.

Feeding. Thomas and Moore (60) observed an increase of 11 heart beats per minute in cows fed 120 per cent of energy requirements over cows fed 100 per cent. Ritzman and Benedict (49) observed that there was an average fall of 8.5 beats per minute when extra feed was decreased to normal. When the ration of steers was changed from maintenance to submaintenance, there was an average decrease of 10 beats per minute during the first week. It was observed that there was a significant increase in heart rates when the TDN was increased and a definite fall when TDN was lowered. At least a 30 day observation was found to be necessary in order to evaluate properly the effect of additional TDN consumption on heart rate. The maximum effect on heart rate occurred after 25 to 50 days feeding of extra TDN.

Ritzman et al. (48) also observed that the body temperature of underfed goats was irregular and that the betterfed flock had a more

uniform temperature. The heart rate of goats varied from 68 to 88 beats per minute and the average was 81 beats.

Ralston and co-workers (44) reported that there was a seasonal variation in the heart rate of dairy cows. They thought that the seasonal effect would have its origin in increased TDN during the flush pasture seasons of April and October or due to increased incidence of calving effects during spring and fall. The variation in milk yield corresponded with the variation in heart rate. Blaxter and Price (7) were of the opinion that the heart rate was directly proportional to the total metabolism of the dairy cow. They found that a heavy meal was followed by a significant increase of heart rate and even a small meal was capable of producing a small increase. When eating was over, the heart rate dropped suddenly. They noticed an increase of 8 per cent in rate after the feed was consumed compared to the pre-feeding rate. Although cows showed acceleration of the heart during eating, some cows showed greater response than others and it was not abnormal to find heart rates above 100 per minute in the last stages of consumption of a heavy meal.

Ritzman and Benedict (49) observed pulse rates of steers under maintenance, submaintenance and supermaintenance conditions and found that pulse rate was reflected in the changes in rate of energy transformation on different feed levels. The increase of metabolism from submaintenance to fattening represented higher basal metabolism as well as increases due to muscular activity caused by greater food

stimulus, the absorption, transformation and distribution of excess quantities of digested food, and the elimination of a large amount of waste resulting from high feeding. The pulse rates of steers during maintenance feeding ranged between 40 and 49 beats per minute and on submaintenance ration showed a range of 25 to 37 beats per minute. Pulse rates for fattening steers fed heavy grain rations showed a range of 73 to 89 beats per minute. The averages for different feed levels were 44, 33 and 78 pulse beats per minute for maintenance, submaintenance and fattening, respectively. The reduction in pulse rate was due to reduction in feed and not due to seasonal influences as shown by comparison with controls which maintained a constant rate. When grain feeding was increased to fattening level, the heart rates increased to 78 beats on an average. Moore (39) observed an increase in heart rate of 25 per cent when cows were fed above Morrison's standards.

Alfredson and Sykes (1) studied the electrocardiac changes in calves fed on low and increased potassium rations and found most of the animals showing pronounced changes in the electrocardiogram. The QRS intervals were approximately two times as long as those displayed by the electrocardiograms of the controlled animals. Cardiac arrhythmias and changes in heart rate were observed at regular intervals.

Thomas (59) observed 40 cows for varying periods of time and found the heart rates of the producing cows increased when they

consumed TDN at 120 to 130 per cent of requirements. The maximum increase in heart rate was attained 30 to 40 days after the increase in TDN consumption. Thyroprotein produced only a transient increase in heart rate when TDN was consumed at 100 per cent of requirement.

Hundley et al. (26) observed that in thiamine deficiency in rats, there was a fall of 150 to 200 beats per minute and after therapy it rose 100 to 120 beats per minute. MacDonald and McHenry (36) reported that pigeons fed exclusively on polished rice developed bradycardia and partial heart block prior to the onset of polyneuritis. Gopalan et al. (20) observed the electrocardiac changes in cases of severe malnutrition in children and adults. Variations were observed and, in some, bradycardia was noticed. Wilhelmy et al. (62) observed that the level of feeding was correlated with the heart rates in dogs. Blaxter (7) observed that an increase of 2.5 pounds of starch equivalent consumed per day caused an increase of 4.9 beats per minute and an increased production of 5.1 pounds of milk yield per week over the normally fed animal. Decreased feeding of the same amount of feed showed a fall of 7.1 beats per minute and 14.4 pounds of milk per week. There was a relation between total metabolism and milk production. It was also found that the total metabolism of cows was lower during winter months because of lower nutrition.

Thyroxine and feeding of other compounds. Reece (45) found that heart rates increased from 62 to 86 beats per minute after 15 grams of Protomone were fed daily. In two weeks after withdrawal the heart rates

of treated animals decreased 17 beats per minute, while the controls increased three beats per minute.

Bartlett et al. (4) summarized the relative potencies of L-triiodothyronine and L-thyroxine in evoking the various phases of the galactopoietic response and tachycardia in the lactating cows. Thyroxine caused a progressive increase in heart rate throughout the feeding period, while triiodothyronine evoked an immediate tachycardia which thereafter rapidly declined. Thyroxine caused a progressive increase in heart rate over the whole of the experimental period, the maximum occurring in the third week.

Blaxter (5) observed that there was a total increase in milk production per cow, approximately 25 gallons, by treating with iodinated casein. Heifers did not increase in milk yield so markedly as did the mature cows and this was probably the result of higher metabolic rate in the heifer. There was an increase of 10.2 beats per minute in treated animals and it was more in smaller heifers than in mature cows. Swanson (55) observed that thyroprotein feeding produced an increase in milk yield, heart rate, slight to insignificant changes in respiration, temperature, and milk fat test.

Sykes et al. (58) observed that electrocardiograms on cows fed thyroprotein in successive lactations were typical and essentially normal. Sykes et al. (56) observed that the effect on heart rate expected by levels of TDN and that caused by thyroprotein seemed to be additive because changes in heart rate were attributed to thyroprotein

at all levels of energy intake. Seath and co-workers (53) noted the average increase of pulse rates was 10 to 13 beats more per minute than normal, and the body weight losses averaged 32 pounds for the first 8 weeks of feeding iodinated casein. The treated cows were more sensitive to atmospheric temperatures than control cows. Sykes et al. (56) observed that heart rates at all levels of consumption were higher when thyroprotein was fed, but in spite of the hyperthyroidism induced by the thyroprotein which was severe enough to cause loss of body weight even when animals were being fed in excess of requirements, increased or decreased feed consumption resulted in changes in heart rate. Ralston et al. (44) observed that pulse rate was roughly proportional to the level of metabolism. He proposed that the pulse rate multiplied by pulse pressure was a better indication of metabolism levels than the rate alone.

Age. Bartlett (3) compared the variations in heart rate with the variation in the solids-not-fat percentage, under the influence of increasing age of the cow. As the age advanced, both declined; and in the pregnant cow, both the heart rate and the solids-not-fat rose when she was late in lactation. Blaxter (7) made a study of heart rates of calves newly born, and during the first week of life they showed a range of 140 to 200 beats per minute. He stated that high rates were obviously related to the high basal metabolism of the young calf. The heart rate of younger cows was sometimes 100 or more per minute regardless of their milk yield.

Alfredson and Sykes (1) noted the heart rate of cattle as a whole averaged 71.6 beats per minute. The rate for animals up to 18 months of age was significantly greater, averaging 82.5, while for animals over 18 months of age the rate averaged 67.8. The QRS interval also varied with the heart rate, and the index was relatively constant in the animals of over one year of age. Thomas and Moore (60) found the heart rates of heifers during their first lactations higher than the rate found for cows in their second to fifth or seventh lactations, with a difference of about 4 beats per minute. Blaxter (6) found a difference of 6 beats per minute between heifers and old cows. Fuller (17) observed that a variation in heart rate or of respiration might be caused by one or more of several factors. Young animals showed the highest rate and exercise, temperature, feed and other factors also influenced the heart rate. Peterson and co-workers (43) in their electrocardiographic study on Beagle dogs ranging in age from 5 to 28 months found that heart rates varied from 90 to 180 with a mean of 138.

Lactation and gestation. Thomas and his co-workers (60) observed large variations in heart rate between individual cows at comparable stages of lactation. Cows during early lactation showed higher heart rates than at late stages. The cows having faster heart rates than others during early lactation continued to be faster almost during their entire lactation. They observed variations between cows and all the cows followed a definite trend downward in heart rate as the lactation period progressed. Heart rate during early lactation was

observed to correspond to average milk production curves. The variability in heart rate was found to be higher during the first 50 days of lactation than at later stages of lactation.

Alfredson and Sykes (1) observed variations in heart rates in cows at various stages of lactation and gestation when these animals were all kept on high planes of nutrition necessary for optimum production. Heart rates varied from 48 to 98 beats per minute and the average was 71.6 beats per minute. The mean heart rate for Jerseys was 65.9 and for Ayrshires was 76.4. Fuller (17) noted that the average pulse and respiration rates of milking cows were higher than those of dry cows kept in stanchions. The average per cow in the stanchion dry group was 69 beats per minute. Milking Ayrshires cows showed an average of 77.1 beats per minute as compared to 62.7 for the Jersey average. The Holsteins in a high production group showed appreciably higher average pulse rates than did the cows in the rest of the milking herd. There was an increase in the respiration rate of the high producing group with an average of 35 while the average of the stanchion dry cows was only 28.6 per minute.

Moore (39) found a definite increase in heart rates of cows during the last three months of gestation. As the lactation period increased, there was a decrease in heart rate. There was a direct relationship between total metabolism of the animal and the heart rate. Thomas (59) noted that the heart rate was faster in early lactation than during the second half of the lactation period. A rapid decrease

in heart rate was usually accompanied by a rapid decrease in milk production. Heart rate increased rapidly in a cow just before calving. At 70 to 90 days before calving, it averaged 65 beats per minute, at 30 to 50 days before it averaged 72 beats, and 0 to 10 days before calving, it averaged 92 beats.

Blaxter and Price (6) observed the effect of different lactation yields on heart rate and found a correlation between the heart rate and milk production. It was noticed over long periods that the relationship was not direct and there was a general decline of milk yield regardless of the level of the heart rate. During short periods, the normal decline in lactation could not often be discerned. Blaxter (7) stated that the relation between milk and heart rate was significant statistically ($P < 0.01$) as 71 per cent of the variation in the milk yields of these cows was associated with variation in their heart rates. The regression coefficients showed on the average an increase of 10 beats in the heart rate was associated with an increase of three gallons of milk per week. He also observed in autumn and spring calvers that those which gave the most milk had shown the highest heart rates during late pregnancy. During poor grazing conditions and high environmental temperatures, he found cows showing lower heart rates.

Estrus. Thomas (59) observed that a cow usually showed a more rapid heart rate during estrus than immediately before or after estrus. Ralston et al. (44) observed that an increased heart rate was observed

in cows during estrus. The average was 73 to 82 per minute during estrus and from 72 to 73 two or three days after estrus.

Summary of review of literature. The heart rate or pulse rate of an individual dairy cow varies within narrow limits if she is normal in health. The nature and number of beats per minute indicate the physiological condition of the animal. The normal heart rate of a dairy cow varies from 60 to 70 beats per minute, provided she is not influenced by other factors. The rate of beat changes quickly in response to variations in either internal or external conditions. The blood circulation is reflexly adjusted through nervous regulation to meet the changing needs of the organism and adapted to alterations in the external environment.

Many factors influence the heart rate in animals. The heart beat is directly proportional to the basal oxygen consumption per unit of body weight in mature animals of different species. There is an inverse relationship between heart rate and body size found within the species and among different species. The smaller animals have a higher pulse rate than larger ones as in the former there is rapid consumption of oxygen in the tissues and an increased demand for oxygen is met by the acceleration of the flow due to quicker beat of the heart. Heart rate varies with age as it is higher in young animals than in matured ones. A seasonal variation in heart rate of dairy cows occurs, and heart rate is higher during October (fall) and less during June (summer).

Other physiological factors that influence the heart rate are excitement, muscular exercise, high environmental temperature, estrus, gestation and lactation. Changes in heart rates have been observed in a variety of pathological conditions.

There are natural variations in heart rates of dairy cows depending upon the effects of various levels of feed intake, as the heart rate is directly proportional to the total metabolism of the dairy cow. High production or low production has a bearing on the rate of beat and is correlated with the stage of gestation and also the level of feeding. Significant variations in heart rate have been found to occur during the first month of lactation when compared to later months of lactations. Similarly the heart rates of cows during the last 30 days of gestation are higher than in earlier periods. Feeding thyroxine and other galactopoietic compounds causes a progressive increase in heart rate over a long period, the maximum occurring in the third week. Standing versus lying and ruminating versus non-ruminating cause little variations in heart rate. Environmental temperature and metabolism due to a heavy meal cause considerable heart rate variations. Additional factors like endocrine stimulation, muscular activity, tension of muscles, shivering, fever, excessive humidity coupled with high temperature and increased respirations, contribute to the changes in the pulse rate. Within physiological limits, there may be slight fluctuations in the heart rates depending upon variations in body temperatures.

CHAPTER III

MATERIALS AND METHODS

This study was conducted at the University of Tennessee Agricultural Experiment Station dairy farms from the middle of June to the end of October, 1960. Most of the observations were made in the Knoxville herd and additional data were secured from the Lewisburg herd.

The most reliable method of recording the rate of beat of the heart is by direct auscultation, as nervous movements of the cow result in many cases in the inability to hold surface arteries well enough to obtain a correct pulse record. A stethoscope was used to record the heart rates by placing it on the left chest wall between the second and sixth rib, behind the region of the elbow joint. Precautionary measures were taken not to excite the animals. In some cases an initial elevated heart rate of 2 to 3 beats per minute was observed. To insure the uniformity of heart rate recordings, counts were made for about 2 minutes after placing the stethoscope and were repeated until the heart rate was constant. Though some of the cows were slightly excited at the beginning, they got used to the person and the operation of the stethoscope. The number of beats per minute was recorded from a 60 second count until a uniform rate was observed.

The feeding and management of the milking cows was the same for all the cows except the animals under experimental conditions. The

dairy cows of this experimental station were fed hay and silage ad lib. Grain mixture rationed according to milk production was fed while milking. Heifers which had not been bred or had not yet calved were maintained on pasture only during the period of study. The pasture was sparse, which resulted in slightly below normal condition of this class of animals. During the period of study, the highest barn temperature recorded was 86°F on some days in August and September, the lowest barn temperature observed was 59°F during the last week of October. Because of the limited time, a systematical study of the effects of temperature or season was not conducted.

In the studies of factors affecting heart rates, the mean and standard deviations of heart rates of different groups were calculated. Although the statistical significance can be determined from these values, actual calculations of statistical significance of various differences were not made. In discussing the results, the word "significant" is used to imply a noticeable change and it does not mean statistically significant.

Studies were made of a large number of cows so that many factors which might affect heart rates were represented. The major categories studied included the following:

1. Different stages of lactation.
2. Different stages of gestation.
3. Different age groups.

4. Effects of nutritional levels in experimental animals.
   a. Grain feeding vs. no grain feeding in Dairy Experiment Station milking heifers.
   b. Grain feeding vs. no grain feeding in cows during dry periods.
   c. Subnormal vs. normal level of feeding in identical twin heifers.

5. Variations due to resting, pre-milking time in the milking parlor, and while milking.

6. Effects of triiodothyronine implantation.

Different stages of lactation. In the lactation studies 61 Jerseys and 39 Holsteins were observed approximately twice per week for a period of 3 months from August to October. During this period 377 observations were made in Jerseys and 317 in Holsteins. The heart rates of these animals were observed when they were at rest in the stanchion barn or in a loose pen stable. The heart rates of the animals were divided into different stages depending on the number of days in lactation at the time the observation was made. The lactation period was divided into 10 sections of 30 days each and a final section which included all cows which had been milking 300 days or more. Most of the animals observed in this study were in either the early or late months of lactation periods. The mean heart rate and standard deviation for each stage of lactation period were obtained from all heart rate

observations which fell in that period. Averages were calculated for Jerseys and Holsteins separately and combined.

Different stages of gestation. Cows and heifers which were assumed to be pregnant were classified into lactating and non-lactating groups and into four stages of gestation to determine the effects of gestation on heart rate. The objective was to determine how the lactating pregnant animals differed in their heart rates from the non-lactating pregnant ones. The gestation period was divided into four sections for this study. The early gestation period included those animals which had been bred more than 60 days and less than 120 days. Other classification periods were 121 to 180, 181 to 240, and above 240 days of gestation. The heart rates of these animals were observed under undisturbed conditions while they were at rest in the stables. Most of the animals observed for gestation studies were in the last stages of gestation and/or early period of lactation, as they had been bred to calve in the fall. As a result there was only a small number of animals in the mid-gestation groups during the observation period. The mean heart rate and the standard deviation for each segment of the gestation period were obtained from all of the appropriate heart rate observations for each period.

Different age groups. The age of each animal from which heart rates were determined was recorded to the nearest month for each observation. The heart rates were then grouped according to the age and

condition of the animal. These divisions were unbred heifers 19 to 24 months old, 24 to 36 months old pregnant heifers which had not calved, 24 to 36 months old heifers in their first lactation, 3 to 4 year old lactating cows, and cows over 4 years old. The total number of animals included in this phase of the investigations was 145, of which 73 were Jerseys and 72 Holsteins. Heart rates were determined on all animals while they were at rest in a stable. The mean heart rate and standard deviations were determined for each age and condition category for Jerseys and Holsteins separately, and for both breeds combined.

Effect of nutritional levels. Heart rate observations were made from animals in three nutritional experiments in each of which a difference in the level of feeding occurred between paired heifers or cows. The first group studied were 20 Jersey heifers used to compare milk production from an all roughage ration with that from grain and roughage. These heifers were placed on an all forage ration until they calved. After calving they were placed in the stalls in an experimental barn where good quality hay and silage were fed ad lib. As the heifers freshened, they were alternately assigned to the all roughage and grain plus roughage rations until 10 from one sire had completed the first lactation. The grain mixture was fed at the rate of 1 pound of grain for each 3 pounds of milk, but not to exceed 10 pounds daily per cow. Heart rates were observed in these heifers on July 25 and 26 at the Dairy Experiment Station, Lewisburg, Tennessee. The average

current weekly consumption of silage, hay and grain, milk production and stage of lactation and gestation at the time the heart rate observations were made was recorded. The heart rates of these animals were observed from 3 to 5 A. M. and 3 to 5 P. M. on two different days. The temperature of the stable varied from 79°F to 92°F during the period of study. The average heart rates were determined according to the feeding regime for each group of 10 heifers. Data from these heifers were also used in a study of effect of milking on heart rates.

The second nutritional experiment was grain feeding vs. no grain feeding in cows during dry periods. This experiment was conducted at Knoxville with 10 pairs of Holsteins and 9 pairs of Jerseys. Cows with one or more previous lactations which were to calve in the fall were selected on the basis of age, time of calving and production characteristics, including total milk yield and the weekly changes in milk yield. One cow of each pair was allowed free access to roughage, including variable pasture, hay and silage. The other cow of each pair was fed in the same manner, except it was also fed 8 pounds of grain daily beginning at 42 days before expected calving. The cows in each pair were fed identical concentrate rations after calving and had free access to the same roughage. The grain feeding schedule for each pair was prepared in advance on the basis of a liberal allowance for the expected production. Roughages were fed free choice throughout the lactation. These animals were observed both during the dry period and after calving to determine whether any observed dry period effect would

be continued in the lactation period. During the dry period, 70 observations were made in the grain fed cows and 117 in the non-grain fed group. During the lactation period 44 observations were made in the group fed grain in the dry period and 60 were made in the group not fed grain in the dry period. All of the lactation heart rates were observed within the first 2 months of lactation. The mean heart rate for each group and the standard deviations were calculated from all of the heart rates observed in each category.

The third nutritional experiment was different levels of feeding to growing heifers. In this study 3 pairs of identical twin heifers were used. One of each pair was underfed by restricting hay to an amount which allowed them to weigh only 75 per cent as much as the normal heifers. The latter were fed hay ad lib. After calving both of the groups were fed alike irrespective of the amount of milk production. Before parturition, 24 observations were made in each of the normally fed and underfed groups. After calving 18 observations were made in the normally fed and 17 in the underfed group. This study was continued into the lactation period to observe whether any effect of underfeeding before calving would be carried over after calving. Two of the three pairs had calved before this study was terminated.

Effects of feeding and milking on heart rates. A group of 21 Jersey and 24 Holstein cows at the Knoxville Dairy Farm and 20 experimental Jersey heifers at Lewisburg were used in this study. Their

heart rates were observed first in the stanchion barn or stable about one hour before milking while they were at rest. Their heart rates were again determined just after they entered the milking parlor before milking. The third heart rate determination was made on each cow after the milking machine was attached and she was actually milking. While taking the heart rates, care was taken not to disturb the cow at any time. During the pre-milking period, all of the cows in the Knoxville herd were fed grain. Some of the Lewisburg animals were fed grain in the milking parlor, while the others were not. A total number of 464 observations were made in each of the resting, pre-milking and milking stages in a total of 65 animals. The changes in heart rates were calculated separately for each breed and station group. The mean and standard deviation of the combined groups were also determined.

Effect of triiodothyronine implantation. The effect of triiodothyronine was studied for a period of 18 weeks in two cows, having a third cow as a control. These animals were not selected on the basis of high production or body weight although all were of predominately dairy breed type. The cows 41 and 44 were in their third lactations and cow 9 in her fifth lactation. Cow 44 was used as a control. Cows 41 and 9 were implanted with 60 milligrams of triiodothyronine in the neck region under aseptic conditions. The quantity (60 milligrams) was considered satisfactory enough to show a positive effect in milk yield and physiological responses comparable to thyroxine feeding.

After 7 weeks, cow 41 was reimplanted with 80 milligrams of triiodothyronine. The milk production, heart rate, and body weight were observed during the course of each treatment. The experiment was conducted to study the galactopoietic effect of implanted triiodothyronine in milk cows, and to determine whether this could be used without any adverse effect on the normal health of the cows.

CHAPTER IV

RESULTS AND DISCUSSION

Heart rate determinations were made on a total of 169 cows and heifers including 95 Jerseys and 74 Holsteins in different stages of lactation, gestation and age groups. The effects on heart rates of milking nutritional and triiodothyronine treatments were also studied. The period of study was for five months from June to October, 1960. The data collected are presented and discussed in six sections which deal with the respective subjects of the studies.

Effects of stage of lactation on heart rates. In this study, 61 Jerseys and 39 Holsteins were divided into monthly lactation groups according to the dates when heart rates were determined. Each cow appears in no more than three of the monthly periods, and many were in only one. Most of the animals whose heart rates were observed were either in the early stage or late stages of lactation. The results are summarized in Tables I and II. In the early lactation periods (up to 60 days) there was an increase in heart rates, the average ranging between 78 to 80 beats per minute in Jerseys and 76 to 79 beats per minute in Holsteins. There was a progressive decline in heart rates as the stage of lactation advanced. In the 121 to 150 and 150 to 180-day periods, there were slight variations (slightly higher) probably due to small numbers of animals and observations made in these periods. The lowest months were the eight and ninth

TABLE I

HEART RATES OF JERSEY AND HOLSTEIN COWS
AT DIFFERENT STAGES OF LACTATION

Stage of Lactation	Jerseys			Holsteins		
	Cows	Observations	Average heart rate	Cows	Observations	Average heart rate
(days)	(No.)	(No.)	(beats/min.)	(No.)	(No.)	(beats/min.)
1-30	42	134	80.0±4.8*	15	50	79.2±4.1*
31-60	21	56	78.3±3.3	11	24	76.2±3.4
61-90	9	25	78.6±2.7	3	10	73.8±2.6
91-120	4	10	76.0±1.9	3	9	75.5±2.8
121-150	3	5	76.3±1.7	2	6	75.0±4.1
151-180	3	11	77.0±5.1	4	10	73.2±1.9
181-210	3	7	75.7±4.7	7	20	74.0±3.3
211-240	8	18	73.0±2.6	13	35	72.0±4.5
241-270	10	33	73.1±3.6	12	36	70.8±4.0
271-300	11	31	77.2±4.4	13	38	70.8±2.6
over 300	12	47	75.2±5.6	11	79	72.0±4.0

*Standard deviation

TABLE II

HEART RATES OF ALL JERSEY AND HOLSTEIN COWS
OBSERVED AT DIFFERENT STAGES OF LACTATION

Stage of Lactation (days)	Total cows observed (No.)	Heart rate observation (No.)	Average heart rate (beats/min.)
1-30	57	184	79.6±4.8*
31-60	32	80	77.1±3.4
61-90	12	35	76.2±3.4
91-120	7	19	75.7±2.3
121-150	5	11	75.7±3.2
151-180	7	21	75.1±4.4
181-210	10	27	74.8±3.7
211-240	21	53	72.5±3.9
241-270	22	69	71.9±4.4
271-300	24	69	74.0±4.7
Over 300	23	126	73.6±4.9

*Standard deviation

for Jerseys and the minth and tenth for Holsteins. After these low months, there was a trend towards slightly higher heart rates in both breeds. This may have been due to an association with advanced gestation in many of these cows in late lactation, as discussed below. The combined heart rates of all Holstein and Jersey cows (Table II) showed a decrease in the rate as lactation advanced from the first to the ninth month. Thereafter a gradual rise occurred.

The increase in heart rate during the early part of lactation might have been due to increased metabolism accompanying high milk production and increased feed consumption during this period. The gradual decline from the third month onwards might be due to a decrease in milk production and reduced metabolic rate. The effect of season accompanied by temperature might affect the rates during this period from summer to fall. A seasonal variation in the heart rate of dairy cows was observed by Ralston and co-workers (44), the highest rates being in April and October, and the lowest in June and August. They stated that the seasonal effect may have its origin in increased feed during flush pasture of April and October or due to increased incidence of calving effects during spring and fall. In this study there was little change in feed from summer to fall, as it was nearly all dry lot feeding. The time interval studied was not long enough to determine any seasonal effect. The increased heart rate during the last months of lactation might have been due to a gestation effect in some animals. These observations are in general

agreement with those of Thomas and Moore (60) and Blaxter and Price (7) who also found that cows during early lactation showed higher heart rates than in late lactation.

Effect of gestation on heart rates. All of the pregnant Jerseys and Holsteins observed were divided into non-lactating and lactating groups for a study of the effect of the gestation period on heart rates. The gestation was divided into four periods, less than 120 days, 121 to 180, 181 to 240, and over 240 days. The non-lactating animals were all heifers in their first gestation. The lactating cows were of all ages to maturity. The average heart rates for the two breeds and groups are shown in Table III. The non-lactating Jersey group of heifers showed a higher heart rate (78.2) than the lactating animals (75.2). The Jerseys averaged a slightly higher rate than the Holsteins in both the lactating and non-lactating groups in all periods except the 120 to 180-day period for the non-lactating group. Even in this period, the Holsteins in the lactating group averaged less than the Jerseys. The breed differences are so small however that they are not considered significant. In the 181 to 240-day period, in both the groups and breeds, the heart rates increased over the previous gestation stage average. In the period over 240 days gestation, the heart rates of both breeds were increased much higher due to the very advanced stage of gestation approaching calving and lactation.

Combining all observations, the heart rates averages 75 ± 5.2, 72.7 ± 4.9, 75.6 ± 4.9, and 79.5 ± 3.8 for stages of gestation less than

TABLE III

HEART RATES OF LACTATING AND NON-LACTATING JERSEY AND HOLSTEIN COWS AT DIFFERENT STAGES OF GESTATION

Stage of gestation	Lactating			Non-Lactating		
	Cows	Observations	Average heart rate	Cows	Observations	Average heart rate
(days)	(No.)	(No.)	(beats/min.)	(No.)	(No.)	(beats/min.)
Jerseys:						
<120	4	24	75.2±3.6*	9	61	78.2±3.7*
121 to 180	11	47	73.4±5.9	4	21	71.8±4.7
181 to 240	34	131	74.1±5.2	18	68	78.2±4.3
>240	29	90	78.7±3.4	13	41	81.7±3.5
Holsteins:						
<120	15	79	72.3±4.0	2	4	60.0±4.6
121 to 180	14	60	71.8±4.3	5	21	73.4±3.9
181 to 240	28	117	74.4±4.4	9	32	74.5±3.8
>240	23	136	78.0±3.8	5	22	79.0±3.7
Both Breeds:						
<120	19	103	73.0±4.1	11	65	77.1±5.8
121 to 180	25	107	72.6±5.1	9	42	72.7±4.4
181 to 240	62	248	74.2±4.8	27	100	77.0±4.5
>240	52	226	78.3±3.7	18	63	80.8±3.8

*Standard deviation

CHAPTER IV

RESULTS AND DISCUSSION

Heart rate determinations were made on a total of 169 cows and heifers including 95 Jerseys and 74 Holsteins in different stages of lactation, gestation and age groups. The effects on heart rates of milking nutritional and triiodothyronine treatments were also studied. The period of study was for five months from June to October, 1960. The data collected are presented and discussed in six sections which deal with the respective subjects of the studies.

Effects of stage of lactation on heart rates. In this study, 61 Jerseys and 39 Holsteins were divided into monthly lactation groups according to the dates when heart rates were determined. Each cow appears in no more than three of the monthly periods, and many were in only one. Most of the animals whose heart rates were observed were either in the early stage or late stages of lactation. The results are summarized in Tables I and II. In the early lactation periods (up to 60 days) there was an increase in heart rates, the average ranging between 78 to 80 beats per minute in Jerseys and 76 to 79 beats per minute in Holsteins. There was a progressive decline in heart rates as the stage of lactation advanced. In the 121 to 150 and 150 to 180-day periods, there were slight variations (slightly higher) probably due to small numbers of animals and observations made in these periods. The lowest months were the eight and ninth

120 days, 121 to 180, 181 to 240, and more than 240 days respectively. According to Thomas and Moore (60), the heart rate of cows showed a definite increase during the last three months of gestation and it was significantly higher during the last 6 weeks of pregnancy. Blaxter and Price (7) noticed that the heart rates of cows increased considerably during the latter part of pregnancy, the increase being most noticeable during the last 12 weeks before calving.

From the gestation studies, it was observed that the stage of gestation had no consistent effect on heart rates until after 6 months, when an increase occurred. A further increase was observed in the last month of gestation. The cause of the increased heart rate may be increased feed consumption and increased metabolic activity in the dry period in preparation for the coming lactation.

Effect of age on heart rates. Age group studies were made using 73 Jerseys and 72 Holsteins which were divided into five age groups. These data are summarized in Tables IV and V. In the first group of non-bred Holstein cows under 24 months of age, 56 observations showed an average heart rate of 68.2. None of the Jerseys came into this category, as they were all bred. In the 2 to 3 year-old group of Jerseys which were pregnant but had not yet calved, the mean heart rate was 78.1, which was 3.6 more than the Holsteins of this category. The average rate of the 2 to 3-year old lactating group of Jerseys was 78.0, which was only 1.2 more than the comparable Holsteins. In the

TABLE IV

HEART RATES OF JERSEY AND HOLSTEIN COWS AT DIFFERENT AGES AND CONDITIONS

Age groups	Jerseys			Holsteins		
	Cows (No.)	Observations (No.)	Average heart rate (beats/min.)	Cows (No.)	Observations (No.)	Average heart rate (beats/min.)
19 to 24 mos. non-bred	--	--	--	14	56	68.2±6.1*
2 to 3 yr. Pregnant, not calved	25	187	78.1±4.9*	13	55	74.5±4.9
2 to 3 yr. Lactating	25	182	78.0±4.1	6	19	76.8±3.3
3 to 4 yr. Lactating	15	150	77.2±5.1	19	194	76.2±4.7
Above 4 yr.	21	209	75.4±5.7	24	238	73.4±5.7

*Standard deviation

TABLE V

HEART RATES OF ALL JERSEY AND HOLSTEIN COWS
OBSERVED AT DIFFERENT AGES AND CONDITIONS

Age groups	Total cows observed (No.)	Heart rate observations (No.)	Average heart rate (beats/min.)
19 to 24 mos.	14	56	68.2±6.1*
2 to 3 yr. pregnant not calved	38	242	76.3±5.08
2 to 3 yr. Lactating	31	201	77.4±4.07
3 to 4 yr. Lactating	34	344	76.4±4.9
Above 4 yr. Lactating	45	447	74.4±5.4

*Standard deviation

next higher age group, there was a slight decline of heart rate. There was a significant decrease in the heart rate of the over 4 year old group as compared to the 2 to 3-year old group.

It was observed that the Jerseys in all age groups had slightly higher average heart rates than the Holsteins. In general, young animals had a higher heart rate than older ones; but this was not true of the non-bred yearling Holsteins. This would indicate a lower metabolic rate and lower physiological activity in this group. This may have been due to feeding levels, as these heifers were not fed grain. Gestation effects may also have been responsible for the higher heart rates of the next age group. The first lactation Jerseys had practically the same heart rates as the bred non-lactating heifers; but the lactating 2 to 3-year old Holsteins had slightly higher heart rates than those non-lactating. As the number of lactations increased with age, there was a progressive decline in the 3 to 4-year old group (Table V) and it further declined in the next higher age group. As the age and lactations increased there was a constant decrease in heart rates, implying that age is a salient factor affecting the physiological changes in the system.

Thomas and Moore (60) observed that the heart rates of heifers during the first lactations were higher than the cows in their second to fifth or seventh lactations. They reported a difference of 4 beats per minute which compares favorably with the average difference of 3 beats per minute observed here. Blaxter (6) found a difference of 6

beats per minute between yound and old cows. Alfredson and Sykes (1) observed that the average rate in animals up to 1.5 years of age was 82.5, and for animals over 1.5 years old the average rate was 67.8. In this study, animals of less than 1.5 years of age were not observed, but the average for the non-bred Holsteins, 19 to 24 months was 68.2±6.1, which was considered lower than normal.

Effect of different levels of feeding on heart rates. The effects of levels of feeding on heart rates were studied at Knoxville and also in the Dairy Experiment Station herd at Lewisburg. These studies were made on animals which were in different types of feeding experiments in the Agricultural Experiment Station program. At Lewisburg 80 observations were made in 20 Jersey milking heifers during the course of two days. Heart rates were determined at rest, during pre-milking, and while milking. The average results for each heifer are shown in Table VI. The heifers which were fed grain averaged 75.6 beats per minute at rest, 80.6 during pre-milking, and 83.6 while milking. The heifers which were not fed grain showed a mean of 68.6 beats per minute at rest, 74.0 while pre-milking, and 75.7 while milking. There was a difference between the grain fed and non-grain fed animals of 7.0 beats per minute in the resting heart rates, 7.6 in the pre-milking, and 7.9 in the milking heart rates. The average of all observations for the grain fed group was 80.3 compared to 72.7 for the no grain group, a difference of 7.6 beats per minute. The daily average TDN consumption of the grain fed group was 17.5 pounds, while those not

TABLE VI

HEART RATES OF LACTATING JERSEY HEIFERS COMPARING GRAIN VS. NON-GRAIN FEEDING DURING THE LACTATION

No. of cows	Heart rate at rest	Heart rate pre-milking	Heart rate while milking	Daily TDN	Daily milk yield	Days in lactation	Days in gestation
	(beats/min.)			(lbs.)	(lbs.)	(days)	(days)
Grain Fed							
859	69	78	79	18.7	24.8	267	122
861	77	81	83	18.7	28.1	153	86
900	83	86	89	18.6	27.3	75	--
887	73	82	83	18.6	29.2	87	--
888	68	74	76	18.1	29.8	64	--
863	73	79	82	18.1	22.6	175	53
890	81	86	87	17.5	30.9	10	--
875	80	83	86	16.8	26.5	88	18
902	82	84	87	15.2	29.8	2	--
879	68	80	81	14.7	21.6	130	47
Group av.	75.6	81.6	83.6	17.5	27.1	105.1	32.6
Not Grain Fed							
898	66	67	70	13.6	23.6	53	--
893	65	73	75	13.3	24.9	73	--
874	63	68	69	13.1	25.4	144	51
884	74	85	86	12.7	25.2	206	122
876	65	70	72	12.6	25.2	46	--
894	66	72	73	12.4	23.1	75	--
867	74	78	79	12.2	13.0	282	183
873	69	80	81	10.3	25.1	52	--
901	74	76	81	9.1	28.0	9	--
882	68	69	70	5.2	12.1	113	16
Group av.	68.6	74.1	75.7	11.45	22.6	105.1	37.2

receiving grain averaged only 11.5 pounds TDN. There was an average difference of 4.5 pounds daily milk production in favor of the grain fed group. This shows that the level of feeding was an important factor, resulting in increased metabolic activity and which in turn raised the heart rate and milk production.

Effects of different feeding levels during the dry period. A different feeding experiment was conducted at the University of Tennessee Dairy Farm. Ten pairs of Holsteins and 9 pairs of Jerseys were used to determine the effects of feeding grain during the last 6 weeks of the dry period. One cow of each pair was fed grain and its mate was fed only roughage in this period. After calving they were fed alike, both receiving ample grain rations. The heart rates determined on these cows are presented in Table VII. The average for the grain fed Jerseys and Holsteins, respectively, during the dry period was 78.9±3.4 and 78.5±3.1. Heart rates of the cows not fed grain averaged 75.5±4.4 and 75.9±5.3 for Jerseys and Holsteins, respectively. The respective averages for all of the grain fed and non-grain fed cows were 78.8±3.2 and 75.7±4.9 during dry period observations. During the lactation period of study it was observed that the formerly grain fed Jerseys averaged 82.1±3.4 while the group formerly not fed grain averaged 82.0±3.9. The grain fed Holsteins averaged 78.7±2.5, while their controls averaged 79.2±3.7 beats per minute. The early lactation average for all of the cows fed grain in the dry period was

TABLE VII

HEART RATES OF JERSEY AND HOLSTEIN COWS USED FOR COMPARING GRAIN VS. NO GRAIN FEEDING IN THE DRY PERIOD

Period and breed	Grain-Fed			Non-grain-fed		
	Cows	Observations	Average heart rate	Cows	Observations	Average heart rate
	(No.)	(No.)	(beats/min.)	(No.)	(No.)	(beats/min.)
Dry Period:						
Jerseys	9	32	78.9±3.4*	9	57	75.5±4.4*
Holsteins	9	38	78.5±3.1	10	60	75.9±5.3
Both breeds	18	70	78.7±3.2	19	117	75.7±4.9
Lactation:						
Jerseys	7	22	82.1±3.4	4	18	82.0±3.9
Holsteins	4	22	78.7±2.5	8	42	79.2±3.7
Both breeds	11	44	80.5±3.4	12	60	80.1±3.9

*Standard deviation

80.5±3.4 compared to 80.±3.9 for the controls. No carry-over effect was observed in the lactating period of the no grain group, as the heart rates of these animals were similar to those of the grain fed group during the lactating period. A probable reason is that the same supply of TDN was fed to both groups after calving and this effect was more important than possible effects due to different calving conditions.

Effects of different levels of feeding during growth of Jersey twin heifers. A heart rate study in 6 Jersey twin nutritional experimental heifers was made during a pre-calving period of 6 weeks and again after calving. Three of these animals were normally fed and received hay ad lib. Their mates were underfed and were restricted in feed so that they would weigh 75 per cent as much as the normal heifers. A summary of the data from this study is shown in Table VIII. The underfed group showed a range in heart rate from 44 to 72 beats per minute while the normals ranged from 64 to 84 beats per minute. The pre-calving average for the 24 observations of the normally fed group was 76.0±6.6 compared to 62.3±7.7 in the underfed group. The underfed animals were fed normally after calving. After calving, a significant average increase in heart rate to 79.8±3.9 occurred in the underfed heifers and it was also observed that the underfed animals averaged 1.6 beats per minute higher than the normal group. The heart rates of the normal group exceeded the subnormals before calving on account of the different feeding levels and increased energy production due to

TABLE VIII

HEART RATES OF IDENTICAL TWIN HEIFERS COMPARING NORMAL VS. UNDERFEEDING BEFORE CALVING AND EQUAL FEEDING AFTER CALVING

Heifer	Normal Fed		Heifer	Underfed	
	Observations (No.)	Average heart rate (beats/min.)		Observations (No.)	Average heart rate (beats/min.)
Before calving					
59	8	80.5±1.8*	60	8	65.2±5.3*
61	8	68.5±4.4	62	8	55.2±6.8
63	8	79.0±4.8	64	8	66.5±5.7
Total & av.	24	76.0±6.6		24	62.3±7.7
After calving					
59	10	76.2±2.3	60	7	79.7±3.1
63	8	80.7±1.4	64	10	79.8±4.4
Total & av.	18	78.2±3.1		17	79.8±3.9

*Standard deviation

increased metabolic activity. There was no evidence that there was any carry-over effect in the lactating period of the underfed group.

Effects of feeding and milking on heart rates. Studies were made of 21 Jersey and 24 Holstein cows at the Knoxville Dairy Farm and of 20 experimental Jersey heifers at Lewisburg. They were observed in stables while at rest, then in the milking parlor before milking, and finally while they were actually milking. A summary of these data is presented in Table IX. A significant increase in the heart rate was observed when the cows moved from the stable to the milking parlor. The three groups showed increased heart rates ranging from 5.7 to 7.9 beats per minute with an average increase of 7.1 over the resting condition. Between the pre-milking and milking condition, a further significant increase occurred. The Knoxville Jerseys increased their rate by 6.5, the Holsteins increased by 3.8, and Lewisburg heifers by 1.8 beats per minute. The average increase for all groups was 4.3 for the milking over the pre-milking rate. Experimental Jerseys at Lewisburg which were not fed grain in the milking parlor did not increase quite as much as the grain fed animals. This is shown in Table VI. The difference was so slight (8.0 vs. 7.1) however, that the actual feeding could not be considered of major importance.

These results are striking, though they are normal and physiological. A slight exercising effect, due to movement of animals from the resting condition to the parlor, eating of grain or anticipation of eating by those not actually fed grain, and factors accompanied with

TABLE IX

HEART RATES OF JERSEY AND HOLSTEIN COWS AT REST, PRE-MILKING IN MILKING ROOM, AND DURING THE MILKING PERIOD

Breed	Cows at Rest			Cows at Pre-milking			Cows while milking		
	Cows	Observations	Average heart rates	Cows	Observations	Average heart rates	Cows	Observations	Average heart rate
	(No.)	(No.)	(beats/min.)	(No.)	(No.)	(beats/min.)	(No.)	(No.)	(beats/min.)
Knoxville Jersey	21	168	67.9±3.6*	21	168	74.4±3.4*	21	168	80.9±2.9*
Knoxville Holstein	24	216	66.1±2.6	24	216	74.4±2.8	24	216	77.8±3.2
Lewisburg Jersey	20	80	72.1±6.7	20	80	77.8±6.9	20	80	79.6±7.1
Total	65	464	67.8±4.5	65	464	74.9±4.2	65	464	79.2±4.3

*Standard deviation

with the milk let down process must be the stimulating factors for the increased heart rates in the milking parlor.

Effects of triiodothyronine on heart rates. The effect of triiodothyronine implantation was studied in two cows, having a third cow as a concurrent control. The heart rates, body weights and milk production were observed for a period of 18 weeks. The results of this study are summarized in Table X. The control cow had an average of 70 beats per minute during pretreatment, and an average of 68.8 beats per minute for the entire period. Cow number 41 had an average rate of 67 before treatment. After implantation her heart rate rose to 80 per minute, which persisted for 3 weeks and thereafter declined. After the reimplantation, it again increased to 80 per minute and this effect lasted for 3 to 4 weeks and then declined to normal. Cow number 9, whose average pretreatment heart rate was 63.5 per minute increased her rate to 72 after implantation. Her heart rate remained high for 2 to 3 weeks and then it gradually declined to a normal level of 60 to 64 beats per minute. During the observation period the heart rate of the control cow gradually declined to about 64 and then rose again to about 68.

Implantation of triiodothyronine caused an increased metabolic activity and milk production. The galactopoietic effect of triiodothyronine was, however, only temporary. At the time of implantation, the weekly milk production for cow 41, 9 and 44 (control) was

TABLE X

HEART RATES OF TWO COWS TREATED WITH TRIIODOTHYRONINE AND ONE CONTROL COW AT WEEKLY INTERVALS

Period	Control cow 44	Treated cow 41	Treated cow 9
(wk.)	(beats/min.)		
1	68	68	67
2	72	66	60
3	72	79[a]	72[a]
4	70	80	72
5	69	80	68
6	68	72	66
7	65	72	64
8	64	68	60
9	64	65	60
10	62	80[b]	60
11	64	80	64
12	64	78	64
13	64	76	64
14	64	74	62
15	68	72	64
16	68	64	62
17	68	64	64
18	70	64	64

[a]Cows 41 and 9 implanted with 60 mg. triiodothyronine 6 days before this observation.

[b]Cow 41 implanted with 80 mg. triiodothyronine 6 days before this observation.

216, 120.9 and 169.4 pounds respectively. After implantation, milk yield increased for 3 or 4 successive weeks and thereafter gradually declined. In case of cow 41, it increased from 216 to 227.5 pounds in the fourth week and then declined. In cow 9 the milk production rose from 120.3 to 147.7 pounds and then declined to 137.5 pounds in the fourth week, and then it gradually declined further. Cow 44 (control) decreased in weekly milk production from 169.4 to 136.6 pounds during the course of 4 weeks. The heart rate stimulus and the galactopoietic effect were correlated. The heart rates increased during the period of increased milk production and declined as the milking stimulus diminished. Bartlett and others (4) observed similar results from injected triiodothyronine.

CHAPTER V

SUMMARY

This study was made to determine the natural variations in heart rates and how they are influenced by the stage of lactation, gestation, age, feed intake, milking and triiodothyronine treatment.

Observations were made on 169 animals of the Jersey and Holstein breeds in different stages of lactation, gestation, age groups and on different nutritional levels. The period of study was from June to the end of October.

A total number of 377 observations was made on 61 Jerseys and 39 Holsteins in different stages of lactation. Cows in the first 2 to 3 months of lactation had a higher heart rate than those in later stages of lactation. As the lactation period progressed, there was a decrease in the heart rate, except in the tenth month of lactation when it rose again. Most of the cows were also affected by advanced gestation periods in the group which had been milking 10 months.

The heart rates of 65 Jerseys and 74 Holsteins were observed during their gestation periods. They were divided into lactating and non-lactating groups in order to separate lactation and gestation effects. As the gestation period increased above 120 days, the heart rate increased. The greatest increase occurred after the 240-day period and in the last month of gestation. The average heart rate was 79.5 for this period which was an increase of 3.9 beats per minute over the average of the 181 to 240-day period.

A total of 73 Jerseys and 72 Holsteins was used for a study of the effect of age on heart rate. In the early age group, 19 to 24 months, non-bred Holsteins showed a low heart rate of 68.2 beats per minute. The 2 to 3 year-old groups, bred but not calved and lactating animals of the same age, had an average of 78.1 and 78.0 beats per minute, respectively. There was a decrease in the heart rate of lactating cows as the age increased over 3 years. In general, young animals had a higher heart rate than old ones, except in the unbred heifers. As the age and number of lactations increased, there was a gradual decline in the heart rates indicating that age is a notable factor affecting heart rates of animals in the same condition otherwise.

Variations in heart rates were observed in Lewisburg Jerseys which were put under grain vs. no grain treatments in the lactation period. The animals fed grain averaged 7.5 beats per minute higher in heart rate than those not fed grain.

The grain fed Jerseys and Holsteins at the Knoxville dairy farm showed an overall average of 78$\pm$3.2 beats per minute during the dry period while those not fed grain averaged 75.7$\pm$4.9. The higher heart rate during the dry period of the grain fed group did not affect the heart rates after calving when they were fed alike. Both groups were about equal in heart rates after calving. From the experiment of normal feeding vs. under feeding in 3 pairs of identical twins, it was observed that the normally fed animals averaged 13.7 beats

per minute higher than the underfed before their first paturition. A study of these animals after calving revealed that the prepartum heart rate effect was not continued in this period. It was noticed that current levels of feeding affected the heart rate, possibly due to changes in metabolic activity, irrespective of the previous treatment or condition of the cows.

Observation of heart rates of cows at rest, pre-milking and while milking were made on 21 Jerseys and 24 Holsteins at Knoxville and 20 Jerseys at Lewisburg. It was noticed that the heart rate during milking averaged 4.3 beats per minute higher than the pre-milking rate and the latter was 7.1 beats per minute more than the heart rate while the cows were resting in the stable. The increase in the pre-milking and milking heart rates must be due to a slight exercising effect, as well as eating and neurohormonal factors accompanying the milk let down process.

The effect of triiodothyronine implantation was studied in two cows, with a third cow as control. The heart rates, body weights and milk production were observed for 18 weeks. The heart rate of the control cow gradually declined from an average of 68 to 64 beats per minute and then rose again to 68. The heart rates of the treated cows, 41 and 9 increased 13 and 8.5 beats per minute respectively, over their pretreatment period rates for 3 weeks after implantation and then gradually returned to normal. These changes in heart rates paralleled increases and decreases in milk production due to treatment.

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