12-1971

Growth parameters in the quarter horse

James C. Heird

To the Graduate Council:

I am submitting herewith a thesis written by James C. Heird entitled "Growth parameters in the quarter horse." I have examined the final electronic copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Animal Husbandry.

J. B. McLaren, Major Professor

We have read this thesis and recommend its acceptance:

Charles S. Hobbs, Robert R. Shrode, W. R. Backus

Accepted for the Council:
Carolyn R. Hodges

Vice Provost and Dean of the Graduate School

(Original signatures are on file with official student records.)

14 3

November 30, 1971

To the Graduate Council:

I am submitting herewith a thesis written by James C. Heird entitled "Growth Parameters in the Quarter Horse." 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 Animal Husbandry.

J.B. McLaren
Major Professor

We have read this thesis and recommend its acceptance:

Charles S. Hobbs

Robert R. Shrode

Wm. R. Backus

Accepted for the Council:

Hilton A. Smith
Vice Chancellor for
Graduate Studies and Research

GROWTH PARAMETERS IN THE QUARTER HORSE

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

James C. Heird

December 1971

ACKNOWLEDGEMENT

The author wishes to express his sincere appreciation and gratitude to the following persons who assisted in the preparation of this thesis.

To his wife Elaine, who continually encouraged and supported his studies.

Dr. J. B. McLaren, major professor, for his direction of the research and for his critical review of the manuscript.

Professor E. R. Lidvall for his encouragement, timely assistance, and guidance during the course of graduate study.

Dr. C. S. Hobbs, department head, for his encouragement in pursuing a graduate program and for serving on the graduate committee.

Dr. William R. Backus for his assistance and guidance and for serving on the graduate committee.

Dr. R. Shrode for serving on the graduate committee and for his interest and suggestions.

To the many quarter horse owners and trainers who offered their horses for use in this experiment.

ABSTRACT

Various body measurements were collected on 136 horses from 22 leading Quarter Horse farms in the Southeast. Offspring, ranging in age from one month to maturity, from 43 stallions were included in the study. Factors developed by Cunningham and Fowler (1961) were used to adjust each measurement to a mature-equivalent, sex-constant basis. Several horses were measured twice at six months interval and coefficients of intra-class correlation between the two adjusted measurements ranged from .454 to .987.

The mean values for all measurements at each age, except for width of chest, were larger for males than for females. Average mature values were larger for males except width of head, depth of neck, length of body, depth of hindflank and depth of foreflank. Males tended to be larger than females, for most measurements taken, from birth to three months of age. However, the females tended to grow faster from three to six months and at six months of age were about the same size as the males. Although males tended to increase in size faster from six months of age to maturity, there was little difference between males and females at maturity. Linear growth increased faster than width growth in both males and females.

Males achieved 99.6 percent of their elbow to ground growth and 100 percent of their knee to ground and hock to ground growth by 12 months of age. Females developed slower in the foreleg area attaining only 97.2 percent of their mature elbow to ground growth and

98.7 percent of their knee-to-ground growth by 12 months of age. However, they achieved 100 percent of their hock-to-ground growth by six months of age. Both males and females reached 100 percent of their height at withers by 36 months of age.

Heart girth was highly related ($P < .01$) to height at withers ($r = .93$), length of body ($r = .95$), width of quarters ($r = .93$), depth of foreflank ($r = .95$), circumference of cannon bone ($r = .89$) and body weight ($r = .90$). It was concluded that heart girth was a good indicator of many different measurements of development.

The estimates of genetic parameters calculated in this study were biased due to the confounding of herd effects and sire effects. However, these results indicated that the procedures used in this study would be satisfactory for use in adjusting data from which genetic parameters are to be estimated.

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CHAPTER I

INTRODUCTION

The number of horses in the United States has increased at an accelerated rate during the last fifteen years. The present horse population has been estimated to be over 7.5 million head. This industry, with its related jobs, has been estimated to provide over 164,000 jobs and to exceed 12 billion dollars in value. Thus, the horse industry has become a vital force in our economy, as well as a growing segment of our nation's recreational activities.

Leading this growth in horse numbers has been the American Quarter Horse. Since its development as a recognized breed in the early 1940's, it has grown more than three times as fast as any other breed. The Quarter Horse acquired its name in colonial times due to its ability to run short distances, up to one-quarter mile, with a remarkable speed unequalled by any other breed. Also, in the breed's history is a reputation for agility, intelligence, calm disposition and endurance. These qualities have combined to make it an ideal breed for many uses varying from ranch work and showing to general leisure-time riding.

However, with this resurgence in numbers there has not been a resurgence in equine research. This is especially true in the area of genetics and selective breeding programs. As far as can be determined from available literature, no work has been done in the area of heritability estimates for size and muscling in the Quarter Horse.

Knowledge of heritability estimates would provide the Quarter Horse breeder with information for evaluating and improving his breeding program. It would enable him to determine traits in which improvement could be made by mass selection. This could help the breeder reach a desired goal or correct a weakness in his breeding program more quickly and more accurately. Therefore, accurate estimates of genetic parameters could conceivably result in improvement of the entire breed due to the use of more effective selection and breeding programs.

The purpose of this study was to evaluate the use of adjustment factors to remove fixed environmental effects and to estimate coefficients of heritability of various traits of size and muscling in the Quarter Horse. It is hoped also that this study can be used as a basis for further research that is needed in equine breeding.

CHAPTER II

LITERATURE REVIEW

A review of the available literature revealed that very little information was available on growth and development in horses. Most of the work reported pertained to the growth rate of draft horses rather than light horses. Only one published article pertained to growth and development of the Quarter Horse.

I. GROWTH AND DEVELOPMENT OF THE DRAFT HORSE

In studying 297 light horses, Dawson et al. (1945) found that growth was normal from birth to 18 months of age when management and nutrition were adequate. These same horses developed more slowly when they were placed on range pasture at 18 months. Weight was affected more than height by these adverse conditions. Trowbridge and Chittenden (1932) reported that skeletal growth was noticeably different for colts fed limited grain rations and those fed more liberally. In this work, 50 to 60 percent of the total increase in body weight of the foals occurred during the first year of life. For some of the measurements which described growth or size, as much as 90 percent of the total increase had occurred by the end of the first year. In general, the measurements indicated a gradual deceleration of the growth process as an animal began to reach maturity at about four to five years of age. Duncan and Murphree (1957) working with draft mules reported that approximately 80 percent of the mature height was attained at six months of age. They also reported that approximately 9 percent of the mature weight was attained at birth and that approximately 60 percent was attained by one year of age.

Reporting a study involving 409 draft colts, Crampton (1923) suggested the following growth-weight relationships: one year of age, 50 percent of mature weight; two years of age, 75 percent; three years, 90 percent; and between four and five years of age mature weight was attained. This work was in agreement with Trowbridge and Chittenden (1932). In addition, Brody (1927) found that height at withers in draft horses was the first physical trait to reach maturity. This was followed by circumference of chest and weight, respectively.

Brody (1928) stated that environmental conditions, especially the differences in quality and amount of normal food intake, exerted a very marked influence on earliness or age of maturity. He concluded that early maturity resulted in efficient growth. This is due to the fact that the cost of maintaining animals is by far the largest item in the total cost of growth. He stated that the obvious practical application of this fact is to grow the animals rapidly and thereby save much of the cost of maintenance during growth. The mature weight of a draft horse, which is reached at four to five years of age, depends on a number of factors according to Crampton (1923a). He suggested that these factors are: (1) the inherited growth potential and (2) proper care, feed and management to allow expression of this potential. Crampton (1923b) found also that horses after four years of age gained little except fat when well-fed.

II. GROWTH AND DEVELOPMENT OF THE QUARTER HORSE

Cunningham and Fowler (1961) presented tables indicating the percentage of mature development for various traits measuring growth or size which Quarter Horses reach at different ages. These values for selected variables are shown in Chapter III. They reported a wide variation in the rate at which various measures of growth approached mature value. Length of leg (elbow to ground) was about 71 percent mature at birth in both sexes. Length of cannon bone (measured from knee to ground) was about 82 percent mature at birth. Height at withers and length of body were two of the earliest maturing linear measurements of growth. Body weight represented the smallest percentage of mature size at birth and was one of the last measures of growth to reach maturity.

III. ESTIMATION OF GENETIC PARAMETERS

Methods of Standardizing Analyses

High (1970) reported that in evaluating the genetic merit of an individual, the effects of various environmental factors such as year, location, sex, and season of birth should be considered. In order to determine the genotypic values of a group of animals, Lasley (1971) suggests the following steps: (1) standardize the environment, standardize the management practices, (3) determine the amount of inbreeding, (4) evaluate the production level of the individual families.

Heritability

Knapp and Nordskog reported the first estimates of heritability in 1946 (McLaren, 1970). Rice et al. (1962) stated that the estimation of coefficients of heritability depends upon an evaluation of the degree to which individuals with similar genotypes are more alike than unrelated or less closely related individuals. The two most widely used methods for estimating heritability are: (1) the parent-offspring method, and (2) the paternal half-sib method. A coefficient of heritability can also be defined as the fraction of the deviation of the parents from their generation mean that is expected to be transmitted to their progeny (Rice et al., 1962). They discussed also the importance of estimating coefficients of heritabilities for various traits. In a breeding program based on individual selection of the most desirable animals as potential parents, the anticipated progress is a function of heritability of the trait or traits being selected for and the superiority of the selected parents over the average of the population from which they were chosen. The intensity of selection determines the superiority of the individuals selected as potential parents.

Heritability, according to Lush (1940), may be defined as the fraction of the observed variance which was due to differences in heredity. McGuire (1969) interpreted this to indicate that heritability is the degree to which animals with similar genotypes resemble each other more than do less closely related animals. He suggested that heritability can be expressed as the genetic coefficient of determination of the phenotypic variation of a population, or a group of animals, for a particular characteristic. Assuming that phenotypic variance can be explained by genetic and environmental causes, the phenotypic (P) measure of a character can be expressed as:

$$P = H + E + HE$$

where H, E, and HE are the heredity, environmental and the genetic-environmental interaction factors, respectively. If all genetic effects are considered in estimating heritability, the estimate is referred to as heritability in the broad sense (Lush, 1940, 1945, 1948). This value is expressed as follows:

$$h_B^2 = \frac{\sigma H^2}{\sigma H^2 + \sigma E^2 + \sigma EH^2} = \sigma H^2 / \sigma P^2$$

Where: $\sigma H^2 = \sigma G^2 + \sigma D^2 + \sigma I^2$

With: σG^2 = genic variance

σD^2 = effect due to dominance

σI^2 = effect due to non-allelic gene combinations

σE^2 = effect due to environment

σEH^2 = effect due to genetic-environmental interaction

This is a measure of the expression of the genotypes as a whole. In order to obtain a more valid estimate of the heritability of a trait only that portion of the variation due to average gene effects is used and a "narrow sense" heritability may be expressed as follows:

$$h_N^2 = \sigma G^2 \Big/ \left(\sigma G^2 + \sigma D^2 = \sigma I^2 + \sigma E^2 + \sigma EH^2\right) = \sigma G^2 \Big/ \sigma P^2$$

As mentioned previously, there are two widely used methods of determining heritability. The paternal half-sib method will be used and discussed in this paper. Half-sibs have on the average one-fourth of their genes in common as compared to one-half with parent and offspring relationship (Rice _et al._, 1962). Paternal half-sibs are used since there are fewer maternal half-sibs in a set.

Falconer (1960) states that where half-sib data are used to estimate heritability, the variance component due to sires $\left(\sigma_S^2\right)$ from an anlysis of variance is equal to one-fourth the additive genetic variance for the trait. Furthermore, the error mean square or variance within families $\left(\sigma_W^2\right)$ is equal to the phenotypic variance plus three-fourths of the genetic variance. Snedecor (1956), Steel and Torrie (1960), Fisher (1967) and other statistical texts show that an intra-group correlation coefficient of half-sib data can be calculated as follows:

$$r_I = \sigma_S^2 \Big/ \sigma_W^2 + \sigma_S^2$$

Assuming no inbreeding, a sire contributes to each animal an average of one-fourth of the same genes as its half-sibs. Thus, the intra-sire correlation of half-sibs is due to these "common" genes and the intra-sire correlation is equal to one-fourth the genetic portion of the phenotypic variation. Heritability on a half-sib basis can be computed as follows:

$$\hat{h}^2_N = 4\ \sigma^2_S \Big/ \left(\hat{\sigma}^2_W + \hat{\sigma}^2_S \right)$$

Genetic Correlation

The relationship between phenotypes of two traits is measured by the phenotypic correlation. The phenotypic correlation includes the correlation between the genotypic values, correlation between environmental factors and the correlation between non-additive genetic effects. For computational purposes, the last two components are combined (McLaren, 1970).

Genetic correlation is the ratio of the genetic covariance between the two traits and the product of the square root of their genetic variance. According to Lush (1948), the formula may be written as:

$$\hat{r}_{G_1G_2} = \frac{\widehat{\overline{\text{Cov } G_1G_2}}}{\sigma G_1 \sigma G_2}$$

Where: $\widehat{\overline{\text{Cov } G_1\ G_2}}$ is the estimate of genetic covariance between the two traits.

CHAPTER III

EXPERIMENTAL PROCEDURE

I. SOURCE OF DATA

Data were collected on horses from 22 leading Quarter Horse farms in the Southeast. The study included 136 individual animals, 36 of which were measured twice (initially and six months later) during the six-month study. Offspring from 43 stallions were included in the study with a minimum of three offspring from each stallion.

II. MEASUREMENT PROCEDURE

All animals were measured in a normal standing position with most being haltered and held by an assistant. The following measurements were taken on various body parts:

1. Head measurements
    (a) Length of head
    (b) Width of head
2. Neck measurements
    (a) Length of neck
    (b) Depth of neck
3. Body measurements
    (a) Height at withers
    (b) Length of body
    (c) Width of chest

(d) Width of quarters

(e) Heart girth

(f) Depth of foreflank

(g) Depth of hindflank

4. Leg measurements

(a) Circumference of forearm muscle

(b) Foreleg length (elbow to ground)

(c) Foreleg length (knee to ground)

(d) Hind leg length (hock to ground)

(e) Circumference of cannon bone

5. Condition score

6. Withers rating

7. Weight

All linear measurements were recorded in inches. The description of the measurements are as follows:

1. Length of head. The distance from the center of the poll to the middle of the nostrils, as measured with a steel tape.

2. Width of head. The distance across the widest point of the head, as measured with a wooden caliper.

3. Length of neck. The distance from the top of the withers to the center of the poll, with the head in a normal position, as measured with a steel tape.

4. Depth of neck. The depth through the shoulderbed, as measured with a wooden caliper.

5. Height at withers. The distance from the ground to the highest point of the withers, as measured with a conventional measuring stick and a steel tape.

6. Length of body. The distance from the point of the shoulder to a straight edge held flush across the point of the buttocks, with the horse standing normally, as measured with a steel tape.
7. Width of chest. The distance between the points of the shoulders, as measured with a wooden caliper.
8. Width of quarters. The distance across the widest point of the quarters, as measured with a wooden caliper.
9. Heart girth. The distance along a steel tape drawn tight around the body just behind the forelegs and at the base of the withers.
10. Depth of fore flank. The vertical distance from the chest floor just behind the forelegs to the base of the withers, as measured with a wooden caliper.
11. Depth of hind flank. The vertical distance from the flank just forward of the stifle to the top of the back, as measured with a wooden caliper.
12. Circumference of forearm muscle. The distance along a steel tape drawn tight around the forearm muscle at the elbow.
13. Foreleg length (elbow to ground). The distance from the elbow to the ground, as measured with a steel tape.
14. Foreleg length (knee to ground). The distance from the mid-point of the knee joint to the ground, as measured with a steel tape.
15. Hind leg length (hock to ground). The distance from the point of the hock to the ground, as measured with a steel tape.

16. <u>Circumference of cannon bone</u>. The distance along a steel tape drawn tight around the cannon bone midway between the knee and the fetlock.

17. <u>Condition score</u>. Subjective appraisal of the animal with a score assigned according to the following scale: (1) thin, (2) moderate flesh, (3) fat.

18. <u>Withers rating</u>. Subjective appraisal of the animal with a score assigned according to the following scale: (1) flat, mutton withers, (2) moderately flat, (3) moderately sharp, and (4) sharp.

19. <u>Weight</u>. Determined by weighing in a portable scale to the nearest pound.

III. ADJUSTING FOR FIXED ENVIRONMENTAL EFFECTS

In a preliminary analysis the object was to compute sums of squares and products as in a standard analysis of variance and covariance of comparable orthogonal data. It was assumed that fitting of condition score would remove some of the variation between farms or locations. It was intended to equate appropriate variances and covariances from this analysis to their expected values under the assumption that all effects were random and non-correlated. By this procedure, components of variance and covariance could be calculated according to Method I described by Henderson (1953) without adjusting each record. However, dependency among the subclasses of different independent variables resulted in biased estimates of certain parameters.

Prior to the final analysis, the actual measurements were adjusted to a mature equivalent, sex-constant basis using the factors developed by Cunningham and Fowler (1961). These facts are shown in Tables 1 and 2. To determine the reliability of their factors, measurements of 36 animals, taken at different ages, were adjusted to a mature basis. An intra-class correlation between the two estimates of the mature value of the various traits was computed. On the basis of these intra-class correlations, presented in Table 3, it was assumed that the factors were satisfactory for removal of variation due to age of the animal when measured.

Least-squares estimates of the effect of various farms and condition scores of the individual animal were used to adjust the data for the influence of farm and nutritional level. However, a better test of the effectiveness of the factors would be to estimate variance due to age differences in age-adjusted records. This test was conducted, and the results are given in Chapter IV.

IV. ESTIMATION OF GENETIC PARAMETERS

The adjusted data were analyzed on a within-sire basis, using Method II suggested by Henderson (1953). The variance and covariance were equated to their expected value to solve for the components of variance and covariance.

Heritability estimates were obtained by the method discussed by Lush (1948) as:

Table 1. Percentage of mature size attained at various ages by Quarter Horse males[1]

Age	No.	Weight	Length of Head	Width of Head	Length of Neck	Depth of Neck	Height at Withers	Length of Body	Width of Chest	Width of Quarters	Circ. of Heart Girth	Depth of Foreflank
Birth	5	08.5	58.4	62.7	43.6	37.8	60.0	47.2	36.8	40.0	42.5	43.6
3 mo.	6	25.3	74.8	74.7	62.4	56.2	72.9	67.1	55.4	60.7	61.8	62.0
6 mo.	11	43.8	83.8	81.9	74.7	68.3	82.1	78.6	67.0	73.7	74.5	73.5
12 mo.	7	57.8	89.5	87.6	81.5	75.0	89.4	89.0	77.0	82.1	83.4	82.4
18 mo.	9	81.3	97.3	94.4	92.2	88.3	95.3	95.2	87.4	91.1	96.5	92.9
24 mo.	9	87.3	98.0	96.9	97.4	89.7	97.7	100.0	88.5	93.6	97.3	93.6
36 mo.	3	92.6	100.0	100.0	100.0	100.0	93.4	98.2	92.0	93.9	98.5	98.2
48 mo.	3	96.8	100.0	100.0	96.2	99.1	93.9	98.9	95.9	100.0	99.4	93.2
60 mo.	13	100.0	99.9	98.7	100.0	98.7	100.0	100.0	99.9	100.0	100.0	99.9

Age	No.	Depth of Hindflank	Circ. of Forearm Muscle	Elbow to Ground	Knee to Ground	Hock to Ground	Circ. of Cannon Bone	Width of Cannon Bone	Depth of Cannon Bone	Circ. of Hoofhead	Withers Rating
Birth	5	47.9	49.0	70.7	81.2	78.2	58.7	64.4	56.1	49.9	48.0
3 mo.	6	69.0	66.7	82.1	90.5	86.1	72.0	69.0	69.1	64.1	46.8
6 mo.	11	80.4	78.5	89.2	100.0	96.3	82.2	79.9	79.9	74.0	43.6
12 mo.	7	84.4	83.9	93.5	100.0	98.1	90.9	86.8	88.8	82.9	80.0
18 mo.	9	93.2	93.8	100.0	100.0	99.1	93.8	94.3	96.0	90.7	57.6
24 mo.	9	99.0	94.3	100.0	100.0	99.3	98.4	97.7	99.6	93.3	93.2
36 mo.	3	98.2	93.4	99.2	96.5	100.0	99.1	97.7	98.2	92.8	93.2
48 mo.	3	96.3	96.1	98.6	97.6	99.6	100.0	100.0	100.0	98.8	100.0
60 mo.	13	99.9	99.9	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

[1]Cunningham and Fowler (1961).

Table 2. Percentage of mature size attained at various ages by Quarter Horse females[1]

Age	No.	Weight	Length of Head	Width of Head	Length of Neck	Depth of Neck	Height at Withers	Length of Body	Width of Chest	Width of Quarters	Circ. of Heart Girth	Depth of Foreflank
Birth	6	08.3	57.5	59.3	47.4	40.2	61.0	43.3	41.1	43.6	41.6	42.5
3 mo.	16	28.0	73.6	74.4	68.3	59.1	76.4	65.6	64.1	65.7	64.0	63.2
6 mo.	26	43.7	82.6	82.0	78.2	72.6	84.5	76.2	74.6	75.9	74.8	74.8
12 mo.	22	62.5	89.4	89.4	89.1	82.1	91.9	86.2	86.7	84.9	85.2	84.7
18 mo.	15	77.2	94.7	93.5	92.3	92.9	95.4	91.1	94.6	92.4	92.2	91.2
24 mo.	22	81.0	95.8	95.6	97.3	97.1	96.4	94.2	94.7	94.4	94.5	94.6
36 mo.	12	91.5	97.5	96.0	100.0	99.9	97.7	98.4	97.6	95.1	97.0	98.1
48 mo.	9	98.5	99.4	98.5	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
60 mo.	60	100.0	100.0	100.0	97.8	98.5	99.7	100.0	99.9	99.3	98.8	99.1

Age	No.	Depth of Hindflank	Circ. of Forearm Muscle	Elbow to Ground	Knee to Ground	Hock to Ground	Circ. of Cannon Bone	Width of Cannon Bone	Depth of Cannon Bone	Circ. of Hoofhead	Withers Rating
Birth	6	42.8	52.0	70.6	81.7	80.0	59.7	62.4	58.6	49.3	35.7
3 mo.	16	64.9	73.7	85.8	93.4	92.2	75.8	73.3	74.3	63.6	35.7
6 mo.	26	77.0	85.9	92.5	99.4	98.7	83.4	81.2	83.9	75.1	41.1
12 mo.	22	81.7	94.1	96.4	99.9	99.7	93.8	91.5	95.8	84.7	56.8
18 mo.	15	89.5	100.0	100.0	100.0	100.0	96.9	95.8	99.2	90.2	63.2
24 mo.	22	90.0	99.9	98.5	100.0	100.0	97.0	97.0	100.0	91.9	74.6
36 mo.	12	93.4	99.0	98.4	98.4	99.1	97.0	98.2	98.9	93.6	80.4
48 mo.	9	97.6	100.0	100.0	100.0	100.0	98.8	100.0	100.0	98.0	95.4
60 mo.	60	100.0	96.5	100.0	99.4	100.0	100.0	100.0	100.0	100.0	98.9

[1]Cunningham and Fowler (1961).

Table 3. Intra-class correlation between mature equivalents of animals measured twice

Measurement	Intra-class Correlation (r_I)
Length of Head	.454
Width of Head	.781
Length of Neck	.712
Depth of Neck	.696
Height at Withers	.720
Length of Body	.722
Width of Chest	.820
Width of Quarters	.623
Heart Girth	.608
Depth of Foreflank	.604
Depth of Hindflank	.527
Circumference of Forearm Muscle	.640
Foreleg Length (elbow to ground)	.987
Foreleg Length (knee to ground)	.705
Hindleg Length (hock to ground)	.740
Circumference of Cannon Bone	.787
Body Weight	.894

$$\hat{h}^2 = \frac{4\hat{\sigma}^2_S}{\hat{\sigma}^2_S + \hat{\sigma}^2_W}$$

where: $\hat{\sigma}^2_S$ is the estimate of the component of variance due to differences between sires,

$\hat{\sigma}^2_W$ is the estimate of the component of variance due to differences among paternal half-sibs.

Algebraically, genetic correlation is the ratio of the genetic covariance between the two traits and the product of the square roots of their genetic variances. In this study, the value was computed as follows:

$$\hat{r}_{G_1 G_2} = \frac{\hat{Cov}\ G_1 G_2}{\hat{\sigma} G_1 \hat{\sigma} G_2}$$

where: Cov G_1 G_2 is the genetic estimate of covariance between the two traits.

CHAPTER IV

RESULTS AND DISCUSSION

I. GROWTH AND DEVELOPMENT

Several factors can influence the normal growth pattern and development of an individual. These factors include: environment, plane of nutrition, inherent growth potential, sex, type, and chance variation. Also, drastic changes in management practices over a prolonged period of time can change the shape of a growth curve.

Due to differences in these environmental factors, it would be difficult, if not impossible, to derive a uniform growth curve for the entire Quarter Horse breed. However, some accurate method of predicting mature values of various traits at an early age would be valuable in a selection program. Therefore, the results of this experiment and other similar reports should provide information which will increase the predictive value of early indices of mature size and development. The results of this experiment are in general agreement with those found by Cunningham and Fowler (1961) concerning growth percentages and growth data.

Mean Body Measurements

Average body measurement with respect to size would be useful in a breeding program to determine the direction in which that breeding program was progressing. Mean body measurements of Quarter Horse males taken at various ages are presented in Table 4. Similar measurements for Quarter Horse females are shown in Table 5.

There was variation in some measurements after the animals had apparently reached mature age. This variation was due to a difference in condition and/or other environmental factors as well as differences in genetic potential for growth. More animals in the younger age groups were measured than in the older age groups. The values presented are least-squares means.

The mean value of all of the measurements, except width of chest, taken between birth and three months of age were greater for males than females. The greatest difference between measurements of males was found in heart girth, height at withers and length of head. The measurements which were most similar at birth were depth of hindflank, circumference of cannon bone and width of head.

Mean values of all measurements taken at later ages, except width of head, depth of neck, length of body, depth of hindflank and depth of foreflank, were greater for males than for females. Cunningham and Fowler (1961) generally found the same results. The measurements with the greatest differences between males and females were length of body and circumference of forearm muscle. The length of body of the mature males were 3.71 in. shorter than the females measured. The mature males had a 2.38 in. larger circumference of forearm muscle than did the females. The measurement with the most similarity was the length from elbow to ground with both mature males and females measuring 35.50 in. In general, males tended to be larger than females for most measurements taken between birth and three months of age.

Table 4. Least-squares means and their standard errors for differences in measurements for Quarter Horse males from birth to 60 months of age

	Age																	
	Birth		3 mo.		6 mo.		12 mo.		18 mo.		24 mo.		36 mo.		48 mo.		60 mo.	
Measurement	Av.[a]	S.E.[b]	Av.[a]	S.E.[b]	Av.[a]	S.E.[b]	Av.[a]	S.E.[b]	Av.[a]	S.E.[b]	Av.[a]	S.E.[b]	Av.[a]	S.E.[b]	Av.[a]	S.E.[b]	Av.[a]	S.E.[b]
Length of Head (in.)	18.11	.58	18.44	.46	20.55	.60	21.25	.32	22.47	.34	22.69	.19	23.11	.26	23.24	.32	22.56	.37
Width of Head (in.)	6.46	.27	7.14	.21	7.89	.28	8.08	.15	8.40	.16	8.48	.09	8.59	.12	8.69	.15	8.81	.17
Length of Neck (in.)	19.29	1.37	20.14	1.09	25.00	1.41	27.16	.77	27.74	.80	27.98	.46	29.07	.62	31.44	.76	29.20	.88
Depth of Neck (in.)	11.74	.77	11.56	.62	15.90	.80	16.10	.44	17.61	.45	17.98	.26	17.63	.35	18.70	.43	18.44	.50
Height at Withers (in.)	46.04	1.21	47.82	.98	53.08	1.26	56.21	.68	58.02	.71	58.24	.40	58.62	.55	59.36	.68	58.41	.78
Length of Body (in.)	39.34	1.54	42.90	1.24	54.64	1.60	54.33	.87	57.98	.90	59.62	.51	59.68	.70	61.50	.86	61.03	.99
Width of Chest (in.)	11.01	.71	12.08	.57	14.43	.73	14.37	.40	15.97	.41	15.60	.24	15.63	.32	16.96	.40	17.29	.45
Width of Quarters (in.)	14.36	.88	15.23	.70	18.61	.91	18.94	.49	20.64	.51	21.19	.29	21.34	.40	22.56	.49	22.60	.56
Heart Girth (in.)	46.98	1.59	50.34	1.28	60.20	1.64	63.98	.90	68.89	.92	70.29	.53	70.01	.72	73.23	.89	72.45	1.02
Depth of Foreflank (in.)	17.57	.79	17.81	.64	22.05	.82	23.20	.45	25.91	.46	25.36	.26	25.60	.36	26.95	.44	26.01	.51
Depth of Hindflank (in.)	12.34	.78	12.50	.63	16.33	.81	16.96	.44	18.70	.46	17.92	.26	17.94	.36	18.38	.44	18.06	.50
Circ. of Forearm Muscle (in.)	17.94	1.10	18.33	.88	19.19	1.14	22.16	.62	21.65	.64	22.52	.37	22.31	.50	23.71	.62	24.68	.71
Elbow to Ground (in.)	31.61	1.04	32.00	.83	33.22	1.07	35.36	.59	36.28	.60	35.56	.34	34.84	.47	35.86	.58	35.50	.67
Knee to Ground (in.)	17.21	.57	17.51	.46	18.05	.59	18.74	.32	18.87	.33	18.13	.19	18.12	.26	18.17	.32	18.24	.37
Hock to Ground (in.)	21.99	.65	22.35	.52	23.05	.67	23.90	.37	23.93	.38	23.60	.22	23.70	.30	23.65	.36	23.60	.42
Circ. of Cannon Bone (in.)	5.83	.28	6.13	.22	6.55	.29	7.34	.16	7.69	.16	7.45	.09	7.80	.13	7.86	.16	7.81	.18
Weight (lb.)	409	95.6			622	48.8	761	33.7	879	29.8	962	19.2	1045	34.2	1091	56.8		

[a]Least-squares mean.

[b]Standard error.

Table 5. Least-squares means and their standard errors for differences in measurements for Quarter Horse females from birth to 60 months of age

	Age																	
	Birth		3 mo.		6 mo.		12 mo.		18 mo.		24 mo.		36 mo.		48 mo.		60 mo.	
Measurement	Av.[a]	S.E.[b]	Av.[a]	S.E.[b]	Av.[a]	S.E.[b]	Av.[a]	S.E.[b]	Av.[a]	S.E.[b]	Av.[a]	S.E.[b]	Av.[a]	S.E.[b]	Av.[a]	S.E.[b]	Av.[a]	S.E.[b]
Length of Head (in.)	15.73	.34	18.39	.57	20.35	.46	20.74	.28	21.60	.34	22.36	.17	22.36	.26	22.00	.32	22.76	.57
Width of Head (in.)	6.19	.14	7.58	.24	8.07	.20	7.98	.12	8.34	.14	8.53	.07	8.77	.11	8.58	.13	9.33	.24
Length of Neck (in.)	17.22	.83	23.79	1.39	24.74	1.14	27.43	.70	26.01	.83	28.47	.41	28.09	.64	28.06	.79	27.54	1.39
Depth of Neck (in.)	10.83	.42	13.19	.71	15.19	.58	16.33	.35	17.61	.42	18.25	.21	18.81	.32	18.04	.40	17.49	.71
Height at Withers (in.)	43.64	.61	47.66	1.03	53.04	.84	54.84	.51	57.60	.61	58.06	.30	58.82	.47	58.96	.58	58.66	1.03
Length of Body (in.)	38.16	1.62	46.24	1.33	52.85	.81	55.61	.96	55.29	.48	59.34	.74	59.89	.92	59.54	.96	64.74	1.62
Width of Chest (in.)	11.20	.69	13.01	.56	13.83	.34	14.72	.41	15.10	.20	15.60	.32	15.26	.39	15.78	.69	16.81	.41
Width of Quarters (in.)	14.07	.44	16.40	.75	18.20	.61	19.10	.37	19.68	.44	21.17	.22	21.44	.34	22.16	.42	22.95	.75
Elbow to Ground (in.)	31.13	.81	31.50	1.37	33.76	1.12	34.51	.68	33.21	.81	35.22	.40	35.00	.63	35.01	.78	35.50	1.37
Knee to Ground (in.)	16.77	.30	17.44	.50	17.35	.41	17.21	.25	18.27	.30	17.72	.14	18.00	.23	17.54	.28	17.44	.50
Hock to Ground (in.)	21.48	.33	22.42	.55	23.18	.45	23.30	.28	23.71	.33	23.72	.16	23.50	.25	23.67	.31	22.79	.55
Circ. of Cannon Bone (in.)	5.60	.12	6.34	.20	6.71	.17	6.92	.10	7.19	.12	7.44	.06	7.51	.09	7.63	.12	7.59	.20
Heart Girth (in.)	44.15	1.04	51.98	1.74	59.10	1.43	63.26	.87	66.48	1.04	69.89	.51	70.31	.80	70.98	.99	73.61	1.74
Depth of Foreflank (in.)	16.43	.39	19.50	.65	22.16	.54	23.58	.33	24.69	.39	25.53	.19	25.46	.30	25.78	.37	26.55	.65
Depth of Hindflank (in.)	12.33	.40	14.16	.68	16.39	.55	17.36	.34	17.12	.40	18.00	.20	18.28	.31	17.54	.38	19.91	.68
Circ. of Forearm Muscle (in.)	15.98	.58	18.17	.97	17.86	.79	20.86	.48	19.64	.58	22.42	.28	22.41	.44	22.01	.55	22.30	.97
Weight (lb.)					648	92.7	775	84.2	952	54.8	974	39.4	1075	78.0	1145	91.2		

[a]Least-squares mean.

[b]Standard error.

However, the females tended to grow faster from birth to six months and at six months were about the same size as the males of that age. From six months of age to maturity, males tended to increase in size faster than females. On the other hand, at maturity, there was little difference between males and females in most measurements. Figure 1 shows the male and female growth curve for height at withers.

Standard Error of Measurements

A standard error is a statistical measure of variation. When this value is added to or substracted from the mean measurement the resulting values represent the expected limits within which about two-thirds of a population would fall. This value gives some indication of variability in the sample or population. In this case, the population would be the horses in this study. Standard errors for these measurements are listed in Tables 4 and 5. The standard error for various measurements of the males in this study tended to increase as age increased. The standard error of the same measurements for females tended to decrease as age increased. Cunningham and Fowler (1961) reported that standard deviations tended to increase from birth to maturity. The difference between the variability at different ages between these results and those reported by Cunningham and Fowler (1961) can be explained by the fact that they reported standard deviations and in this study standard errors were used to describe the populations.

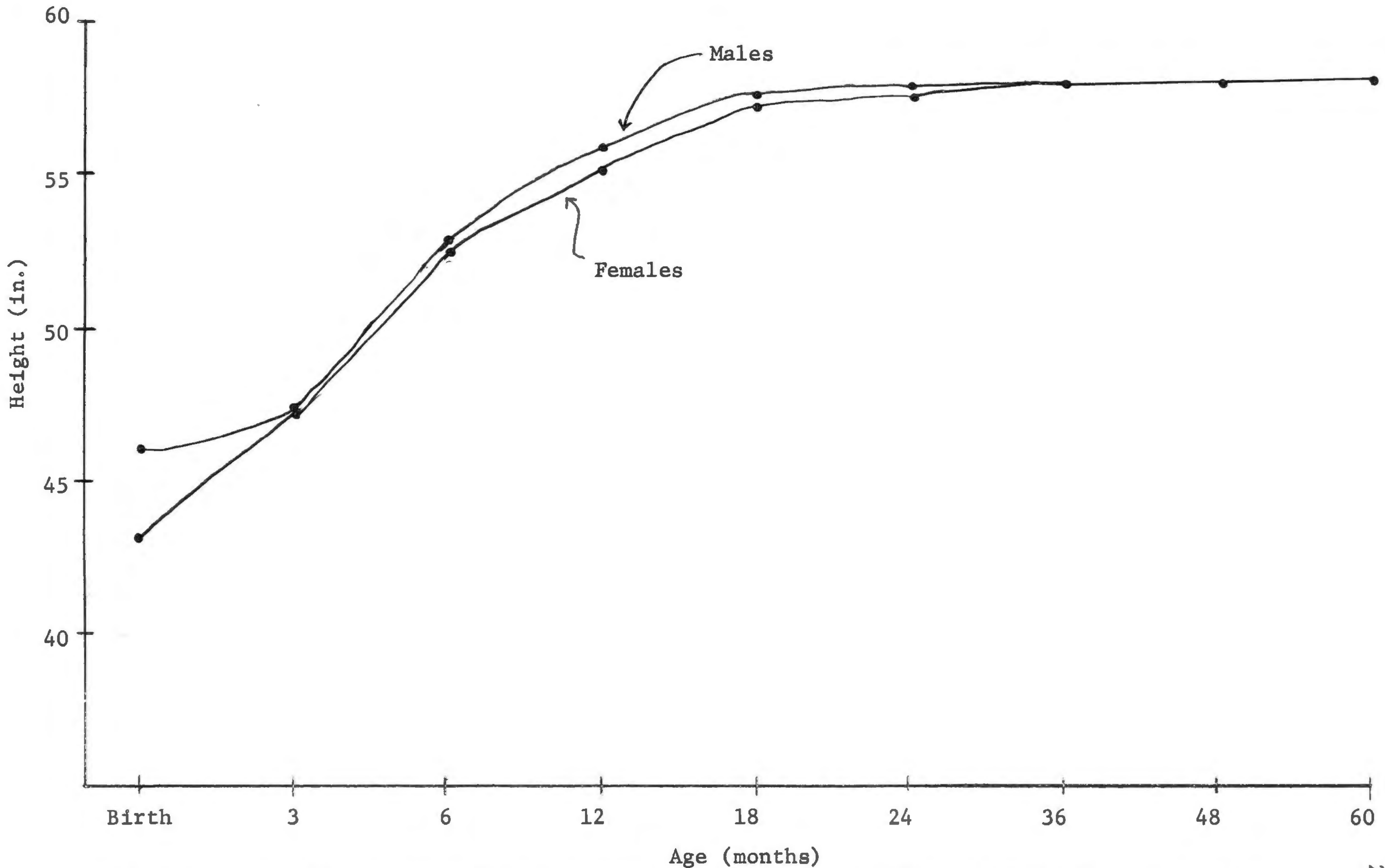

Figure 1. Growth curve (height at withers) of Quarter Horse males and females from birth to 60 months of age.

Rate of Development of Body Parts

The rate of development of various body components is important in a breeding program for two reasons. Cunningham and Fowler (1961) site these as: (1) it aids in evaluating an animal as to conformation or type by placing relative values on various regions of the body with respect to expected percentage of mature size present at a given age and (2) it serves as an index to proper feeding and management by pointing out critical periods in growth and development. The percentages of mature size for various body components attained by male and female Quarter Horses at different ages are shown in Tables 6 and 7.

In general, the male Quarter Horses were larger at birth and reached maturity faster than the females with the exception of two measurements. These measurements were from knee to ground and from hock to ground. Although females were smaller at birth, they tended to have more rapid growth, and a greater percentage of the mature size for the various measurements was attained at earlier ages than did the males.

Linear growth increased faster than did width growth in both males and females. Linear measurements also tended to reach mature values at younger ages than did width measurements. This indicated that poor nutrition in older animals has little effect upon linear growth. This information points out also the need for proper nutrition and management during the early development stages of an animal, especially between birth and 12 months of age.

The percentages of mature size listed for early ages are in slight disagreement with the findings of Cunningham and Fowler (1961).

Table 6. Percentage of mature size attained at various ages by Quarter Horse males

Age	Length of Head	Width of Head	Length of Neck	Depth of Neck	Height at Withers	Length of Body	Width of Chest	Width of Qtrs.	Heart Girth	Depth of Fore-flank	Depth of Hind-flank	Circ. of Forearm Muscle	Elbow to Ground	Knee to Ground	Hock to Ground	Circ. of Cannon Bone
Birth	80.3	73.3	66.1	63.7	78.8	64.5	63.7	63.5	64.8	67.5	68.3	72.7	89.0	94.4	93.3	74.6
3 mo.	81.7	81.1	69.0	62.7	81.9	70.3	69.8	69.8	69.5	68.4	69.2	74.3	90.2	96.0	94.8	78.5
6 mo.	91.1	89.5	85.6	86.2	90.9	89.5	83.4	83.4	83.1	84.8	90.4	77.8	93.6	98.9	97.8	83.8
12 mo.	94.2	91.8	93.0	87.3	96.2	89.0	83.1	83.1	88.3	89.2	93.9	89.8	99.6	100.0	100.0	94.0
18 mo.	99.6	95.4	95.0	95.5	99.3	95.0	92.3	92.3	95.1	99.6	100.0	87.7	100.0	100.0	100.0	98.5
24 mo.	100.0	96.2	95.8	97.5	99.7	97.7	90.2	90.2	97.0	97.5	99.2	91.3	100.0	99.3	100.0	96.8
36 mo.	100.0	97.6	99.6	95.6	100.0	97.8	90.4	90.4	96.6	98.4	99.3	90.4	98.2	99.3	100.0	99.8
48 mo.	100.0	98.6	100.0	100.0	100.0	100.0	98.1	98.1	100.0	100.0	100.0	96.1	99.9	99.6	100.0	100.0
60 mo.	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

Table 7. Percentage of mature size attained at various ages by Quarter Horse females

Age	Length of Head	Width of Head	Length of Neck	Depth of Neck	Height at Withers	Length of Body	Width of Chest	Width of Qtrs.	Heart Girth	Depth of Fore-flank	Depth of Hind-flank	Circ. of Forearm Muscle	Elbow to Ground	Knee to Ground	Hock to Ground	Circ. of Cannon Bone
Birth	69.1	66.4	62.5	61.9	74.4	58.9	66.6	61.3	60.0	61.9	61.9	71.6	87.7	96.2	92.3	73.9
3 mo.	80.8	81.2	86.4	75.4	81.2	71.4	77.4	71.4	70.6	73.4	71.1	81.5	88.7	100.0	98.4	83.5
6 mo.	89.4	86.6	89.8	86.9	90.4	81.6	82.3	79.3	80.3	83.5	82.3	80.1	95.1	99.5	100.0	88.4
12 mo.	91.1	85.5	99.6	93.4	93.5	85.9	87.6	83.2	85.9	88.8	87.2	93.5	97.2	98.7	100.0	91.2
18 mo.	94.9	89.4	94.5	100.0	98.2	85.4	89.8	85.8	90.3	92.9	85.9	88.1	93.6	100.0	100.0	94.8
24 mo.	98.2	91.4	100.0	100.0	99.0	91.6	92.8	92.2	95.0	96.2	90.3	100.0	99.2	100.0	100.0	98.1
36 mo.	98.2	94.0	100.0	100.0	100.0	92.5	90.7	93.4	95.5	95.9	91.8	100.0	98.6	100.0	100.0	99.0
48 mo.	96.6	92.0	100.0	100.0	100.0	92.0	93.9	96.5	100.0	97.1	88.1	100.0	98.6	100.0	100.0	100.0
60 mo.	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

However, in general, the trends in growth and development were similar in both studies. The need for further study in the area of growth and development in young foals is obvious.

The earliest measurements to reach mature value were the lower limb measurements, knee to ground and hock to ground. In Quarter Horse females, the mature size of both measurements was reached by the time the foal was six months of age. The males reached maturity with respect to these two measurements by 12 months of age. Although the majority of a horse's mature leg length was reached by a year of age, he did not reach maturity with respect to wither height until 36 months of age. This could be due to the slow development in the foreflank area which does not approach maturity as fast as do the legs.

In the modern Quarter Horse shows, criteria of evaluation tend to discriminate against long heads and thick necks. The results of this study indicate that development of the Quarter Horse with respect to these measurements was rapid at young ages and tended to slow as maturity was approached. This growth pattern substantiates the old adage that "a horse grows to his head." Both males and females had attained over 80 percent of their mature head length by three months of age. In addition, they had achieved over 85 percent of their head width by six months of age. Therefore, a person buying a young foal with plans for showing it would be relatively sure that most of the foal's head growth is completed if he is six months of age or older. On the other hand, a foal at three months of age has attained only about 60 percent of its mature depth of neck. Therefore, a foal with a thick neck will tend to increase in depth of neck as he approaches maturity. In addition, a short-necked foal will tend to be a short-necked mature horse since over 85 percent of its mature length of neck is achieved by six months of age.

In forearm development, contrasting differences were found between males and females. Circumference of forearm muscle of females reached maturity by 24 months of age. On the other hand, circumference of forearm muscle did not reach maturity in the males until 60 months of age. This is in agreement with findings of Cunningham and Fowler (1961). However, width of quarters, another indication of muscling, showed somewhat the opposite trend. For this measurement the males tended to increase in width at earlier ages, but both males and females did not reach their full width until maturity.

Relationships Among Weights and Measurements

Coefficients of correlation were calculated between members of pairs of measurements. These correlations are shown in Table 8.

The measurement most closely associated with height at withers is depth of foreflank ($r = .936$) followed closely by circumference of heart girth ($r = .932$). Two common laymen measurements used to predict the approximate mature size of a horse are twice the foreleg length or four times the knee to ground length. The results of this study indicate that these predictions are less accurate than is generally assumed. The correlations of elbow to ground and knee to ground with height at withers is ($r = .68$) and ($r = .44$), respectively.

Heart girth is a measurement often used by horsemen as a general indication of size and strength. This tended to remain true in this

Table 8. Correlations among body measurements of Quarter Horses

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
1. Len. of Head	1.00	0.85	0.81	0.82	0.90	0.90	0.76	0.83	0.90	0.89	0.80	0.73	0.58	0.43	0.60	0.87	0.73
2. Wid. of Head		1.00	0.78	0.81	0.85	0.89	0.79	0.86	0.87	0.85	0.82	0.79	0.51	0.37	0.55	0.84	0.69
3. Len. of Neck			1.00	0.79	0.83	0.85	0.75	0.85	0.84	0.83	0.75	0.79	0.54	0.35	0.57	0.78	0.76
4. Dep. of Neck				1.00	0.87	0.89	0.73	0.87	0.92	0.88	0.81	0.79	0.55	0.31	0.55	0.81	0.83
5. Ht. at Withers					1.00	0.92	0.78	0.88	0.93	0.93	0.86	0.78	0.68	0.44	0.68	0.89	0.83
6. Len. of Body						1.00	0.83	0.92	0.95	0.93	0.87	0.81	0.60	0.34	0.58	0.86	0.87
7. Wid. of Chest							1.00	0.83	0.83	0.83	0.72	0.75	0.50	0.27	0.51	0.77	0.57
8. Wid. of Qtrs.								1.00	0.83	0.83	0.90	0.79	0.86	0.57	0.32	0.86	0.87
9. Heart Girth									1.00	0.95	0.84	0.82	0.59	0.33	0.59	0.89	0.90
10. Dep. of Foreflank										1.00	0.84	0.78	0.61	0.34	0.59	0.88	0.78
11. Dep. of Hindflank											1.00	0.70	0.59	0.35	0.51	0.78	0.76
12. Circ. of Forearm Muscle												1.00	0.62	0.41	0.59	0.84	0.85
13. Elbow to Ground													1.00	0.57	0.68	0.67	0.44
14. Knee to Ground														1.00	0.60	0.47	0.44
15. Hock to Ground															1.00	0.62	0.41
16. Circ. of Cannon Bone																1.00	0.81
17. Weight																	1.00

study. Heart girth was highly and significantly related (P < .01) to height of withers (r = .93), length of body (r = .95), width of quarters (r = .93), depth of foreflank (r = .95), circumference of cannon bone (r = .89), and body weight (r = .90). Therefore, it was concluded that heart girth was a good indicator of many different measurements of development.

Length of head, an easily obtained measurement, was highly (P < .01) correlated with height at withers (r = .90) and length of body (r = .90). Width of head was not highly correlated with distance from elbow to ground (r = .51) and distance from knee to ground (r = .37). These results indicate width of head was a less accurate measure of size and/or muscling than are certain other measurements.

An easily obtained measurement indicating muscling is the circumference of the forearm muscle. It is highly correlated with width of quarters (r = .86). Horsemen have believed for years that bone size is highly correlated with overall muscle and mature size and that it is a good indication of overall muscling. In this study, circumference of cannon bone was highly (P < .01) correlated with height at withers (r = .89), width of quarters (r = .86), of heart girth (r = .89) and circumference of forearm muscle (r = .84). This information tends to substantiate the use of general bone size as an indicator of muscling and potential size.

Adjustment of the Measurements

Individual values for each measurement were adjusted to a mature-equivalent, sex-constant basis using factors calculated by

Cunningham and Fowler (1961). These factors are presented in Tables 1 and 2, pages 15 and 16. The use of these factors was based on the analysis of animals measured twice at intervals of not less than six months. The coefficients of intra-class correlation between mature-equivalent values of these two measurements are presented in Table 3, page 17. These coefficients ranged from .454 to .987 for the various measurements. It was concluded that these factors should be relatively efficient in removing variation due to age and sex of the animal. Analysis of variance of the effect of age, sex and condition of the animal on the mature-equivalent, sex-constant values for each measurement are shown in Table 9. With the exception of the measurement from hock to ground, and from knee to ground and of heart girth, the effect of sex was effectively removed by these adjustments. The adjustment factors were less effective in removing variation due to differences in age.

II. GENETIC PARAMETERS

Attempts were made to calculate estimates of heritability and genetic correlation. Both Methods I and II described by Henderson (1953) were used. The estimates of genetic parameters were biased due to the confounding of sire and herd effects.

The estimates of heritability are shown in Table 10. These values and the estimates of efficiency of the adjustment factor in removing variation due to differences in age and sex indicate that these procedures would be satisfactory for use in adjusting data from which

Table 9. Analysis of variance of the effect of age, sex and condition of the animals on mature-equivalent, sex-constant values for various measurements

		Mean Square															
Source	df	Length Head	Width Head	Length Neck	Depth Neck	Height Withers	Length Body	Width Chest	Width Qtrs.	Heart Girth	Depth F. Flank	Depth R. Flank	Circ. Forearm	Elbow Ground	Knee Ground	Hock Ground	Circ. Cannon
Cond. Score	2	4.72	0.19	4.95	1.63	0.27	17.46	13.49	1.22	0.46	4.09	1.19	7.62	0.46	2.50	0.46	0.01
Age	8	0.98	0.46	11.09	8.40	13.00	19.28	105.77	5.91	1.13	8.38	4.52	11.91	7.95	1.62	1.14	0.22
Sex	1	0.04	0.31	1.13	0.87	0.09	1.07	1.35	0.00	38.46	0.20	0.03	0.02	1.59	2.21	38.46	0.40
Residual	124	0.62	0.13	4.35	1.31	2.81	5.51	23.87	1.47	0.75	1.57	1.42	2.44	1.75	0.55	0.75	0.13

Table 10. Heritability estimates

Trait	$\hat{h}^2$
Length of Head	0.656
Width of Head	1.544
Length of Neck	1.741
Depth of Neck	1.495
Height at Withers	1.430
Length of Body	1.037
Width of Chest	0.359
Width of Quarters	1.391
Heart Girth	0.456
Depth of Foreflank	1.260
Depth of Hindflank	0.943
Circ. of Forearm	1.430
Elbow to Ground	1.422
Knee to Ground	0.477
Hock to Ground	0.456
Circ. of Cannon Bone	0.814

genetic parameters are to be estimated. These results indicate the need for further development, refinement and evaluation of adjustment factors to remove fixed environmental variation in equine breeding studies.

CHAPTER V

SUMMARY

Various body measurements were collected on 136 horses from 22 leading Quarter Horse farms in the Southeast. Offspring, ranging in age from one month to maturity, from 43 stallions were included in the study. Factors developed by Cunningham and Fowler (1961) were used to adjust each measurement to a mature-equivalent, sex-constant basis. Several horses were measured twice at six months interval and coefficients of intra-class correlation between the two adjusted measurements ranged from .454 to .987.

The mean values for all measurements at each age, except for width of chest, were larger for males than for females. Average mature values were larger for males except width of head, depth of neck, length of body, depth of hindflank and depth of foreflank. Males tended to be larger than females, for most measurements taken, from birth to three months of age. However, the females tended to grow faster from three to six months and at six months of age were about the same size as the males. Although males tended to increase in size faster from six months of age to maturity, there was little difference between males and females at maturity. Linear growth increased faster than width growth in both males and females.

Males achieved 99.6 percent of their elbow to ground growth and 100 percent of their knee to ground and hock to ground growth by 12 months of age. Females developed slower in the foreleg area attaining only 97.2 percent of their mature elbow to ground growth and 98.7 percent of their knee-to-ground growth by 12 months of age. However, they achieved 100 percent of their hock-to-ground growth by six months of age. Both males and females reached 100 percent of their height at withers by 36 months of age.

Heart girth was highly related ($P < .01$) to height at withers ($r = .93$), length of body ($r = .95$), width of quarters ($r = .93$), depth of foreflank ($r = .95$), circumference of cannon bone ($r = .89$) and body weight ($r = .90$). It was concluded that heart girth was a good indicator of many different measurements of development.

The estimates of genetic parameters calculated in this study were biased due to the confounding of herd effects and sire effects. However, these results indicated that the procedures used in this study would be satisfactory for use in adjusting data from which genetic parameters are to be estimated.

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VITA

James C. Heird was born December 28, 1948 in Blount County, Tennessee. He attended public schools at Friendsville and Maryville, Tennessee. He graduated from Maryville High School in 1966. He entered the University of Tennessee at Knoxville pursuing a Bachelor of Science degree in Animal Husbandry.

While at the University of Tennessee he was a member of the Block and Bridle Club and the Livestock and Quarter Horse Judging Teams. He was also active in helping to organize the Tennessee Quarter Horse Association.

After graduating from the University of Tennessee in 1970, he entered Graduate School at the same institution. Upon completion of his Master's degree, he plans to work for the North Carolina Extension Service as Horse Specialist.