Examination of New Zealand sport horse performance records and their suitability for the calculation of breeding values

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Abstract

Currently, there is no system for genetic evaluation of sport horse sires in New Zealand; however, the implementation of such a system would be beneficial to the sport horse industry. Official performance data for the 2008/09 and 2009/10 competition seasons were obtained from Equestrian Sport New Zealand. Initially data were examined using descriptive statistics. There were 1123 and 1472 horses registered for dressage, 902 and 1255 horses registered for eventing and 1326 and 1331 horses registered for show jumping during the 2008/09 and 2009/10 seasons respectively. 13.2% and 14.2% of horses registered for dressage, 15% and 3.8% of horses registered for eventing and 16.3% and 17.2% of horses registered for show jumping had no sire recorded. Between 63.6% and 75% of sires had only 1 progeny record. For dressage and eventing points and number of starts were recorded. Zero points were recorded for 1.8% and 1.1% of horses in dressage and 64.6% and 13% of horses in eventing. For show jumping, prize money was recorded and records were usually only available for horses which placed in competition.

Data on points, number of starts and prize money was skewed but approached normality under $\log_{10}$ transformation for all 3 disciplines. EBVs were calculated for these variables. 11.8%, 11.3 % and 14.2% of sires had 5 or more progeny records available for genetic analysis. Estimated breeding values for points per start ranged from -0.066 to 0.158 and -0.076 to 0.182 for dressage and eventing. Estimated breeding values for number of starts ranged from -0.117 to 0.232 and -0.101 to 0.168 for dressage and eventing respectively and from -0.523 to 0.993 for prize money in show jumping.

In conclusion, the use of estimated breeding values could lead to increased genetic gain and improved performance of New Zealand sport horses on the international stage. However, the current data recording has some limitations as records have not been kept for the purpose of genetic evaluation. Hence, there is a need for greater listing and reliability of pedigree data in order to effectively utilise estimated breeding values for selection of New Zealand sport horse sires.

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List of Abbreviations

BLP	Best Linear Prediction
BLUE	Best Linear Unbiased Estimates
BLUP	Best Linear Unbiased Prediction
dnst	log(number of starts) for dressage
dpps	log(points per start+1) for dressage
EBVs	Estimated Breeding Values
enst	log(number of starts) for eventing
epps	log(points per start+1) for eventing
ESNZ	Equestrian Sport New Zealand
FEI	Federation Equestre Internationale
GLM	General Linear Model
HHANZ	Holsteiner Horse Association of New Zealand
LSE	Least Squares Equations
MME	Mixed Model Equations
MSI	Missing Sire Information
NZHS	New Zealand Hanoverian Society
NZWBA	New Zealand Warmblood Breeders Association
REML	Restricted Maximum Likelihood
Sib(s)	Sibling(s)
SPT	Stallion Performance Test
SQRT	Square Root
tpm	log(total prize money+1)
UELN	Unique Equine Life Number
VCE	Variance Components Estimator
WBFSH	World Breeding Federation for Sport Horses
WSI	Wrong Sire Information

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Chapter 1

Introduction

Equestrian Sport New Zealand (ESNZ) is responsible for registering horses and organising registered competitions in all disciplines within New Zealand. ESNZ has approximately 5,000 horses registered for competition each year and has an annual budget of $1,459,420 (Rogers and Firth, 2005, Equestrian Sports New Zealand, 2009a). In New Zealand, one of the major problems with utilising competition results for stallion selection is that there is very intense genetic selection at an early age due to the gelding[1] of horses to be used in competition (Rogers, 1993a, Rogers and Firth, 2005).

Sport horse competition data tends to be highly skewed by nature of the competition structure, as there are large numbers of horses which earn few or zero points and little or zero prize money during the season and a small number of horses that are exceptionally competitive (Whitaker and Hill, 2004). Therefore, sport horse data must be transformed in order to approach a normal distribution and be useful for genetic analysis (Langlois and Blouin, 1998). Data transformations which are commonly applied to sport horse performance data are logarithmic, power and square root transformations (Langlois and Blouin, 2004, Arnason, 1999, Luehrs-Behnke et al., 2002).

An estimated breeding value (EBV) is a measure of phenotypic performance which can be used as a predictor of true breeding value (Lynch and Walsh, 1998). However, the reliability of an EBV as a predictor depends on the quality of the data. Reliability of EBVs calculated from datasets with wrong or missing sire information, small progeny groups or data with incomplete records for the model effects (such as age and gender) will be low (Woolliams, 2006, Kearsley et al., 2008). Utilising pedigree and progeny records in conjunction with the sire's competition record increases the reliability[2] of EBVs. A minimum of 5-10 progeny records is required to achieve sufficient reliability in EBV calculation. The greater the number of progeny records, the higher the reliability of the EBV (Sun et al., 2009, Phocas et al., 2008). In European sport horse

[1] A neutered male horse
[2] How accurate the EBVs are as a measure of true genetic merit. Reliability is increased by collecting more phenotypic information on an animal or its relatives

populations, the average number of progeny records is approximately 50 progeny per stallion and 5 progeny per broodmare (Langlois, 1983).

Estimated breeding values are calculated via the use of a general linear model (GLM), REML or best linear unbiased prediction (BLUP) method (Stewart et al., 2010, Arnason, 1999). EBV calculations are generally based on a single trait animal model, multi trait animal model or a sire model (Tavernier, 1991, Langlois and Blouin, 1998, Dietl et al., 2005, Klemetsdal, 1994). Many fixed and random effects have been included in sport horse models. However, the most common appear to be age (of the sire or progeny), gender and season (Langlois and Blouin, 1998, Langlois, 1980a, Huizinga and Vandermeij, 1989). The use of reasonably reliable EBVs (generally with a reliability of approximately 14% or higher based on Interstallion guidelines) complements the use of a detailed breeding objective in animal breeding programmes, as choices of animals selected for breeding can be made more effectively (Harris and Newman, 1994, Interstallion, 2005).

EBVs have not previously been calculated for New Zealand sport horses; however EBVs are utilised in many European sport horse industries including in Germany, France and the Netherlands (KWPN, 2010, Tavernier, 1990a). In France, annual results (logtransformed earnings, number of starts and number of placings) and details from each event (rank in each competition) are utilised (Tavernier, 1990a, Langlois, 1980a). In Germany the variable earnings per start is analysed (Huizinga and Vandermeij, 1989).

In this study it was suggested that the New Zealand sport horse performance dataset would not lend itself well to genetic analysis due primarily to limited and inaccurate pedigree information. The aim of this thesis was to describe the current sport horse population in New Zealand by looking at ESNZ records for dressage, eventing and show jumping from the 2008/09 and 2009/10 competition seasons. The accuracy and completeness of the data available for genetic analysis and the opportunities available to compete in the three disciplines of dressage, eventing and show jumping (during the 2010/11 spring season) were also investigated. The purpose of these investigations was to analyse the suitability of New Zealand sport horse data for genetic evaluation and to calculate estimated breeding values in the New Zealand sport horse population.

Chapter 2

Literature Review

2.1 SPORT HORSES

2.1.1 Definition of a sport horse

A sport horse has been defined as a horse which competes in, or is suited to, the Olympic disciplines of dressage, eventing and show jumping (Tavernier, 1990b). The Federation Equestre Internationale (FEI) now also recognises endurance, vaulting, reining, driving and para-equestrian among the sport horse disciplines (Rogers and Wickham, 1993b). However, only the disciplines of dressage, eventing and show jumping were considered in this thesis.

2.1.2 True age versus official age

An official age is designated to all horses competing in sport horse disciplines in New Zealand. The cut off for assigning an official birth year is 1 August each year. Therefore, all horses born each season before 1 August each year will have an official birth year of one year earlier than their true birth year. Horses born each season on or after 1 August each year will have the same official birth year as their true birth year (Langlois and Blouin, 1998).

2.2 SPORT HORSE COMPETITIONS IN NEW ZEALAND

2.2.1 Dressage

In dressage, points are awarded according to the horses final percentage score for each event, (points awarded being 7, 5, 3 or 1 irrespective of grade of competition). A horse can compete in up to three dressage tests per day of competition (Equestrian Sports New Zealand, 2009b).

2.2.2 Eventing

Eventing in New Zealand has three major grades in which horses can earn points. These are Advanced, Intermediate and Novice. Points are awarded in eventing on an ascending scale, with increasing points awarded with higher grades, such that a win earns 6, 9 or

12 points for Novice, Intermediate or Advanced grade (Equestrian Sports New Zealand, 2009b).

2.2.3 Show jumping

Prize money won in show jumping is positively associated with height of jumps and difficulty of competition, and is usually allocated with each placing receiving 60% of the prize money given to the placing above it. Horses may compete in multiple show jumping rounds in a single day of competition (Equestrian Sports New Zealand, 2009b).

2.3 SPORT HORSE INDUSTRY

2.3.1 European sport horse industries

In Europe, many horses are bred specifically to be competitive in the sport horse disciplines. European sport horse populations tend to be large and there is ample government support and funding for equestrian sport (Barneveld, 1996). There are strong links between the sport horse governing bodies and breeding industries, which allows national breeding objectives and breeding schemes to be developed (Aurich and Aurich, 2006).

The development of national schemes includes the utilisation of stallion performance tests (SPT) and progeny tests. In order to gain entry into a stud book, stallions must undergo stallion performance testing to ensure they meet the standard required by that stud book (Ducro et al., 2007). The central performance testing procedure ranges from one week to 100 days dependent on the stallion age (generally 2.5 to 5 years), competition success and specific regulations of the different studbooks (Hellsten et al., 2006, KWPN, 2003). Stallions are evaluated for soundness, conformation, gaits under rider, free jumping and jumping under rider. Temperament and general appearance scores and a pedigree evaluation, based on ancestors' performance in dressage and show jumping, are also incorporated into the final score (Olsson et al., 2008). Progeny tests are used to provide information for genetic evaluation of mares and stallions. They are also useful to evaluate the quality of young sport horses, particularly their ability in both dressage and show jumping (Olsson et al., 2008). The highly integrated systems utilised in Europe lead to complete and accurate records on both pedigree and performance for all horses registered for competition. Hence, it is possible to estimate breeding values on these horses, which can then be utilised in the selection of sport horses.

2.3.2 New Zealand sport horse industry

Equestrian sport in New Zealand is managed by ESNZ which is responsible for registration of horses and organising registered competitions in all disciplines. ESNZ has approximately 5,000 horses registered for competition each year and has a current annual budget of $1,459,420 (Rogers and Firth, 2005, Equestrian Sports New Zealand, 2009a). The comparative sizes of the German (largest) and New Zealand sport horse industries are shown in *table 2-1*.

Table 2-1: Relative sizes of the sport horse industries in Germany and New Zealand (Rogers, 2008, Rogers and Firth, 2005).

	Germany	**New Zealand**
Annual budget	$NZ12.6 million	$NZ1.5 million
Number of horses	87,000	5,000

In New Zealand, few horses are bred specifically for the sport horse disciplines. Horses bred for racing that were unsuccessful as race horses are commonly re-trained as sport horses. The New Zealand Thoroughbred has traditionally been very successful in eventing. However, race horses are not selected based on traits that are indicative of successful sport horses (Rogers and Wickham, 1993a). In contrast, leading European countries, including Germany and France, have instigated specific sport horse breeding programmes aimed at genetic improvement toward the sport horse objective. Hence, it is highly likely that the European bred sport horses will become superior to the Thoroughbred in sport horse competitions. The instigation of sport horse breeding programmes would ensure New Zealand remains competitive in international sport horse competition (Rogers and Wickham, 1993b). European societies and systems tend to lend themselves to the development of structured and integrated breeding programmes. The English system (similar to that in New Zealand) may not lend itself to an integrated breeding programme as there is limited breeding towards national objectives and greater separation exists between the breeding and sport sectors (Whitaker and Hill, 2004).

2.4 INTERNATIONAL EQUESTRIAN SPORT

2.4.1 The International Equestrian Federation

The FEI was founded in 1921 as the international body responsible for governing equestrian sport. It is now the sole controlling authority for all international events in jumping, dressage, eventing, endurance and para-equestrian. There are 133 national federations affiliated with the FEI and 65 studbook members compiled by the World Breeding Federation for Sport Horses (WBFSH) (Federation Equeste Internationale, 2010, World Breeding Federation for Sport Horses, 2011). The international grades recognised by the FEI are the same for all countries. These grades are listed in *table 2-2*.

Table 2-2: Grades of competition recognised by the FEI for show jumping, eventing and dressage (Federation Equeste Internationale, 2010).

Discipline	FEI grades
Show jumping	1*, 2*, 3*, 4* & 5* maximum heights are 1.20m, 1.35m, 1.45m, 1.50m and 1.60m respectively
Eventing	CCN/CNC (national competitions), CIC/CICO 1-3* (short format international competitions), CCI/CCIO 1-4* (official international competitions incorporating an official teams competition), CCIJ/CICJ (junior rider classes, 18 years and under), CCIY/CICY (young rider classes, 21 years and under)
Dressage	CDI 1*-5* (international competitions), CDI-W (world cup competitions), CDIO 3*-5* (international competitions open to riders from any number of foreign nations), CDIY/CDIOY (riders 21 years and under), CDIJ/CDIOJ (riders 18 years and under), CDI-YH (Young horse competitions)

Competition grades are relevant to genetic evaluation as different aptitudes tend to be measured in different grades. Therefore, using competition data from lower grades may not be representative of performance in elite sport. However, records from young progeny, competing in lower grades, will always be used for genetic analysis as a short generation interval[3] is necessary to increase the rate of genetic gain[4] (Aldridge et al., 2000).

2.4.2 World Breeding Federation for Sport Horses (WBFSH)

The WBFSH is the only international federation of studbooks for sport horses. It registers approximately 130,000 foals each year, 80% of which are bred in Europe (Koenen and Aldridge, 2002). It provides a major connection between breed organisations and the FEI (UELN, 2010).

2.4.3 Interstallion

Sport horse breeding is becoming an increasingly international endeavour. Therefore, the correct interpretation of performance test results and genetic evaluations is important to ensure accurate selection of foreign genetic material. The Interstallion Committee was established in 1998 in order to develop understanding of these information sources (Interstallion, 2010). Interstallion has been working to compile a systematic overview of testing and genetic evaluation methods as practised by various organisations. They have also compiled recommendations on the publication of breeding values and collaborated with the FEI and WBFSH to increase the availability and quality of information on horses that compete internationally (Interstallion, 2010).

2.4.4 Unique Equine Life Number (UELN)

The Unique Equine Life Number (UELN) is an initiative started by the WBFSH and the FEI in 2000, with the aim to maintain horse identity in every database worldwide (Vandenplas, 2010, Koenen and Aldridge, 2002). At present, each organisation (stud book and national equestrian federation) has an independent identification system, making data exchange difficult. The intention of the UELN initiative is to develop a common language between all organisations responsible for registering horses to ensure

[3] Measures how quickly progeny will be able to replace parents in the breeding population.
[4] A measure of how much genetic improvement, towards a specific breeding goal, is seen in a given population.

that each horse can be uniquely identified. This is useful as stallions may now have progeny registered in many different countries (Hellsten et al., 2008). Hence, registration with a unique number will make exchanging data and progeny records between countries much easier, allowing for complete progeny records to be obtained on a sire (UELN, 2010, World Breeding Federation for Sport Horses, 2010, Federation Equeste Internationale, 2010, Koenen, 2002b).

2.4.5 Importance of the UELN for genetic evaluation

There have been significant improvements in reproductive techniques, such as increased use of chilled and frozen semen, in the equine industry (Koenen and Aldridge, 2002). Hence, breeding stallions can now be used in multiple countries and genetic connectedness among these countries is much higher than before. This has led to a greater need for transparency in breeding objectives for sport horses and a greater ability to track the progeny of a stallion which have been exported to a foreign country (Bruns et al., 2004, Koenen et al., 2003).

At present, estimated breeding values (EBVs) are calculated on national data and results from FEI competitions are excluded due to a lack of complete information on internationally competing horses. A horse's name and identification number are often changed after export; hence, it is difficult to trace pedigree details. This is one of the most serious drawbacks in international sport horse breeding, as many top sport horses are not properly identified and are therefore lost from genetic analysis, which introduces significant bias in EBV calculations (Koenen and Philipsson, 2007).

2.4.6 Genetic connectedness

Genetic connectedness between any two countries is quantified as the average prediction error variance of differences in EBVs between both countries. UELN implementation would greatly improve the ability to estimate genetic connectedness among horse populations. However, the UELN system has yet to be implemented in all countries (Bruns et al., 2004). A UELN code exists for the New Zealand sport horse; however, it is not presently used in the identification of horses registered with ESNZ (UELN, 2010). In order for EBVs to be effectively used across countries, genetic connectedness must exist, as this makes it possible to accurately estimate differences in the average genetic merit of populations and determine the genetic correlation between performance results obtained from any combination of two populations. The lack of an original identification number for each horse and the high potential for names to be changed during export, means underestimation of genetic connectedness will result (Ruhlmann et al., 2009). It is possible to estimate EBVs without a good degree of connectedness; however, this reduces the reliability of the estimate. Using populations with weak connectedness could introduce large bias in the estimation of genetic merit of populations across countries, because the differences among populations may not be estimable, but are still assumed to be zero (Hellsten et al., 2008, Koenen and Aldridge, 2002).

2.5 SPORT HORSE BREEDING

2.5.1 Sport horse breeding in New Zealand

Sport horse breeding in New Zealand is controlled by the major breed organisations including the New Zealand Warmblood Horse Breeders Association (NZWBA), the New Zealand Hanoverian Society (NZHS) and the Holsteiner Horse Association of New Zealand (HHANZ). These organisations are responsible for the registration of horses that meet the requirements of the stud book, defining the parameters for and instigating stallion testing procedures to develop a list of approved stallions. Integration of breed associations is very limited and they operate independently with no input from ESNZ (New Zealand Warmblood Breeders Association, 2010, The New Zealand Hanoverian Society, 2010, New Zealand Hanoverian Horse Association, 2009, Equestrian Sports New Zealand, 2009b).

The major breeding evaluation programme in New Zealand is the New Zealand Sport Horse Breed Improvement Programme. This programme is based on genetic improvement without the inspection of mares and stallions before breeding. The emphasis is on voluntary publication of performance data (Rogers, 2010). Sport horse breeding organisations in New Zealand (NZWBA and NZHS) are small compared with large European sport horse breeding organisations, such as the Holsteiner Verband in Germany. The sizes of the NZWBA and NZHS are given in *table 2-3*.

Table 2-3: The number of currently approved stallions and examples of influential stallions, measured by number of progeny, in the NZWBA and NZHS studbooks in New Zealand (The New Zealand Hanoverian Society, 2010, New Zealand Warmblood Breeders Association, 2010, Friedrich, 2010).

Breed organisation	Number of approved stallions	Influential stallions include:
NZWBA	36	Dream Boy Anamour
NZHS	7	Winnebago Witzbold Distelfink Aberlou

2.5.2 The potential impact of culture

European horses are successful in international competition. This is largely due to the highly integrated breeding programmes the breed associations are utilising. The successful instigation of these programmes in Europe may in part be the result of the inland nature of many European countries. Due to this inland nature in many European countries, an integrated system, where a select group of people were responsible for decision making for the country as a whole developed. This was beneficial during times of war and conflict (Hamann and Distl, 2008). Today this mindset still holds, hence, European breeders tend to be open to the idea of an integrated breeding system operating toward a commonly defined goal. Anglo-Saxon cultures, such as that in New Zealand, tend to be less inclined to accept an overall authority and breeding is more segmented and independent. This mindset could create challenges with respect to sport horse breeding in New Zealand (Rogers, 2010).

2.6 CENTRAL PERFORMANCE TESTING

2.6.1 Definition of central performance testing

There are three different systems of central performance testing utilised in Germany, Sweden and the Netherlands for sire selection. Central performance tests are performed over long time periods (typically 70-100 days) and are very extensive, covering both dressage and jumping. A major advantage of central performance testing is that all horses are tested in a consistent environment. Therefore, the environmental component of phenotype is reduced. As phenotype (P) = genotype (G) + environment (E), the test is more accurate at determining genotype when E is smaller (Hintz, 1980). However, due to the high cost associated with performance testing only a small number of candidates can be tested. Central performance testing is a multi stage selection system (selection occurs in many stages), with initial selection usually based on indirect selection criteria such as conformation and movement (Dubois et al., 2008, Hellsten et al., 2006, Wallin et al., 2003).

2.6.2 Use of central performance testing in sport horses

Central performance testing is labour intensive and expensive due to the length of the testing process and the facilities and personnel required. These tests may be more reliable (have higher reliability) than field tests, as the component traits of successful competition performance are measured as discrete traits over a period of time (Hellsten et al., 2006). However, central performance tests may not be the most effective method of selection for competition success, with accuracy of selection (r_{TI}) of 60-70%. The generation interval is shorter than that of field testing, as stallions can be selected and licensed at an earlier age, with no need to wait for competition results. Selection intensity ($\bar{\imath}$)[5] for entry into the central performance test via the Keuring[6] is quite high. For example, in Germany, where approximately 40/4000 stallions are selected ($\bar{\imath}$= 2.66) (Holsteiner Verband, 2010). However, once a stallion has been selected to participate in the stallion performance test, it will almost certainly be approved during testing; hence, selection at the performance test itself tends to be very low. The age at selection for stallions is usually 3-4 years; hence, the generation interval would be approximately 4-5 years. However, generation interval, selection intensity and overall rate of genetic gain will vary depending on the exact system implemented (Teegen et al., 2009). From the genetic gain equation:

$$\Delta G = \frac{\bar{\imath} r_{TI} \sigma_g}{L}$$

[5] Determined by the proportion of available animals selected as replacements in the breeding population.
[6] A test performed at 2.5 years of age over 3-4 days. Young stallions are tested in walk, trot, canter and free jumping.

Where:

ΔG = genetic gain

$\bar{\iota}$ = selection intensity

r_{TI} = accuracy of selection (the correlation between true and estimated genetic merit)

σ_g = genetic standard deviation

L = generation interval

It can be seen that increasing selection intensity ($\bar{\iota}$) and reducing generation interval (L) will lead to a faster rate of genetic gain (Hazel, 1943).

2.7 FIELD TESTING

2.7.1 Definition of field testing

Field testing is a method of genetic analysis which utilises competition data as a means of selecting sport horses for breeding. Field testing is utilised in sport horse selection in France, Finland, Norway and Belgium (and now also in Germany due to public pressure). It is useful for selecting horses for a single discipline, as competition results are separate for each discipline (Hellsten et al., 2006). However, a major problem in the use of field testing is the gelding of horses for competition. Field testing also has a greater environmental component as it is based on competition data. Hence, the accuracy of selection is lower (Dubois and Ricard, 2007).

2.7.2 Use of field testing in sport horses

Field testing is less accurate than performance testing, as it is based on the individual's pedigree records and those of their progeny. However, it is cheaper and easier than performance testing (Thoren and Philipsson, 2010). The generation interval is slightly longer due to the use of progeny testing to increase reliability (Olsson, 2006). However, the use of early progeny performance records has greatly reduced this disadvantage. Early progeny performance records can be used, as high correlations between low grades and high grades and performance at a young age and later in life have been calculated (Aldridge et al., 2000, Huizinga and Vandermeij, 1989). The selection intensity is high; however, the precise value will depend on the specific system implemented. The rate of genetic gain is much higher than if no system is implemented. The significantly lower cost of field testing often makes it the most realistic option. For this reason, field testing would be a suitable option for genetic analysis in New Zealand (Rogers and Firth, 2005).

2.7.3 New Zealand

Central performance testing systems would not be implementable in New Zealand, as funding for equestrian sport is limited and the sport horse population is small (approximately 5,000 horses registered for sport each year) (Rogers and Firth, 2005). However, a simple field testing system could be utilised based on standard competition data for the calculation of estimated breeding values (EBVs). However, this would result in a longer generation interval than seen from central performance testing.

At present, the New Zealand performance data set, which includes information on number of starts and points and prize money earnt during each competition season, is incomplete with regards to pedigree information. Therefore, to utilise a field testing scheme effectively, data captured and recorded by breed associations and ESNZ would need to be improved. To do this, breed associations and ESNZ would need to work together more closely and utilise unique identification numbers for all horses. Pedigree records could also be improved. For example, by charging breeders/owners more if they register a horse without a sire listed. In New Zealand, there is very high selection at an early age due to the gelding of horses to be used in competition. This is also a problem in utilising competition results for stallion selection as horses are gelded before competition results can be collected and analysed; however, records from related animals can also be used (Rogers and Firth, 2005, Rogers, 1993b).

2.7.4 Using competition results for genetic evaluation

Evaluating a stallion based on its phenotypic competition records alone leads to a biased outlook with respect to breeding potential, as it gives a less detailed indication of the stallion's transmitting ability to his offspring than evaluation which also utilises pedigree and progeny records (Mrode and Thompson, 2005). Also, the stallion may only compete in one discipline, whereas his offspring may be competed in multiple or different disciplines (Hellsten et al., 2006). Therefore, when using competition results in genetic analysis it is important not only to look at the results of the stallion himself, but also to utilise pedigree and progeny records. This significantly increases reliability; however, progeny testing will increase the generation interval. Hence, progeny testing must occur at the youngest age possible so that the generation interval remains reasonable (Huizinga and Vandermeij, 1989, Thoren and Philipsson, 2010).

Moderate to high correlations (between 0.4 and 0.98) have been found between early competition results and performance later in life (Hassenstein, 1998, Reinhardt and Schmutz, 1997). However, it is still argued that the use of competition data from lower grades may not be representative of performance in elite sport due to different aptitudes being measured in different grades. For example, low grade jumping classes have lower fences and a lesser degree of technical difficulty than higher grades (Aldridge et al., 2000). This has led to the suggestion by some horse breeders in Ireland that progeny testing should only include progeny performing in higher grades. However, this suggestion has been rejected by Aldridge et al. (2000), on the basis that it would lead to a biased sample of progeny from the parent being evaluated since at least 50% of performance records are from lower grades. Performance records from lower grades will also become available from progeny at a younger age. Therefore, utilising information from lower grades would result in a shorter generation interval than waiting for results from higher grades. Hence, the rate of genetic gain would increase (Aldridge et al., 2000).

As these low grade results are utilised it is important to know the relationship between performance in low grades and high grades. These correlations have been calculated in two studies. Aldridge et al. (2000) found that genetic correlations (r_g) for different levels varied between 0.07 and 0.78 depending on the amount of difference between the levels. Correlations were smaller as the difference between the levels increased. It was concluded that results from low and medium level competition are useful indicators of high level performance and can be used in genetic evaluation. Huizinga and Van Der Meij (1989) found high correlations between performance at different ages ($r_g = 0.75$). This indicates that genetic evaluation at an early age will be effective in making genetic progress in performance.

The age of stallions is also important. Older stallions will have been subjected to more selection than younger stallions and stallions that were considered better would have more progeny entered in competition. Therefore, the most unbiased estimates for parameters relating to genetic analysis (variance and heritability) would be from young stallions, based on data from their oldest progeny when these progeny reach 4-6 years of age and can first contribute a competition record for genetic analysis (Huizinga and Vandermeij, 1989).

2.7.5 Successful field testing schemes suitable for sport horse breeding

Field testing schemes have been successfully implemented in European sport horse breeding industries including France and Germany. In France, annual results (log transformed earnings, number of starts and number of placings) and details from each event (rank in each competition) are utilised (Tavernier, 1990a, Langlois, 1980a). Ricard and Chanu (2001) evaluated eventing competition results over a 17-year period. The number of records available for analysis was large with 13,000 horses, 30,000 annual results and 110,000 starts. Horses with no earnings during the year were removed from the analysis of annual results. All horses with performances had pedigree information (sire and dam) for at least two generations of ascendants. All pedigree information was utilised in the variance component estimation, however, most pedigree information was from paternal half sibs.

In Germany the variable earnings per start has been analysed (Huizinga and Vandermeij, 1989). Bruns et al. (1981) analysed 136,000 German competition records (data from one season) for horses placed in dressage and jumping. Horses with zero placings recorded (60-70%) were not included in the analysis.

Field testing schemes such as these would be implementable in the New Zealand sport horse breeding industry. However, the number of records available for analysis would be much smaller and pedigree information much sparser; hence, the reliability of genetic evaluation would be lower than in the French and German systems.

2.8 BREEDING OBJECTIVE

2.8.1 Defining the breeding objective

The breeding objective is defined as a list of traits and their relative importance in achieving the desired breeding goals (Hazel and Lush, 1942). The most common breeding objective traits used in sport horses are jumping and dressage ability, conformation, movement and temperament. These traits, in contrast to those selected for in other livestock species, are often subjective and difficult to measure (Koenen et al., 2003, Koenen and Aldridge, 2002, Rogers and Wickham, 1993a).

2.8.2 Traits weightings

The practical value of an animal is always affected by several traits (Hazel and Lush, 1942). Therefore, as several traits must be considered, the use of a selection index to properly weight each trait in the model is a more efficient method of selection than selection for a single trait or selection for several traits each with independent culling levels. Hence, the use of multi trait objectives has developed in animal breeding (Hazel, 1943).

Traits included in the model which determine profit are weighted according to their relative economic importance to the breeding objective. Economic weightings are a measure of how much profit is expected to increase for each unit of improvement in the trait. Traits with a higher weighting have a larger influence on the final value (Harris and Newman, 1994). Economic weightings can be calculated using the first derivatives of profit with respect to the traits of interest. They can also be derived by incrementing the mean of the trait of interest by a small amount and calculating the difference in profit (Hazel and Lush, 1942, Visscher et al., 1994). It is also possible to calculate economic weightings by translating inputs and outputs into monetary terms (Pearson and Miller, 1981).

2.8.3 Targets of the breeding objective

The definition of the breeding objective directs the genetic improvements in the target population. For a breeding objective to be well defined, expected future demands must be taken into account (Koenen, 2010). Hence, the issue of who will benefit from any genetic improvements achieved arises. There are two viewpoints from which profits from genetic gain are seen; the national viewpoint and the individual producer's viewpoint. From a national perspective, when supply and demand are in equilibrium then decreases in expenses are worth more than increases in production income, as there is a limited market for any additional output. However, to the individual producer, increases in production are much more valuable as increased production can be marketed without materially affecting price per unit to that individual (Pearson and Miller, 1981). In the sport horse industry increased production would be measured as a unit of performance. Maximising genetic gain can result in lower than expected economic returns. This is often due to the inadequate or incorrect description of the breeding objective (Miller, 1977, Harris and Newman, 1994). Breeders, riders and national breeding organisations will benefit differently from improvements in the genetic merit of populations.

2.8.4 Profit satisfiers and profit maximisers

Recent years have seen a shift from viewing farming as a lifestyle with income attached toward viewing farming as a business in which maximum economic returns are the desired outcome. Hence, a shift has occurred away from profit satisfiers toward profit maximisers. However, in the sport horse industry, breeders tend to be passionate about horses and are involved in sport horse breeding for the non monetary lifestyle values it offers. Hence, sport horse breeders often tend to be profit satisfiers and their motivation to increase production efficiency as individuals and to breed toward a specifically defined breeding objective is limited (Rogers, 1993b).

2.8.5 Examples of breeding objectives for sport horse populations

In sport horses, breeding objectives are developed with the intention of improving performance in elite competition; however, the majority of riders only require a fun, easy sport horse for amateur competition. The traits selected to achieve these breeding objectives are qualitative in sport horses; hence, it is difficult to quantify improvement in an economical sense. The choice of traits also differs between studbooks, as the traits most highly correlated with success vary between the sport horse disciplines. For example, the Holsteiner stud book primarily aims to produce show jumping horses. Hence, their objectives differ from those of the Trakehner stud book which primarily aims at producing dressage horses (Koenen et al., 2003). Examples of breeding objectives for the Dutch Warmblood, Oldenburg, Holsteiner and Trakehner stud books are shown in *table 2-4*.

Table 2-4: Breeding objectives of some of the German studbooks (Dutch Warmblood, Oldenburg, Holsteiner and Trakehner) (Holsteiner-verband, 2003, KWPN, 2003, Oldenburger-pferde, 2004, Trakehner-Verband, 2005).

Stud book	Breeding Objectives
Dutch Warmblood	Sport horses at the highest level of international competition in dressage and show jumping, with good conformation.
Oldenburg	A noble, high performance horse with active impulsion and elastic movements, which is suitable for any type of sport.
Holsteiner	An athletic, expressive riding horse to perform at national and international level particularly in show jumping. Good control and intelligence. Must have typical high knee action of the Holstein horse.
Trakehner	Sound, Trakehner type horse, big frame, correct body proportions, easy to ride. Elastic, energetic movement. Spirited but kind, willing to perform, tremendous stamina.

2.9 RELATIVES' PERFORMANCE

Pedigree information is valuable in predicting an animal's worth and performance potential as progeny will on average express half of the genes of each parent (Henderson, 1974). However, this is no guarantee of ability, as Mendelian sampling determines that the potential performance of progeny may be significantly better or worse than that of either parent (Mrode and Thompson, 2005). The risk of selecting animals based on pedigree information is that this can place too great an emphasis on distant relatives (mathematically less genetically significant), which can reduce the accuracy of selection. The pedigree records may also be biased, as progeny from favoured individuals may have received greater management and training; hence, showing superior performance to equally talented individuals on this environmental basis (Rogers, 1993b, Mrode and Thompson, 2005). The attention paid to records from a particular ancestor should depend on:

- How closely related the ancestor is to the individual: coefficient of relationship for parents is $^1/_2$, grandparents $^1/_4$ and great grandparents $^1/_8$.

- Heritability of the trait: the higher the heritability, the greater the accuracy of selection for that trait based on ancestry (Mrode and Thompson, 2005, Rogers, 1993b).

Information from the performance of full and half sibs can be useful when estimating breeding values. The accuracy of selection is higher when a greater amount of relevant information is utilised in the breeding value calculations (Mrode and Thompson, 2005). However, the coefficient of relationship and heritability must be considered (as for pedigree records above) when deciding to include sibling records in breeding value calculations (Rogers, 1993b).

2.10 THE IMPACT OF WRONG OR MISSING SIRE INFORMATION

2.10.1 Influence on variance

Wrong sire information (WSI) and missing sire information (MSI) influence the variance of EBVs of the sire and reduce the response to selection (Sanders et al., 2006). WSI and MSI may have a greater effect on genetic gain of lowly heritable traits, such as those commonly seen in sport horse populations, as in this case the impact of pedigree information on the EBV under BLUP is higher (Sanders et al., 2006, Woolliams, 2006).

2.10.2 Reliability

The reliability of EBVs calculated will be lower as the amount of WSI and MSI increases (Woolliams, 2006). In dairy cattle the reliability of EBVs has been calculated as 0.17-0.9 for heritability values of 0.1-0.5 with 0-30% of sire information being wrong or missing (Sanders et al., 2006). Hence, there is likely to be low reliability of EBVs calculated for New Zealand sport horses as the dataset is incomplete (Rogers and Firth, 2005).

2.11 HERITABILITY

2.11.1 Definition of heritability

The proportion of observed phenotypic variance that results from differences in genotype between individuals is known as heritability (Lush, 1949, Lynch and Walsh, 1998). Investigations into the genetic and phenotypic parameters of competitive sport horse performance are limited, particularly for competition performance from field test data. Heritability values for sport horse competition traits tend to be low (Ducro et al., 2007).

2.11.2 Heritability estimates in sport horses

Heritability values derived from field test data in *table 2-5* ranged from 0.1-0.27 for ability in dressage or show jumping. No heritability values are shown for eventing, as each of the three phases may have a separate heritability value and need to be considered separately, hence, investigations of eventing data are relatively rare (Kearsley et al., 2008). Low estimates of heritability are expected for sport horse competition traits, as the effect of rider influence on horse performance cannot be accurately accounted for (Ducro et al., 2007, Koenen et al., 1995). The criteria measured when field test data is analysed varies between countries. Earnings per start and number of points are the criteria used in France and Germany respectively (Huizinga and Vandermeij, 1989, Luehrs-Behnke et al., 2002).

Using information from the youngest stallions and their oldest progeny (when these progeny reach 4-6 years of age) has been shown to give the most accurate measure of heritability while maintaining a reasonable generation interval. Older stallions have been subjected to more selection. Therefore; some stallions would have more progeny than others in competition as decisions on their relative strengths as sires have been made based on the performance of older progeny. Hence, heritability values tend to be less consistent when data from older stallions is utilised (Huizinga and Vandermeij, 1989). Heritability values which have been calculated from field test data in sport horses are shown in *table 2-5*.

Assumptions of heritability values of 0.16-0.36 for conformation and movement traits have previously been made for genetic analysis of New Zealand data based on European values (Rogers, 1993a). However, when doing this it is essential to note that European horses are commonly from uniform environments, as horses tend to be boxed and training methods are uniform. New Zealand tends to have a highly heterogeneous environment as horses tend to be paddocked and training methods are highly variable depending on individual preferences. Hence, heritability values calculated on European data may be higher than those applicable to New Zealand’s more heterogeneous environment (Rogers, 1993a).

Table 2-5: Heritability values of performance traits for sport horses based on field test data.

Author	Breed	Age of progeny	Discipline	Criteria	Heritability Estimate
(Bruns, 1981)	German sport horse	< 8 years	show jumping	Earnings per start (log)	0.14
				Relative place number	0.14
				Place value	0.13
			dressage	Earnings per start (log)	0.15
				Relative place number	0.27
				Place value	0.19
(Huizinga and Vandermeij, 1989)	Dutch Warmblood	4-6 years	show jumping	Cumulative lifetime total of scores (SQRT)	0.20
			dressage	Cumulative lifetime total of scores (SQRT)	0.10
(Ducro et al., 2007)	Dutch Warmblood	All ages	show jumping	Classification scores (SQRT)	0.14
			dressage	Classification scores (SQRT)	0.14
(Olsson et al., 2008)	Swedish Warmblood	All ages	show jumping	Accumulated lifetime upgrading points ($\log_{10}$)	0.27
			dressage	Accumulated lifetime upgrading points ($\log_{10}$)	0.17

2.12 POTENTIAL SOURCES OF BIAS IN HERITABILITY ESTIMATES

2.12.1 Assortative mating

In the case of equestrian sport where a large number of sires contribute only one progeny record, heritability tends to be overestimated when utilising methods for regression of offspring on one parent and for analyses of variance. The paternal component of variance is higher when the mean number of offspring per stallion is lower. The number of offspring per stallion is highly variable. Homogamy is mostly due to poor quality stallions as they only serve poor quality mares (high quality stallions serve both high and lower quality mares). However, as stallions with small progeny numbers are numerous and rapidly replaced, they must be included in genetic analysis in order to sufficiently describe the population (Langlois, 1980b).

2.12.2 Non random effect of environment

The non random effect of environment is an extremely large source of bias in sport horse populations which leads to the overestimation of heritability (O'Ferrall and Cunningham, 1974). A major aspect of environment which affects sport horse performance is management of the stud farm. However, it is generally agreed that stud owners and managers take equally good care of all horses and that problems which arise could occur anywhere (Langlois, 1980b). Hence, the effect of management of stud farms may not be as great as anticipated. The sale of young stock is another major aspect of environment. Young horses which are sold at a high price are likely to end up in competitive homes and receive more or better training giving them a greater chance of becoming superior performers (Langlois, 1980b).

2.13 METHODS OF DATA ANALYSIS

2.13.1 Methods

EBVs can be calculated via many models including the use of a sire or animal model using the BLUP or REML procedures.

2.13.2 Best Linear Unbiased Prediction (BLUP)

The selection index (Best Linear Prediction or BLP) is a useful procedure for calculating breeding values and has been widely used for genetic analysis in animal breeding (Tavernier, 1988, Árnason, 1987, Henderson and Quaas, 1976). However, there are two major problems with the selection index method:

- Records must be adjusted for fixed or environmental factors before doing calculations. Hence, it is assumed these factors are known when most often they are not known (Henderson, 1953).
- Index equation solutions require calculation of the inverse of the covariance matrix for observations. Determination of the inverse matrix is difficult when the data set is large (Mrode and Thompson, 2005, Henderson, 1974).

BLUP was developed by Henderson in 1949 in order to overcome the problems seen in the BLP. BLUP means that fixed effects and breeding values can be estimated at the same time. The methodology for BLUP is very similar to that of BLP (Mrode and Thompson, 2005). The properties of BLUP are:

- It maximises the correlation between true (G) and predicted (X) breeding value or minimises the prediction error variance [Var(G-X)].
- Predictions are linear functions of the observations.
- Estimations are unbiased, both for the breeding value and the estimation of fixed effects.
- Is a method of predicting the true breeding value (Mrode and Thompson, 2005).

2.13.3 Restricted Maximum Likelihood (REML)

In order to utilise BLUP to calculate genetic merit, the covariance structure of the model elements must be known. However, in practical situations these are usually unknown and must be estimated. Hence, restricted maximum likelihood (REML) emerged as the method of choice for variance component estimation in animal breeding (Neumaier and Groeneveld, 1998, Gilmour et al., 1995).

2.13.4 Animal and Sire models

An animal model utilises all available pedigree information (sire, dam, dam sire, progeny and so on) in genetic evaluation. A sire model only utilises progeny information of each sire. The more information available on an animal, the more accurate the EBV for that animal will be; hence, an animal model is preferable when calculating EBVs (Groeneveld et al., 2008).

2.14 BREEDING VALUES

2.14.1 Definition

A true breeding value is the sum of the values of all of an animal's alleles, summed over a pair of alleles at a locus and over all loci that affect the trait of interest. True breeding values are not measureable; therefore, a measure of phenotypic performance is taken to provide a predictor of the true breeding value. This is known as the Estimated Breeding Value (EBV) (Lynch and Walsh, 1998). For stallions a minimum of approximately 5-10 progeny records are required to achieve sufficient reliability in EBV calculation. The greater the number of progeny records for a stallion, the higher the reliability of the EBV (Sun et al., 2009, Phocas et al., 2008). The average number of records in horse populations in Europe is approximately 50 progeny per stallion and 5 progeny per broodmare (Langlois, 1983).

2.14.2 Estimation of breeding values

Breeding values are generally estimated using a computer programme such as SAS, ASREML or PEST (Stewart et al., 2010, Lynch and Walsh, 1998). These programmes solve the mixed model equations (MME) based on the model created by the user. Examples of models used in sport horse populations are shown in *table 2*-6. The general form of the model when there is one random effect is:

$$y_{ij} = p_i + a_j + e_{ij}$$

where: y_{ij} = is the trait measured in the objective

p_i = the fixed effect of the i^{th} gender

a_j = the random effect of the j^{th} animal

e_{ij} = random error effect

The statistical model includes both genetic and non-genetic effects. The main non-genetic effects used in the analysis of sport horses are age and gender. The model is often also adjusted for the effects of location, rider and permanent environment (Koenen, 2002a). The construction of the mixed model equations requires a matrix X (relates records to fixed effects) and a Z matrix (relates records to all animals). Least

Square Equations (LSE) must be set up in order to construct the MME (Mrode and Thompson, 2005). The LSE are:

$$\begin{bmatrix} X'X & X'Z \\ Z'X & Z'Z \end{bmatrix} \begin{bmatrix} \hat{b} \\ \hat{a} \end{bmatrix} = \begin{bmatrix} X'y \\ Z'y \end{bmatrix}$$

The addition of $A^{-1}\alpha$, to the Z'Z in the LSE yields the MME, where A^{-1} is the inverse of the relationship matrix and $\alpha = \sigma_e^2 / \sigma_g^2$. Solving the MME by direct inversion of the coefficient matrix yields the estimated breeding value for the trait of interest for each animal, as well as the fixed effect averages (Mrode and Thompson, 2005).

Table 2-6: *Genetic evaluation systems that have been utilised on horse population data.*

Country of population studied	Discipline(s)	Model/programme	Fixed and random effects included in the model	Author
France	Race horses	E-KMP model	Age, gender, season	Langlois (1980a)
Germany	Dressage, show jumping and eventing	-	Birth year of sire, gender, season, effect of breed society, category of tournament. Age was included indirectly by splitting the dataset in two by age	Bruns (1981)
The Netherlands	Dressage and show jumping	REML	Age class, district, number of years in competition, season, gender, sire	Huizinga and Vandermeij (1989)
France	Show jumping	BLUP	Gender, age, permanent environment	Tavernier (1990a)
France	Race horses (trotters)	BLUP animal model	No fixed effects were used as particular conditions of each race were the same for each horse and effect of rider cannot be utilised in a dataset where the majority of riders have only one horse	Tavernier (1991)
Norway	Race horses (trotters)	Mate corrected sire model	Gender, birth year	Klemetsdal (1994)

France	Dressage, show jumping and eventing	GLM in SAS	Gender, age, season, month of birth	Langlois and Blouin (1998)
Sweden	Race horses (trotters)	REML animal model	A vector of unknown fixed systematic ronmental effects	Arnason (1999)
Germany	Mare performance test	Multi trait animal model in VCE 4.2.5	Season, month and place of test, age group, breed	Dietl et al. (2005)
Belgium	Show jumping	Bayesian sampling using the Gibbs sampler	Age of horse, gender, competition, random permanent environmental effect	Janssens et al. (2007)
United Kingdom	Eventing	Antedependence model of order 1 using ASReml	Gender, age, competition, sire, residual horse, rider	Kearsley et al. (2008)
Hungary	Show jumping	Repeatability animal model	Gender, breeder, age of horse, season, place of competition, rider, permanent environment	Posta et al. (2009)
United Kingdom	Dressage	REML using the programme ASReml	Gender, competition standard, age, height	Stewart et al. (2010)
Sweden	Dressage and show jumping	DMU package for multivariate mixed models	Birth year and gender	Viklund et al. (2010)

2.14.3 Advantages of the use of breeding values to the New Zealand sport horse industry

If EBVs with adequate reliability can be calculated for New Zealand sport horses then they could be used to increase the accuracy of selection towards specified breeding objectives, assuming such objectives are in place. Increased genetic gain would ideally lead to the production of higher quality sport horses, which would increase the chances of success of New Zealand horses and riders in international competition. Increased success would result in greater recognition of New Zealand horses on the international market; hence, would lead to higher prices for export sales. This could also lead to an increase in the funding available for equestrian sport in New Zealand. The use of clearly defined EBVs also has the potential to develop a clear and accurate system for both breeders and buyers, which would allow them to make more accurate and informed decisions on breeding (Rogers and Firth, 2005).

2.14.4 Transformations of sport horse data

Sport horse competition data commonly lacks a normal distribution due to the high frequency of zero records that result from many horses earning zero points or prize money. The most common reasons for non-earning in sport horses are likely to be lack of talent, injury or unsuitable temperament (Janssens et al., 2007, Ricard and Fournet-Hanocq, 1997). The non-normal distributions seen in sport horse performance data mean that data must frequently be transformed for analysis (Langlois and Blouin, 1998). In France, logarithmic transformed earnings are analysed (Tavernier, 1990a). In Germany, logarithmic transformed earnings per start are analysed (Huizinga and Vandermeij, 1989). Data transformations which have been effectively used on sport horse performance data are logarithmic, power and square root transformations as shown in *table 2-7*.

Table 2-6: Previous transformations of sport horse and racing horse performance data.

Type of transformation	Country of population studied	Discipline(s)	Authors who have used this method
Logarithmic transformations	United states	Dressage, show jumping and eventing	Hintz (1980)
	Germany	Dressage, show jumping and eventing	Bruns (1981)
	United States	Race horses	Buttram et al. (1988)
	France	Sport horses and race horses	Tavernier (1988, 1989, 1991)
	France	Race horses	Langlois (1980a, 1989)
	France	Dressage, show jumping and eventing (1998) and race horses (2004)	Langlois and Blouin (1998, 2004)
	France	Eventing	Ricard and Chanu (2001)
	Sweden	Dressage and show jumping	Wallin et al. (2003)
	United Kingdom	Dressage, eventing and show jumping	Whitaker and Hill (2004)
	New Zealand	Eventing	Rogers and Firth (2005)
	France	Show jumping	Dubois and Ricard (2007)
Power transformations	Sweden	Race horses (trotters)	Arnason et al. (1989)
	Norway	Race horses (trotters)	Klemetsdal (1994)
	Sweden	Race horses (trotters)	Arnason (1999)
Square root transformations	The Netherlands	Dressage and show jumping	Huizinga and Vandermeij (1989)
	The Netherlands	Race horses (trotters)	Minkema (1975, 1981)
	The Netherlands	Dressage and show jumping	Koenen et al. (1995)
	Germany	Dressage, eventing and show jumping	Luehrs-Behnke et al. (2002)

Materials and Methods

3.1 DESCRIPTION OF THE SPORT HORSE POPULATION

3.1.1 Dataset

Official performance records for the 2008/09 and 2009/10 seasons for the disciplines of dressage, eventing and show jumping were obtained from ESNZ, the body responsible for administering equestrian sport within New Zealand. Data were provided as an electronic extract of each horse's performance, total points and prize money won in the 2008/09 and 2009/10 seasons and as another extract of rider and horse details which contained a unique registration number, horse's name, sire name and breed code.

3.1.2 Editing the datasets

Within Microsoft Office Excel 2007, data were manipulated, cleaned and uploaded to a customised Microsoft Office Access 2007 database. Data editing involved removing records from ponies[7] and horses with an unknown gender or sire. Performance records from stallions were also removed due to very small numbers. The spelling of sire names was also checked and corrected. Data linking horse performance with sire and rider records were extracted for analysis. Performance records from both seasons were combined to produce a dataset which included all records from the 2008/09 and 2009/10 seasons for each discipline using Microsoft Office Excel 2007. Records on stallions, ponies, horses of unknown gender or age and horses with no sire listed were removed from the datasets from all three disciplines. A 'new sire' list was created for all horses registered with ESNZ in which spelling errors of sire names were corrected. New variables of sire ID, Year ID, official birth year and amateur (1) or professional (2) rider were created for each dataset. Variables which came from separate ESNZ data sheets were linked to the three datasets using the query design function of Microsoft Office Access 2007. These variables were gender of horse, rider ID and new sire name.

[7] 147.5cm or shorter when measured at the whither.

3.1.3 Investigation of opportunities for starts

The official ESNZ Bulletin schedules (October 2010) and the Eventing Omnibus for the 2010/11 spring season were used to investigate the average number of starts available and the opportunities to win points and/or prize money in dressage, eventing and show jumping during the 2010/11 spring competition season. Investigations were conducted using Microsoft Office Excel 2007 . The three disciplines were considered separately and each event available within each discipline was listed, along with all grades, points and/or prize money available at the event. When multiple events were held on the same day in different locations they were considered as one opportunity to start.

3.1.4 Performance measures

The criteria to quantify performance differed between the disciplines. For show jumping records were usually only available for horses which placed (1^{st}-8^{th}) in a competition, whereas for eventing and dressage an event was recorded every time they entered a competition. The performance data suitable for analysis was number of starts and total points awarded (dressage and eventing) and total annual prize money (show jumping). Within dressage, points are awarded according to the horses final percentage score for each event, (7, 5, 3 and 1 point irrespective of grade of competition). Points awarded in eventing use an ascending scale, with increasing points awarded with higher grades, such that a win earns 6, 9 or 12 points for Novice, Intermediate or Advanced grade. Prize money won in show jumping is positively associated with height of jumps and difficulty of competition, and is usually allocated with each placing generally receiving 60% of the prize money given to the placing above it.

Attempts were made to examine the effect of rider level on performance records. Riders were categorised into professional (riders of 3 or more horses in the season) and amateur (up to 2 horses registered for sport in a given season) (Rogers and Firth, 2005). However, these classifications were very subjective; hence, were not included in the model for genetic analysis.

3.1.5 Statistical analysis

Descriptive analysis was performed within Microsoft Office Excel, SAS v9.1.3 (SAS Institute, 2009) and PASW Statistics 18 (IBM Corporation, 2009). The raw data and the transformation of the raw data or the transformation of the raw data plus 1 were examined for normality using the Shapiro-Wilk test. Data used for transformation were for all animals with performance records for the 2008/09 or the 2009/10 season. Hence, all horses registered for either season that entered at least one competition (dressage and eventing) and all horses which placed during the season (show jumping) were included in the analyses. Show jumping horses with no records were not included as they were not available from the dataset. For all analysis significance was set at $p < 0.05$.

In this analysis a mixture of both the French and German systems were used to calculate EBVs in sport horses due to the type of data available for each discipline. For the disciplines of dressage and eventing information on points won and number of starts during the season was available. Therefore, EBVs can be calculated based on points per start, which permits separation of horses which won a large number of points in a few competitions from horses which have won the same number of points over many competitions. In show jumping, only the number of starts in which the horse was placed were recorded and available, therefore, number of starts cannot be utilised. Hence, EBVs were calculated for prize money won.

3.2 ESTIMATED BREEDING VALUES

3.2.1 Definition of the estimated breeding value traits

Three traits were analysed for the calculation of estimated breeding values for New Zealand sport horse sires. Points per start (dpps and epps) and number of starts (dnst and enst) were analysed for dressage and eventing and total prize money (tpm) was analysed for show jumping. These traits were defined as:

1. **Points per start (dpps for dressage and epps for eventing):** The average number of points per start the horse has earnt based on records from two competition seasons (2008/09 and 2009/10). Using average points per start allows the difference to be seen between a horse which earns 10 points over two competitions and a horse which earns 10 points over ten competitions. EBVs for dressage and eventing horses were based on this. A horse which earns a greater number of points per start is performing better in its chosen discipline. Data was transformed in such a way that EBVs are for $\log_{10}(\text{pps}+1)$.

2. **Number of starts (dnst for dressage and enst for eventing):** One start is any time the horse begins a competition, whether they completed it or not, in which points are on offer. One start in eventing is one weekend of competition. One start in dressage is one dressage test. Therefore, in dressage a horse may have several starts on the same day. If new points are offered, this counts as a new start. Having more starts during the season suggests a horse is performing well in competition and is also indicative of soundness. The variable for analysis was $\log_{10}$(number of starts).

3. **Total prize money (tpm):** An estimate of a horse's ability to perform in competition based on the total amount of prize money the horse has earnt per season. Records were available from two seasons (2008/09 and 2009/10). EBVs for show jumping are based on this, as true start data is absent. A horse which earns more prize money is performing better in its chosen discipline. Data was transformed in such a way that EBVs are for $\log_{10}$(tpm+1).

3.2.2 Model and method

The model for genetic analysis was as follows:

$$y_{ij} = \text{season} + \text{gender} + \text{age} + \text{animal} + e_{ij}$$

where y_{ij} is $\log_{10}$(points/start+1), $\log_{10}$(number of starts) or $\log_{10}$(total prize money+1) for the i^{th} animal in the j^{th} season. The fixed effects were season, gender and age. Season was either 2008/09 (1) or 2009/10 (2). Gender was either mare (1) or gelding (2). In dressage and show jumping, for horses between 5 years and 18 years, age was defined in steps of one year. For horse 3-4 years old this effect was combined as a single age class because there were few records in these categories. Horses 19-24 years old were combined as a single age class for the same reason. The same procedure was followed for the eventing dataset but with horses 6-17 years defined in steps of one year and 4-5 years old and 18-21 years old combined as two single age classes. The assumptions of the model were no inbreeding, no genetic groups, no covariates, unrelated sires and no full sibs (half sibs only). The assumption that there are no full sibs must be assumed in the absence of dam details.

Data and pedigree files were created in Notepad. The order of variables in the data file was animal, sire, dam, season, gender, age, dpps or epps, dnst or enst (or tpm for show jumping). The pedigree files contained animal, sire and dam in that order. As information on dam was not available, all dams were denoted by a zero. AIREML was used to calculate the EBVs (Johnson, 2010). Heritability was assumed at 0.15 for all traits (Bruns, 1981). These values were estimated from previous research, as they could not be calculated from the ESNZ data due to lack of convergence. EBV outputs from AIREML were then linked with the ESNZ datasets (Microsoft Office Excel 2007) to retrieve sire names via Microsoft Office Access 2007. The distribution of EBVs for each variable were tested for normality using the Shapiro-Wilk test with significance set at $p<0.05$.

Chapter 3

Results

4.1 DESCRIPTION OF THE SPORT HORSE DISCIPLINES BASED ON OPPORTUNITIES TO START

4.1.1 Eventing

In eventing it was found that the number of starts available decreased as level of competition increased. In the 2010/11 spring season there were 33 Novice, 17 Intermediate and 5 Advanced level competition starts available nationally. The average points on offer for each grade increased as level of competition increased. The average points per start available for horses which place (1^{st}-6^{th}) were 3.5, 5 and 7 for Novice, Intermediate and Advanced grades respectively (*Figure 4-1*).

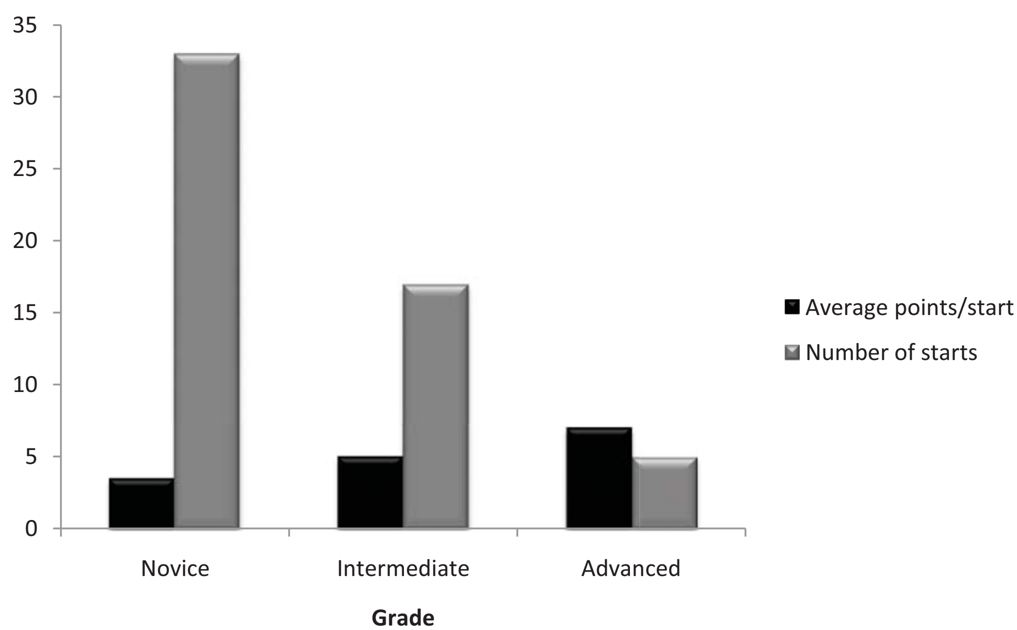


Figure 3-1: Average number of points per start and number of starts available in eventing during the spring 2010/11 season, by level of competition.

4.1.2 Dressage

The number of tests that could be entered for in the 2010/11 competition season decreased as competition level increased. 26 tests were available at level 1 (Preliminary) and 10 tests at level 9 (Grand Prix) (*Figure 4-2*). Levels 7, 8 and 9 were often combined as one competition class where riders could choose which test to ride. The number of points won at each level was the same as 1, 3, 5 and 7 points are awarded to horses scoring over 57%, 60%, 63% and 67% respectively, regardless of grade. As the system for earning points is so different between the disciplines of dressage (points earnt by percentage and eventing (points earnt by placing), similar opportunities to earn points do not exist between the two disciplines and horses in dressage tend to win more points than those competing in eventing. Hence, EBVs are unlikely to be comparable across these two disciplines for New Zealand sport horse sires.

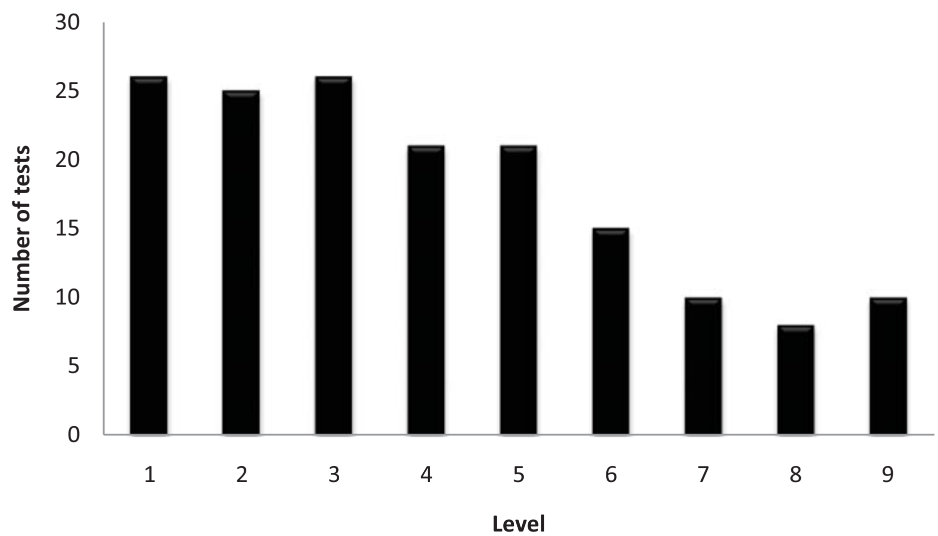


Figure 3-2: Number of tests available at each level in dressage during the spring 2010/11 season.

4.1.3 Show jumping

In show jumping the number of starts available for the 2010/11 spring season appeared normally distributed with the greatest number of starts available at the 1.1-1.19m class. The average prize money on offer across all placings at a competition (1st-8th) increased from $6.03 for classes jumping the height of 0.8-0.89m to $164.44 for the 1.4-1.49m classes. The average prize money offered increased dramatically to $490.83 and $375 for the 1.5-1.59m and 1.6-1.69m classes respectively (*Figure 4-3*). The use of total prize money as a measure of performance makes it unlikely that EBVs for show jumping sires will be comparable with those calculated for sires in dressage or eventing.

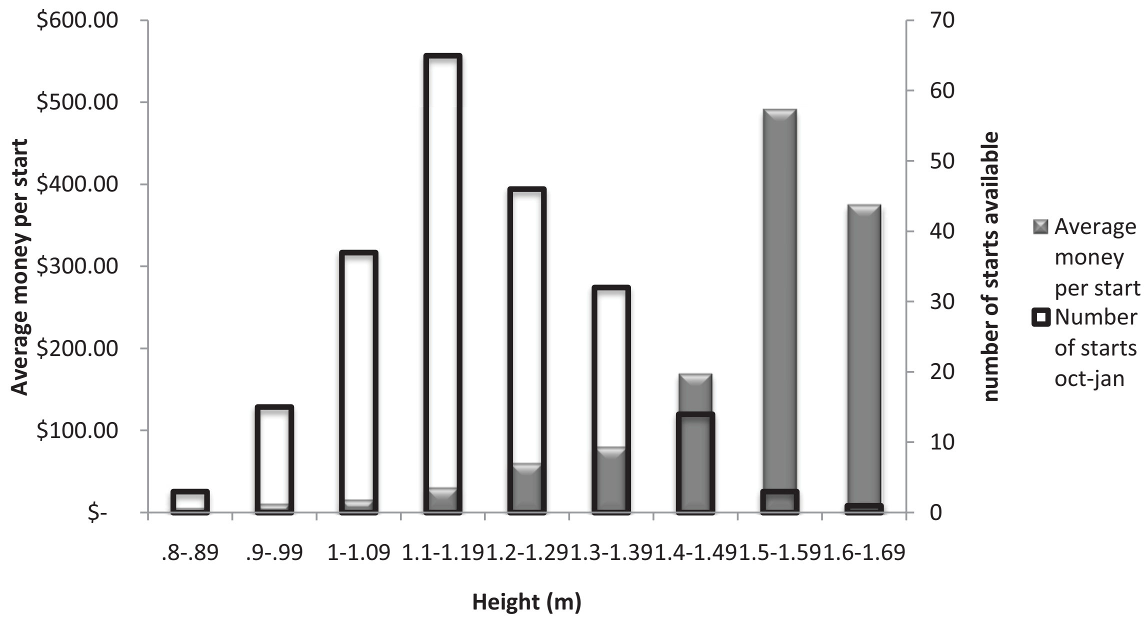


Figure 3-3: Number of starts available and average money per start on offer for show jumping during the spring 2010/11 season.

4.2 ANALYSIS OF THE 2008/09 AND 2009/10 COMPETITON SEASONS

4.2.1 Description of the population

During the 2008/09 season there were 1123, 902 and 1326 horses registered for the equestrian disciplines of dressage, eventing and show jumping respectively. Sire was not recorded for 13.2%, 15.0% and 16.3% of registered horses within each discipline. There were 51, 115 and 43 riders with 3 or more horses registered for dressage, eventing and show jumping (*Table 4-1*). 26.8% of horses registered for show jumping in the 2008/09 season did not have a rider identification number available and were included as amateur.

Table 3-1: Description of the data set for the equestrian disciplines of dressage, eventing and show jumping during the 2008/09 and 2009/10 competition seasons.

	Discipline					
	Dressage		***Eventing***		***Show jumping***	
Parameter	***2008/09***	***2009/10***	***2008/09***	***2009/10***	***2008/09***	***2009/10***
Number of horses registered	1123	1472	902	1255	1326	1331
Number of riders	860	1200	583	835	950	836
Number of professional riders (3 or more horses registered)	51	52	115	72	43	106
Total number of starts within discipline during the season	10400	13677	4133	5169	n/a	n/a
Horses with no sire listed (%)	13.2%	14.2%	15.0%	10.5%	16.3%	17.2%
Number of sires represented	511	621	434	236	533	566
Sires contributing only 1 progeny record (%)	70.8%	69.4%	63.6%	75.0%	63.8%	67.7%
Horses earning zero points on record (%)	1.8%	1.1%	64.6%	13%	n/a	n/a
Horses earning no prize money on record (%)	43.9%	56.6%	70.8%	16.3%	2.7%	5.6%

During the 2009/10 season there were 1472, 1255 and 1331 horses registered for the equestrian disciplines of dressage, eventing and show jumping respectively. Sire was not recorded for 14.2%, 10.5% and 17.2% of registered horses within each discipline. There were 52, 72 and 106 riders with 3 or more horses registered for dressage, eventing and show jumping (*Table 4-1*).

4.2.2 Progeny numbers

There were very few stallions registered for competition in all three disciplines. In dressage, there were 21 and 30 stallions with competition records for the 2008/09 and 2009/10 seasons respectively. In eventing, there were 5 and 2 stallions with competition records for the 2008/09 and 2009/10 seasons respectively. In show jumping, there were 22 and 26 stallions with competition records for the 2008/09 and 2009/10 seasons respectively. The number of progeny records available for each sire was on average very small indicating a highly heterogeneous sport horse population (*Tables 4-2, 4-3 and 4-4*). The allocation of sire names was relatively inaccurate as there were 2487 spelling errors from 11926 records (20.9%) for sire names in the original data set (records of all horses registered with ESNZ) which had to be corrected before analysis to enable linking of progeny groups.

Table 3-2: The ten stallions with the greatest number of progeny records (nprog) in dressage during the 2008/09 and 2009/10 seasons.

Sire	nprog
Anamour	193
Dream Boy	46
Voltaire II	45
Gymnastik Star	37
HP Corlando	31
Falkensee	22
Worldwide P.B	21
Littorio	18
Jaguar	18
Zabalou	17

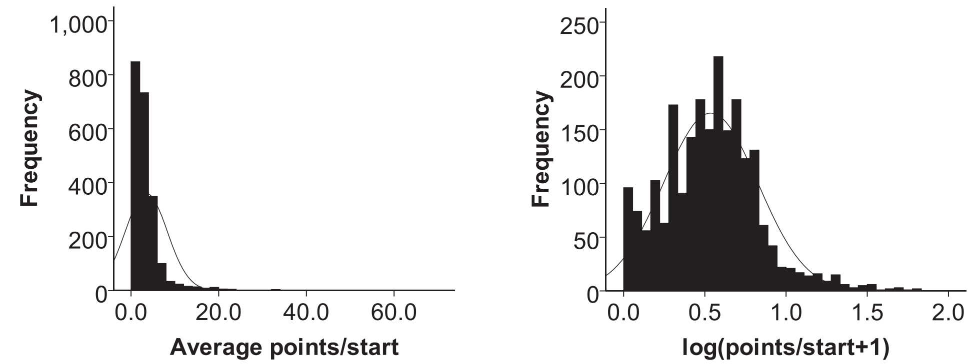
Table 3-3: The ten stallions with the greatest number of progeny records (nprog) in eventing during the 2008/09 and 2009/10 seasons.

Sire	nprog
Voltaire II	17
Drums of Time	17
Grosvenor	15
Anamour	14
Hula Town	14
Internet	12
Lone Arrow	10
Senor Pete	8
Laughton's Legend	8
Ebony Groove	8

Table 3-4: The ten stallions with the greatest number of progeny records (nprog) in show jumping during the 2008/09 and 2009/10 seasons.

Sire	nprog
Voltaire II	69
Ramirez	26
Kingsway Diamond	25
HP Corlando	24
Littorio	24
Anamour	23
Laughton's Legend	21
Kahurangi Valiant	18
Hula Town	18
Distelfink	18

(a)



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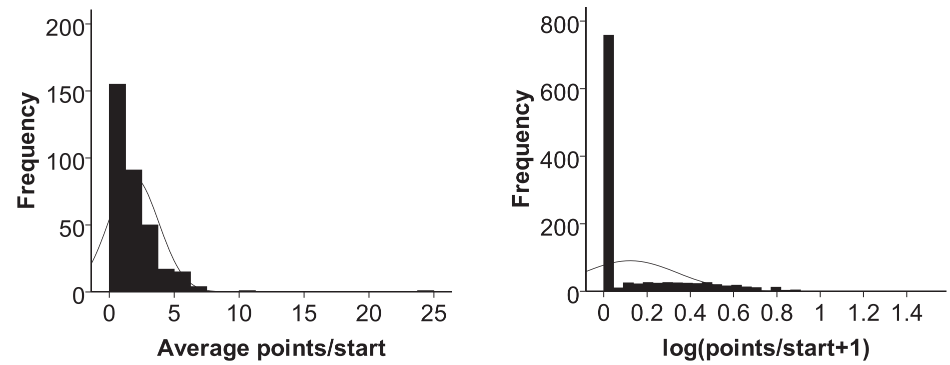

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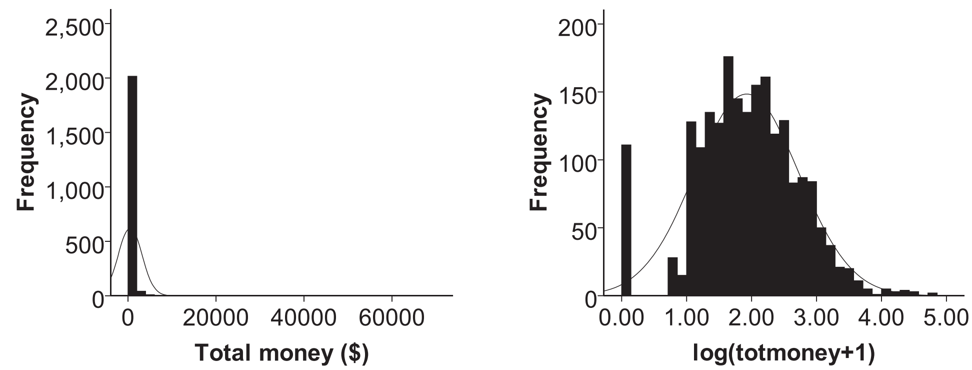
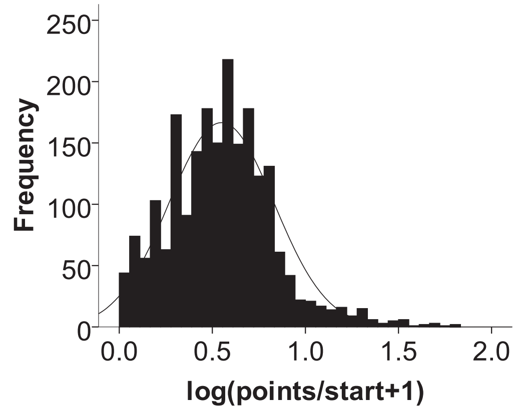


Figure 3-4: Histograms of raw (left) and transformed ($\log_{10}$ data plus 1) (right) data for the equestrian disciplines of (a) dressage (points/start); (b) eventing (points/start) and (c) show jumping (prize money). Data is combined for the 2008/09 and 2009/10 seasons. Normality curves show the ideally desired distribution for the given data.

(a)



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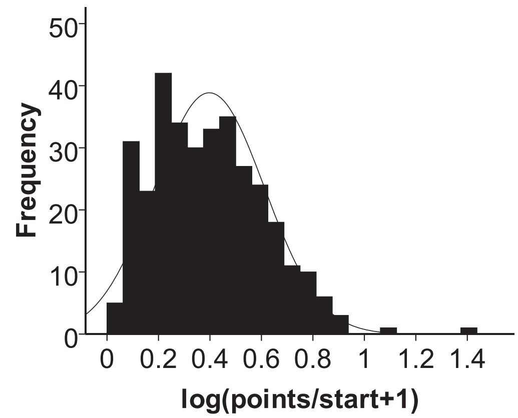

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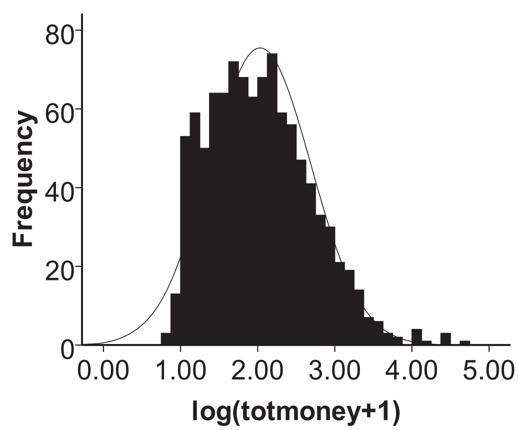
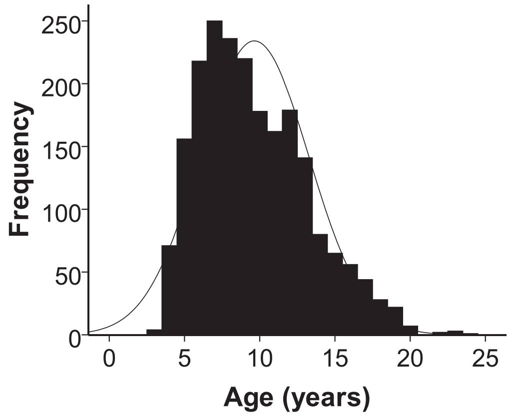
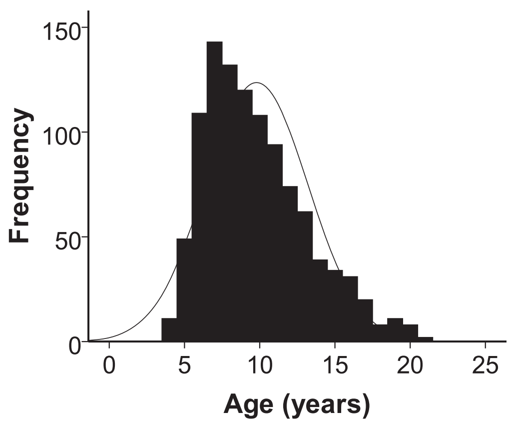


Figure 3-5: Histograms of log(points per start+1) with records valued at zero removed to show improved normality of excluding these records for horses in dressage (a) and eventing (b) and log(total money+1) for show jumping (c). Data is combined for the 2008/09 and 2009/10 seasons. Normality curves show the ideally desired distribution for the given data.

(a)



(b)



(c)

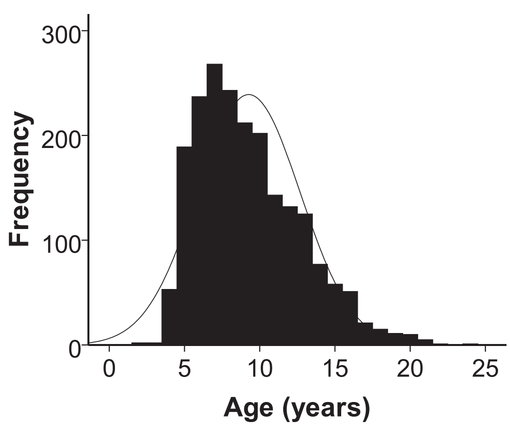


Figure 3-6: Histograms of the age distribution of horses competing in dressage (a), eventing (b) and show jumping (c). Data is combined for the 2008/09 and 2009/10 seasons. Normality curves show the ideally desired distribution for the given data.

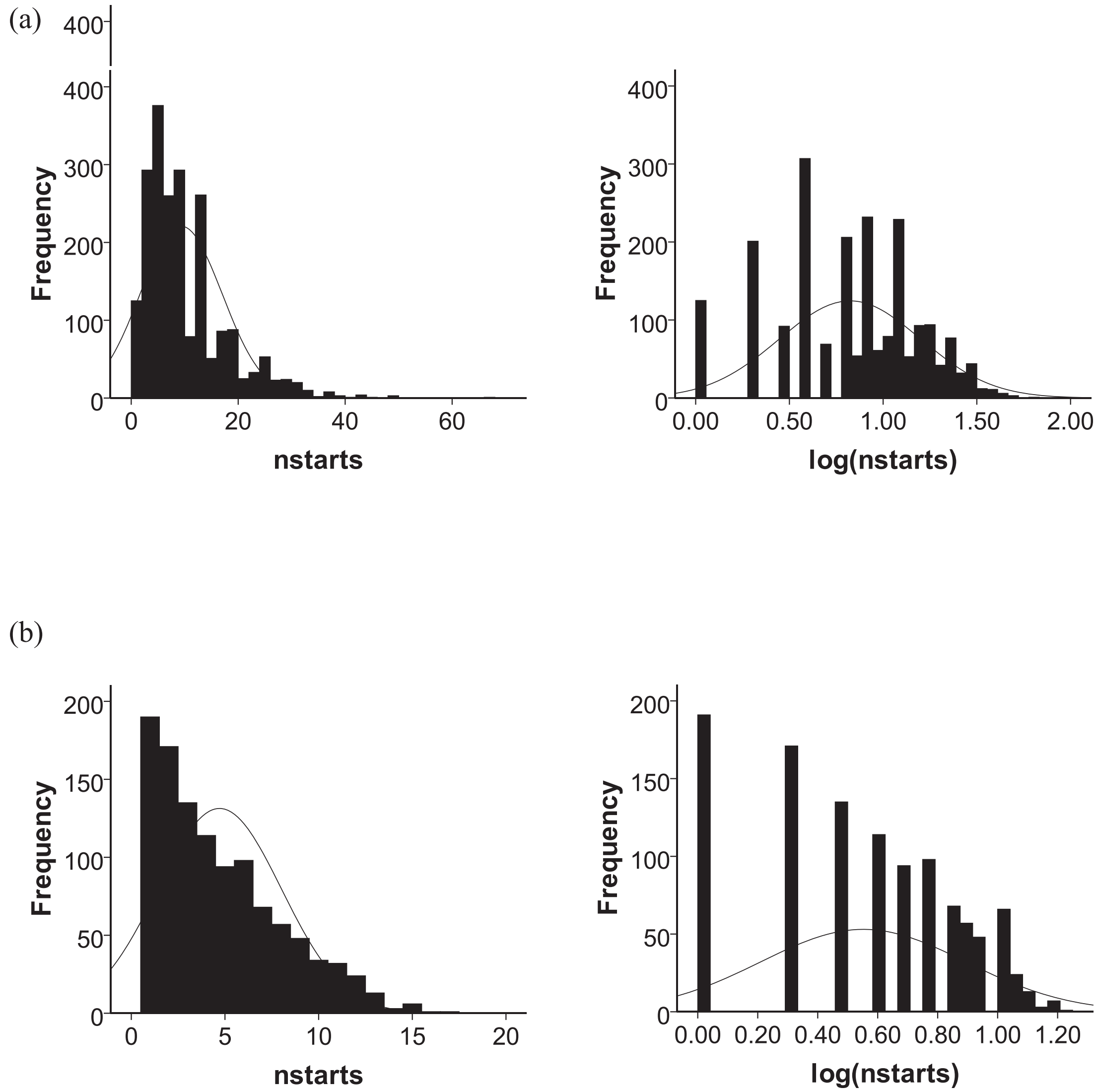


Figure 3-7: Histograms for number of starts and log(number of starts) in dressage (a) and eventing (b). Data is combined for the 2008/09 and 2009/10 seasons. Normality curves show the ideally desired distribution for the given data.

4.2.3 Normality tests

Tests for normality identified that none of the raw performance data or data on number of starts was normally distributed. Transformation of the data plus 1(log_{10}) significantly improved the distribution of the performance data (*Figures 4-4 and 4-7*), though the large number of horses with zero performance records continued to skew the distributions ($p<0.05$). Removal of horses with zero records resulted in the transformed data approaching a normal distribution ($p<0.05$) (*Figure 4-5*). However, these records were retained for the calculation of EBVs as removing them would result in a biased progeny sample for each sire.

4.2.4 Population age structure

The population age structure for all three disciplines shows that there is a large loss of horses from competition at a young age. This is a common trend in sport horses as many horses are lost from competition early on as a result of lameness/musculoskeletal injury or lack of talent (Rogers and Firth, 2005). The official ages of competing horses ranged from 3-24 years for dressage, 4-21 years for eventing and 3-24 years for show jumping. The average age of a horse in competition was 9.6 years, 9.8 years and 9.3 years for dressage, eventing and show jumping respectively. The median age was 7 years for all three disciplines (*Figure 4-6*).

4.2.5 Investigation of the variables for genetic analysis

An investigation of the raw means of points per start, number of starts and total prize money was performed. The average number of points per start for stallions in dressage during the 2008/09 season was zero. The number of stallions in dressage competition was low in both seasons with 21 and 30 competing in the 2008/09 and 2009/10 seasons respectively (*Figure 4-8*). In eventing the average points earnt per start and number of starts appeared much lower than seen in dressage due to the different systems for earning points between the two disciplines and the different competition formats. The average number of points per start for stallions during the 2008/09 and 2009/10 seasons was zero. The number of stallions in competition was low in both seasons with 5 and 6 competing in the 2008/09 and 2009/10 seasons respectively (*Figure 4-9*). In show jumping, the number of stallions in competition was low in both seasons with 22 and 26 competing in the 2008/09 and 2009/10 seasons respectively (*Figure 4-10*). These zero values suggest poor performance of the stallions. However, stallions are usually kept entire as they are potentially superior performers, hence, averages of zero points per start could be the result of the very small numbers of stallions. Stallions are also physiologically different from geldings; hence, should be considered as a separate gender group. Stallions as progeny records were removed from genetic analysis as grouping them with geldings could have overvalued them and stallion numbers were too low for them to be considered as a separate gender (Stewart et al., 2010).

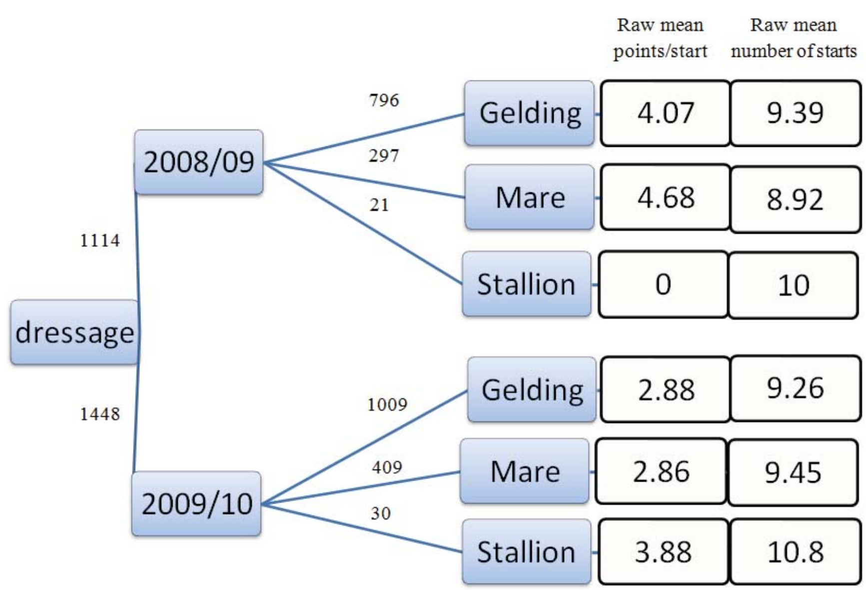


Figure 3-8: Breakdown of the variables included in the model for genetic analysis showing the average points per start and number of starts for mares, geldings and stallions in dressage during the 2008/09 and 2009/10 seasons.

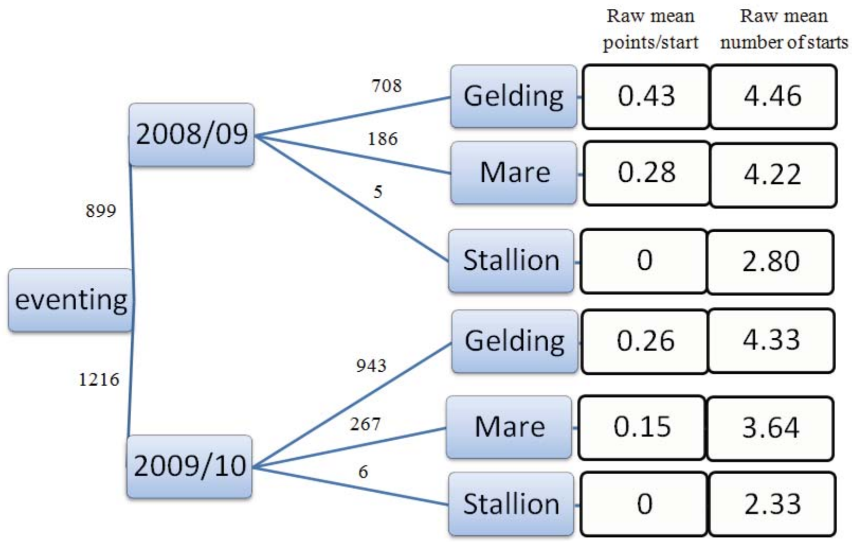


Figure 3-9: Breakdown of the variables included in the model for genetic analysis showing the average points per start and number of starts for mares, geldings and stallions in eventing during the 2008/09 and 2009/10 seasons.

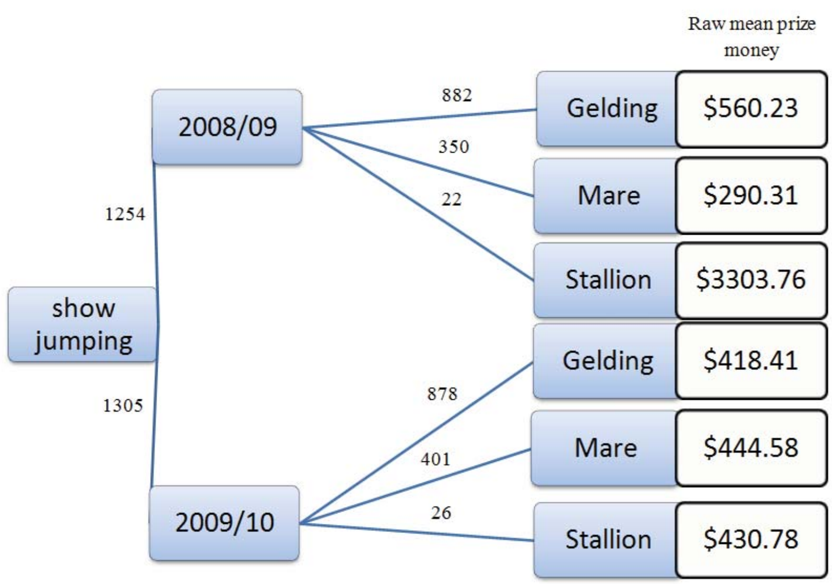


Figure 3-10: Breakdown of the variables included in the model for genetic analysis showing the average prize money won by mares, geldings and stallions in show jumping during the 2008/09 and 2009/10 seasons.

4.3 ESTIMATED BREEDING VALUES

4.3.1 Description of the estimated breeding values calculated for New Zealand sport horse sires

The limitations in the New Zealand dataset suggest that the EBVs calculated here should only be considered as initial indicators of the genetic merit of New Zealand sport horse sires. The variables dpps and dnst measured in dressage and epps and enst measured in eventing showed a smaller range of EBVs than the variable tpm in show jumping. The population means were zero to four decimal places in all three disciplines (*Table 4-5*). The standard errors of all EBVs were reasonably large, due in part to the fact that only 11.8%, 11.3% and 14.2% of sires in dressage, eventing and show jumping respectively contributed 5 or more progeny records for genetic analysis.

Table 3-5: Percentile bands for the distribution of EBVs calculated for the New Zealand data set using data from the 2008/09 and 2009/10 seasons in dressage, eventing and show jumping. The variables are dpps and epps (log(points per start+1)), dnst and enst (log(number of starts)) and tpm (log(total prizemoney+1)).

	Dressage		Eventing		Show jumping
	dpps	**dnst**	**epps**	**enst**	**tpm**
Top 10%	0.021	0.025	0.048	0.043	0.191
Top 20%	0.011	0.015	0.020	0.026	0.105
Top 30%	0.006	0.009	0.000	0.017	0.058
Top 40%	0.003	0.004	-0.006	0.007	0.020
Top 50%	0.000	-0.001	-0.009	-0.002	-0.010
Top 60%	-0.005	-0.005	-0.013	-0.008	-0.038
Top 70%	-0.009	-0.010	-0.016	-0.020	-0.075
Top 80%	-0.015	-0.018	-0.022	-0.031	-0.110
Top 90%	-0.021	-0.027	-0.030	-0.043	-0.175
$\boldsymbol{\mu_{population}}$	-0.000008	-0.00001	0.00002	-0.000009	0.00002
Range	-0.066-0.158	-0.117-0.232	-0.076-0.182	-0.101-0.168	-0.523-0.993

4.3.2 Sire results

The six top ranked sires based on EBVs for dpps in dressage were also included in the list of ten highest ranked sires based on number of progeny records available for analysis. The four top ranked sires based on EBVs for dnst were included in the ten highest ranked sires based on number of progeny records. This could in part be a reflection of the increased number of records available to calculate EBVs for these sires. Anamour had the greatest number of progeny records (193). Dream Boy had the highest EBV for dpps (0.158±0.062) and Anamour had the highest EBV for dnst (0.232±0.052). There were 5 records in dressage (for both dpps and dnst) rated in the top ten stallions based on progeny records for which negative EBVs were calculated (*Tables 4-6 and 4-7*).

Two of the ten highest ranked sires based on EBVs for epps in eventing were also included in the list of ten highest ranked sires based on number of progeny records available for analysis. These sires were Grosvenor and Voltaire II. Four of the ten top ranked sires based on EBVs for enst were included in the ten highest ranked sires based on number of progeny records. Voltaire II and Drums of Time had the greatest number of progeny records (17). A Touch of Hillbilly had the highest EBV for epps (0.182±0.099) and Grosvenor had the highest EBV for enst (0.168±0.109). There were 4 records in eventing (for both epps and enst) rated in the top ten stallions based on progeny records for which negative EBVs were calculated (*Tables 4-8 and 4-9*).

One of the ten highest ranked sires based on EBVs for tpm in show jumping was also included in the list of ten highest ranked sires based on number of progeny records available for analysis. This sire was Kahurangi Valiant. Voltaire II had the greatest number of progeny records (69) but did not feature on the list of ten best stallions by EBV. Wishing Well had the highest EBV for tpm (0.993±0.307). There were 3 records in show jumping (for tpm) rated in the top ten stallions based on progeny records for which negative EBVs were calculated. These were Kingsway Diamond (-0.013±0.264), Laughton's Legend (-0.025±0.282) and Distelfink (-0.061±0.294) (*Table 4-10*). Histograms of the distribution of EBVs[8] for each discipline show that the values obtained for dressage (dpps and dnst), eventing (epps and enst) and show jumping (tpm) approach normality around a mean approaching zero ($p<0.05$) (*Figures 4-11 to 4-15*).

[8] The full EBV lists can be found on a CD at the back of this thesis.

Table 3-6: Comparison of sires with the greatest number of progeny records (nprog) and sires with the highest EBVs (for the variable dpps) for dressage. Values are from data combined for the 2008/09 and 2009/10 seasons.

Top 10 stallions by popularity				Top 10 stallions by EBV			
Sire	**EBV_{dpps}**	**SE**	**nprog**	**Sire**	**EBV_{dpps}**	**SE**	**nprog**
Anamour	0.152	0.040	193	Dream Boy	0.158	0.062	46
Dream Boy	0.158	0.062	46	Gymnastik Star	0.156	0.064	37
Voltaire II	0.079	0.061	45	Anamour	0.152	0.040	193
Gymnastik Star	0.156	0.064	37	Voltaire II	0.079	0.061	45
HP Corlando	0.072	0.066	31	Worldwide P.B	0.078	0.071	21
Falkensee	-0.029	0.070	22	HP Corlando	0.072	0.066	31
Worldwide P.B	0.078	0.071	21	Injustice	0.059	0.081	4
Littorio	0.011	0.073	18	Woodstock Recaro Reel	0.054	0.081	5
Jaguar	-0.027	0.072	18	Riverman	0.053	0.083	2
Zabalou	-0.020	0.073	17	Horace	0.052	0.081	4

Table 3-7: Comparison of sires with the greatest number of progeny records (nprog) and sires with the highest EBVs (for the variable dnst) for dressage. Values are from data combined for the 2008/09 and 2009/10 seasons

Top 10 stallions by popularity				Top 10 stallions by EBV			
Sire	**EBV_{dnst}**	**SE**	**nprog**	**Sire**	**EBV_{dnst}**	**SE**	**nprog**
Anamour	0.232	0.052	193	Anamour	0.232	0.052	193
Dream Boy	0.117	0.080	46	Gymnastik Star	0.189	0.083	37
Voltaire II	-0.010	0.079	45	Worldwide P.B	0.152	0.090	21
Gymnastik Star	0.189	0.083	37	Dream Boy	0.117	0.080	46
HP Corlando	0.023	0.085	31	Lone Arrow	0.104	0.097	12
Falkensee	0.007	0.090	22	Witzbola	0.092	0.099	8
Worldwide P.B	0.152	0.090	21	Salutation	0.084	0.103	7
Littorio	0.026	0.093	18	Weltmeyer	0.083	0.102	5
Jaguar	-0.041	0.093	18	Genius	0.073	0.098	10
Zabalou	0.018	0.093	17	McHamish	0.061	0.103	4

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Table 3-8: Comparison of sires with the greatest number of progeny records (nprog) and sires with the highest EBVs (for the variable epps) for eventing. Values are from data combined for the 2008/09 and 2009/10 seasons.

Top 10 stallions by popularity				Top 10 stallions by EBV			
Sire	**EBV_{epps}**	**SE**	**nprog**	**Sire**	**EBV_{epps}**	**SE**	**nprog**
Voltaire II	0.130	0.075	17	A Touch of Hillbilly	0.182	0.099	2
Drums of Time	0.006	0.074	17	Grosvenor	0.136	0.077	15
Grosvenor	0.136	0.077	15	Turbulent Dancer	0.135	0.090	6
Anamour	0.016	0.078	14	Voltaire II	0.130	0.075	17
Hula Town	-0.076	0.078	14	Waikiki Star	0.129	0.089	6
Internet	0.079	0.082	12	Lantham	0.120	0.099	2
Lone Arrow	-0.043	0.083	10	Telesun	0.111	0.093	4
Senor Pete	0.068	0.087	8	Bahhare	0.108	0.096	3
Laughton's Legend	0.042	0.086	8	Haajiisan	0.101	0.096	3
Ebony Groove	0.038	0.086	8	Engagement	0.094	0.099	2

Table 3-9: Comparison of sires with the greatest number of progeny records (nprog) and sires with the highest EBVs (for the variable enst) for eventing. Values are from data combined for the 2008/09 and 2009/10 seasons.

Top 10 stallions by popularity				Top 10 stallions by EBV			
Sire	**EBV_{enst}**	**SE**	**nprog**	**Sire**	**EBV_{enst}**	**SE**	**nprog**
Voltaire II	0.118	0.108	17	Grosvenor	0.168	0.109	15
Drums of Time	0.100	0.106	17	Anamour	0.131	0.110	14
Grosvenor	0.168	0.109	15	Voltaire II	0.118	0.108	17
Anamour	0.131	0.110	14	Charlton Javelin	0.111	0.122	6
Hula Town	-0.005	0.110	14	Little Brown Jug	0.111	0.124	5
Internet	0.071	0.114	12	Kingdom Bay	0.103	0.124	5
Lone Arrow	-0.033	0.115	10	NK Prince Ferdinand	0.101	0.123	6
Senor Pete	0.064	0.118	8	Drums of Time	0.100	0.106	17
Laughton’s Legend	0.047	0.119	8	Spectacular Love	0.087	0.127	4
Ebony Groove	0.033	0.118	8	Aston Magnum	0.083	0.122	5

Table 3-10: Comparison of sires with the greatest number of progeny records (nprog) and sires with the highest EBVs (for the variable tpm) for show jumping. Values are from data combined for the 2008/09 and 2009/10 seasons.

Top 10 stallions by popularity				Top 10 stallions by EBV			
Sire	**EBV_{tpm}**	**SE**	**nprog**	**Sire**	**EBV_{tpm}**	**SE**	**nprog**
Voltaire II	0.205	0.192	69	Wishing Well	0.993	0.307	16
Ramirez	0.321	0.261	26	Salute the Stars	0.712	0.318	13
Kingsway Diamond	-0.013	0.264	25	San Mateo Second Chance	0.619	0.383	4
HP Corlando	0.253	0.266	24	Cabdula du Tillard	0.6	0.339	9
Littorio	0.173	0.264	24	Omnicorp	0.577	0.331	11
Anamour	0.117	0.274	23	Kahurangi Valiant	0.546	0.296	18
Laughton's Legend	-0.025	0.282	21	Indoctro	0.486	0.372	5
Kahurangi Valiant	0.546	0.296	18	Zig Zag	0.478	0.383	4
Hula Town	0.178	0.289	18	Fetiche du pas	0.472	0.348	8
Distelfink	-0.061	0.294	18	Leo Caylon	0.449	0.336	10

4.3.3 The distribution of estimated breeding values for dressage sires

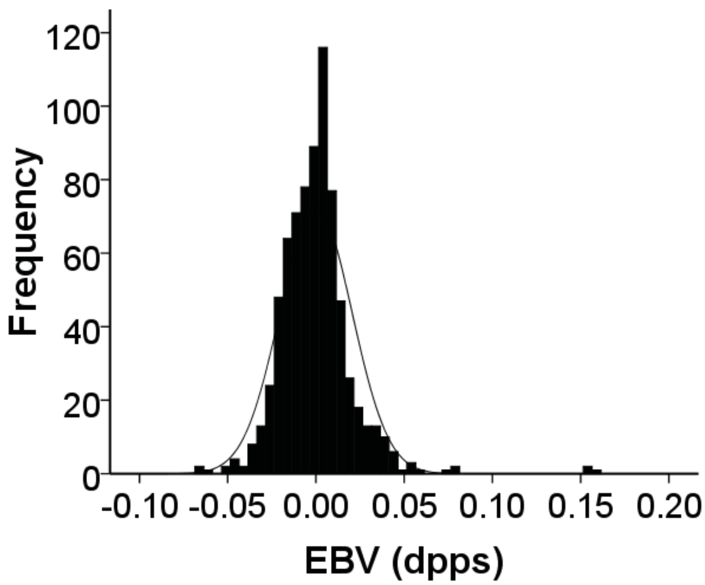

Figure 3-11: Histogram of the distribution of EBVs calculated from New Zealand data over the 2008/09 and 2009/10 competition seasons for the variable log(points per start+1) in dressage (dpps).

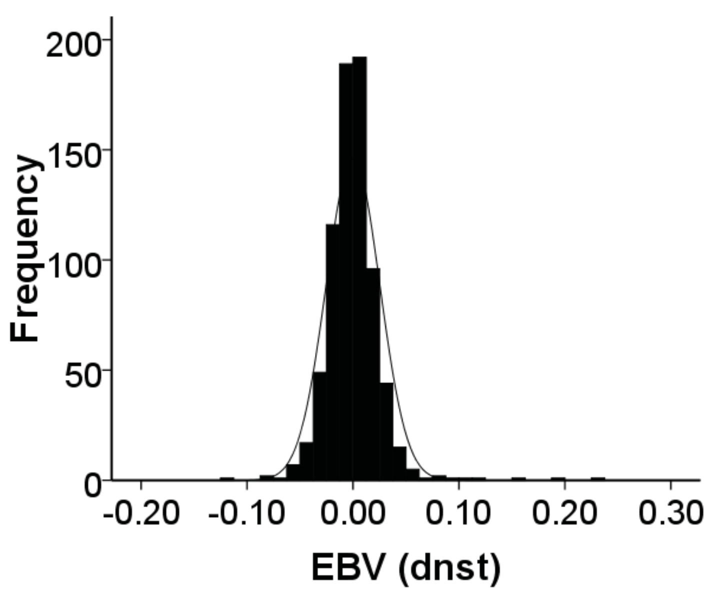

Figure 3-12: Histogram of the distribution of EBVs calculated from New Zealand data over the 2008/09 and 2009/10 competition seasons for the variable log(number of starts) in dressage (dnst).

4.3.4 The distribution of estimated breeding values for eventing sires

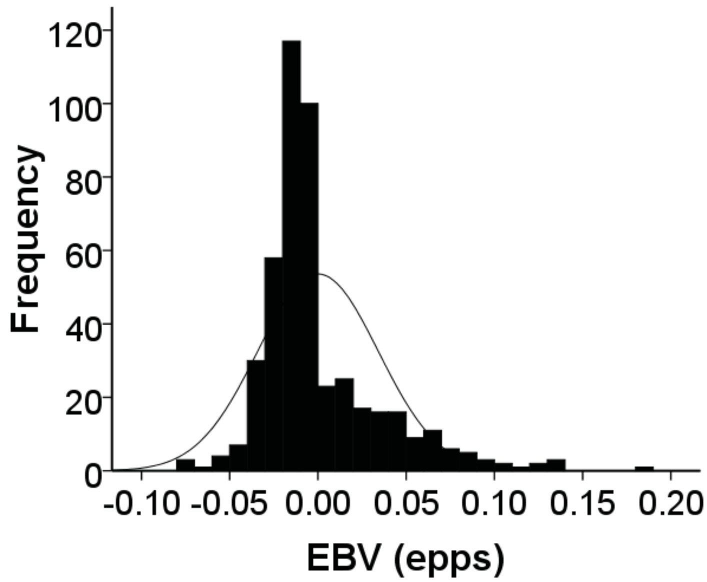

Figure 3-13: Histogram of the distribution of EBVs calculated from New Zealand data over the 2008/09 and 2009/10 competition seasons for the variable log(points per start+1) in eventing (epps).

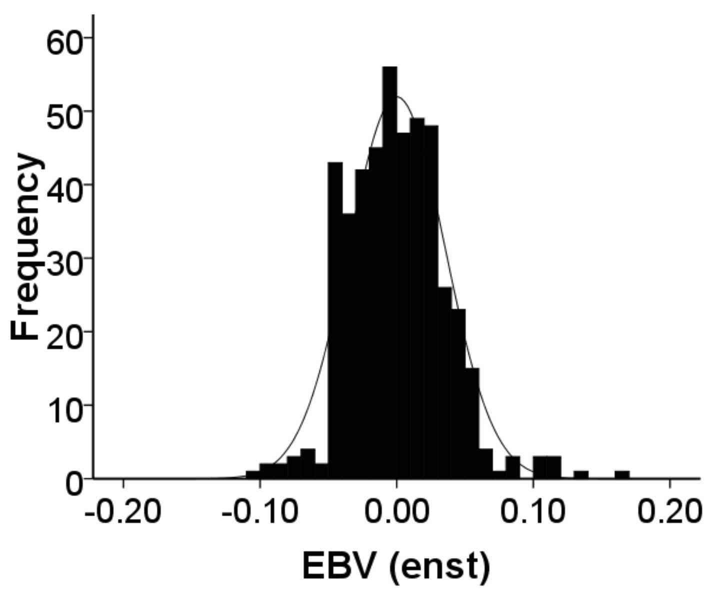

Figure 3-14: Histogram of the distribution of EBVs calculated from New Zealand data over the 2008/09 and 2009/10 competition seasons for the variable log(number of starts) in eventing(enst) .

4.3.5 The distribution of estimated breeding values for show jumping sires

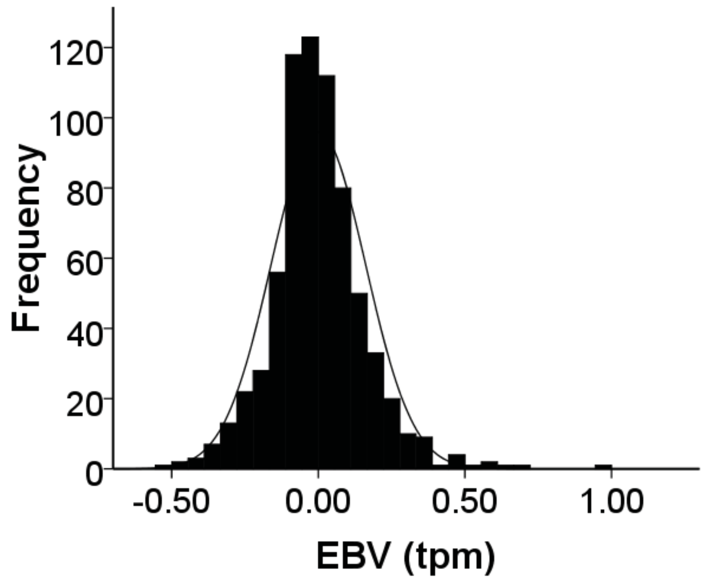

Figure 3-15: Histogram of the distribution of EBVs calculated from New Zealand data over the 2008/09 and 2009/10 competition seasons for the variable log(total prize money+1) in show jumping (tpm).

Chapter 4

Discussion

5.1 SYSTEM OF EARNING POINTS AND PRIZE MONEY AND STARTS AVAILABILE IN NEW ZEALAND SPORT HORSE COMPETITIONS

5.1.1 Starts, points and prize money availability

The number of starts available and the number of points and amount of prize money available during the 2010/11 spring season were found to differ between competition grades for all three disciplines. In eventing, it was found that the average number of points per start available increased as competition level increased (from novice to advanced). However, the number of starts available decreased as competition level increased (*Figure 4-1*). Based on this, talented eventing horses competing at advanced level may not appear sufficiently superior to horses in lower grades based solely on points data.

In dressage, the same trend was observed, the number of tests available decreased as competition level increased (from level 1 to level 9). The points available per start were the same for each level (*Figure 4-2*). In show jumping it was also seen that the number of starts available decreased as competition level increased (apart from in very low grades where few starts were offered) and average prize money on offer increased as level increased (*Figure 4-3)*. This is useful for genetic analysis as horses earning more prize money are likely to be more talented than horses earning less. Including competition level in the genetic model would standardise the points earnt per start across each level. Hence, competition level was excluded from the model as competition levels test different aptitudes and points earnt in a higher grade should hold greater weight (Aldridge et al., 2000).

There were a similar number of starts available in novice eventing (33) as in level 1 dressage (26) and advanced eventing (5) and level 9 dressage (10). Hence, the opportunities to earn points were similar in both disciplines. In show jumping, the highest number of starts was much higher than in eventing and dressage (65 in the 1.10m-1.19m division) but there was only 1 start in the highest grade (1.60-1.69m). However, how the number of starts compares to the other disciplines is of little relevance as the system for show jumping is so different from that of eventing and dressage and analysis must be based on prize money instead of points per start.

5.1.2 Comparisons across disciplines

International comparisons of EBVs are difficult due to different data recording systems in different countries (Koenen, 2002a). Similarly, EBVs will not be comparable across disciplines for New Zealand sport horse sires due to different data recording systems between disciplines.

5.2 THE UNIQUE SITUATION IN EQUESTRIAN SPORT

5.2.1 Normality of the data

Points per start data for dressage and eventing and total prize money data for show jumping had a highly skewed distribution, with the majority of horses earning no points or prize money and a select few which were high earners (*Figure 4-4*). The same highly skewed distribution was seen for number of starts data analysed for dressage and eventing, with a large number of horses only starting once during the season (*Figure 4-7*). Hence, transformation of the points, prize money and number of starts data was required for genetic analysis (Langlois and Blouin, 1998). Of the three transformations attempted (logarithmic (base 10), square root and power ($x^{0.2}$)), the logarithmic transformation was found to be most effective for improving normality of the data. This is consistent with previous research, as logarithmic transformations have been widely used as a scale on which to measure horse performance (Tavernier, 1991).

Very non-normal distributions are common in equestrian sport data due to the high frequency of zero records. Assigning horses which earnt zero points or prize money with a zero record categorises these horses as bad performers. However, care should be taken when doing this, as some of these horses will simply not yet have been tested in competition (Ricard and Chanu, 2001). There were no missing records on points or prize money in the ESNZ dataset and all horses had at least one start during the competition season, hence, a zero record was assumed to be the result of poor performance. Therefore, as in the study of Klemetsdal (1994) and Minkema (1989) zero records were assigned to all nonearning or nonscoring horses. The main reasons for nonearning in sport horses are likely to be lack of talent, injury or unsuitable temperament (Janssens et al., 2007, Ricard and Fournet-Hanocq, 1997).

In the case of points and prize money, one was added to each record before transformation to enable logarithmic transformation of zero records. These zero records meant that the data still showed a non-normal distribution after transformation. Removal of these zero records improved the normality of the data (*Figure 4-5*). However, these records were retained for genetic analysis, as removing them would lead to a biased sample of progeny from each sire (Aldridge et al., 2000). The effect of zero records on normality was greatest for the eventing data, as the proportion of zero records was much higher than in dressage or show jumping. Hence, the distribution of eventing data changed significantly (appeared far more normal) when zero records were removed. Logarithmic transformation of number of starts data resulted in less than ideal normality of the data for analysis, particularly for eventing ($P<0.05$) (*Figure 4-7*).

The age distribution of the sport horse population was similar for all three disciplines and showed that a small number of horses started in competition at a young age (3 years in dressage and show jumping or 3-4 years in eventing) and a large number of horses competed in the general range of 4 to 19 years of age (*Figure 4-6*). Very few horses were retained in competition past the age of 19 years. Mares in particular are often removed from sport early to be used for breeding (O'Brien et al., 2005). There were large losses of horses at a young age which is common in sport horse populations. The main reasons for loss of horses from competition at a young age are lameness/musculoskeletal injury and lack of talent (Rogers and Firth, 2005).

5.2.2 Heterogeneity of the sport horse population

Sport horse populations tend to be relatively heterogeneous (Wallin et al., 2003). The New Zealand data set was found to be particularly heterogeneous with 63.6%-75% of sires contributing only one progeny record (*Table 4-1*) and only 11.3% to 14.2% of sires had 5 or more progeny records. A minimum of approximately 5-10 progeny records is required to achieve sufficient reliability in EBV calculation (Sun et al., 2009, Phocas et al., 2008). Hence, the reliability of the EBVs for the majority of sport horse sires in New Zealand, based on current data, would have been extremely low (Woolliams, 2006). This heterogeneity will partly be the result of missing information on sire affecting the data records.

The number of progeny competing in sport horse disciplines demonstrates how heterogeneous the New Zealand sport horse population is with even popular stallions in each discipline having relatively few progeny. Anamour's progeny in dressage were the only exception with 92 and 101 progeny competing during the 2008/09 and 2009/10 seasons respectively.

5.2.3 Missing records

There were many missing or inaccurate sire records in the ESNZ database. Information on sire was not available for 3.82% to 17.2% of horses competing in dressage, eventing and show jumping (*Table 4-1*). Horses with an unknown sire had to be excluded from genetic analysis; hence, progeny information from these horses is missing, which influences the variance of sire EBVs, leading to a reduced response to selection (Harder et al., 2005, Sanders et al., 2006). Information on sire was not available as either it was not provided when the horse was registered or the sire was simply not known.

Inaccurate spelling of sire names was a large problem within the New Zealand dataset. The impact of wrong sire information on reliability and genetic gain has been found to be twice that of missing sire information (Woolliams, 2006). Across all three disciplines 20.9% of horses registered with ESNZ had incorrectly spelt sire names. If the spelling of sire names is not corrected prior to analysis, different versions of the same sire will be counted as different sires, as no sire identification number is provided in the dataset. Hence, the sport horse population will appear more heterogeneous and EBVs will be based on incomplete progeny samples.

5.2.4 The effect of rider

Equestrian sport is unique in the animal breeding sector in that there is a confounding effect of the rider on sport horse performance (Kearsley et al., 2008). This rider effect makes it difficult to separate a horse's own talent from that of its rider, as more experienced riders tend to achieve better results on less talented horses than less experienced riders. Horses which are thought to be better performers also often end up with better riders (Bruns, 1981). Hence, horses are often categorised as ridden by either amateur or professional riders for genetic analysis. Categorisation of riders as amateur or professional is simple in European systems, as professional riders are registered under a different licence to amateur riders and they compete in separate classes

(Federation Francais d'Equitation, 2009). However, in New Zealand all riders are registered under the same licence and compete in the same classes (Equestrian Sports New Zealand, 2009b). Hence, riders could only be assumed to be amateurs or professionals based arbitrarily on the number of horses they registered to ride in a given discipline during the season.

Riders were assumed to be amateurs if they registered one or two horses during the season and professional if they registered three or more horses during the season (*Table 4-1*). This cut off was decided based on the sudden decrease in the number of riders registering three or more horses, as the number of professional riders was assumed to be much smaller than that of amateurs in all disciplines. Rider identification numbers were only available for 26.8% of riders in show jumping during the 2008/09 season, and therefore all horses with unknown riders were categorised as amateurs for analysis. As horses ridden by professionals are assumed to be on average greater earners of points and prize money, classifying a horse ridden by an unknown rider as having an amateur rider is less presumptuous. The classification of amateur and professional riders was so ambiguous for the New Zealand dataset that rider effect was not included in the model to calculate EBVs, as it would have introduced a large source of bias (Rogers and Firth, 2005).

5.2.5 Stallions

There were very few stallions in competition (between 2 and 30) in all three disciplines in New Zealand. This is very different from European countries where competing stallions is common and up to 89% of sires had a performance record of their own by 4 years of age (Dubois and Ricard, 2007). Due to the small numbers of stallions in the New Zealand dataset, the average points and prize money earnt by stallions were zero in many cases, particularly in eventing. Hence, the gender stallion could not be included in the genetic model. Categorising stallions and geldings together as ‘male’ could potentially overvalue the stallions, as there could be selection for stallions remaining entire because they are believed to be superior individuals. Stallions are also physiologically different from geldings. For these reasons, stallions as progeny records were excluded from genetic analysis (Stewart et al., 2010). The effect of gelding is important in the New Zealand sport horse population as it introduces a high selection rate prior to entry into competition; hence, it reduces the effectiveness of utilising competition results for stallion selection (Rogers and Firth, 2005).

5.2.6 Mares

There were few horses registered with ESNZ which included information on the dam. Hence, dams were all assumed to be unknown and all sires were assumed unrelated for genetic analysis. Mares often are removed from competition early to become breeding animals if they are not successful competitors or suffer an injury. Hence, there could be a bias towards mares in competition performing better, on average, than geldings as only successful mares are kept in competition (Hennessy and Quinn, 2007). This also leads to the problem of a long generation interval for successful competition mares (Langlois, 1983).

5.3 INTERPRETATION OF ESTIMATED BREEDING VALUES

5.3.1 Usefulness of estimated breeding values

The use of EBVs by the New Zealand sport horse population would lead to improvements in the selection of competition sires, as sires with reasonable EBVs can be used more effectively to achieve genetic gain, particularly in show jumping. However, more accurate and complete recording of sport horse pedigree information is required in order for the New Zealand dataset to be used to calculate breeding values with reasonable reliability. The issues of normality and heterogeneity are common to all sport horse breeding industries; hence, must be dealt with in the genetic model (Wallin et al., 2003, Langlois and Blouin, 1998). The range of breeding values was very small (*Table 4-5*) for all variables and all disciplines; therefore, there appear to be limited opportunities to achieve genetic gain in the current New Zealand sport horse population. Hence, there may be insufficient differences for effective selection (Van Vleck et al., 1992).

Many traits analysed in sport horse competition data are subjective and difficult to measure (Koenen et al., 2003). The variables analysed were dpps and epps (log(points per start+1)), dnst and enst (log(number of starts)) and tpm (log(total prize money+1)). Positive EBVs were desired, as positive increases in the number of points and amount of prize money won would be indicative of improved performance. Horses which are capable of a greater number of starts during the season could also be desirable, as this may suggest that the horse is successful in competition and could also be indicative of soundness (Dubois and Ricard, 2007).

5.3.2 Heritability value assumptions

As the dataset was not sufficiently complete to calculate values for heritability, a heritability value of 0.15 was assumed for all variables (dpps, epps, dnst, enst and tpm). This lack of convergence was also encountered by Koerhuis and Van der Werf (1994) in the bivariate analysis of a simulated horse population. Assumptions of heritability values of 0.16-0.36 for conformation and movement traits have previously been made for genetic analysis of New Zealand data based on European values (Rogers, 1993a). A heritability value of 0.15 was chosen based on heritability values which have previously been calculated for sport horse competition variables from overseas data which ranged from 0.10-0.27 (Bruns, 1981, Huizinga and Vandermeij, 1989, Ducro et al., 2007, Olsson et al., 2008). As European sport horses are commonly from uniform environments, heritability values may be higher than those applicable to New Zealand's more heterogeneous environment (Rogers, 1993a). To account for this, a lower heritability value (0.15) from within the range generally seen in Europe was used. The EBVs calculated appeared reasonably normally distributed around a mean near zero (*Figures 4-11 to 4-15*).

5.3.3 Individual sire indicators

Based on the EBVs calculated in this analysis, there appear to be sires in dressage, eventing and show jumping which could be utilised more effectively in order to improve genetic gain in the sport horse population. Sires which were included in the ten highest EBVs in dressage based on dpps which could be utilised more effectively were Injustice, Woodstock Recaro Reel, Riverman and Horace. Based on dnst, stallions which could be utilised more effectively were Lone Arrow, Witzbola, Salutation, Weltmeyer, Genius and McHamish (*Tables 4-6 and 4-7*).

Sires which were included in the ten highest EBVs in eventing based on epps which could be utilised more effectively were A Touch of Hillbilly, Turbulent Dancer, Waikiki Star, Lantham, Telesun, Bahhare, Haajiisan and Engagement. Based on enst, sires which could be utilised more effectively were Charlton Javelin, Little Brown Jug, Kingdom Bay, NK Prince Ferdinand, Spectacular Love and Aston Magnum (*Tables 4-8 and 4-9*).

Sires which were included in the ten highest EBVs in show jumping based on tpm which could be utilised more effectively were Wishing Well, Salute the Stars, San Mateo Second Chance, Cabdula du Tillard, Omnicorp, Indoctro, Zig Zag, Fetiche du pas and Leo Caylon (*Table 4-10*).

5.3.4 Multi-trait animal model

A multi-trait animal model could be useful for future genetic evaluation of New Zealand sport horses, assuming sufficient data can be made available to effectively utilise this model. Effective use of a multi-trait animal model would make it possible to predict EBVs with better reliability; hence, greater increases in genetic gain would be seen. In this way, the New Zealand sport horse industry could benefit from increased quality of their sport horses, leading to better results in international competition and increased profits from selling New Zealand horses overseas.

5.4 RECOMMENDATIONS

5.4.1 A template for estimated breeding values

Due to the limitations of the current sport horse performance dataset in New Zealand, the EBVs calculated here are primarily aimed to be an initial template for future calculation rather than a recommendation of which current sires to utilise.

Based on the above analyses of the current sport horse population in New Zealand, data available for analysis and the EBVs calculated, the following recommendations have been made with the objective of improving the data available for use in future genetic analyses:

1. **Recording sires on registration:** The number of horses registered with a sire needs to be increased. An incentive to include sire name, such as a discount on registration fees or an additional charge for registering a horse without a sire could improve completeness of these records. A similar system is implemented by the FFE (France), as a horse cannot be registered under list A (to compete in official competitions) with an unknown sire, except in special cases (Federation Equestre

Internationale, 2011). Longer term, implementing a similar scheme to encourage the inclusion of dam information in horse registration would further strengthen the dataset.

2. **Accurate sire names:** The implementation of a system to improve the accuracy of spelling of sire names would help reduce inaccurate heterogeneity in the sport horse population. One way to do this would be for ESNZ to utilise a programme which stores sire names that have been entered before and comes up with past options which can be selected when a new record is added. Alternatively, a unique sire identification number could be assigned to each sire so that there is no longer any reliance on the spelling of sire names. Implementing the UELN system in New Zealand could be a way to achieve this.

3. **Differentiating amateur and professional riders:** It is impractical to implement separate amateur and professional grades in New Zealand due to relatively small competitor numbers and limited competition funding (Rogers and Firth, 2005). However, it would be advantageous to record whether a rider is an amateur or professional in the ESNZ database. This could be achieved by asking riders whether equestrian sport is their main source of income and recording those who respond with 'yes' as professional riders.

4. **More stallions competing:** Encouraging riders to compete stallions would help reduce the high selection prior to competition. This could be achieved by improving the facilities to keep stallions at competitions, such as having a greater number of stallion yards on offer at competition venues.

5.4.2 Conclusion

Implementation of these recommendations could help to improve the accuracy and completeness of the data available on sport horses in New Zealand; hence, improve the accuracy of calculating EBVs for sport horse sires. If reasonably accurate EBVs could be obtained for New Zealand sport horse sires, their use could lead to increases in genetic gain and improved performance of New Zealand's sport horses on the international stage.

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