UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA

Genetic parameters and breeding values for the South African warmblood horse population

By

Nicola Boers

Submitted to the department of Animal and Wildlife Sciences, faculty of Natural and Agricultural Sciences,
University of Pretoria

In partial fulfilment of the requirements for the degree of

M.Sc.(Agric)

PRETORIA
July 2001

Supervisor: Mr GTJ Vermeulen
Co-Supervisor: Dr GJ Delport

TABLE OF CONTENTS

1. INTRODUCTION

The South African Warmblood horse is a specialised sport horse for the disciplines of show jumping, dressage and eventing. Selection efforts are directed at improving sports performance and conformational correctness.

The possibility for rapid annual genetic improvement for performance traits in horse breeding is limited due to a long generation interval (Klemetsdal, 1990) and low reproductive efficiency. The generation interval is determined by the joint action of the age at first mating, the length of the horse's reproductive life, and the average number of offspring per parent. Every effort must therefore be made to select superior breeding stock in order to maximise this progress. Another reason for selection of superior breeding stock is the recent increase in the use of artificial insemination in the horse industry (Christmann and Bruns, 1997). The consequences of this increase in the use of artificial insemination are: 1) top stallions are bred to a larger number of mares; 2) The use of stallions is no longer linked to a small area, as it is possible to ship semen; 3) There is more competition between stallions.

Thus the South African Warmblood Horse Society, the governing body for Warmblood horses in the Republic of South Africa, needed an efficient method of identifying superior stock. The Society had been using individual selection up until the time of this project's implementation.

The method of individual selection as used by the South African Warmblood breeders, had many shortcomings,. Prior to this project, records had not been computerised, and consequently there was a lack of readily available information to breeders. This meant that breeders had limited access to information from other breeders in the country, and what they gleaned was from word of mouth. They had no access to other breeders' records or regularly published assessments. Additionally, their own records were often kept inaccurately. It was thus difficult for breeders to keep track of progress made in their own breeding programs and in other breeding programs in South Africa as they could only evaluate the progress by the horses they saw on their own farms and other breeders' farms, and by their own opinion of whether one year's foal crop was better than the previous years'.

In addition to inaccurate and non-computerised records, there was no knowledge of the population parameters. Therefore breeders did not know which traits to select for, and which would yield the greatest response and a correlated response in other traits. Thus the breeding programs were often blindly set about, and sometimes yielded athletic, desirable horses and other not.

Much research has been conducted on the Warmblood breeds of Europe, but this is the first research program to be implemented on the South African Warmblood horse population. It is hoped, as stated by Klemetsdal (1990), that genetic improvement will stimulate domestic horse production, and so reduce the cost connected with importation of high quality stock and increase the income from export of animals. It will reduce the labour cost involved in producing horses for competitions, due to the fact that better horses require less training than horses with conformational or mental aspects that need corrective training; as well as reducing the frequency of injuries that occur due to poor conformation and hence labour and recruiting costs involved with replacing an unsound horse.

1.1 The breeding goals of the South African Warmblood Horse Society

The breeding goal of the SA Warmblood Horse Society is to breed horses of internationally acceptable standards that will enable the South African riders and breeders to take their rightful place in the international equestrian arenas. An ideal Warmblood riding horse must be competitive in dressage, show jumping and eventing (Klemetsdal, 1990). This breeding goal is very similar to that of other Warmblood Societies in Europe and, as Arnason and Sigurdsson (1997) point out, the breeding goal includes functional and aesthetic conformation and rideability traits in which genetic improvement is supposed to increase the demand and value of the horse on the domestic as well as the international market.

1.2 History of the South African Warmblood Horse Society

The Society was formed in 1989, but Warmbloods were first imported from Europe to South Africa in 1965. The European Warmbloods were crossed with the local horses, mainly of Thoroughbred stock, and this crossbred population is what formed the base generation for most of the horses registered with the SA Warmblood Horse Society at the time the data was collected for this project, 1998. This F1 generation produced by the Warmblood-Thoroughbred population comprises 23.75% of the current population. The F1 cross has been used to create an F2 generation by crossing again with Full Warmblood stallions. This has a stabilising effect on the type of horse produced and these horses constitute 49.53% of the current population. The F3 generation produced by crossing these 25% Thoroughbred and 75% Warmblood horses with 100% Warmbloods constitutes 17.69% of the population. These horses are considered "Full Warmbloods", and are classed in the same category as imported horses. The remaining 9.03% of the population is composed of registered brood mares of unknown origin, and horses that cannot be considered Full Warmbloods or part-breds due to poor conformation. These poorly conformed horses might have a large percentage of Warmblood breeding, but are still not included. Imported Warmblood stallions and mares from Europe are still entering the country, and are used to improve the local Warmblood population. Selected breeding animals are defined as mares and stallions with studbook registration. This definition might not be correct since it is possible that a few included sires did not have offspring, and that some dams without stud book registration could have had offspring.

Conformation plays an important role in horse breeding. Not only does a correctly conformed horse have possibly greater athletic potential, but correct conformation also increases the longevity of a competition horse (Evans, 1992). Riding horses reach their maximum sport potential as 10-15 year olds, which shows the necessity of a long productive life (Wallin *et al*, 2001).

Evaluation of various conformation traits of horses has a long tradition (Saastamoinen *et al*, 1998). In Europe the complex breeding goal of producing a horse that is competitive in dressage, show jumping and eventing is manifested in a sophisticated, widely used performance test system. Germany, the Netherlands, Denmark and Sweden all use stationary performance testing of their three year old stallions (Huizinga *et al*, 1989). At the station test, all stallions to be tested in one group are sent to a central station where a group of trainers train and ride the horses. During and at the end of the test period external judges are brought in to evaluate the horses. This stationary performance test allows stallions to be assessed at a young age and under standard conditions, and thus reduces the environmental component of variance.

Another advantage of testing horses at a young age is that it reduces the generation interval, allowing production of better horses sooner (Aldridge *et al*, 2000). A disadvantage of stationary performance test is the high costs of testing, and consequently the low test capacity which results in lowered selection intensities. Stationary performance tests have not yet been introduced in South Africa, as stallion numbers do not support this expensive and time-consuming exercise. Another method of analysis of breeding stock is the conformation shows that have been held as a part of horse breeding evaluations in Europe from as early as the end of the nineteenth century (Gerber *et al*, 1997a; Eriksson *et al*, 1998). The main objectives of these shows are to: 1) select mares for breeding; 2) evaluate progeny in order to test mares and stallions; 3) to accept mares for the studbook; and 4) to give horse owners advisory service about breeding and management of horses.

No such tradition exists in South Africa for Warmblood breeding. The current method of assessment of SA Warmblood horses consists of a panel of inspectors who visit the farms if numbers of horses to be inspectedwarrant it, or inspect horses at a central venue. At the time that this research was done, three inspectors were needed to evaluate a mare, and five were needed for a stallion. The head inspector has the final say on the marks the horse receives, but it is usually a joint decision of the inspectors present. The inspectors have remained constant over the years with few changes, although there are different inspectors for the different regions. The head inspector, who travels to the different regions, usually accompanies these regional inspectors.

Horses should be inspected at as early an age as possible. This would have the advantages of early availability of information, direct comparability of traits (if all horses are inspected at the same age), horses would be unselected, the breeding value estimation would be more precise, resulting in substantial genetic gain (Von Velsen-Zerweck and Bruns, 1997). The South African Warmblood Horse Society requires horses to have reached a minimum height before they can be inspected which means that horses are generally over the age of three years at the time of inspection. Mares and geldings must be a minimum height of 15.1 hands high and stallions must be a minimum of 16 hands high.

An individual's own phenotypic value is not the only source of information pertaining to its breeding value (Falconer, 1990). Additional information is provided by the phenotypic values of relatives, particularly by those of full sibs and half sibs. All horses registered with the South African Warmblood Horse Society are required to have a four-generation pedigree. If no pedigree exists, the animal is placed in the second lowest register, termed F1. The use of information from relatives is of great importance in the application of selection to animal breeding for two reasons. Firstly the traits to be selected are often of low heritability, and so selection to obtain genetic improvement should be based on progeny, collateral relatives and pedigree information in addition to the animal's own records (Hintz, 1980). And secondly, when the outcome of selection is a matter of economic gain (as with horses), even quite a small improvement of the response will repay the extra effort of applying the most accurate technique.

In 1989 inspectors belonging to the SA Warmblood Society started to score the SA Warmblood horses subjectively for conformation and movement abilities. In 1998 this research project was initiated with the aim of implementing the BLUP animal model for routine genetic evaluation, based on the inspection results.

1.3 Population parameters

A unifying theme in horse breeding is that all the purposes for which modern horses are bred require moderate to extreme athletic ability and the general ability to interpret and obey the rider's commands (Evans, 1992). These abilities are usually quantitative traits. Quantitative traits are measurable and influenced by the environment, for example nutrition, training and season, as well as by genes. Our comprehension of the inheritance of performance traits strongly depends on our ability to identify and measure genetic and environmental effects as separate components. Since environmental factors can enhance or mask genetic effects the breeder needs to know to what degree performance excellence is inherited (Evans, 1992).

Heritability of body measurements is a significant indicator of success in horse breeding and selection. Knowledge of genetic and phenotypic parameters for body measurements makes it possible to choose those horses with the optimal development and a desirable body frame (Baban *et al*, 1998).

The parameters calculated in this project are:

- **The variance, additive and environmental.** The additive variance is the portion of the total observed variance between individuals that is due to genotypic values. It is the chief cause of resemblance between relatives and therefore the chief determinant of the observable genetic properties of the population and of the response of the population to selection. Moreover it is the only component that can be readily estimated from observations made on the population (Falconer, 1990). Estimation of the additive variance rests on observation of the degree of resemblance between relatives. The environmental variance is the proportion of the total observed variance between individuals that is due to environmental deviations.
- **The correlation between traits**. Correlated characters are of interest for two main reasons. Firstly in connection with the genetic causes of correlation through the pleitropic action of genes. And secondly, in connection with the changes brought about by selection. In this study we are concerned mostly with simultaneous changes in other traits when one trait is changed.
- **The heritability of traits.** The heritability determines the degree of resemblance between relatives, and is therefore of the greatest importance in breeding programs (Falconer, 1990).

1.4 Breeding Values

Parents pass on their genes and not their genotypes to their progeny. It is therefore the average effects of the parents' genes that determine the mean genotypic value of their progeny (Falconer, 1990). The value of an individual judged by the mean genotypic value of its progeny is called the breeding value of an individual. Breeding values can be expressed in absolute units, but are more conveniently expressed as deviations from the population mean. It must be noted, as Falconer (1990) points out, that the breeding value is the property of an individual and the population from which its mates are drawn. One cannot speak of an individual's breeding value without specifying the population in which it is to be mated.

Because the breeding value expresses the value transmitted from parents to offspring, it follows that the expected breeding value of any individual is the average of the breeding values of its two parents, and this is also the individual's expected phenotypic value excluding environmental effects. The transmission of value from parent to offspring can be expressed by the equation taken from Falconer (1990):

$$P_0 = A_0 = \frac{1}{2}(A_S + A_D)$$

Where P_O = The phenotypic value of the offspring
A_O = The additive value of the offspring
A_S = The additive value of the sire
A_D = The additive value of the dam

The inclusion of all relatives in the population has considerable advantages in the estimation of breeding values. It ensures more accurate breeding values and estimations of breeding values.

1.5 Use of the BLUP animal model

BLUP methodology and the animal model has become the standard method for genetic evaluation in horse breeding. Klemetsdal (1990) considers BLUP to be the method of choice in predicting breeding values in horses. Langlois (1990) states that the animal model is often considered as the universal solution for the genetic evaluation of horses. Arnason (1997) states that the implementation of the BLUP animal model seems to have caused profound enhancement in the genetic selection intensity. And Arnsaon (1990) states that the increased application of the mixed model methodology to assess genetic values by BLUP (particularly by the animal model) has been the most important contribution to breeding for performance traits in horses.

The advantages of using the animal model are:

- It maximises the accuracy of breeding values (Langlois, 1990; Klemetsdal, 1990).
- It maximises the expected genetic gain from selection (Klemetsdal, 1990).
- It yields unbiased estimators of genetic and environmental trends in the population (Klemetsdal, 1990).
- It corrects automatically for non-random mating.
  Several authors have pointed out the existence of assortive mating in horse breeding and the necessity of correcting for it (Arnason *et al*, 1982).
- It improves the estimation of fixed effects and genetic parameters (Klemetsdal, 1990; Arnason, 1990).
- It uses all available information in the prediction of breeding values (Klemetsdal, 1990). Therefore the breeding values are directly comparable among animals.
- Furthermore the genetic trend in a population can be predicted by averaging the breeding values of all animals by birth year (Klemetsdal, 1990), and thus BLUP methodology allows follow up studies to be done on the efficiency of breeding work by estimating both genetic and environmental trends (Arnason, 1990).

The genetic information required for the use of animal models is: the additive genetic variance of the trait and a genetic correlation between individuals (Langlois, 1990).

These requirements are fulfilled by the traits and individuals in the South African Warmblood Horse population.

Countries that are currently using BLUP animal model in horse breeding are: Iceland, whose first programs were implemented in 1980 (Sigurdsson *et al*, 1997; Arnason and Sigurdsson, 1997); Sweden began using a multiple trait BLUP animal model in 1986 for the evaluation of approved stallions (Gerber *et al*, 1997b) and Swedish standard bred trotters (Arnason, 1997); the Netherlands, whose programs began in 1988 (Hartmann and Schwark, 1991; Van Bergen and van Arendonk, 1993; and Koenen *et al*, 1995); and in the following year Germany (Reinhardt and Schmutz, 1997; von Velsen-Zerweck and Bruns, 1997) and France (Ricard, 1997; Langlois *et al*, 1997) started similar programs. The Czech Republic followed suit in the nineties (Misar *et al*, 1998) with Finland (Thuneberg-Selonen *et al*, 1998), and Italy (Miglior *et al*, 1997).

1.6 Objective of this study

The objective of this study is two-fold:

1. To establish population parameters applicable to the SA Warmblood horse population
2. To produce breeding values for the South African Warmblood horse population from which accurate decisions could be made about selection of breeding stock.

2. MATERIALS AND METHODS

2.1 Description of data

The data for this project was obtained from the South African Warmblood Horse Society. Records were collected from 1989 to 1998.

Desired criteria for a trait to be recorded and analysed are, according to Gerber *et al* (1997a): traits that are closely correlated with the total breeding objective; traits that are highly heritable to ensure reasonable accuracy in selection; traits that are easy to measure and record on a large scale to ensure that records of unselected animals are as easy to obtain as possible; and traits that can be recorded reasonably early in the animal's life to keep the generation interval low. Most traits recorded for the South African Warmblood horse population do comply with these criteria; although some recorded traits had low heritability (see section 3.2.3).

Correct and unique identities of all animals linked into a computerised system with information on the traits recorded is essential to any analysis (Gerber *et al*, 1997a). Data for the South African Warmblood horses was captured using Microsoft Excel, which was then translated into a text file for further analysis.

Data was provided on 2143 horses. This data included information from the Horse Registration form and Birth Notification form, and the Inspection Score Sheet. The Horse Registration form is for horses entering the Society from Europe or South Africa that have not been produced from registered horses. The Birth Notification form is for horses whose sire and dam are both registered with the Society. The Inspection Score Sheet is the form completed by the inspectors when judging a horse.

Information provided on the Horse Registration form and Birth Notification form is:

- Identification of the horse (colour and markings)
- Name of the horse
- Bloodline (whether the horse is a thoroughbred or not – relevant only on the horse registration form)
- Breeder of the horse
- Owner of the horse
- Gender of the horse
- Birth date of the horse
- A four-generation pedigree (if available)
- Date of registration or birth notification with the Society.

This information was initially recorded in two separate files for the purpose of checking and correcting the data: a "horse details" file which contained the horse's name, bloodline, gender, birth date, breeder, owner, and status assigned by the Society; and a "pedigree" file which contained the horse's name, sire and dam. Also included in this pedigree file was the parent generation listed as horses with their sire and dam. Complete four-generation pedigrees were given for 57.35% of the horses, the remaining 42.65% horses either had no pedigree recorded, or only had pedigrees going back to the 1st, 2nd or 3rd generation. The pedigree file containing information on horse, sire and dam had 6389 records. 1.52% had no known sire, 2.39% had no known dam, and 1.30% had no information on either sire or dam.

Information provided on the Inspection form is:

- Name of horse
- Birth date of horse
- Gender of horse
- Owner of horse
- Place of inspection
- Date of inspection
- Name of Head Inspector
- Subjective marks for four aspects of the horse: Movement, Conformation of limbs, Body Conformation and Breed and sex type. (Diagram 2.1 shows the divisions and marks awarded to each of the traits in these divisions.) The traits analysed in the South African Warmblood horse population are very similar to those studied in Europe, the only noticeable difference being that height and girth size are not measured in South Africa. Traits studied in the Swedish Warmblood are type, head-neck-body, legs, walk and trot in hand, and height at withers (Gerber *et al*, 1997b). Traits studied in Hanoverians are: breed and sex type, head, neck, saddle position, frame, forelegs, hind legs, correctness of gaits, trot, walk, and overall impression and development (Christmann and Bruns, 1997). Traits studied in Finland were leg stances, hardness of legs, hoof quality and movements (length, elasticity and regularity) (Saastamoinen *et al*, 1998).

		MARKS	TOTAL
MOVEMENT			
Walk & Trot: *Correctness & straightness*	10		
Walk: *Four-beat rhythm, ground covering strides and swing.*	10		
Trot: *Swing, elasticity and balance (can be shown in hand and loose)*	10		
Canter: *Swing, elasticity and balance (can be shown in hand and loose)*	10		
		/2 = 20	
CONFORMATION: LIMBS			
Feet: *Quality and correctness*	10		
Foreleg: *Quality and correctness*	20		
Hind leg: *Quality and correctness*	10		
		/2 = 20	
CONFORMATION: BODY			
Head and Neck: *(including mouth quality and correct setting)*	10		
Shoulder and Saddle Position	10		
Hindquarters	10		
Top line and Frame	10		
		/2 = 20	
BREED AND SEX TYPE			
General Impression *(consider age and development, suitability for competition and/or desirability as breeding stock)*	20		
		* 2 = 40	
GRAND TOTAL:			**100**

DIAGRAM 2.1 The layout of the inspection sheet used by the South African Warmblood Horse Society showing the total marks that can be awarded for each trait and the sections these traits are divided into.

As can be seen from diagram 2.1 all traits except for Foreleg and Breed and Sex Type are scored out of 10 as with the Swedish Warmblood (Gerber *et al*, 1997b), the Hanoverian (Von-Velsen Zerweck and Bruns, 1997), the Swedish Ardenner (Eriksson *et al*, 1998) and the Finnhorse Trotter (Saastamoinen *et al*, 1998). These two sections were scored out of 20 instead of 10, because they are deemed of more importance to the breed, and will hold more weight in the calculation of the overall total. All total values were recalculated by SAS®[1] to eliminate human error.
1

Inspection results were provided for 1086 horses. Stallion inspection results were included in the horse inspection file without the information for ride under saddle and breed and sex type.

---

[1] The SAS ® system is an integrated system of software providing complete control over data access, management, analysis and presentation; and is obtainable from the SAS institute: 93 Central Street, Houghton, Johannesburg, RSA.

Of the horses currently registered with the Society, 66.87% have been born within the last ten years (see diagram 2.2). This indicates a positive trend within South Africa towards Birth Notification and Registration of horses with the Society. The far right column indicates the horses of unknown birth year. It can safely be assumed that these will be evenly spread over the years of birth.

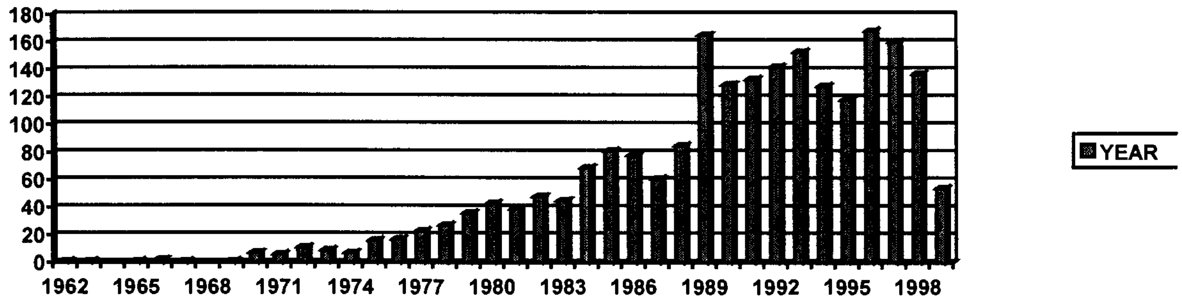


DIAGRAM 2.2 Distribution of horses registered with the Society by year of birth

62% of the horses registered with the Society are female, the remaining 38% are divided between colts and geldings (which were grouped together due to the fact that they are not used for mating purposes) and stallions. Stallions constituted only 5% of the population as depicted in diagram 2.3 below:

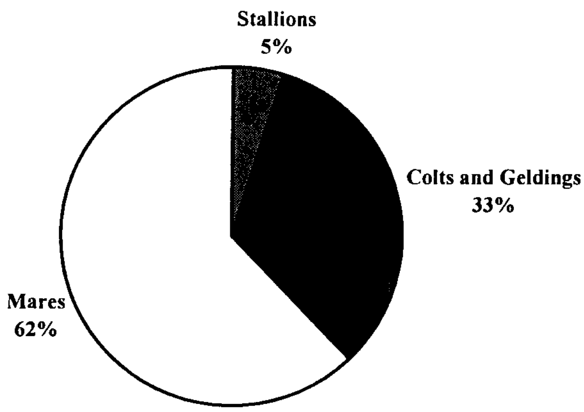


DIAGRAM 2.3 Distribution of genders in the South African Warmblood horse population.

2.2 Statistical methods

For analysis of this data, four steps were taken:

1. Editing of the data
2. Determination of fixed effects using SAS®

3. Estimation of population parameters using VCE (Groeneveld, 1997).
4. Estimation of breeding values using PEST (Groeneveld, 1990).

2.2.1 Editing of data

Data was edited manually. Common problems found were:

- The horses were identified by name. This name was not unique and often recurred for other horses in the pedigree files, as they included horses from a variety of countries especially in the third and fourth generation. Unique numbers were thus assigned to the horses registered with the Society and horses found in the pedigree file, creating a list of horse names containing 9084 records of the name, sire and dam.
- Breeders, owners and horses in the pedigree file were recorded with variations in their names, which had to be manually corrected. This was a significant problem in the pedigree file, where a horse with four generations recorded would not register all four generations due to slight variations in the names of the parents when listed again as horses with their parents.
- Missing data was prevalent.

Once the names had been edited, a single file containing the following information was created:
Horse Number, Gender, Breeder, Owner, score for movement at the walk and trot (correctness and straightness), score for movement at the walk, score for movement at the trot, score for movement at the canter, total score for movement (recorded as a percentage); score for feet, score for foreleg, score for hind leg, total score for conformation of the limbs (recorded as a percentage), score for head and neck, score for shoulder and saddle position, score for hindquarters, score for top line and frame, total score for body conformation (recorded as a percentage), score for breed and sex type, and total score (recorded as a percentage). New variables calculated from the available data as described below, were also included. These were: category of age at inspection, birth year, birth month, inspection year, inspection month, combined variable of bloodline and status within the Society.

Age at inspection was thought to be a possibly significant effect, and so was included as a new variable. As age at inspection is unique to the horse due to varying birthdates and dates of inspection. Because of the diverse range of values that were created, it was included as categories. 32 categories were created, beginning at the age of 1.5 years (as no horse had been inspected when it was younger than 1.5 years due to the fact that it is not mature and has not reached the height required to be inspected by the Society), separated by intervals, resulting in a maximum age of 24 years of age at inspection. Some categories of age groups were wider than others to ensure a sufficient number of horses fell in these groups; thus the categories encompassing older age groups covered up to six and a half years.

Information from the date of birth was separated into date of birth year and date of birth month. Inspection date information was also split into year of inspection and month of inspection. This was done to evaluate contrasts in climate over the years and months and the effect this had.

The information on bloodline and status within the Society was combined because this information is inextricably linked. A horse of non-Warmblood origin cannot enter the F4 register, while a Warmblood is able to enter all registers depending on the type of horse and inspection marks it obtains. The Society has six possible registers that a horse can be placed into: The pre-register, the F1, F2, F3, F4 and prospective stallion register. The Pre-register is for horses which fail the inspection test (receive a mark lower than 65% overall); the F1 register is for horses of unknown pedigree; the F2 register is for Thoroughbred horses of known pedigree; the F3 register is for the offspring of the first cross between a full Warmblood and a Thoroughbred horse; the F4 register is for full Warmblood horses (either imported or produced by the cross between a F3 mare and a F4 stallion); and the prospective stallion register is for Thoroughbred stallions and Warmblood stallions which fail the stallion licensing due to some small conformational defect that would not inhibit performance.

Table 2.1 illustrates which bloodlines can enter which register.

	Pre-register	F1	F2	F3	F4 (including licensed stallions)	Prospective stallion
Thoroughbred and non-Warmbloods	✓	✓	✓	✓	✗	✓
Warmblood	✓	✓	✓	✓	✓	✓

TABLE 2.1 Illustration of which bloodlines can enter the various registers provided by the Society

As can be seen from the table, 11 levels were assigned to the variable Bloodline-status as indicated by the ticks.

2.2.2 Estimation of fixed effects

SAS® was used to determine the significant effects. The independent variables were:

- Bloodline-status, 11 levels as described above.
- Gender, 3 levels: female, colts and geldings, stallions.
- Breeder, 201 levels.
- Owner, 311 levels.
- Date of birth month, 12 levels.
- Date of birth year, 26 levels (1966, 1970, 1972-1995).
- Date of inspection month, 12 levels.
- Date of inspection year, 9 levels (1990-1998).
- Category of age at inspection, 32 levels.

2.2.3 Estimation of population parameters

VCE (Groeneveld, 1997), a program used to estimate covariance matrices, was used to determine the population parameters. This seems to be the standard method of estimating population parameters in horse populations, as authors who used REML with an animal model to determine the population parameters include Eriksson *et al* (1998), Saastamoinen *et al* (1998), Arnason and Sigurdsson (1997), Miglior *et al* (1997) and Christmann and Bruns (1997). Gerber *et al* (1997b) used a multi trait sire model, although use of the sire model gives lower heritability values than the animal model, as it does not consider the variation in the base population (only the variation in the last generation is represented) (Gerber *et al*, 1997b). Significant effects on the dependent variables as calculated by SAS® were entered into models used to estimate the population parameters.

The following general model was used in the estimation of population parameters with VCE (Groeneveld, 1997):

$Y_{ijklmnopq} = \mu + A_i + B_j + C_k + D_l + E_m + F_n + G_o + H_p + I_q + e_{ijkl}$

Where $Y_{ijklmnopq}$	= the dependent variable
μ	= least square means
A_i	= the fixed effect of the i'th gender
B_j	= the fixed effect of the j'th breeder
C_k	= the fixed effect of the k'th owner
D_l	= the fixed effect of the l'th category of age at inspection
E_m	= the fixed effect of the m'th year of birth
F_n	= the fixed effect of the n'th month of birth
G_o	= the fixed effect of the o'th year of inspection
H_p	= the fixed effect of the p'th month of inspection
I_q	= the fixed effect of the q'thbloodline and register
$e_{ijklmnopq}$	= random error

Four separate runs were used to estimate all the population parameters.

1. In the first run traits for feet, foreleg, hind leg, conformation limbs total and breed and sex type were combined. This gave an AG log likelihood of 6895.2957. 1086 animals had usable data animals had values for all the traits, 21 animals had missing values for one trait. Thus the analysis was run on all the records of the 1086 animals with inspection results.
2. In the second run traits for walk and trot (correctness and straightness), walk, trot, canter, total movement, feet, foreleg, hind leg, total limbs conformation, total body conformation and overall total were combined. This combination had an AG log likelihood of 6765.2364. 754 animals had values for all the traits, 331 animals had values missing for one or more traits, and 1 animal had no values for this section. Thus the analysis was run using a total of 1085 animals.
3. In the third run traits for movement total, conformation limbs total, head and neck, shoulder and saddle position, hindquarters, top line and frame and breed and sex type were included. This gave an AG log likelihood of 90008.7878. 1060 animals had values for all traits, 26 animals had one value missing in a trait. Thus the analysis was run on all the records of the 1086 animals with inspection results.
4. In the fourth run traits for walk and trot (correctness and straightness), walk, trot, canter, head and neck, shoulder and saddle position, hindquarters and top line and frame were included. This gave an AG log likelihood of 11023.9186. 755 animals had records for all the traits, 309 animals had values present in the other traits, and 22 animals had no values for this section. Thus the run was made using the records of 1064 animals.

The reason for using four runs and not combining all dependent variables into a single run was that by splitting the traits into four separate runs there was no dependency between the traits that could affect the. The run with the highest AG log likelihood, the fourth run as listed above, was used to calculate the parameters for all the traits in that run. The run with the second highest AG log likelihood, the third run as listed above, was used to calculate the parameters for all the traits which it included which had not been included in the fourth run. The run with the third highest AG log likelihood, the second run as listed above, was used to calculate the parameters for all the traits it included that had not been included in the third and fourth run. The run with the lowest AG log likelihood, the first run as listed above, was used to calculate those parameters that it included that had not been covered by the other three runs.

This resulted in a comprehensive view of all the population parameters that will be discussed in chapter 3.

2.2.4 Estimation of breeding values using PEST

The population parameters obtained by the analysis using VCE (Groeneveld, 1997) were used to determine the breeding values using the software package PEST (Groeneveld, 1990) for multivariate prediction and estimation.

As in the estimation of population parameters, four runs were used to calculate the breeding values, as the program could not create results when all dependent variables were entered simultaneously. For each of these four groups a separate run to estimate breeding values was conducted with the multiple trait animal model described in the following chapter. Christmann and Bruns (1997) also used this method of four runs in their analysis on Hanoverian mares.

The runs were roughly separated according to the four divisions in the inspection test. The first run included the traits: movement for walk and trot (correctness and straightness), walk, trot and canter. The second run included the traits for limbs conformation: feet, foreleg and hind leg as well as breed and sex type. The third run included the traits for body conformation: head and neck, shoulder and saddle position, hindquarters and top line and frame. The fourth run included the traits movement total, limbs conformation total, body conformation total and overall total. The number of animals with records for the various traits is illustrated in table 2.2 below.

TRAIT	NUMBER OF ANIMALS WITH RECORDS
Walk and trot (correctness and straightness)	1057
Walk	1077
Trot	1058
Canter	777
Movement total	1079
Feet	1085
Foreleg	1085
Hind leg	1086
Limbs total	1086
Head and neck	1086
Shoulder and saddle position	1086
Hindquarters	1086

Top line and frame	1086
Conformation total	1086
Breed and sex type	1067
Overall total	1086

TABLE 2.2 Number of horses with records for the traits used in the analysis.

As can be seen from table 2.2, not all horses had values for all the traits. Movement traits were particularly lacking due to the fact that horses that are unsound at the inspection are not scored for movement. The canter had the lowest number of records out of all the traits, due to the fact that older horses that are inspected are sometimes not expected to canter, combined with the fact that unsound horses would not have a value for this section. Another contributing factor might be that the canter is scored when the horse is loose (i.e. not being led by his handler), and thus a suitable arena is needed in which the horse can illustrate this pace. If no suitable arena is present, no mark can be given. The section for conformation has all values present for all horses, except for one missing value for the feet and foreleg. This was due to an injury of the horse inspected where the front leg and feet had been deformed and so could not be given a mark. The breed and sex type had several missing values. This is possibly due to marks for this section not being awarded to the horse inspected by the inspectors, as they felt the horse was immature or out of condition, and could thus not reflect its true breed and sex type.

Best linear unbiased estimations were produced for all the independent variables in the traits for which they were significant (as determined by SAS®). Best linear unbiased predictions were produced for all animals for all traits. These results are discussed in chapter 3.

3. RESULTS AND DISCUSSION

Table 3.1 below indicates the minimum and maximum values, as well as the means and standard deviations of the marks awarded for the inspection test.

	Minimum	Maximum	Mean	Standard Deviation
Walk and trot (correctness and straightness)	4.00	9.00	6.92	0.71
Walk	5.00	9.00	7.19	0.65
Trot	5.00	9.50	7.25	0.70
Canter	6.00	9.50	7.33	0.61
% Total movement	53.33	90.00	71.55	5.24
Feet	4.00	9.00	6.87	0.73
Foreleg	8.00	18.00	13.59	1.56
Hind leg	4.50	9.00	7.07	0.70
% Total limbs	45.00	87.50	68.83	5.73
Head & neck	5.00	10.00	7.29	0.74
Shoulder & saddle position	5.00	9.00	7.19	0.65
Hindquarters	5.00	10.00	7.32	0.71
Top line & frame	5.00	9.00	7.18	0.66
% Total conformation	53.89	88.33	71.30	4.79
Breed and sex type	9.00	16.00	14.49	1.80
% Overall total	53.89	88.33	71.30	4.79

TABLE 3.1 Minimum and maximum values for the marks awarded for the inspection test, showing also the mean values and standard deviations.

3.1 Significant effects

The effects found to be significant on the dependent variables are detailed in table 3.2 below.

	Gender	Breeder	Owner	Category age at inspection	Year of birth	Month of birth	Year of inspection	Month of inspection	Bloodline and Register
Walk and trot (correctness and straightness)	✗	*	*	✗	*	✗	* * *	✗	✗
Walk	✗	*	✗	✗	✗	✗	* * *	✗	✗
Trot	✗	✗	*	✗	* *	✗	* * *	✗	✗
Canter	* * *	✗	* * *	✗	✗	* *	* * *	* *	✗
Movement total	* * *	✗	✗	✗	*	*	* * *	✗	✗
Feet	✗	* *	*	✗	✗	✗	*	* * *	✗
Foreleg	✗	*	✗	✗	✗	✗	* * *	✗	* * *
Hind leg	✗	✗	✗	*	* * *	✗	✗	✗	* * *
Limbs total	* *	* * *	* *	✗	* *	✗	* * *	*	✗
Head and neck	* *	✗	*	✗	✗	✗	* * *	✗	* * *
Shoulder and saddle position	✗	✗	* * *	✗	✗	✗	* *	✗	* * *
Hindquarters	✗	* *	✗	✗	✗	✗	* * *	✗	✗
Top line and frame	✗	✗	✗	✗	*	✗	* * *	✗	* * *
Body conformation total	✗	✗	* *	✗	*	✗	* * *	✗	* * *
Breed and sex type	✗	✗	✗	*	*	✗	*	✗	* * *
Overall total	*	✗	* *	✗	✗	✗	* * *	✗	* * *

* = Significant (P<0.05); * * = Significant (P<0.01); * * *= Significant (P<0.001); ✗ = Non-significant for trait.

TABLE 3.2 Significant effects for the dependent variables, with possible fixed effects listed on the horizontal axis, and traits listed on the vertical axis.

The traits that were included in the indices were determined by the potential for genetic improvement as indicated by the P-value.

As can be seen from the table above, gender was significant for 5 of the 16 traits, although Huizinga (1990) found gender not to be significant in his study on the Dutch Warmblood horse. Gender plays a role in that the males are generally bigger and more muscled, thus scoring higher for head and neck, canter, movement total and overall total.

Breeder was found to be significant for 6 traits. The breeder can be a significant effect as he chooses the parents he believes are most suited and has a large effect on the foal in the early stages of its life through feeding and care.

Owner was significant for 9 dependent variables. The owner is highly significant as he produces the horse for the inspection and can thus either increase or decrease the horse's marks by the amount of training and preparation he has put into the horse prior to the inspection.

Category of age at inspection was significant for 2 dependent variables. The age of the horse at inspection can affect the marks through the physical maturity of the horse and the level of training that it has reached.

Year of birth was significant for 8 of the dependent variables. It was theorised that the years would indicate the effect of large-scale weather patterns such as droughts and rainy seasons, as well as changes in economic climate in South Africa that could affect the manner in which the foal is reared and trained thus impacting on the scores it received for inspection.

Month of birth was significant for 2 dependent variables. Month of birth effects would indicate the seasonal effects of a foal being born in the winter or the summer months, thus impacting on the scores the horse received for the inspection.

Year of inspection was significant for 15 dependent variables. This significance of year of inspection for many traits is in agreement with studies done by Saastamoinen *et al* (1998) and would indicate the effect the changes in inspectors had over the years.

Month of inspection was significant for 3 dependent variables. Month of inspection would indicate the effect of the condition of the horse due to seasonal effects of summer and winter months. This is not relevant for stabled horses that are mostly inspected in the cities, but it is relevant for the horses kept under extensive farm conditions. In extensive farming the horses are likely to grow long winter coats to protect themselves from the cold, and possibly lose some weight due to fat reserves being used to conserve heat. This loss of condition could affect the marks awarded for inspection, particularly in the traits top line and frame and breed and sex type. As indicated in Table 3.2, month of inspection was significant for the canter, feet and total score for limbs; all traits that are not directly dependent on the condition of the horse. The significance of month of inspection on feet could be explained by the dry winter conditions being more suited to hard, correct feet than the wet summer months when the hoof is softer. The canter might receive higher marks in winter when the horses are more active due to the cold, but no obvious reason for higher total limbs score in the winter months presents itself.

Bloodline and register was significant for 8 dependent variables. The combined effect of the bloodline of the horse and consequently which register it was entered into by the Society plays a role in that horses in the pre-register, the F1 and F2 registers would not achieve scores as high as those horses in the F3 and F4 (Full Warmblood) registers.

The results from the inspection test were used as the basis for this analysis. As can be seen from table 3.1, no score below 4 was given, but marks of ten were awarded for the traits head and neck and hindquarters. Thus the judges did not use the whole range of scores from 1-10, although this has been found to be the case in other populations (Eriksson *et al*, 1998). To obtain a larger variation in the scores given to the horses, and so make the selection of breeding animals more efficient, the range of scores should be better used. Another option to counteract the narrow range of scores inspectors use was discussed by Samore *et al* (1997). They explained a type classification system based on linear scales, where the conformation of the horse is objectively described in terms of a biological scale. Linear type scoring has been used in Germany for German Warmblood horses (Hartmann and Schwark, 1991), in the Netherlands for the Dutch Shetland Pony (Van Bergen and van Arendonk, 1993) as well as for the Dutch Trotter population (Koenen *et al*, 1995). The system seems effective and should possibly be considered for South African Warmblood horses.

The results from the estimation of population parameters using VCE (Groeneveld, 1997), and the breeding values as estimated by PEST (Groeneveld, 1990) are discussed below.

3.2 Population parameters

To predict breeding values of breeding candidates for selection, knowledge of genetic parameters is essential (Huizinga *et al*, 1989); criteria used to measure performance, environmental factors that influence performance and estimates of heritability are needed to estimate genetic differences (Hintz, 1980). Samore *et al* (1997) also draw attention to the necessity of predicting genetic parameters in order to determine breeding values and to set up selection programmes and to improve classification systems.

The model used in this analysis considered different significant effects for each trait (see table 3.2). Many significant effects in this analysis were taken into account in other analyses. In an analysis done by Gerber *et al* (1997b), the effects of animal, year and place of test and gender were taken into account. The significant effects included in a study on German riding horses were place and date of inspection (Von-Velsen Zerweck and Bruns, 1997). In a study on Haflinger horses by Samore *et al* (1997) the statistical model included the combination of classifier by year (to take into account the effect of each classifier for every year of evaluation), and the herd group (to consider the effects of geographical region and management, stable or pasture on breeding). Because the number of horses for each herd in their analysis was low, they included the combination variable of the group of herd and the year of birth. Samore *et al* (1997) tested the other possible fixed effects of gender, season of birth (month of birth in this analysis) and age at analysis, and found them not significant. Christmann and Bruns (1997) found the fixed effect for studbook inspections to be the combined effect of site and year. Eriksson *et al* (1998) suggest including the effect of the combination of year and region to correct for the difference between judges. But as too few horses were judged in the same region at the same time (similar to the situation in South Africa), such a model was not useful to them. Instead only year, only region, or both year and region were regarded as effects in the models for the various traits. In this analysis only year of inspection was included. Gerber *et al* (1997b) took the significant effects to be year and place of test and gender. Saastamoinen *et al* (1998) included the fixed effects of gender, age of horse at inspection, year of judging and breeding region and judging team.

The population parameters were estimated using VCE (Groeneveld, 1997) as described in chapter 2. The population parameters that were calculated were the environmental and genetic variance, the environmental and genetic correlations, and the heritability.

3.2.1 Variances

Table 3.3 below illustrates the environmental (VE) and additive variances (VA) obtained for the various traits.

	VE	VA
Walk and trot (correctness and straightness)	0.404	0.022
Walk	0.373	0.014
Trot	0.307	0.125
Canter	0.219	0.084
Movement total	21.288	2.200
Feet	0.356	0.085
Foreleg	2.076	0.018
Hind leg	0.398	0.050
Limbs total	24.294	2.411
Head and neck	0.333	0.137
Shoulder and saddle position	0.282	0.064
Hindquarters	0.413	0.045
Top line and frame	0.350	0.038
Body conformation total	23.443	1.259
Breed and sex type	1.557	0.303
Overall total	19.017	11.343

TABLE 3.3 Environmental and phenotypic variances determined by VCE

It can be seen from table 3.3 that the environmental variance ranges from 0.212 for total movement score to 1.038 for foreleg. Once the magnitude of possible environmental effects and relationships between the selected traits are known, the judging results can be used with better accuracy in horse breeding and in genetic improvement of conformation, as well as in the evaluation of the horse's monetary value (Saastamoinen *et al*, 1998).

The genetic variance had values ranging from 0.014 for walk to 11.343 for overall total. The phenotypic variances given here are lower than those reported by Arnasson and Sigurdsson (1997) whose values ranged from 0.219 to 24.294. It should be noted, however, that all components of genetic variance are dependent on the gene frequencies, so any estimates of them are valid only for the population from which they are estimated (Falconer, 1990).

3.2.2 Correlations

The correlations, obtained from the VCE (Groeneveld, 1997) analysis on the data, are illustrated in table 3.4.

TRAITS	Walk and trot	Walk	Trot	Canter	Movement total	Feet	Foreleg	Hind leg	Limbs total	Head and neck	Shoulder and saddle position	Hindquarters	Top line and frame	Body conformation total	Breed and sex type	Overall total
Walk and trot (correctness and straightness)	*	*-0.197*	*-0.268*	*-0.112*	**0.535**	0.214	0.332	0.196	0.335	*-0.060*	0.137	**0.587**	0.317	0.132	0.303	0.496
Walk	0.321	*	0.095	*-0.053*	**0.726**	0.027	0.396	0.383	0.426	0.036	*-0.331*	**0.567**	0.173	0.331	**0.592**	**0.670**
Trot	0.289	**0.539**	*	**0.838**	**0.817**	0.023	0.130	0.271	0.146	0.214	0.229	*-0.103*	0.228	0.407	**0.628**	**0.561**
Canter	0.213	0.402	0.411	*	**0.802**	0.016	0.261	0.361	0.271	0.448	0.388	*-0.020*	**0.506**	0.426	**0.810**	**0.681**
Movement total	**0.621**	**0.717**	**0.657**	**0.848**	*	0.093	0.376	0.414	**0.562**	**0.887**	0.330	0.499	**0.944**	0.451	**0.911**	**0.825**
Feet	0.256	0.207	0.034	0.167	0.228	*	**0.992**	0.350	**0.590**	*-0.104*	.0354	0.023	0.218	**0.857**	0.425	0.309
Foreleg	0.273	0.215	0.097	0.230	0.284	0.256	*	0.415	**0.956**	*-0.028*	0.234	0.446	0.354	**0.883**	0.486	**0.619**
Hind leg	0.151	0.270	0.267	0.301	0.346	0.058	0.268	*	**0.801**	0.360	0.193	**0.581**	**0.641**	**0.781**	**0.997**	**0.660**
Limbs total	0.217	0.301	0.197	0.310	0.443	**0.553**	**0.924**	**0.747**	*	0.210	0.214	**0.996**	**0.667**	**0.718**	**0.884**	**0.678**
Head and neck	0.197	0.191	0.192	0.295	0.201	0.035	0.245	0.262	0.188	*	**0.569**	0.165	**0.872**	**0.814**	**0.639**	0.450
Shoulder and saddle position	0.196	0.264	0.248	0.274	0.301	0.112	0.122	0.386	0.219	0.473	*	0.227	**0.602**	**0.783**	0.224	**0.572**
Hindquarters	0.169	0.190	0.294	0.317	0.289	0.162	0.276	0.453	0.257	0.272	0.318	*	**0.572**	**0.809**	**0.806**	**0.807**
Top line and frame	0.213	0.262	0.284	0.246	0.307	0.130	0.265	0.374	0.316	0.463	**0.522**	**0.572**	*	**0.942**	**0.904**	**0.894**
Body conformation total	0.085	0.448	0.456	0.429	0.490	0.041	0.233	0.422	**0.719**	**0.726**	**0.752**	**0.745**	**0.867**	*	**0.829**	**0.718**
Breed and sex type	0.361	0.360	0.478	0.410	0.466	0.088	0.393	0.351	0.393	**0.507**	**0.516**	0.384	**0.623**	**0.669**	*	**0.690**
Overall total	0.478	0.416	0.210	**0.539**	**0.571**	**0.533**	**0.815**	**0.682**	**0.880**	0.489	**0.589**	**0.588**	**0.787**	**0.788**	**0.794**	*

TABLE 3.4 Environmental (below diagonal) and genetic (above diagonal) correlations for the dependent variables.
Italics indicate negative values, values over 0.5 are in bold.

Table 3.4 shows the environmental correlations range from 0.034 (feet with trot) to 0.924 (limbs total and foreleg). The correlations between the total values for the subsections of the inspection test are highly correlated with the overall total, as would be expected due to the part-whole relationship.

The genetic correlations range from –0.331 (walk and shoulder and saddle position) to 0.997 (hind leg and breed and sex type).

The negative correlation that exists between the walk and shoulder and saddle position suggests that what the inspectors perceive as a good shoulder and saddle position actually inhibits the movement at the walk. However shoulder and saddle position is positively correlated with trot and canter as well as movement total. The high correlation between hind leg and breed and sex type indicates that a major factor in determining breed and sex type for the inspectors is the hind leg. The inspectors might be well advised to consider more aspects of the horse in determining the breed and sex type.

Other remarkably high correlations exist between feet and foreleg as well as hindquarters and hind leg. The correlation between feet and foreleg is a logical one, the more straight and correct the foreleg, the better shape the hooves will have, as the body weight is directed straight down onto the hooves. Consequently less stress is placed on different sides of the hooves, which prevents the formation of flares and similar hoof deviances that would result in a low score. The high correlation between the hindquarter and the hind leg indicates that the more correct the hind leg the better the overall hindquarter is. As with the environmental correlations, high genetic correlations exist between the total scores for the subsections of the inspection test and the overall total; as well as between movement total and limbs total, body conformation total and limbs total, but the correlation between body conformation total and movement total was not as high as the other total scores correlations.

Negative genetic correlations exist between the trait walk and trot (correctness and straightness) and walk, trot and canter. Thus the straighter and more correct the horse's walk and trot are, the less scope the movement had, and the less fluid the movements are at the walk, trot and canter. It stands to reason that a horse with short strides would find it easier to move straighter and more correctly than a horse with extravagant movement. Another contributing factor might be that it is easier to judge the horse with less expressive movement for correctness and straightness, and thus these horses are awarded higher marks. The correctness and straightness of the walk and trot also has a negative correlation with the mark given for head and neck. Thus the better the head and neck, the less correct the walk and trot, although head and neck are positively correlated with the walk, trot and canter. Negative correlations also exist between the walk and the canter, which is not supported by the literature (Christmann and Bruns, 1997; and Gerber-Olsson *et al*, 2000); and between walk and shoulder and saddle position. Other negative genetic correlations produced by the data are between trot and hindquarters, and canter and hindquarters; and between head and neck and feet and foreleg. Theoretically the better the hindquarter the better the trot and canter should be as a correctly conformed hindquarter should give the horse more power to trot and canter well; thus the results indicated here would need to be verified in further studies.

The correlations reported here are in agreement with values reported in the literature (Samore *et al*, 1997; Christmann and Bruns, 1997). However Eriksson *et al* (1998) and Gerber *et al* (1997b) got only positive genetic correlations that were in the most cases high, but their results are qualified by the fact that there were a low number of horses in the study, and consequently there were high standard errors for the genetic correlations.

3.2.3 Heritability

Heritability estimates are illustrated in table 3.5 below.

TRAITS	HERITABILITY VALUE
Walk and trot (correctness and straightness)	0.052
Walk	0.037
Trot	0.289
Canter	0.276
Movement total	0.094
Feet	0.193
Foreleg	0.009
Hind leg	0.112
Limbs total	0.090
Head and neck	0.291
Shoulder and saddle position	0.184
Hindquarters	0.097
Top line and frame	0.098
Body conformation total	0.051
Breed and sex type	0.163
Overall total	0.374

TABLE 3.5 Heritability estimates for dependent variables.

Heritability estimates range from very low (0.009 for foreleg) to moderately high (0.374 for overall total). Most traits except foreleg, walk, total body conformation, and walk and trot (correctness and straightness) would respond to phenotypic selection. The overall total has a moderate to high heritability of 0.374, which indicates that selection on phenotypic values using just the overall total could result in an improvement in the breed.

These heritability values are in the same range as values reported in the literature (Samore *et al*, 1997; Van Bergen and van Arendonk, 1993; Koenen *et al*, 1995; Miglior *et al*, 1994; Arnasson and Sigurdsson, 1997; Evans 1992; Saastamoinen *et al*, 1998; and Christmann and Bruns, 1997), and in some cases lower (Gerber *et al*, 1997b). It must be noted that trait classification systems used in different breeds and countries are not always comparable, thus a trait may be highly heritable in one population and only moderately heritable in another. This may also be due to differences in genetic and environmental background (Evans, 1992).

3.3 Best Linear Unbiased Estimates

Estimates were obtained for the independent variables for the traits in which they were significant. Thus estimates for gender were produced in the traits canter, movement total, limbs total, head and neck, and overall total. Estimates for breeder were produced for the traits walk and trot (correctness and straightness), walk, feet, foreleg, limbs total, and hindquarters. Estimates for owners were produced for the traits walk and trot (correctness and straightness), trot, canter, feet, limbs total, head and neck, shoulder and saddle position, body conformation and overall total. Estimates for the category of age at inspection were produced for the traits hind leg and breed and sex type. Estimates for the year of birth were produced for the traits walk and trot (correctness and straightness), trot, movement total, hind leg, limbs total, top line and frame, total body conformation, and breed and sex type. Estimates for the month of birth were produced for the traits canter and movement total. Estimates for the year of inspection were produced for all the traits except the hind leg. Estimates for the month of inspection were produced for the traits canter, feet and limbs total. Estimates for bloodline and register were produced for the traits foreleg, hind leg, head and neck, shoulder and saddle position, top line and frame, total body conformation, breed and sex type, and overall total. Breeding estimates for all animals were produced for all traits.

The estimates for the significant effects are illustrated in tables 3.6 – 3.14 below. The estimates for the breeder and owner illustrate only the highest and lowest 10% of the results due to the large volume of results produced.

3.3.1 Best linear unbiased estimates for gender

Gender	Canter	Movement total	Limbs total	Head and neck	Overall total
Colt	0	68.784	67.99	8.3976	76.7492
Female	-0.10226	71.069	68.449	7.2434	71.0752
Gelding	0.15307	72.513	69.844	7.3022	71.7684
Stallion	0.50968	73.717	71.303	7.7073	73.1057

TABLE 3.6 Best linear unbiased estimates for the significant effects of gender.

Table 3.6 shows that stallions have higher values than other genders in the canter, movement total and limbs total. Colts are superior to stallions in the head and neck and overall total. The higher value for stallions in most traits is to be expected due to the large amount of pre-selection that occurs with stallions. Von Velsen-Zerweck and Bruns (1997) found the mean scores for all traits of the stallions, as taken from the stallion test, to be higher than the values the mares obtained; as did Saastamoinen *et al* (1998). These differences indicate the higher genetic potential of the strongly pre-selected stallions as opposed to the less strongly selected mares.

In the trait canter colts had a neutral value, while females were negative and geldings had a small positive value. Stallions had the highest value of 0.50968.

For movement total colts had the lowest value of 68.784. This is explained by the fact that colts could be immature at inspection; if mature they are termed stallions or have been gelded and fall under another categories. This immaturity would mean they had not yet learnt to carry themselves correctly in their paces. The highest value for total movement went to the stallions with a value of 73.717.

In the trait limbs total colts and females were again low while geldings and stallions had higher values. The lowest value of 67.99, ascribed to colts, can again be explained by immaturity, in that the limbs of colts were not fully formed, and thus did not have as much bone and were not as correct as the legs of more mature horses. The highest value was 71.303, which was for stallions.

In head and neck all breeding estimates were very close between the genders. Interestingly colts had the highest estimate of 8.3976, while stallions only scored 7.7073. This is unusual, as one would expect a mature stallion to have a more developed and correct head and neck than a colt. This should be verified by further studies on the data when more information has been collected. Females received the lowest estimate of 7.2434, which indicates the lack of pre-selection on breeding females, and consequently a lower quality.

In overall total colts had the highest estimate of 76.7492, which exceeded the other genders estimates by a significant margin. Females had the lowest estimate of 71.0752. The fact that colts received a higher overall total than stallions could be due to the stricter inspection which stallions undergo, which means that inspectors are more critical of stallions than colts. This explanation is tentative and will need to be studied further to determine if valuable colts are not being kept as stallions and used for breeding.

3.3.2 Best linear unbiased estimates for bloodline and register

BLOODLINE AND REGISTER	Foreleg	Hind leg	Head and neck	Shoulder and saddle position	Top line and frame	Body conformation total	Breed and sex type	Overall total
Unknown	-0.1579	6.6851	-0.166	-0.0179	-0.27922	-2.054	-0.5156	-0.5401
Warmblood-F4	0.213	7.3189	0.2456	0.1322	0.19118	1.823	0.476	1.5605
Warmblood-F1	-0.127	7.053	0.0929	-0.1109	-0.12851	-1.018	-0.3566	-0.6212
Thoroughbred-F1	-0.8038	6.7403	-0.3897	-0.3494	-0.41789	-3.477	-1.851	-4.5168
Warmblood-F2	-0.3492	6.8976	-0.1507	-0.0779	-0.13212	-1.1	-0.3561	-0.0699
Thoroughbred-F2	0.2493	6.9639	-0.0755	-0.0185	0.00896	0.037	0.0824	-0.2541
Warmblood-F3	-0.3637	7.0835	-0.0696	-0.0606	0.04708	-0.748	-0.077	-0.3222
Thoroughbred-F3	0.5614	6.9138	0.2839	-0.312	-0.09145	-0.937	-0.4245	-2.5204
Warmblood pre-register	-0.6322	7.1095	-0.0331	-0.0493	-0.38722	-1.291	-1.3699	-1.4375
Thoroughbred pre-register	-0.7641	5.7789	0.0523	-0.0306	-0.6911	-1.658	-3.2271	-8.7757
Warmblood-Prospective stallion	0.5523	7.3991	-0.0642	0.5584	0.13334	2.519	-0.1291	2.0484
Thoroughbred-Prospective stallion	2.0902	7.4299	1.4743	1.6288	0.39972	11.489	6.3706	5.5776

TABLE 3.7 Best linear unbiased estimates for the significant effects of bloodline and register.

As is expected, table 3.7 shows that full Warmbloods (in the F4 register) have high estimates. However Thoroughbred stallions in the prospective stallion register were superior in all traits. This might at first appear contradictory, as one would expect the full Warmbloods in the F4 register to have the highest estimates. But it can be explained by the fact that for a Thoroughbred stallion to enter the Warmblood breeding program it must be of a very high quality, and as a Thoroughbred is unable to enter the F4 register, the prospective Thoroughbred stallion must necessarily have very high marks.

The lowest estimates were equally distributed between the Thoroughbred in the F1 register and the Thoroughbred in the pre-register. This stands to reason, since the pre-register and F1 register are reserved for horses that failed the inspection test due to the low marks they received.

3.3.3 Best linear unbiased estimates for the category of age at inspection

Category of age at inspection	Hind leg	Breed and sex type
Unknown	0.07847	0.1526
1.5-2 years	-0.41052	0.3103
2-2.5 years	-0.12287	-0.2324
2.5-3 years	-0.05433	0.1845
3-3.5 years	-0.05464	-0.1733
3.5-4 years	-0.1069	-0.3058
4-4.5 years	-0.08398	-0.027
4.5-5 years	0.02043	0.0778
5-5.5years	-0.14908	-0.3642
5.5-6 years	-0.06392	-0.0457
6-6.5 years	-0.5023	-1.8098
6.5-7 years	-0.28391	-1.2927
7-7.5 years	0.25488	-0.5596
7.5-8 years	-0.00817	1.3893
9-9.5 years	-0.38014	-1.3709
10.5-11 years	0.73868	1.402
11-11.5 years	0.17297	-6.4845
14-14.5 years	0.46525	1.1024
14.5-15 years	-0.13691	-9.3864
15-15.5 years	-0.38761	0.1011
15.5-16.5 years	0.79709	0
17.5-18.5 years	0.82945	0
18.5-24 years	0.71187	-1.5925

TABLE 3.8 Best linear unbiased estimates for the significant effects of the category of age at inspection.

The category of age at inspection shows no consistent trend for estimates for hind leg and breed and sex type. It is interesting to note that horses of the age of 1.5 to 4.5 years have a low estimate for hind leg. This could be due to the fact that the hind leg is still developing at this age. The highest breeding estimate for hind leg was for the age category of 17.5 to 18.5 years. Very few horses were inspected at this age, and their quality was good, hence the fact they had been inspected and begun breeding at such a late age.

The estimate for breed and sex type is inconsistent over the age groups. The highest estimates was given for the age group of 10.5 to 11 years, which is when the horse is mature, but not showing any of the ill effects of old age. Noticeably neutral breeding estimates were assigned to the ages 15.5 to 16.5 and 17.5 to 18.5. Again few horses were inspected in these categories, and old age could have influenced inspectors assigning marks to this category.

3.3.4 Best linear unbiased estimates for year of birth

Year of birth	Walk and trot (correctness and straightness)	Trot	Movement total	Hindleg	Limbs total	Topline and frame	Body conformation total	Breed and sex type
Unknown	-0.2272	-0.153	-0.6019	-0.1207	4.7015	0.1722	74.2572	0.1745
1966	-0.5437	-0.2744	-4.6532	-0.0785	-0.504	-0.13157	71.25	-0.1526
1970	2.5077	1.4218	-2.2903	-0.3696	6.403	-0.09228	78.4966	-0.5559
1972	-0.2851	0.0801	-0.2739	-0.4067	-2.9848	-0.1177	72.0518	-0.0782
1973	-0.1918	-0.2262	-4.1947	-0.3866	-0.0938	-0.22728	71.2447	-0.8139
1974	0.4253	0.1983	1.6103	0.1841	3.7106	0.45831	76.5468	0.7012
1975	-0.1011	-0.6551	-2.8141	-0.3004	-1.5618	-0.22113	70.8284	-0.5085
1976	-0.1373	-0.3156	-1.0926	0.0501	2.5887	-0.34957	71.309	-0.5111
1977	0.1449	0.1913	1.1456	-0.058	1.3151	-0.2229	72.409	-0.252
1978	-0.0423	-0.2663	-0.4114	-0.3458	-0.3534	-0.28349	71.8605	-0.1875
1979	-0.016	0.0037	-0.8129	-0.2322	1.0151	-0.30354	70.6145	-0.0267
1980	-0.1523	-0.0493	-0.6988	-0.1917	-1.8919	0.09155	72.8854	0.0426
1981	0.1295	0.0119	-1.2809	-0.3527	-0.5075	-0.13167	70.9283	-0.5073
1982	-0.0852	-0.2848	-1.757	-0.1027	-0.8433	-0.16386	71.3929	-0.3381
1983	-0.0627	-0.0149	-0.8433	-0.0773	-2.3983	-0.0052	70.8271	-0.0276
1984	-0.2689	0.0624	-0.363	-0.1507	-0.956	-0.04775	71.6354	-0.2641
1985	0.0393	0.1781	0.2694	0.0448	1.0822	0.10871	72.6746	-0.1467
1986	0.0253	-0.048	0.4873	-0.1266	-0.4457	-0.06018	71.499	0.1262
1987	0.1641	0.0551	-0.091	-0.1002	1.1393	-0.06084	72.4295	0.2108
1988	0.1598	-0.1502	-0.0812	0.1125	0.7907	-0.02464	72.376	-0.0125
1989	0.3295	0.2469	1.3547	0.0265	2.4162	0.14343	73.8871	0.3479
1990	-0.2937	-0.1653	-1.1391	-0.0029	-1.1545	0.01068	72.3124	0.0092
1991	0.0373	0.1423	1.0038	0.1522	0.0099	0.08177	73.291	-0.032
1992	-0.1435	0.0554	0.7525	0.0475	-1.9377	-0.09527	71.7859	-0.1664
1993	0.1093	0.0754	1.1187	0.3477	0.3279	0.10839	73.3095	0.425
1994	0.0821	0.0383	0.585	0.263	-1.5708	0.22836	73.5517	0.1103
1995	0.1403	-0.1398	0.8779	0.0964	0.696	0.1412	73.1167	0.2793
1996	-0.7673	-0.543	-1.5866	1.1556	3.1169	0.3113	76.2185	2.5026
1997	-0.5767	-0.7619	-2.4427	1.4109	3.183	0.31648	75.8556	0
1998	-0.7363	0.3732	3.9541	0.0694	-0.3568	0.59944	77.2418	0.4222

TABLE 3.9 Best linear unbiased estimates for the significant effects of year of birth.

As with category of age at inspection, very little consistency is shown with the estimates for year of birth. For the trait walk and trot (correctness and straightness) the highest estimate was for the year 1970 (2.5077) and the lowest was for 1996 (-0.7673). Over the past few years there has been no marked increase in the estimates for walk and trot (correctness and straightness), with the second lowest estimate (-0.7363) given for the year 1998. It must be noted that horses born in 1996, 1997 and 1998 would most likely not have their own inspection marks, and estimates would have been calculated from pedigree information only. The accuracy of these estimates could therefore be low.

1970 appears to have been a good year as three of the traits (walk and trot (correctness and straightness), trot and body conformation total) had their highest estimates in this year. However other estimates for movement total, hind leg and limbs total around 1970 are low; thus no definite projection from the conditions that occurred in and around 1970 can be made on the type of horse these conditions helped to produce.

Although 1996-1998 had low estimates in walk and trot (correctness and straightness) and trot, the estimates for the other significant traits were the highest. This seems to indicate that the most recently born horses are the ones with the highest estimates for most traits. Although, as stated earlier, these horses will not have been inspected yet themselves, it does indicate that the management program should be producing horses of an increasingly high standard.

The estimates for total movement are variable, but the highest estimate (3.9541) was assigned to 1998, which shows some improvement due to environmental management. 1966 received the lowest estimate of –4.6532.

Hind leg estimates according to year of birth showed a definite positive trend. Estimates up to 1990 are low and often negative, but from 1990 to 1998 estimates increase and are positive. 1972 had the lowest estimate of -0.4067, while1997 had the highest estimate of 1.4109.

Total limbs score mirrored the improvement in recent years seen in the hind leg, but was more variable and not as pronounced. The highest estimate was assigned to the year 1997 (3.183) although 1996 was very close and the lowest to 1972 (-2.9848).

Estimates given for top line and frame according to year of birth were very close to the mean. The highest estimate (0.59944) fell in 1998, and the lowest (-0.34957) in 1976. The results given here do seem to support the fact that there has been an improvement in recent years. This improvement would be due to environmental conditions, such as management, improving; it does not indicate genetic improvements.

Total body conformation estimates were again variable. The highest estimate of 77.2418 fell in the year 1996, and the lowest of 70.8271 in 1983 with 1975 very close on 70.8284.

Breed and sex type estimates showed a definite improvement from 1966 to 1998. The lowest value of –0.8139 fell in 1973, while the highest of 2.5026 was in 1996. From

1966 to 1978 the estimates are low negatives, from 1979 to 1992 the estimates lie around the mean, and after 1992 the estimates are positive. From this we can deduce that the foals being produced now are more the type of horse the Society wants to have on its records.

3.3.5 Best linear unbiased estimates for month of birth

Month of birth	Canter	Movement total
Unknown	0.11117	0
January	-0.05569	-0.6102
February	0.15946	1.2362
March	0.01589	0.5595
April	0.17668	1.2629
May	0.17909	1.8185
June	0.27781	1.8195
July	0.76385	-1.0117
August	0.08801	0.7296
September	0.008	-0.2657
October	0.0006	0.1094
November	-0.19778	-0.662
December	-0.09307	-0.3251

TABLE 3.10 Best linear unbiased estimates for the significant effects of month of birth.

Estimates for the canter indicate that horses born in November, December and January are inclined to have poor canters. The lowest estimate of –0.19778 was given for the month of November (summer), while the highest of 0.76385 was for the month of July, in other words, the exact opposite season (winter). One possible explanation for this would be that foals born in winter do more moving around than foals born in summer, due to the fact that they need to keep warm, and movement helps in heat production. This early movement could result in stronger paces later in life. Another possible reason is that weak foals born in winter are less likely to survive than if they had been born in summer when there is more grazing available and conditions are less harsh. Thus the estimates for horses born in the summer months could include a few weak individuals that would bring the score down. A third possible explanation is that the nutritional supplements fed in winter to supplement the sparse grazing, which are not fed in summer when grazing is plentiful, could aid stronger muscle formation which would aid better movement.

This trend was mirrored in the total movement score. The lowest estimate of –0.662 fell in November and June had the highest estimate of 1.8195. Estimates are again low for November and December, but January has a positive breeding estimate. There seems to be no consistency in these estimates, and no explanation for the negative estimate found in July. More research on more records would clarify this point and establish trends.

3.3.6 Best linear unbiased estimates for year of inspection

Year of inspection	Walk and trot (correctness and straightness)	Walk	Trot	Canter	Movement total	Feet	Foreleg	Limbs total	Head and neck	Shoulder and saddle position	Hindquarters	Top line and frame	Body conformation total	Breed and sex type	Overall total
Unknown	-0.05189	0.17755	-0.00356	-0.10765	0.5189	-0.0954	0.3969	-0.0482	-0.15441	-0.07876	7.3471	7.0652	-1.2204	14.216	0.1157
1989	-0.10476	0.8474	0.56207	0	-5.8681	3.3329	-0.1824	5.3465	-0.13047	-0.31508	7.2382	7.2016	-1.531	13.413	3.7663
1990	0.18975	0.08526	0.12596	-0.10896	1.6197	0.1058	0.188	0.4269	-0.02906	0.08961	7.2366	7.0915	0.1666	14.104	-0.1218
1991	-0.16501	-0.00846	-0.07401	-0.2275	-1.7308	0.1505	-0.2747	-0.3995	-0.05992	-0.05035	7.4454	7.0363	0.0649	14.185	-0.9963
1992	-0.36917	-0.34307	-0.40013	-0.3819	-2.5866	-0.0969	-0.5777	-3.0234	-0.27234	-0.31869	7.1555	6.9752	-2.707	14.049	-2.4519
1993	0.06765	-0.11455	-0.09141	-0.17124	-0.6884	0.04	-0.224	0.2894	0.00766	-0.02308	7.1695	6.986	-1.0664	14.074	-0.9051
1994	0.00986	-0.14638	0.03337	-0.02645	-0.3199	-0.2511	-0.2696	-0.9032	-0.21733	-0.01032	6.9178	7.0745	-1.8073	14.44	-1.0677
1995	0.03807	0.0396	0.14329	0.12374	0.7427	-0.0821	0.1625	0.5763	0.12593	0.07507	7.3882	7.3566	1.0709	14.795	1.0605
1996	0.16992	0.13187	-0.0042	0.13694	0.8237	-0.0571	0.112	0.3452	0.1115	0.09834	7.4089	7.3134	1.1917	14.617	0.829
1997	0.09535	0.035	0.20387	0.08852	0.6354	0.2516	0.2383	2.2086	0.1894	0.13096	7.4109	7.3217	1.535	14.607	1.6259
1998	-0.04329	0.24603	0.16079	0.15079	1.817	-0.2455	0.6622	1.3239	0.12054	0.09934	7.5495	7.3303	1.176	15.105	1.5313

TABLE 3.11 Best linear unbiased estimates for the significant effects of year of inspection.

Most of the lowest estimates across the traits fell in 1992. This was the year in which a change occurred in the Society's inspection system; the official marking sheets were changed and the structure of marking became slightly different. This must have caused some uncertainty in inspectors who consequently did not score horses as they had in previous years. Marks improved after this year once inspectors had gained confidence in the new system of marking.

High estimates are found for most traits in 1998. As the inspectors have not changed, and there has been no change in the system of marking in 1998, this indicates that the quality of horse inspected is higher in 1998 than in most other years. This is reassuring to breeders as it is clear that better horses are being produced now than a few years ago. It must be noted that this improvement, as with the improvements discussed below, is not necessarily genetic but rather reflects an improvement in the environment, such as management and breeding programs.

1989 had the highest estimate for five of the fifteen traits. 1989 was the year in which inspections were started, and unsure inspectors could have been scoring higher than they would have in later years. The reasoning behind this could be that in order to encourage people to support the Society, inspectors rather scored too high than too low which would have created bad feeling towards the Society.

The lowest estimate for walk and trot (correctness and straightness) of –0.36917 fell in 1992, while the highest of 0.18975 was in 1990.

Estimates given for walk over the years of inspection were variable. The lowest estimate (-0.34307) was in 1992, and the highest (0.8474) was in 1989. There was a trend of improvement from 1995 to 1998.

Estimates for trot were again variable over the years, but showing slight improvement from 1995 to 1998. The lowest estimate for trot (-0.40013) was for 1992 and the highest (0.56207) was for 1989.

1992 had the lowest estimate for canter with an estimate of –0.3819. 1998 had the highest estimate of 0.15079. Estimates for the first 6 years of inspection were generally negative after which they became positive.

The estimate for movement total was lowest in 1989 with an estimate of –5.8681, and highest in 1998 (1.817). Movement total had a wider range than the other movement traits, and strongly reflected the positive trend since 1995.

The estimates for feet were highest for 1989 (3.3329), and lowest in 1994 (-0.2511). Although results are close to the mean they show no improvement over the recent years of inspection.

The lowest estimate for foreleg of –0.5777 was for 1992 and highest of 0.6622 was for 1998. A definite positive trend was shown for estimates improving from 1995 to 1998.

The estimates for limbs total had a wide range, the lowest estimate was for 1992 (-3.0234) and the highest was for 1989 (5.3465). Estimates had improved since 1995.

Head and neck had the lowest estimate in 1992 (-0.27234) and the highest in 1995 (0.12593) with a very close estimate of 0.12054 in 1998. Values were mainly negative before 1995 after which they became positive.

Estimates for shoulder and saddle position showed a strong positive trend from 1989 to 1998. The lowest estimate (-0.31869) fell in 1992 and the highest (0.13096) in 1997.

The lowest estimate for hindquarters of 6.9178 fell in 1994, and the highest of 7.5495 fell in 1997. Estimates were variable before 1994, after which they improved.

Estimates for top line and frame were found in a narrow range. The lowest estimate (6.9752) fell in 1994 and the highest (7.3566) in 1995. 1992 and 1993 were the low point, with estimates increasing on either side of these years.

Body conformation estimates showed the same trend of improvement from 1992, although estimates only become positive in 1995. The lowest estimate of –2.707 fell in 1992, and the highest estimate of 1.535 was in1997.

The estimates for breed and sex type had the low in 1989 with 13.413, and the high in 1998 with 15.105. This reflects the improvement in the type of horse produced since inspections were first started.

The estimates for overall total did reflect the improvement seen in other traits, although the highest estimate of 3.7663 was found in 1989. The lowest estimate of – 2.4519 was again in 1992. Estimates for the other years showed little variation.

3.3.7 Best linear unbiased estimates for month of inspection

Month of inspection	Canter	Feet	Limbs total
Unknown	0.12075	0	0.5004
January	-0.38098	-0.15391	-1.6058
February	-0.06268	0.0573	0.7311
March	-0.14129	-0.23915	-1.6359
April	-0.15078	0.18411	1.0957
May	0.21476	-0.14791	-0.2474
June	0.02237	0.28991	1.7352
July	0.02616	-0.28306	-0.7599
August	-0.26215	0.08227	-1.8539
September	0.30908	-0.38389	-1.6405
October	-0.01952	0.03265	0.3595
November	0.06996	0.14549	0.3385
December	0.2554	0.09259	1.3859

TABLE 3.12 Best linear unbiased estimates for the significant effects of month of inspection.

The lowest estimate for canter (-0.38098) was for the month of January while the highest (0.30908) was for September. It would be difficult to explain why a canter would differ from one season to the next, and this is supported in the variable estimates presented for the months. Possibly the holiday period in December results in a slight drop in the fitness of horses brought for inspection in January, and consequently the horse cannot display as good a canter as when it is in full work and fit. It is interesting to note that both the month of inspection and the month of birth had the lowest estimate for canter in January.

The month of September had the lowest estimate for feet (-0.38389) while June had the highest (0.28991). There seems to be no definite trend according to the seasons with the estimates produced for the various months, as the estimates swing from negative to positive to negative again.

The lowest estimate for total score for limbs was given in August with an estimate of –1.8539. The highest was given for June with an estimate of 1.7352. June and August are both winter months, but estimates are variable over the months and no trend seems to exist.

3.3.8 Best linear unbiased estimates for owner

Owner	Walk and trot (correctness and straightness)	Trot	Canter	Feet	Limbs total	Head and neck	Shoulder and saddle position	Body conformation total	Overall total
QUINTAN-D	0.9721	7.134	8.0512	0.2837	9.042	1.8272	9.1109	19.048	12.33
KEICHEL-G	0	6.4434	7.1946	0.798	7.965	1.4023	8.7466	12.841	11.439
BROWN-N	0	7.6964	7.5089	0	0	1.0164	8.3019	13.539	8.057
LARESERVEE-W	-0.9725	7.758	6.7872	0.2121	13.342	0.401	7.8009	6.367	7.45
PARKER-A	0.9967	6.6276	6.9439	1.3017	6.44	2.0758	8.3238	12.494	7.225
OUTRAM-K	-0.2724	7.5523	7.9738	0.8225	9.215	0.6385	7.3713	6.011	7.103
HOBDAY-N	0.1665	7.9874	7.7423	0.3894	4.021	1.2729	6.7513	5.502	6.954
VAN-NIEKERK-H	-1.3599	6.3552	6.9949	0	0	0.2339	7.3648	6.044	6.416
CROSS-A	2.1245	8.193	8.0916	0.8421	12.019	1.2021	7.3668	5.669	6.409
SPREADBURY-D	0	5.9677	7.5438	0.243	1.48	0.8527	7.1199	7.208	6.298
RADEMAN-N	0	7.3095	0	1.0006	10.755	0.4918	7.4981	5.674	6.283
EBERT-L	0.1834	8.1804	7.5569	1.4821	10.492	0.3292	7.8038	6.672	5.987
BRUCKNER-S	1.2599	7.7107	8.4487	0.6313	12.193	0.541	7.3137	1.733	5.342
MULLER-P	-1.3022	7.013	7.2437	0.4248	9.391	0.733	7.8366	5.496	5.339
MOSTERT-V	0	7.7499	8.3407	0.4378	2.538	0.5004	7.63	4.215	5.269
REZEK-D	0	7.7926	7.9508	0.6068	1.9	-0.1016	7.3099	1.41	5.13
MOORE-A	-1.5549	7.4442	8.3011	1.6183	14.448	-0.4845	6.9224	-0.881	5.013
GIERKE-R	0	7.777	7.5724	0	0	-0.3074	6.9161	-1.446	5.005
WUCHERPFENNIG-E	0	7.7996	6.9956	0	0	0.9294	6.7707	-0.398	4.957
CAMPHER-F	-0.2832	7.8788	8.0641	0.0434	-1.687	0.1477	7.4599	1.263	4.695
BIANCI-E	1.56	0	0	0.5557	3.896	0.218	6.4307	-1.443	4.613
MEYER-A	-1.0101	6.3701	6.3899	-0.1913	2.674	0.264	7.7668	4.039	4.566
SCHROEDER-J	-1.151	6.7585	0	-0.3469	-0.86	0.6052	7.5154	2.823	4.518

JOOSTE-A	0.9937	7.4588	6.958	0.3683	2.647	0.1046	7.6453	5.251	4.49
ZAGER-S	-0.0062	7.2113	7.1565	-0.1831	2.651	0.7612	7.9188	3.665	4.378
LOUW-J	-1.0914	6.6864	6.875	0.8265	2.676	0.3858	8.8057	6.429	4.342
SMITH-JH	-0.6722	7.3281	7.5211	0	0	0.7771	7.9366	7.274	4.235
BINJUNG-I	0	8.1422	8.5142	0	0	0.6225	9.0303	8.197	4.16
BECKER-M	0.5823	8.0064	8.3602	-0.0714	5.385	0.5612	7.2616	3.131	4.048
SKINCARE-S	0	7.5164	7.4021	0	0	1.9208	7.3527	6.958	3.658
OUTRAM-F	0.0439	8.2839	7.8844	-0.0232	3.09	0.5535	7.2856	2.379	3.648
HENDRICKS-C	-0.638	8.0013	7.1335	0.081	-2.008	0.883	9.051	6.931	3.646
KUSTERS-E	0.8747	7.2017	7.8654	0.124	6.479	-0.5072	8.0904	2.3	3.592

DEWS-G	-0.2358	6.999	6.0343	0.0325	-2.959	0.1979	7.4334	1.625	-5.168
CONNELLAN-T	0.2592	6.1963	0	-0.6516	-4.801	-0.9261	6.8369	-4.94	-5.215
KNIGHT-A	0.4292	7.6254	7.127	-0.1863	-3.012	-0.8411	6.9097	-5.378	-5.425
BOOYSEN-M	-0.6821	6.6606	6.6574	-0.7792	-5.698	-0.3909	6.9196	-2.06	-5.472
VAN-BESOUW-C	1.1082	7.852	8.0941	0	0	-0.7987	6.7983	-4.65	-5.608
ROSEVEAR-K	-0.9442	5.6791	6.1457	0	0	0.2004	8.3114	0.824	-5.662
LAWRENCE-M	0.1582	7.3527	7.7554	-0.1616	-0.166	-0.6387	6.4289	-6.839	-5.699
GAYMANS-M	0	6.4215	6.6169	0	0	-0.6677	6.4641	-1.771	-5.895
MANDRE-A	0.0081	7.0633	7.5139	-1.5983	-7.559	-1.2974	6.8501	-9.908	-5.929
ELVIN-C	-1.4381	7.7739	7.5192	-1.7318	-12.549	-0.7667	6.9351	-6.322	-6.052
STOCKTON-L	-0.0085	7.0945	7.248	-0.1984	-4.332	-0.3036	6.866	-3.73	-6.179
MCGRATH-S	-0.1135	7.0036	6.835	-2.3008	-15.866	-1.0874	7.024	-8.892	-6.368
ONDERSTEPOORT	0.9347	7.6806	0	-0.072	-4.757	-0.6689	6.2285	-9.577	-6.541
DUNCHAN-C	-0.0031	7.1697	6.3987	-0.8431	-4.649	-0.6281	6.7069	-5.383	-6.574
POTOCNIK-F	-0.1364	7.9577	7.1556	-1.3047	-4.147	-0.82	6.951	-3.525	-6.733
MINENET-CC	0	6.7576	8.0183	-0.4505	1.052	-1.3318	5.792	-5.83	-7.031
ROWAND-G	-0.0681	6.96	7.1077	-0.9311	-6.404	-1.0528	7.0537	-4.085	-7.077
KIRKPATRICK-C	0	6.9664	7.1433	0.141	-4.389	-0.1864	7.2126	-0.524	-7.092
TEMPLETON-A	-0.6251	6.7801	7.1689	0.2496	5.815	-0.7086	7.8602	-8.552	-7.353
BOSMAN-E	-0.7384	7.2959	6.5285	-1.1416	-8.871	-0.8629	6.3741	-7.102	-7.47
SANDER-D	-0.2277	7.8114	0	0	0	-0.9758	6.1862	-8.429	-7.76
ECKHARDT-H	0	5.1911	6.7763	0	0	0.0526	7.3325	-0.302	-8.051
MULLER-D	0.535	7.7468	8.1624	0	0	-0.0575	7.331	1.655	-8.087
COMBRINK-Y	-0.3387	6.618	6.1378	-0.3739	-2.892	-0.7453	5.9626	-5.954	-8.098
SCALLAN-P	0	7.4729	7.3168	-1.2383	-6.876	-1.4513	6.6141	-8.608	-8.224
HEATHFIELD-D	-0.58	6.3238	6.6627	0.0678	-0.935	-1.3527	6.3027	-8.616	-8.534
GILFILLAN-H	-0.6025	6.0925	0	-1.6415	-8.458	-0.4089	6.7217	-9.408	-9.861
DAY-E	0	6.2916	6.7503	0	0	-0.2985	7.2204	-1.932	-9.914
SARARZ-H	0.106	8.2722	6.5323	0	0	-0.1562	6.0556	-5.837	-10.298
GARBADE-G	-3.6648	5.2845	0	-0.753	-14.491	-1.4967	5.9072	-22.842	-10.802
CHALOM-S	-0.4422	6.6665	6.8018	0.3048	-7.07	-1.938	7.368	-10.362	-11.686
BASSON-O	0	4.627	5.1238	0	0	0.0822	6.9073	-6.698	-13.193
VERMEULEN-J	-0.971	7.411	7.8426	0	0	-0.8806	5.3693	-6.934	-13.601

TABLE 3.13 Best linear unbiased estimates for the significant effects of owner, showing the top 10% and bottom 10% of owners as sorted by the breeding estimates for overall total.

The range of overall score is 25.931; the highest estimate is 12.33 and the lowest is – 13.601. More breeders had a negative estimate for overall total than breeders with a positive estimate, 56.57% versus 43.43%.

The lowest score for walk and trot (correctness and straightness) is –3.6648, while the highest is 2.9157. 14.98% of the owners had a neutral estimate for walk and trot (correctness and straightness) while 42.2% were below 0 and 42.82% were above.

The lowest score for trot was 0, while the highest was 9.1404. All estimates were above 0 excluding the one owner who received a neutral estimate.

The lowest score for canter was 0, which 14.37% of the owners received. The highest estimate was 8.6725.

The lowest estimate for feet was –2.7616, while the highest was 1.6183. 15.29% of owners had a neutral estimate, 39.45% had negative estimates and 45.26% had positive estimates.

The lowest score for total for limbs was –17.968, while the highest was 14.448. 15.29% had a neutral estimate for total limbs, 43.12% had negative estimates and 41.59% had positive estimates.

The lowest score for head and neck was –1.938 and the highest was 2.0758. 54.43% had negative estimates while 45.57% had positive estimates.

The lowest score for shoulder and saddle position was 5.3693; there were no negative estimates. The highest estimate was 9.163.

The lowest score for total body conformation was –22.842 while the highest was 19.048. 50.74% of the breeders has estimates under 0, and 49.23% had estimates over 0.

3.3.9 Best linear unbiased estimates for breeder

Breeder	**Walk and trot** (correctness and straightness)	**Walk**	**Feet**	**Foreleg**	**Limbs total**	**Hindquarters**
DEESIDE	7.6931	6.8641	10.262	18.036	29.669	-0.4254
PLENDEGLISE	7.5279	7.9585	8.57	15.374	17.044	-0.1407
DOMS-BROS	6.3861	6.3425	8.345	16.03	14.367	0.5415
GOODWIN-G	6.1656	7.6219	7.519	13.126	14.189	0.3163
GLENELLEN	6.4954	7.2553	6.556	16.336	13.033	0.8888
MOELLER-KLAUS	6.323	7.3304	8.512	15.782	12.894	0.9287
HOFFMANN	5.3987	7.0929	7.52	16.172	12.313	0.0941
BUCHAN-C	7.4563	7.369	8.555	14.709	11.099	-0.6657
EAGLE	8.1707	8.0014	7.897	16.336	11.087	0.41
PYRAMID-BREEDERS	8.3616	7.1101	8.845	13.642	10.543	-0.9169
HIGH-BIRNAM	7.3346	7.4583	7.089	15.326	9.667	-0.1532
PENWILL-D	7.7939	6.8498	7.685	14.178	9.597	0.4951

MOOIMOOL-PROPERTIES	6.9074	7.6787	7.537	14.688	9.455	0.3501
CHAPUNGU	6.2976	7.3597	8.295	15.235	9.399	0.5922
FOLLETT-C	6.6025	6.3431	7.289	13.948	9.08	-0.186
PHILLIPS-BROS	5.5374	7.3321	7.27	14.023	8.701	-0.4625
TOUCHDOWN	7.1772	7.3021	8.428	14.982	8.466	-0.0995
SAHIBI	7.4979	7.3807	7.324	15.584	8.205	0.4056
STS-STUD	7.2639	6.9065	6.763	16.03	8.16	0.5071
GIERKE-R	6.587	6.6134	7.487	15.632	7.954	0.5966
BOKVELD-FARMS	6.7684	7.008	6.731	16.012	7.936	0.5468
MAINE-CHANCE	6.2925	6.8691	5.764	12.024	-8.61	-0.4909
CROMPTON-P	7.0133	7.1498	6.189	14.108	-8.78	-0.9195
VAN-ZYL-D	6.83	6.5172	5.986	11.019	-8.97	-0.4717
LE-ZAR	7.672	7.3533	5.792	14.206	-9.175	0.0418
WINSLOW	7.075	7.3757	4.277	12.965	-9.304	-0.8939
VOIGTLAND	6.9466	7.2549	5.757	12.338	-9.454	-0.4461
BROS-A	6.8519	7.6779	5.878	12.509	-9.639	0.0794
STEADFOOT	6.5903	8.0187	4.906	13.636	-9.746	0.1026
IRWIN-THOROUGHBREDS	6.431	6.917	6.629	11.072	-9.764	0.0783
LOTUS	7.2898	6.1425	4.287	11.221	-10.096	-0.1038
KOHNKE-E	6.2338	7.1487	4.94	12.638	-10.317	-0.4726
THREE-DEE	6.2809	7.1113	5.655	10.991	-12.299	0.3313
BRUCKNER-S	6.7802	8.1287	5.153	13.708	-12.363	-0.1427
HAMMERSLEY-J	6.473	7.1405	5.986	11.693	-13.043	-0.877
PERRY-D	5.5056	6.3585	4.505	12.545	-13.933	-0.2208
VERMEULEN-J	7.5042	7.6112	5.812	9.206	-14.245	-0.1799
CLOVERDENE	5.8719	6.019	5.244	12.176	-14.337	-2.2334
MASSARO-A	6.2496	7.1059	4.459	10.889	-15.262	-0.4046
GARY-PLAYER	3.4273	6.1181	4.658	9.561	-16.486	-1.2594
CUMMING-I	6.8583	7.1745	6.136	11.601	-16.655	-1.3469
GERLACH-ODEKOP-M	8.0652	7.3278	6.252	10.008	-21.496	-0.2322
STELLENWOOD	7.4566	7.0052	3.986	8.986	-26.382	-0.2139

TABLE 3.14 Best linear unbiased estimates for the significant effects of breeder showing the top and bottom 10% of breeders as sorted by the total score for limbs.

For the breeder the lowest estimate for walk and trot (correctness and straightness) was 3.4273, and the highest was 8.8551. There were no negative estimates.

The lowest estimate for walk was 5.1685 and the highest was 8.3627. Again there were no negative estimates.

3.585 was the lowest estimate for feet; 10.262 was the highest.

The lowest estimate for foreleg was 8.986 and the highest was 18.036.

The estimates for total score for limbs ranged from –26.382 to 29.669. 46.67% of breeders had a positive value, while 53.33% had a negative value.

The lowest estimate for hindquarters was –2.2334 and the highest was 1.0944. 53.33% of breeders had a negative estimate for hindquarters, while 46.67% had a positive estimate.

3.4 Best Linear Unbiased Predictions

Only the ten highest scoring horses and ten lowest scoring horses (approximately 0.2% of the total number of horses for which breeding values were calculated) are given below. These horses are sorted according to their breeding value for overall total. The total number of horses for which breeding values were calculated is 9066.

NAME	Walk and Trot (correctness and straightness)	Walk	Trot	Canter	Movement total	Feet	Foreleg	Hind leg	Limbs total	Head and neck	Shoulder and saddle position	Hindquarters	Top line and frame	Conformation total	Breed and sex type	Overall total
TALISMAN	0.07904	0.04964	0.37478	0.00087	1.3514	0.18659	0.02044	0.0515	0.5857	0.46035	0.24809	0.15394	0.11553	0.54876	0.39087	6.8475
LIBRA	0.02848	0.07596	0.42682	0.23288	2.2504	0.03895	0.01526	0.10479	1.1317	0.50081	0.25517	0.12422	0.15912	0.82078	0.69447	6.0904
MALUTI-III	-0.00066	0.04158	0.52439	0.0161	0.6941	-0.1732	0.00784	0.17494	0.4948	0.50949	0.28623	0.09347	0.17396	0.848	0.57284	5.8381
EMERALD-KING	0.01499	0.01808	0.0692	-0.0028	0.3358	-0.00667	0.01415	0.06547	0.0445	0.25963	0.11735	0.16914	0.14218	0.44894	0.51302	5.1389
JUNGLE-PEARL	-0.0085	0.01879	0.01508	-0.06833	0.4023	-0.07573	-0.00058	0.14071	0.1317	0.52428	0.1638	0.1524	0.13301	0.71654	0.6278	4.9777
WILLOWMORE	0.0233	0.04209	0.12015	-0.06397	0.7215	-0.09811	0.0191	0.13064	0.4839	0.21811	0.249	0.08776	0.14971	0.66262	0.29878	4.7064
WATERKLOOF	0.09193	0.01833	0.14872	-0.03927	1.3092	-0.08564	0.00515	0.18886	0.1189	0.36566	0.27873	0.08946	0.10485	0.60603	0.66886	4.5217
BIANCA	0.02962	0.02913	0.13436	-0.0007	0.5712	0.14175	0.02279	0.02616	0.5474	0.27048	0.07529	0.0419	0.06124	0.28792	0.42296	4.502
WATER-FROLIC	0.07516	0.00751	0.05285	0.11705	0.8044	0.16672	0.00984	0.19076	1.1408	0.07801	0.22303	0.25739	0.11945	0.76366	0.52094	4.489
VERSAILLES	-0.01504	0.02586	0.09398	0.17113	0.4034	0.04255	0.01213	0.07028	0.6002	0.22111	0.09808	0.21114	0.18404	0.58722	0.53157	4.3823
JANAINA-BELA-VISTA	-0.02459	-0.03307	-0.24984	-0.13515	-0.7304	-0.0996	-0.01579	-0.04471	-0.2679	-0.1808	-0.11234	-0.05007	-0.02762	-0.29357	-0.48667	-4.5027
ARAK	-0.03112	-0.03824	-0.03524	-0.01339	-0.9179	0.03556	0.00264	-0.09669	-0.014	-0.66925	0.01554	-0.09201	-0.06242	-0.47787	-0.33217	-4.5264
NADIA	-0.07158	-0.03081	-0.24219	-0.17876	-0.8398	-0.18546	-0.03602	-0.18564	-1.6017	-0.18333	-0.08094	-0.05645	-0.02833	-0.20916	-0.4263	-4.6888
CHENILLE	-0.01644	0.0011	-0.38206	-0.00209	-0.4647	0.02309	-0.00346	0.00035	-0.0983	-0.24068	-0.18323	-0.0128	-0.11645	-0.37791	-0.21717	-4.8897
NILE-GAME	-0.03994	-0.01878	-0.14884	-0.18349	-0.4045	-0.20184	-0.03224	-0.14772	-1.4242	-0.35841	-0.34994	-0.13924	-0.13195	-0.8742	-0.35666	-4.9256
LEGAL-SECRETARY	-0.05038	-0.04254	-0.16665	0.01939	-0.806	-0.06781	-0.00699	-0.07694	-0.566	-0.28379	0.00741	-0.07585	-0.02756	-0.27252	-0.34941	-5.1003
THATS-LIFE	-0.09248	0.00369	0	0	-0.8183	-0.12939	-0.0388	-0.18335	-1.4925	0.01667	-0.17531	-0.14076	-0.09102	-0.45977	-0.32629	-5.1512
L UCKY-BOY	-0.0481	-0.04061	-0.29888	-0.18466	-0.7794	0.07088	-0.02286	-0.13038	-0.6625	0.12695	-0.10769	-0.1357	-0.12066	-0.38047	-0.40772	-5.1825
NIAGARA	-0.02346	-0.03647	-0.23025	-0.30432	-0.7589	-0.31726	-0.02561	-0.14996	-1.2543	-0.21353	-0.23984	-0.06317	-0.12991	-0.47847	-0.27412	-5.3425
WORK-BOY	-0.05844	-0.05158	-0.40166	0.01649	-1.2516	0.00837	-0.00422	-0.14398	-0.2271	-0.38356	-0.2595	-0.22428	-0.11683	-0.79709	-0.37745	-6.0952

TABLE 3.15 Breeding values of the top and bottom 10 Warmblood horses (sorted on overall total) for all dependent variables.

The highest value for overall total is 6.8475 (table 3.15), and the lowest is -6.0952, which gives a range of 12.9427. The mean of the population was 0.0533, which is slightly above the neutral point of 0. 48.26% of the horses have a breeding value for overall total that was above zero. 8.45% of the horses had a neutral value of 0, and the remaining 43.29% had a value below 0.

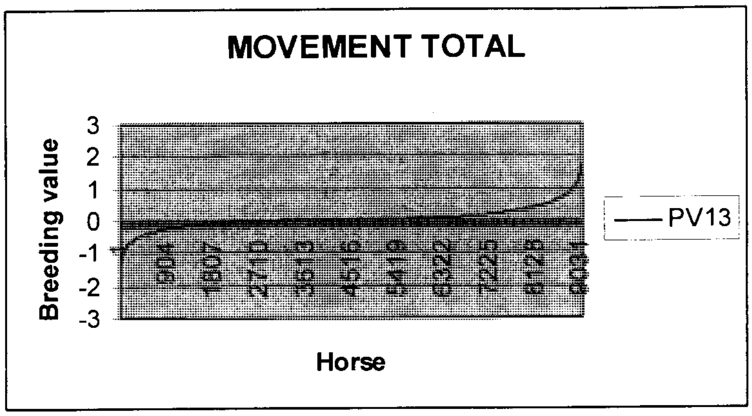
Table 3.16 gives the minimum and maximum breeding values for the traits in the inspection test. It is interesting to note that several horses that received the highest mark for one trait were also among the top few for other traits. Thus a high scoring horse is generally a horse of good quality across all traits. Selection of good quality stock is made simpler for breeders, and matings can be planned to correct a low scoring trait in one horse with another horse that scored particularly high in that trait. The result will be production of offspring with no particular weaknesses, and the overall quality of stock will be improved.

Trait	Minimum breeding value	Maximum breeding value
Walk and trot (correctness and straightness)	-0.11441	0.09193
Walk	-0.00101	0.08409
Trot	-0.59084	0.56575
Canter	-0.35573	0.46332
Movement total	-1.9057	2.5199
Feet	-0.42817	0.34093
Foreleg	-0.04786	0.04733
Hind leg	-0.311	0.28137
Limbs total	-1.6017	1.5363
Head and neck	-0.18333	0.64307
Shoulder and saddle position	-0.08094	0.32377
Hindquarters	0.2973	0.25739
Top line and frame	-0.28855	0.23805
Body conformation total	-0.8742	0.93621
Breed and sex type	-0.62462	0.86438
Overall total	-6.0952	6.8475

TABLE 3.16 Minimum and maximum breeding values for dependent variables.

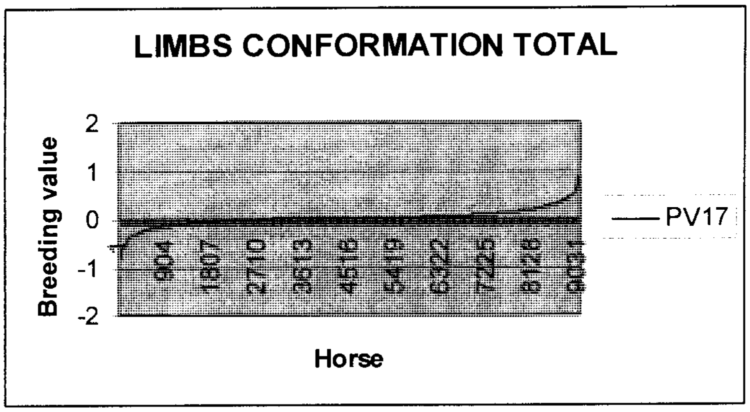
As expected from the amount of additive variance in the total scores (see Table 3.3), the range of the breeding values was broader for the total scores than for the individual traits. Noticeably small ranges occurred for the walk, foreleg and shoulder and saddle position. This could be due to the limited range of marks allocated by the inspectors during the inspection test, and is mirrored in the small amount of additive variance these traits displayed

Graphs 3.1 – 3.4 illustrate the distribution of breeding values for the total scores of the subsections of the inspection test, as well as for the overall total.



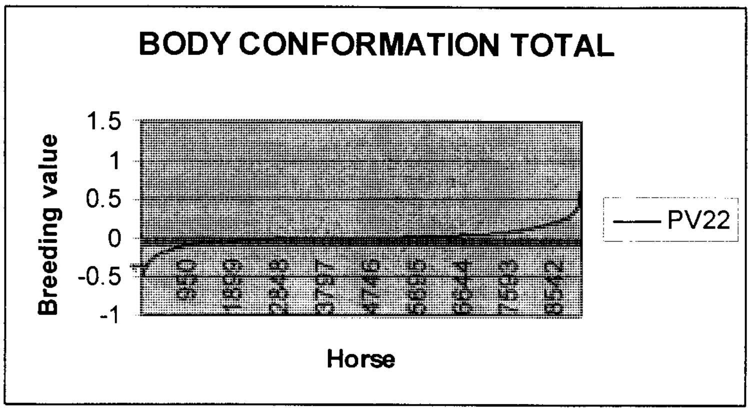
GRAPH 3.1 Distribution of breeding values for total movement score.

From graph 3.1 we see that more horses have a positive breeding value for total movement than a negative value, and that the highest score for movement total is further from 0 than the lowest score. This indicates that the population generally has a high quality of movement, and consequently this is not a section that needs to be focussed on for concentrated improvement programs in the future.



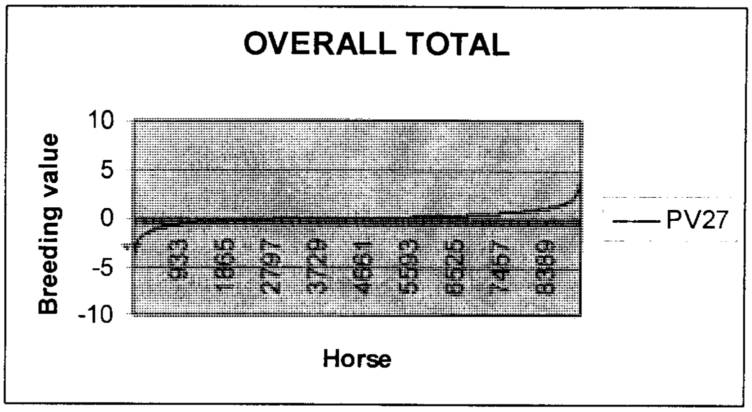
GRAPH 3.2 Distribution of breeding values for total limbs conformation score.

Again, as illustrated by graph 3.2, a larger percentage of horses have a breeding value above 0 for total limbs conformation than below, although a large proportion of the population are very close to 0. Improvement could therefore be made to encourage the production of horses that would be well above 0, and not horses that are slightly above the neutral point.



GRAPH 3.3 Distribution of breeding values for total body conformation score.

Graph 3.3 shows a very small percentage of the population lie below 0 for body conformation total. It does show that approximately 950 horses should not be considered for breeding if body conformation is important to the breeder.

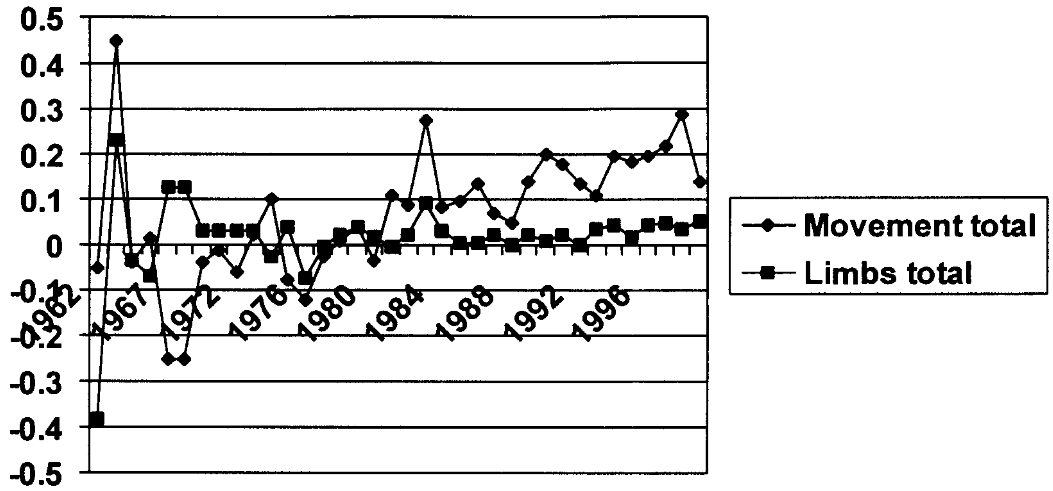


GRAPH 3.4 Distribution of breeding values for total overall score.

Graph 3.4 indicates that approximately one fifth of the population should be considered as breeding animals, and approximately one sixth should immediately be discarded. Some exceptional individuals are present, seen in the spike on the far right, and when linking these high marks to the animals' names, one sees that this does include some of the stallions that are used for breeding in the population. It is clear that there are a large percentage of average horses, for which the choice of stallion should be carefully made in order to promote the production of superior offspring.

3.4.1 Genetic trend in total scores

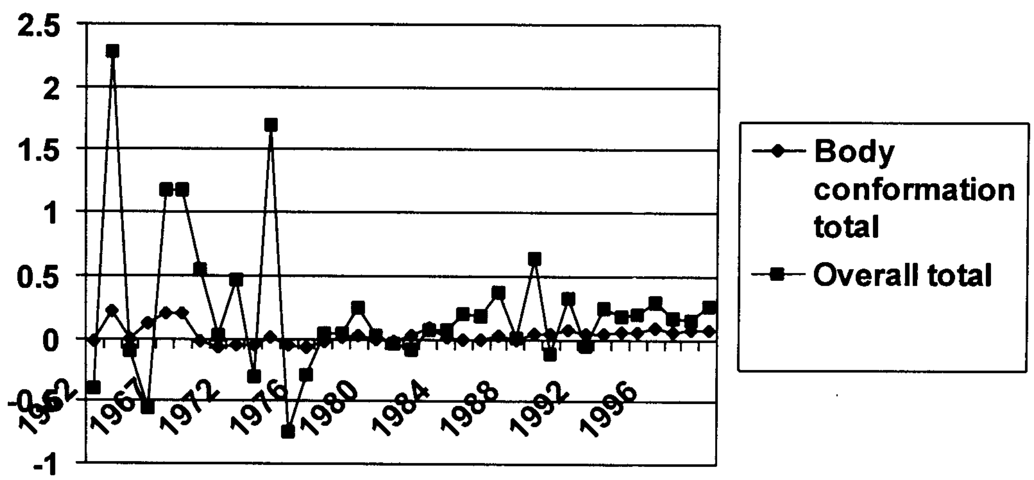
Genetic trends were obtained from the mean breeding value estimates of the total values from the inspection test per birth year. Graph 3.5 and 3.6 below illustrate the genetic trend in the total scores from 1962 to 1998.



GRAPH 3.5 Average scores for movement total and limbs total from 1962 to 1998.

As can be seen from graph 3.5, the breeding values for movement total were variable until 1982 after which they began to stabilise and show an increasing upward trend towards 1998. This also applies to limbs total, although the same marked increase is not seen. Breeders selecting horses more on movement than conformation of legs could explain this marked increase in movement total.

The early instability in the genetic trend seen in the graphs above and below can be ascribed to wide variety in the quality of horse in the formative years of Warmblood breeding in South Africa, as well as to the low number of horses in these early years. Thus a marked difference will be seen between one year in which a good quality horse was born, and the consecutive year when a poor quality horse was born. The consistency in the later years is due to the higher number of horses in these years, which creates a more predictable average.



GRAPH 3.6 Average scores for body conformation total and overall total from 1962 to 1998.

Graph 3.6 shows that the breeding values for body conformation total began to stabilise after 1972, which is early compared to the other traits. Body conformation total did not show much improvement toward 1998, although the small increase there was is consistent. Overall total shows the greatest deviance of all total traits in the early years of the Society, but improvement can be seen from 1984 onwards. The increase in overall total indicates that a better quality of horse is being produced more consistently than in the past although less exceptional individuals are noticed due to the increase in number of horses. From graphs 3.5 and 3.6 it can be seen that the values above 0 seen in graphs 3.1-3.4 are contributed mainly by the horses born after 1980.

4. CONCLUSION

There were three factors which made it essential for the South African Warmblood Horse Society to implement a scientific method of selection: the less efficient previous method of individual selection, the increase in the use of artificial insemination, and the long generation intervals of horses. Much research has already been conducted on the European Warmbloods and the BLUP animal model has been found to be the most efficient method of analysis. This study has been the first implementation of a research project to establish genetic parameters and breeding values for the South African Warmblood horse population. The results from this project will be both a useful tool for current breeders of South African Warmblood horses and a benchmark for future research in the field.

When the Society was established, the main method of improvement of breeding stock was the crossbreeding of imported Warmblood horses with local Thoroughbred mares. This crossbreeding initially resulted in considerable improvement, especially in the F1 generation, which was caused by hybrid vigour. Since the Thoroughbred is produced solely for the purpose of racing, and the number of imported Warmbloods is relatively small, it was unlikely that these breeds could be relied upon for rapid on-going improvement in the average genetic merit of the population of South African Warmblood horses. Thus the alternative system of selection and mating among horses (mainly crossbred, and including the Thoroughbred and imported European Warmblood) was required. This selection system is by no means exclusive of the previous crossbreeding system. To this end the University of Pretoria was approached in 1998 to set up a computerised system for the genetic evaluation of Warmblood horses in South Africa. It was envisaged that this genetic evaluation would guide breeders in their choice of stallion to use on their broodmares, and would lead to an overall improvement in the quality of stock produced.

Riding horse characteristics are related to traits concerning sport, conformation and health. Breeding goals are mostly not well defined and emphasis on considered traits differ between populations (Huizinga, 1990). Concerning performance and durability of a horse, the most important details in the horse's conformation are leg structure and movements (Saastamoinen *et al*, 1998). Furthermore, good conformation is an important factor for horses to obtain high prices (Saastamoinen *et al*, 1998).

4.1 Significant effects

Significant effects were determined for each of the traits in the inspection test. The year of inspection, which incorporated the effect the inspectors had over the years, proved to be the most prominent significant effect. Gender, breeder, owner, category of age at inspection, year of birth, month of birth, month of inspection and the combined effect of bloodline and register also proved to have effects on the various traits.

In future analyses, the individual set of significant effects for each trait need not be included. A standard set of significant effects could be established that would apply to all traits. Significant effects to be included would be the ones in this study with the lowest P-value, and ones that make sense across all traits. Thus one set of proposed significant effects for future studies on this data would be: gender, breeder, owner, year of birth, year of inspection and the combination of bloodline and register. These six effects have been chosen due to the fact that they were shown to be significant in this study with low P-values, and because these six effects have a large impact on the result the horse achieves at the inspection.

4.2 Genetic parameters

The following parameters were calculated for the South African Warmblood horse population: the environmental and genetic variance, the environmental and genetic correlations, and the heritability.

One may expect recurrent changes in the genetic parameters over time within a country due to the subjective nature of scored traits (Arnason and Sigurdsson, 1997), and the change in the genetic make-up of the population. The change in phenotypic variation over time could perhaps be handled by standardisation of scores within a year. Dissimilar proportional changes in the genetic and environmental variance components might inhibit such a simple approach (Arnason and Sigurdsson, 1997).

4.2.1 Variances

The genetics of a metric character centre on the study of its variation. The basic idea in the study of variation is its portioning into components attributable to different causes. The relative magnitude of these components determines the genetic properties of the population, particularly the resemblance between relatives (Falconer, 1990). In this study the variation was partitioned into the environmental and additive genetic causes.

4.2.2 Correlations

The environmental correlations in this study were positive, with high correlations being noted between the subsections and the overall total. This was expected as the sum of the parts of the subsections made up the sub-totals and overall total.

Because of the very high genetic correlations between body measures found in a study by Saastamoinen *et al* (1998), they could reduce the number of traits scored for the horse at inspections. The correlations in this study that were high enough to consider excluding one of the traits (correlations greater than 0.8) were trot and canter; feet and foreleg; head and neck and movement total; hindquarters and limbs total; top line and frame and movement total, and head and neck; body conformation total and feet and foreleg; as well as breed and sex type with canter, movement total, hind leg, limbs total, hindquarters and top line and frame.

4.2.3 Heritabilities

The magnitude of heritability indicates the relative effectiveness of a selection program, particularly when selection is based on the phenotypic value of the animal (Hintz, 1980). In this project information from progeny, collateral relatives and the animal's pedigree were used. The heritability value was most useful in determining which traits would respond to phenotypical selection, and traits that could be expected to respond well to selection would be trot, canter, head and neck, and overall total.

4.3 Best linear unbiased estimates

Values for the significant effects for the various dependent traits were calculated. As a result of the small amount of data estimates were variable. The problem will be solved as more data is collected and analysed.

4.4 Best linear unbiased predictions

Although this was the first analysis of its kind on the South African Warmblood horse population, the breeding values calculated have provided breeders with a useful tool to aid the selection of breeding stock. These breeding values will be used in selection for morphological traits. When producing indexes for all traits the breeders will have more detailed information about the stallions and on their own mares, which might facilitate the choice of suitable stallions for their mares (Gerber *et al*, 1997a). It is likely that the BLUP system will gain in popularity among people in the horse sector when results from more evaluations, and especially from the competitions, are included. As Gerber *et al* (1997a) found in their study, the most successful horses in the competition arena are, with few exceptions, the same as those with the highest breeding value. Breeding values provided for European Warmbloods have been widely accepted by breeders (Christmann and Bruns, 1997), and it is hoped that there will be the same response in South Africa.

It is important for breeders to have a correct understanding of the meaning of these breeding values. The breeding value is the distance in standard deviation from the genetic mean of the trait considered (Samore *et al*, 1997). The results from this study will be made available to local breeders on the internet.

The BLUP results for mares provide good information on which mares should be bred and which mares should be replaced if breeders are to have saleable offspring in the future. The general problem is that too many poor grade mares are kept for too long in breeding, thus impeding the overall progress being made (Gerber *et al*, 1997a).

The breeding values are a valuable new tool that opens new ways in the design of breeding programs (Christmann and Bruns, 1997). However the breeding programs for horses should not be limited to estimation of breeding values with an animal model; development of breeding schemes which guarantee that the best animals have maximum influence on the genetic quality of the next generation are equally important (Klemetsdal, 1990). According to Bruns (1990) and Huizinga *et al* (1989) a large number of stallions should be progeny tested to maximise genetic gain. This test should be followed by high selection intensity among progeny tested stallions, a high number of matings per sire and a low generation interval.

4.5 The future

Emphasis should be put on standardisation of performance traits among countries and international genetic evaluations (Klemetsdal, 1990).

There is an urgent need to develop an estimation of breeding values based on results horses have achieved at shows for showjumping, eventing and dressage. Data is in the process of being collected for a competition performance analysis, and will be included with the inspection data as soon as sufficient data has been collected in order to do a significant study. This study includes only the information from inspection tests and excludes competition results; its focus is thus the correct physical type of horse. Although the correctly built horse is normally the best competition horse, it is possible to find a perfectly formed horse who nevertheless has a poor mind or attitude, and who consequently does not perform well in competition. Conversely some horses that have the will to win overcome physical inadequacies and do very well in competition. Competition results thus provide some measure of the horses' attitude and temperament for competition and must therefore be included as soon as possible to reduce the risk of breeding only for conformation and movement. The Warmblood is a sports horse, and must be able to perform in showjumping, dressage and eventing as well as be conformationally correct

Association of genetic components of performance excellence with blood typing markers, electrocardiogram measurements, and physiological, skeletal or muscular characteristics has been largely unstudied (Evans, 1992). Until such time as these techniques have been perfected, analysis using the BLUP animal model is the most accurate predictor of genetic superiority available.

ABSTRACT

1. The aim of this study was to determine the genetic parameters and breeding values for the South African Warmblood horse population. Information collected by the Society from 1989 to 1998 was provided for 2143 horses. This information included bloodline, breeder, owner, gender, birth date, pedigree, and scores from the inspection test.

2. Non-genetic factors that had a significant effect were determined for all inspection test traits. Year of inspection was significant for most traits; gender, breeder, owner, category of age at inspection, year of birth, month of birth, month of inspection and the combined effects of bloodline and register were all significant for various traits.

3. The parameters calculated were the environmental and genetic variance, the environmental and genetic correlations and the heritability. The environmental variance ranged from 0.212 to 1.038, and the genetic variance ranged from 0.014 to 0.137. Environmental correlations ranged from 0.012 to 0.924, and genetic correlations ranged from –0.331 to 0.997. Heritability estimates ranged from 0.009 to 0.374.

4. Best linear unbiased estimates were calculated for the independent variables in the traits for which they were significant. Best linear unbiased predictions were calculated for all animals in the population. Genetic trends were graphically presented for the total scores of the inspection test. Positive genetic trend was indicated.

ACKNOWLEDGEMENTS

My thanks go to my project supervisors Mr. GTJ Vermeulen and Dr. GJ Delport; Dr. M van der Linde for his help with SAS and the initial phases of the project; Prof. Groeneveld for his help with the statistics; and the South African Warmblood Horse Society for making their information available for this study.

REFERENCES

1. Aldridge, L; Kelleher, D; Reilly, M; and Brophy, P. 2000. Estimation of the genetic correlation between performances at different levels of show jumping competitions in Ireland. Journal of Animal Breeding and Genetics: 117, 65-72.

2. Arnason, T. 1990. Breeding for performance traits in Horses. 4th World Congress on genetics applied to livestock production, XVI. Edinburgh, 23rd – 27th July, 1990.

3. Arnason, T.; Darenius, A.; and Philipsson, J. 1982. Genetic selection indices for Swedish trotter broodmares. Livestock Production Science 8: 557-565.

4. Arnason, T.; and Sigurdsson, A. 1997. Genetic analysis of performance test traits in Icelandic toelter horses in Iceland and Sweden. Proceedings of the 48th Annual meeting of the European Association for Animal Production, Vienna, Austria, 25th-28th August, 1997.

5. Arnason, T. 1997. The selection intensity in standardbred trotters in Sweden as measured by the BLUP animal model index. Proceedings of the 48th Annual meeting of the European Association for Animal Production, Vienna, Austria, 25th-28th August, 1997.

6. Baban, M.; Rastija, T.; Caput, P.; Knezevic, I.; and Stipic, N. 1998. Estimation of heritability of Lipizzaner horses' morphological properties by means of various methods. Proceedings of the 49th Annual meeting of the European Association for Animal Production. Warsaw, Poland. 24th-27th August, 1998.

7. Bruns, E. 1990. Breeding values and estimation of genetic trends in riding horses. 4th World Congress on genetics applied to livestock production, XVI. Edinburgh, 23rd – 27th July, 1990.

8. Christmann, L.; and Bruns, E. 1997. Estimating breeding values based on evaluation of young Hanoverian mares. Proceedings of the 48th Annual meeting of the European Association for Animal Production, Vienna, Austria, 25th-28th August, 1997.

9. Eriksson, S.; Nasholm, A.; and Gerber-Olsson, E. 1998. Inbreeding and genetic parameters for conformation traits in the Swedish Ardenner horse. Proceedings of the 49th Annual meeting of the European Association for Animal Production. Warsaw, 24th-27th August, 1998.

10. Evans, J. 1992. Horse breeding and management. Elsevier. Amsterdam.

11. Falconer, D. 1990. Introduction to quantitative genetics. Longman Scientific and Technical. England.

12. Gerber, E.; Arnason, T.; and Philipsson, J. 1997a. Procedures for genetic evaluation of conformation and performance of riding horses in Sweden. 48th Annual meeting of the European Association for Animal Production, Vienna, Austria, 25th-28th August, 1997.

13. Gerber, E.; Sjoberg, A.; Nasholm, A.; and Philipsson, J. 1997b. Genetic parameters for conformation traits of Warmblood horses in Sweden. Proceedings of the 48th Annual meeting of the European Association for Animal Production, Vienna, Austria, 25th-28th August, 1997.

14. Gerber-Olsson, E; Arnason, T; Nasholm, A; and Philipsson, J. 2000. Genetic parameters for traits at performance test of stallions and correlations with traits at progeny tests in Swedish Warmblood horses. Livestock Production Science: 65, 81-89.

15. Groeneveld, E. 1997. VCE4 User's guide and reference manual. Federal Agricultural research centre. Germany.

16. Groeneveld, E. 1990. PEST User's manual. Federal Agriculture research centre. Germany.

17. Hartmann, O.; and Schwark, H. 1991. Utilization of linear descriptive systems for the evaluation of type trait breeding values of stallions. Proceedings of the 42nd Annual Meeting of the European Association for Animal Production, Berlin, 2. 513 (abstract).

18. Henderson, C. 1988. In: Advances in Statistical methods for Genetic Improvement of Livestock. (Editors: D Gianola and K Hammond). Springer Verlag.

19. Hintz, L. 1980. Genetics of performance in the horse. Journal of Animal Science, 51 (3).

20. Huizinga, H.; Korver, S.; and van der Meij, G. 1989. Estimated parameters of performance in jumping and dressage competitions of the Dutch Warmblood horse. Livestock Production Science, 21: 333-345

21. Huizinga, H. 1990. Considerations on the breeding program for riding horses in the Netherlands. Proceedings of the 4th World Congress on genetics applied to livestock production, XVI. Edinburgh, 23rd – 27th July, 1990.

22. Klemetsdal, G. 1990. Breeding for performance traits in horses – a review. 4th world congress on genetics applied to livestock production XVI: 184-193. Scotland.

23. Koenen, E.; van Veldhuizen, A.; and Brascamp, E. 1995. Genetic parameters of linear scored conformation traits and their relation to dressage and showjumping performance in the Dutch Warmblood riding horse population. Livestock Production Science, 43: 85-94.

24. Langlois, B. 1990. Genetic hypotheses required for the use of the animal model methodology in horse breeding. 4th World Congress on genetics applied to livestock production, XVI. Edinburgh, 23rd – 27th July, 1990.

25. Langlois, B.; Blouin, C.; and Ricard, A. 1997. Global efficiency of BLUP indexes for jumping, trot and gallop races in France. 48th Annual meeting of the European Association for Animal Production, Vienna, Austria, 25th-28th August, 1997.

26. Miglior, F.; Samore, A.; and Pagnacco, G. 1994. Multiple-trait estimation of variance components of body measurements and linear morphological traits in the Italian Haflinger horse. Journal of Animal Science, 72(1): 148 (abstract).

27. Miglior, F.; Pagnacco, G.; and Samore, A. 1997. A total merit index for the Italian Haflinger horse using breeding values predicted by a multi-trait animal model. 6th world congress on genetics applied to livestock production, Armidale.

28. Misar, D.; Pribyl, J.; and Jiskrova, I. 1998. Estimation of breeding value of English Thoroughbred sires in the Czech Republic. 49th Annual meeting of the European Association for Animal Production. Warsaw, 24th-27th August, 1998.

29. Reinhardt, F.; and Schmutz, M. 1997. Estimation of breeding values for sport horses in Germany. 48th Annual meeting of the European Association for Animal Production, Vienna, Austria, 25th-28th August, 1997.

30. Ricard, A. 1997. Breeding evaluations and breeding programs in France. 48th Annual meeting of the European Association for Animal Production. Vienna, Austria, 25th-28th August 1997.

31. Saastamoinen, M.; Suontoma, M.; and Ojala, M. 1998. Environmental factors affecting conformation and correlations between conformation traits in the Finnhorse trotter. 49th Annual meeting of the European Association for Animal Production. Warsaw, 24th-27th August, 1998.

32. Samore, A.; Pagnacco, G.; and Miglior, F. 1997. Genetic parameters and breeding values for linear type traits in the Haflinger horse. Livestock Production Science 52: 105-111.

33. Sigurdsson, A.; Hugason, K.; and Arnasson, T. 1997. Breeding strategies and genetic progress in the Icelandic toelter population. Proceedings of the 48th Annual meeting of the European Association for Animal Production, Vienna, Austria, 25th-28th August, 1997.

34. Thuneberg-Selonen, T.; Paso, J.; Mantysaari, E.; and Ojala, M. 1998. Estimation of genetic parameters for trotting performance based on

individual race results. 49th Annual meeting of the European Association for Animal Production. Warsaw, 24th-27th August, 1998.

35. Van Bergen, H.; and van Arendonk, J. 1993. Genetic parameters for linear type traits in Shetland ponies. Livestock production Science 36: 273-284.

36. von-Velsen-Zerweck, A.; and Bruns, E.. 1997. Estimation of genetic parameters using data from performance tests of young German riding horses. 48th Annual meeting of the European Association for Animal Production, Vienna, Austria, 25th-28th August, 1997.

37. Wallin, L; Strandberg, E; and Philipsson, J. 2001. Phenotypic relationship between test results of Swedish Warmblood horses as 4-year-olds and longevity. Livestock Production Science: 68, 97-105.