Genetic Evaluation of Sport Horses in Britain

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Declaration

I declare that:

(1) this thesis was composed by myself

(2) the work contained in this thesis is my own

(3) this work has not been submitted for any other degree or professional qualification

Charlotte Kearsley

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Abstract

The genetic evaluation of sport horses is common practice on the Continent and in Ireland but, until now, has not been carried out in Great Britain. The aim of this project was to derive models for predicting breeding values for British bred sport horses and hence develop procedures for their evaluation. The research consisted predominantly of the estimation of genetic and phenotypic parameters from two datasets; results from the Young Horse Evaluation Series (YHE), which assesses 4 year old potential sport horses, and competition data on UK eventing horses. Eleven traits were measured in the YHE, including a veterinary score, conformation, paces and jumping ability. A small dataset led to some problems and meant that heritabilities could not be predicted, however, the predicted repeatabilities were sufficient in magnitude and precision to indicate that the YHE may prove useful as a test of individuals. A much larger and more comprehensive dataset was available for UK eventing horses. Penalty points from each of the three phases – dressage, showjumping and cross country – and overall competition were converted to normal scores for analysis. Each phase was separated into 4 different grades of competition – pre novice, novice, intermediate and advanced. Results showed heritabilities significantly different from zero for all phases (0.02–0.23). Correlations between the grades for each phase were high, suggesting that it should be possible to predict a horse's performance at advanced level by its performance at novice or pre novice level. For the first time, the proportions of variance attributed to the rider, permanent environmental effect and genetics of the horse were estimated separately. These estimates showed that for most grades and phases the most important component was the permanent environmental effect, with the rider and genetics becoming more important as the grades become more challenging. This analysis allowed the successful prediction of estimated breeding values (EBVs), horse values (HVs) and rider values (RVs). Using these values, the intensity of selection on sires, horses and riders progressing from the pre novice to advanced grades in each of the phases of eventing competition was investigated. The highest selection intensities were observed between intermediate and advanced grade (0.634-1.163). The lowest selection intensities were observed between pre novice and novice (0.018-0.352).

The main aim of this research was to create a model for the prediction of breeding values for British bred sport horses, an objective that was successfully achieved. Genetic and phenotypic parameters were estimated for the traits analysed and these were consistent with those contained in the literature. There were a number of novel aspects to this study, such as the separation of horse and rider in the model, allowing values to be assigned to each. This led on to another novel aspect of the research which was the analysis of within generation selection of sires, horses and riders moving through the grades of eventing competition. This study has met its objectives and also provided a platform for the launch of further research into sport horse breeding in Britain

Publications

Kearsley C. G. S., Woolliams, J. A., Coffey, M. P. and Brotherstone, S. 2007. Use of competition data for genetic evaluations of eventing horses in Britain: Analysis of the dressage, showjumping and cross country phases of eventing competition. *Livestock Science* (Accepted March 2008)

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1 Introduction

Genetic evaluations are an important tool in livestock breeding, allowing the selection of genetically superior animals proven to pass desired traits onto the next generation. It is a method commonly used in cattle and sheep breeding in the UK, however, thus far it has not been applied to the British sport horse breeding industry. The use of genetic evaluations in sport horse breeding populations is used in countries other than the UK, with France, Ireland, Germany, The Netherlands and Sweden all carrying out evaluations on their sport horses. This is one of the reasons that these countries are all world leaders in equestrian sport and sport horse breeding.

Some of the earliest work on the genetic evaluation of sport horses was carried out on Swedish (Ström & Philipsson, 1978) and German (Bruns *et al.,* 1980; Bruns, 1981) horses. Before genetic evaluations began breeding trends could not be accurately analysed which meant that informed debate about breeding practice and breeding goals was not possible. The Netherlands (Huizinga & van der Meij, 1989; Huizinga *et al.,* 1991a; 1991b; Koenen *et al.,* 1995), France (Tavernier, 1990; 1991; Ricard & Chanu, 2001; Langlois & Blouin, 2004) and Ireland (Reilly *et al.,* 1998; Aldridge *et al.,* 2000) also began to publish work on genetic evaluations whilst work on Swedish horses continued (Philipsson *et al.,* 1990; Holmström & Philipsson; 1993; Olsson *et al.,* 2000; Wallin *et al.,* 2003). Overall, this work has allowed genetic evaluations to be used, not only as a breeding tool but also as a method of examining the dynamics of sport horse populations. In having no genetic evaluations of its own Britain lacks the ability to make the informed decisions on breeding that its competitors can. There is still much research to be done in order to answer questions on sport horse breeding, not just in Britain, but internationally. Work has been widely carried out on showjumping and dressage horses but only a small amount of work has been done on eventing horses (Ricard & Chanu, 2003). To fill the gaps in the literature it would be useful for research to be carried out on British sport horses, particularly those involved in eventing.

Recently initiatives have been put in place to begin the improvement of British breeding stock and sport horses in order that Britain can begin to produce its own research into genetic evaluations and be counted as a top sport horse producing nation. *British Breeding* has been set up by the British Equestrian Federation (BEF) to oversee different aspects of sport horse breeding, one of which is the development of the Young Horse Evaluation Series (YHE) and the Futurity Scheme. The YHE was originally set up to test 4 year old horses and the Futurity Scheme to test foals to 6 year old, as of 2007 the YHE has been incorporated into the Futurity Scheme, however the data used in this project was provided before this merger took place and they are analysed separately in this work. These schemes are designed to identify potential talent in and provide data on young dressage, showjumping and eventing horses by judging and scoring them on criteria such as conformation, paces and jumping ability (see Appendix A for a glossary of terms). This method is based on the station tests and Riding Horse Quality Tests (RHQT) used on the continent. Another important initiative was the commissioning of this project which aims to begin research on the genetic evaluation of British bred sport horses using information from the YHE and Futurity Scheme and eventing competition data, and to develop a model for the prediction of breeding values to be used by the sport horse breeding industry. By putting these initiatives in place Britain would hope to be able to set up genetic evaluations in a similar manner to its competitors and eventually surpass them with future research.

Because this is the first project to research genetic evaluations of British bred sport horses it is necessary to begin by examining the work carried out in other countries to assimilate ideas on methods used and results gained with a review of the relevant literature (Chapter 2). From here it is important to examine what people involved in sport horse breeding and equestrian sport hope and expect to gain from this project by surveying a number of respondents from different sectors of the sport horse industry (Chapter 3). Data analysis can then begin, using ideas and structures gained from these preliminary steps. Data, provided by *British Breeding*, from the Young Horse Evaluation Series (YHE) and Futurity Scheme will be analysed to provide information on potential young sport horses (Chapter 4). British Eventing provided competition data, giving information on horses taking part in eventing competition. This dataset will allow (1) the estimation of genetic and phenotypic variance components using penalty points, for each phase, converted to normal scores. To separate traits for analysis each phase was split into 4 grades, based on the rules of British Eventing (www.britisheventing.com) - pre novice, novice, intermediate and advanced, where pre novice is the lowest grade and advanced the highest (Chapter 5), (2) analysis of the selection differentials based on the estimated breeding values (EBVs) (Chapter 6) and (3) an understanding of how penalty points and breeding values predicted from normal scores can be reconciled (Chapter 7). Chapter 8 will then bring together results and conclusions from the preceding chapters in a discussion of the findings of this project.

2 Literature Review

2.1 Introduction

Sport horse breeding is steadily increasing in commercial importance. Worldwide, the horse industry as a whole is a massive business, generating a large turnover in many countries. In Britain alone, the entire horse industry is worth an estimated £3.4 billion, which includes everything from equipment production and purchase to riding holidays. A recent economic study (The Henley Centre, 2004) shows that breeding and trade contribute around £140 million to the British horse industry as a whole. This means that planned breeding practice and genetic evaluations (the process of predicting genetic merit) are becoming an increasingly necessary practice to keep up with the competition. Countries such as Sweden, The Netherlands, Ireland, France and Germany – all world leaders in equestrian sport - have been carrying out quantitative research on sport horses for a number of years, whereas, until now, Britain has neglected this area.

The following chapter is a review of the research that has been carried out on the genetic evaluation of sport horses. The aim is to bring together information from a number of different countries and sources and to discuss the methods of collection and evaluation of data, the results obtained and how such research can influence and guide a project that aims to initiate the genetic evaluation of British sport horses.

2.2 Sources of data

A number of different traits have been examined in the genetic evaluation of sport horses, with researchers receiving data predominately collected by their country's equestrian boards. The data therefore varies between countries, leading to some differences in the traits measured and the results presented. The methods of data collection fall into two distinct categories: 1) data from the evaluation of youngstock and 2) competition results.

Assessment of youngstock

Youngstock are evaluated at either one day long field tests or longer tests, held at station, of 9 or 100 days duration. In all tests traits are assessed and scored on a scale of 1-10, where 1 equates to poor and 10 to excellent.

In Sweden four year old mares, geldings and stallions are assessed at one day field tests (Riding Horse Quality Test (RHQT)). Horses are assessed on health status conformation, paces, jumping ability and temperament (Olsson *et al.,* 2000) (see Appendix A for definitions of traits).

Performance tests are held for 4 year old stallions in Sweden (9 days) and Germany (100 days) and for 4 year old stallions and mares in the Netherlands (100 days). Similar traits to those measured in the one day field tests are assessed along with rideability (the acceptance of a rider and movement under rider). Animals tested at 100 day station tests can also be assessed on their progress in training because they are tested over a long time period (Bruns *et al.*, 1980; Huizinga *et al.*, 1991a; Huizinga *et al.*, 1991b; Olsson *et al.*, 2000).

Competition results

Different methods have been developed for the use of competition results in genetic evaluations. In Ireland a system has been developed which uses normalised scores calculated from the ranking of showjumping horses based on the faults received in competition (Reilly *et al.*, 1998). This method allows evaluation of all animals in a competition. In France annual earnings and competition placing are used as traits for evaluation (Ricard & Chanu, 2001; Langlois & Blouin, 2004) which only includes animals that have annual earnings or a recorded competition place.

Both assessment of youngstock and competition results yield traits for genetic evaluations, each with their advantages and disadvantages. The assessment of youngstock gives a thorough overview of a number of traits, each important for potential breeding stock and good indicators, but not guarantees, of future performance. Competition results assess ability in competition, which is the final result that a breeder wants. However, this is all that it measures and does not take into account the health, conformation or temperament of an animal. Neither method is mutually exclusive and a combination of the two may be a good system of evaluation.

Data sources and evaluation systems of other horse breeds and species

Sport horses are not the only breeds to be tested to collect data for genetic evaluations. Many studies have been carried out on the evaluation of Icelandic horses, for which EBVs have been produced since 1982 (Hugason, 1994; Árnason & Sigurdsson, 2004). Icelandic horses over the age of 4 years are tested at breeding field tests. Stallions, mares and geldings are placed into different age classes and tested on their conformation and paces; height is also measured (Hugason, 1994; Árnason & Sigurdsson, 2004; Albertsdóttir *et al.*, 2008). Recently evaluations of competition data have also been investigated (Albertsdóttir *et al.*, 2007) with a view to combining data from the breeding field tests and competitions to add to the EBVs already produced (Albertsdóttir *et al.*, 2008). Other breeds that are examined at field tests, with the data used for genetic evaluations, are Shetland ponies in The Netherlands, which are tested on conformation and paces (van Bergen & van Arendonk, 1993) and Andalusian horses in Spain which are tested on conformation, paces and temperament (Molina *et al.*, 1999). In Italy, Maremmano stallions are tested at 100 day performance tests. They are examined on conformation, paces and orthopaedic health. Maremmano mares are similarly tested at 30 day performance tests. A 100 day performance test is also carried out for Italian Saddle Horse stallions, which examines paces and jumping ability (Silvestrelli *et al.*, 2003). Competition data is widely used in the evaluation of trotting and galloping race horses (Tavernier, 1991; Saastamoinen & Nylander, 1996; Villela *et al.*, 2002; Belhajyahia *et al.*, 2003; Langlois & Vrijenhoek, 2004; Bugislaus *et al.*, 2005; Ekiz & Kocak, 2005).

Genetic evaluations using field data are also widely used in other species, particularly cattle and sheep. A range of different traits are analysed in cattle, including conformation (Thompson *et al.*, 1983; Short & Lawlor, 1992; Vukašinović *et al.*,1995; Fatehi *etal.*,2001; Schaeffer *et al.*, 2001; Neuenschwander *et al.*, 2004; Wall *et al.*, 2005a; Wall *et al.*, 2005b; Zwald *et al.*, 2005; de Haas *et al.*,2007) milk production and quality (Neuenshwander *et al.*, 2004; de Haas *et al.*, 2007), fertility (Neuenshwander *et al.*, 2004; Wall *et al.*, 2005b; Wall *et al.*, 2003) and calving traits (Wall *et al.*, 2003; Eriksson *at al.*, 2008). Traits often measured in sheep are wool quality (Castro-Gámez *et al*, 2008), meat quality (van Heelsum *et al.*, 2001; Snowder & Duckett, 2008) and conformation, particularly udder traits in dairy ewes (de la Fuente *et al.*, 1996; Marie-Entancelin *et al.*, 2005; Casu *et al.*, 2006). Milk and meat traits are often measured by parameters such as fat content, weight and muscle depth. Conformation, however, is measured using a linear scale, which is also used to measure conformation traits in horses.

2.3 Evaluation of data

Conformation

Conformation is considered an important trait by sport horse breeders. In a survey carried out by Koenen *et al.* (2004) nearly 90% of breeding organisations in Europe stated that conformation was a breeding objective. A heritability of 0.33 (Ducro *et al.*, 2005) has been estimated for a horses' overall conformation with heritabilties of 0.09-0.28 estimated for the different parts of the horse (Koenen *et al.*, 1995). A relationship has been shown between conformation and performance ability, with phenotypic correlations of 0.55-0.66 estimated between conformation and paces (Holmström & Philipsson, 1993). Koenen *et al.* (1995) estimated low to moderate genetic and phenotypic correlations between conformation and ability in dressage and showjumping. This evidence suggests that conformation is a trait worth breeding for in sport horses, with a moderate heritability and good correlations with performance. This may be particularly useful when assessing youngstock, because conformation can be assessed early in life before a horse has a proven performance record.

Some comparison can be made between horse conformation and cattle conformation because they are both measured on a linear scale. The number of conformation traits measured in cattle can range from 30-39 (Schaeffer *et al.*, 2001), these can include assessment of the udder, body shape and leg traits. Although many of the conformation traits for dairy cattle are irrelevant in sport horses (for example, udder traits), the leg and body traits can be used as an example of scoring and examination methods. Heritabilities for feet and leg traits in cattle range from 0.10 to 0.17 (Short & Lawlor, 1992; Fatehi *et al.*, 2001; Schaeffer *et al.*, 2001). These are slightly lower, but within the same range as those estimated by Koenen *et al.* (1995) for leg traits in horses (0.09-0.23). The grouping of leg traits for horses includes the heritability for 'heels', whereas the cattle leg groupings do not. Interestingly the lowest heritability estimated by Koenen *et al.* (1995) was 0.09 for heels. Fatehi *et al.* (2001) found similar low heritabilities for heel traits in cattle (0.06-0.09); they speculate that this is because the trimming of feet by a handler may reduce the genetic variability. It is possible that this is also the case for horses whose feet are routinely trimmed.

Assessment of young stock

Assessment of young stock, in both field tests for ordinary riding horses and station tests for stallions, has been shown to be a good method for estimating the genetic merit of the tested animals and for selecting young breeding stallions. Data from the 9 day long stallion performance tests in Sweden show medium to high heritabilities estimated in paces (0.37-0.46), loose jumping (0.47) and ridden jumping (0.32) (Olsson *et al.*, 2000), whilst data from the one day long field RHQT give heritabilities of 0.27 for paces, 0.18 for jumping ability and 0.09-0.10 for temperament (Wallin *et al.*, 2003) (Table 2.1). The higher heritabilities observed in the 9 day long stallion performance tests may be due to the reduction in environmental noise caused by both the repeated measurements taken on the animals and the consistency of the testing procedure. The same experienced judges are used for several years and the horses are all tested at the same location, unlike the one day field tests for riding horses in which the animals are tested at various locations, often with less experienced judges. Medium to high heritabilities were estimated for paces (0.54-0.73), ridden jumping (0.31), loose jumping (0.30), rideability (0.64) and temperament (0.52) measured in the 100 day stallion performance test in The Netherlands (Huizinga *et al.*, 1991a). The heritability for paces measured by

Huizinga *et al.* (1991a) is higher than that estimated by Olsson *et al.* (2000) and Wallin *et al.* (2003) for horses in Sweden; this may again be due to the repeated measurements taken in The Netherlands. The heritabilities for ridden jumping ability were similar in all of the studies, although the loose jumping heritability estimated by Olsson *et al.* (2000) for the Swedish stallion performance tests was higher than the heritabilities for ridden jumping shown by Huizinga *et al.* (1991a), Olsson *et al.* (2000) and Wallin *et al.* (2003), which may be due to fewer environmental influences, particularly the rider, affecting loose jumping when compared with ridden jumping.

Table 2.1 Heritabilities (± SE) from assessment of youngstock

Trait	Performance test of stallions		Field test (RHQT)
	(Huizinga *et al.*, 1991a)	(Olsson *et al.*, 2000)	(Wallin *et al.*, 2003)
Paces	0.54±0.16-0.73±0.14	0.37±0.11-0.46±0.13	0.27±0.04
Loose jumping	0.30±0.17	0.47±0.13	-
Ridden jumping	0.31±0.17	0.32±0.14	0.18±0.04
Rideability	0.64±0.15	-	-
Temperament	0.52±0.18	0.23±0.14-0.33±0.23	0.09±0.03-0.10±0.03

RHQT riding horse quality test

It is likely that the higher heritabilities estimated for traits measured at stallion performance tests at station, compared to those estimated at one day field tests of ordinary riding horses, are due to the longer time period which allows for repeated tests to be taken on the horses, and the reduction in environmental influence facilitated by horses being tested at the same location by the same more experienced judges. In The Netherlands the same team of three judges is used for the 100 days of the test and the scores are an average of those given by each judge (Huizinga *et al.*, 1991a). Some bias may be added to these results because the stallions taking part in station tests are pre selected, sometimes based on their pedigree (Huizinga et al., 1991a), although phenotype is also taken into account (Huizinga et al., 1991a; Olsson *et al.*, 2000). Fewer stallions are performance tested than riding horses field tested (approximately 10 times fewer) and the standard errors for the heritabilities calculated from performance test data are high (0.14-0.23) compared to those calculated from field test data (0.03-0.04). This means that the higher heritabilities estimated from performance test data are subject to some bias. Each method of assessing youngstock has its advantages and disadvantages. Performance testing at station over a number of days allows a longer time spent with the horses and the same judges and environment for each horse reduces the variation in the scores given and the data collected. This is specifically important when tests are used for the selection of breeding stallions. However, field tests are a cheaper and more accessible option, available to a much greater number of horses and are a valuable source of data for mass selection and progeny testing.

Competition Results

Competition results can be used independently to estimate breeding values or used in addition to youngstock evaluations to increase the accuracy of breeding values. Philipsson *et al.* (1990) point out that the most accurate breeding values are calculated from a combination of data on conformation, performance tests and competition results, in other words, using all sources of relevant information. However, they recommend that the greatest accuracy is gained when data from the highest level of competition is used, leading to an increased generation interval that may not be compensated for by the extra accuracy. This theory encompasses the two main problems in the use of competition results for genetic evaluations – an increased generation interval and selection bias caused by using only high level competition results. Falconer & Mackay (1996) state that there is a conflict of interest between accuracy and generation interval ($\Delta G = r/L^{\dagger}$) and that a compromise needs to be found between the two. When using data from competition results, the compromise is to take information from all levels of competition. This both decreases the generation interval by evaluating horses at a range of different ages and reduces selection bias. Selection bias cannot be completely eliminated unless the information used for selection is included in the data analysis. Even at low levels of competition there is selection for animals of a certain level of ability, but the wider the scope of competition data the smaller this bias.

[†] ΔG: rate of gain, r: accuracy, L: generation interval

Assessment at a young age is a good indicator of future performance in competition with high genetic correlations estimated between performances at different ages (0.88-1.00) (Huizinga & van der Meij, 1989). Assessment at field tests is also a good indicator of future performance with high genetic correlations estimated between results from the RHQT and ability in dressage (0.63-0.75) and showjumping (0.88-0.93) (Wallin *et al.*, 2003) (Table 2.2). Using assessment of youngstock as an indicator of future performance could help to reduce selection bias if all foals born to registered dams were assessed. By taking data from a whole range of abilities the impact of pre selection would be reduced and could increase correlations between performance test and competition results. Aldridge *et al.* (2000) estimated high genetic correlations between novice and medium level showjumping competition (0.97), novice and high level competition (0.69) and medium and high level competition (0.83). This suggests that performance at novice and medium level competition could be used to predict the future performance of a horse in high level competition.

Table 2.2 Genetic and phenotypic correlations between early performance and future competition performance

Traits	Genetic correlation±SE	Phenotypic correlation	
Novice/medium competition	0.97±0.02	0.46	Aldridge *et al.* (2000)
Novice/high competition	0.69±0.07	0.25	
Medium/high competition	0.83±0.05	0.41	
RHQT jumping/showjumping competition	0.88±0.06-0.93±0.07	0.19-0.23†	Wallin *et al.* (2003)
RHQT paces/dressage competition	0.63±0.09-0.75±0.11	0.25-0.35†	
Different ages	0.88-1.01	0.67-0.86	Huizinga & van der Meij (1989)

† These phenotypic correlations were calculated with the genetic and environmental correlations provided in Wallin *et al.* (2003) using an equation from Cameron (1997)

RHQT riding horse quality test

Progeny Testing

Progeny performance can be used to predict the breeding value of a stallion (Bruns, 1981) or used to increase the accuracy of a breeding value that has been predicted with information from a stallion's own performance (Ström & Philipsson, 1978). Because a horse will be at least 4 years old before its performance can be tested, and possibility even older if higher level competition is taken into account, the generation interval is high when using progeny testing as a predictor of breeding values. To reduce the generation interval, it is possible in initial progeny tests to take into account only the conformation of youngstock (Ström & Philipsson, 1978), which can be done at a very early age – examination of conformation traits in Trakehner foals has been shown to be a good early predictor of sire breeding values for conformation traits (Preisinger *et al.*, 1991).

Disciplines

Genetic evaluations are most commonly carried out for showjumping (Sweden, The Netherlands, Germany, Ireland and France) and dressage horses (Sweden, The Netherlands and Germany). So far France is the only country to have specifically researched eventing, although other countries, such as The Netherlands, have included cross country in performance testing. Often selection for eventing is based on specialist jumping and dressage (Ricard & Chanu, 2001).

Moderate heritabilities, based on competition results, have been estimated for ability in showjumping and dressage (Table 2.3). Koenen *et al.* (1995) found heritabilities of 0.19 and 0.17 for ability in showjumping and dressage, respectively. Huizinga & van der Meij (1989) estimated similar heritabilities (0.12-0.20), however, the heritabilities they estimated for ability in dressage (0.05-0.10) are much lower than that estimated by Koenen *et al.* (1995). Huizinga & van der Meij (1989) suggest that the lower heritabilities they found for ability in dressage (0.05-0.10) compared to ability in showjumping (0.12-0.20) could be a result of environmental variation, which includes the rider. A good or bad rider can influence a horse's performance, particularly in dressage where performance is judged subjectively. However, jumping can also be affected by the rider. Data from Swedish performance tests showed that loose jumping had a higher heritability than ridden jumping (Olsson *et al.*, 2000) possibly due to less environmental influence from the rider. Rider influence is an important aspect of the evaluation of sport horses but is rarely studied. The effect is environmental and not an effect of the horse. Therefore, in order to separate the rider from the rest of the environmental effects a rider would need to ride, on average, a number of different horses, or a number different riders would have to ride the same horse. Information on the rider would need to be included in the model of analysis.

Table 2.3 Heritabilities for ability in showjumping, dressage and eventing

Trait	Heritability±SE	
Dressage ability	0.17±0.05	Koenen *et al.* (1995)
	0.08[†]	Huizinga & van der Meij (1989)
Showjumping ability	0.19±0.04	Koenen *et al.* (1995)
	0.16[†]	Huizinga & van der Meij (1989)
Eventing ability	0.17±0.01	Ricard & Chanu (2001)

† These heritabilities are the means of those given for younger and older stallions

There are differing opinions on the genetic relationship between ability in showjumping and dressage (Table 2.4). The results of Huizinga & van der Meij (1989) and Bruns (1981) show no correlation between the two disciplines. Low to moderate genetic correlations are estimated between paces, as assessed on youngstock, and future performance in showjumping competition (0.04-0.45). Correlations between jumping assessed in youngstock and future dressage performance are lower (0.06-0.34) (Wallin *et al.*, 2001; Ducro *et al.*, 2005). Genetic correlations estimated between eventing and dressage (0.58) and eventing and showjumping (0.45) appear higher (Ricard & Chanu, 2001).

Table 2.4 Genetic and phenotypic correlations between abilities in different disciplines

Traits	Genetic correlation±SE	Phenotypic correlations	
Showjumping /dressage competition	0.00 - -0.27	0.15-0.26	Huizinga & van der Meij (1989)
RHQT paces/ showjumping competition	0.12±0.10-0.45±0.09	0.10-0.16[†]	Wallin *et al.* (2003)
RHQT jumping /dressage competition	0.06±0.13-0.07±0.13	0.09[†]	
Paces /showjumping competition	0.04-0.43[‡]	-	Ducro *et al.* (2005)
Jumping /dressage competition	0.09-0.34[§]	-	
Eventing/ dressage competition	0.58±0.07	0.15-0.2	Ricard & Chanu (2001)
Eventing / showjumping competition	0.45±0.05	0.12	

[†] These phenotypic correlations were calculated from the genetic and environmental correlations provided in Wallin *et al.* (2003) using an equation from Cameron (1997)

RHQT riding horse quality test

[‡] Standard errors range from 0.04-0.09

[§] Standard errors range from 0.04-0.11

2.4 Discussion and Conclusion

A number of different traits and methods can be used to carry out genetic evaluations on sport horses. Evaluation of young stock is widely used and a number of traits are assessed, including health and conformation as well as performance ability, which show a good correlation with future competition performance.

Competition results are also widely used, and because accurately ranking horses according to their genetic ability to succeed in competition is the ultimate aim of the genetic evaluation of sport horses, it is an important trait to use for evaluations. An increased generation interval can be a problem when using competition results for genetic evaluations, however studies have shown that performance and assessment at a young age (Huizinga & van der Meij, 1989; Aldridge *et al.*, 2000; Wallin *et al.*, 2003) can provide a useful indication of how a horse may perform in the future. With this in mind, it seems that the best way to predict breeding values for sport horses is with a combination of data from youngstock assessments and competition results. In this way, breeding values can be assigned to a horse at an early age with estimates based on assessment of youngstock and early competition results. However, by constant review as the horse gets older, the accuracy of this value can be increased by the addition of further competition results, at increasing levels, into the model.

2.5 Summary

Information on genetic evaluations of sport horses from a number of different countries and sources was brought together to examine the different methods of data collection and evaluation, and to examine how this information can influence and guide a project that aims to initiate the genetic evaluation of British bred sport horses. The two main sources of data, assessment of youngstock and competition results, were examined and the conclusion drawn that both have advantages and disadvantages and neither is mutually exclusive. A combination of the two methods may be the best method for evaluating sport horses.

3 Industry perspectives on breeding objectives

3.1 Introduction

As noted in Chapter 2, the horse industry as a whole is a huge business worldwide, generating a large turnover in many countries, and in Britain alone is worth an estimated £3.4 billion. A recent economic study (The Henley Centre, 2004) shows that breeding and trade contribute around £140 million to the entire British horse industry. However, this figure does not include the trade value of Warmblood horses (of which Britain is a net importer). If it did then the figure contributed by trade and breeding could be negative. This means that despite the large sum of money involved in the British breeding industry, Britain is actually losing money by not producing and exporting quality Warmblood sport horses and is relying on other countries for the supply of such animals for dressage and showjumping. At present the sport horse breeding industry favours both Warmblood horses (the preferred type for dressage and showjumping) and the thoroughbred type event horse, which Britain has an excellent reputation for breeding. However, with the new shortened three day event format (which involves the removal of the roads and tracks and steeplechase phases for which the thoroughbred type is most useful), eventing may also begin to favour a more Warmblood type.

These changes suggest that the horse breeding industry in Britain needs to examine its policies and look at what the industry and buyers want in order to (1) persuade people to buy British bred horses (not just for eventing but also for dressage and showjumping) rather than their foreign bred counterparts and (2) to be able to compete on a world stage with other top sport horse breeding countries such as Ireland, Germany, The Netherlands, France and Sweden. One of the strategies to be implemented is the development of estimated breeding values for British bred sport horses. The first stage of the research is detailed in this thesis. In order to develop genetic evaluations it is first important to understand the objectives of sport horse breeders. The initial step of this research was to investigate the industry perspective of the 'ideal' horse and find out what the industry expects from this research. A survey of various individuals and representatives from key bodies in a number of different equestrian sports was carried out. The findings are presented in this chapter.

3.2 Materials and Methods

Survey Questions

A questionnaire was developed with questions asking respondents about:

- What they look for in a horse
- The discipline that they represent
- What they believe measures a horse's quality and ability
- How they would benefit from and use estimated breeding values

A full list of these questions is given in Appendix B.

Respondents

The respondents are separated into two groups (1) individuals and (2) organisations. Eight individuals were consulted: (some fall into one or more of these categories) breeders, Young Horse Evaluation (YHE) judges, dressage judges, event riders (some international), equestrian centre owners and vets. Also consulted were representatives from nine organisations: British Dressage (BD), British Eventing (BE), British Show Jumping Association (BSJA), Scottish Equestrian Association (SEA), The British Horse Society (BHS), British Equestrian Vaulting (BEV), British Reining (BR), British Horse Driving Trials Association (BHDTA) and Endurance GB (EGB).

Most of the questionnaires were carried out in person, however, for practical reasons some were emailed to respondents. Not all questions were answered by all respondents.

3.3 Results

These results present a summary of the views of both the individuals and representatives from the organisations consulted.

Individual views

Breeding objectives:

- **How important is conformation?**
  - Very important for all individuals
  - Includes movement and good limbs and feet
- **How important is temperament?**
  - Very important to 4 individuals
  - Less important than conformation for one individual
  - Can depend on what the horse is bred for
- **How important is health and soundness?**
  - Very important to all individuals
  - None would breed from an animal they knew had a heritable problem
- **What traits would you most like to see eradicated?**
  - Poor feet
  - Muscoskeletal disorders
  - Poor temperament

Ability:

- **What abilities are looked for in a horse?**
  - Brave and willing to learn
  - Can depend on the discipline a horse competes in
    - Dressage: movement, athleticism, intelligence
    - Showjumping: jumping ability
    - Eventing: bravery, jumping ability, movement and intelligence
- **What is the best measure of a horse's ability and quality?**
  - All individuals agree that it is a combination of conformation, assessment at a young age and performance in competition
- **Should a horse be bred for only one discipline or should the discipline it enters depend on ability?**
  - All individuals agree that horses should be able to participate in different disciplines

Improvement of horses:

- **How could recorded information on health be improved?**
    - All horses should be evaluated at a young age. All horses participating in the YHE are given a veterinary exam
- **Will the use of genetic evaluations help improve sport horses in the UK?**
    - All individuals said yes
- **How much would you pay for a young horse now?**
    - Between £4000 and £15,000 for a 4 year old. This could be as high as £30,000 for a particularly outstanding horse
- **Would you pay more if it had a breeding value?**
    - Two individuals said yes
    - Others said yes if they were going to breed from it or if it was a horse they particularly liked
    - One individual said no

Organisation views

Breeding objectives:

- **How important is conformation?**
    - Important for all except BSJA and BR
    - BJSA wouldn't necessarily discount a horse because it had bad conformation
    - BR say that performance is more important
- **How important is temperament?**
    - Very important, even more so than conformation for BD, BEV and BR.
    - Important, but management and rider skill can help with a bad temperament for BE, SEA and BHDTA
    - Not necessarily important for performance horses but is more so as a breeding objective for the BSJA
    - Not important to EGB
- **How important is health and soundness?**
    - Very important for all organisations

- **What traits would you most like to see eradicated?**
  - Conformation and soundness problems for BR, BD, SEA, BSJA and EGB
  - Bad temperament for BR and BEV

Ability:

- **What abilities are looked for in a horse?**
  - BSJA: athleticism, balance, courage, good attitude
  - BHDTA: soundness, trainability, stamina
  - BEV: trainability, trustworthy, good temperament, good canter, balance
  - SEA: athletic, good temperament, jumping ability
  - BD: able to carry weight on hindquarters, trainability
  - BR: athletic, supple
  - BE: paces, conformation, jumping ability,
  - EGB: light framed, good stride length, comfortable
- **What is the best measure of a horse's ability and quality?**
  - A combination of conformation, assessment at a young age and performance in competition for BHDTA, BSJA and BE
  - Conformation and performance in competition for SEA
  - Performance in competition for EGB and BR
- **Should a horse be bred for only one discipline or should the discipline it enters depend on ability?**
  - All organisations believe that training can determine what a horse will do

Competitions:

- **What is the general age range of horses in your discipline**
  - BEV: 5 years (individual), 7 years (team) up to any age
  - BSJA: 4–18 years with a peak at 10-12 years
  - BHDTA: 4 years (club level), 6 years (international) up to about 20 years

  - BD: 4–20 years with a mean of about 10-12 years
  - BR: 3/4 years, now increasing to 6 and 7 years
  - BE: nothing under 5 years, up to 16 or 17 years for 3 day events, most crucial years at top level 12-15 years
  - EGB: 9–18 years
- **Is the sex of the animal important for competition?**
  - Geldings are preferred and most commonly used in BHS, BE and BSJA
  - Stallions used to be preferred by BD but now geldings are becoming more popular because of their good temperament
  - EGB, BR, SEA and BHDTA don't feel that the sex of an animal is important
- **Do you have a preference for coat colour?**
  - Darker colours are preferred by BHS, BE and BD
  - Light colour/grey preferred by EGB and BSJA
  - BHDTA and BR have no preference for coat colour
- **What breeds are most often used?**
  - EGB: Arabs, Anglo Arabs, Akel Teke
  - BE: Most popular are thoroughbreds and thoroughbred types.
  - BR: Quarter horse, Appaloosa
  - BD: Warmbloods
  - BHDTA: Welsh B and C, Gerderlanders and Friesians
  - BSJA: Warmbloods
- **How many horses enter competitions each year?**
  - BHDTA: 450 registered
  - EGB: 12000 entered in rides, 2400 registered
  - BE: 65000 entries per year
  - BR: 131 registered
  - BD: 9000 horses registered, 80000 starts per year
  - BSJA: 3000 competitions per year, newcomers 50 000 starts, 18000 horses registered

- **What are the main reasons for horses retiring?**
    - Unsoundness and age are the main reasons for all organisations
- **What influence do you think the rider has on a horse?**
    - All organisations feel that the rider has an influence on the horse and that it is a partnership

Improvement of horses:

- **How could recorded information on health be improved?**
    - BD: link up with insurance companies
    - BE: radiographic recording
    - BSJA: getting information from riders and owners
    - SEA: sourcing information from vets
- **Will the use of genetic evaluations help improve sport horses in the UK?**
    - Yes for BSJA, BE, BD, EGB and BR
    - BHDTA also says yes, but not immediately
- **How much would you pay for a young horse now?**
    - SEA: £1000-3000
    - BSJA: £5000–50, 000
    - BE: £6000-10,000 (3-4 year old), very special £15,000-20,000
    - BD: £3000-£6000 (3 year old)
    - EGB: £1500-2000
    - BR: £3500 for a yearling. Top quality from good reining stock £10,000
    - BHDTA: £4000-6000
- **Would you pay more if it had a breeding value?**
    - All organisations said yes

3.4 Discussion

The intention of this survey was to assimilate and determine the views and breeding objectives of people involved in the sport horse breeding industry. This was successfully achieved. However, improvements could be made for future surveys to increase the value of the results obtained. Only a small number of respondents were interviewed due to time constraints, it would be have been desirable to use a greater number of respondents which would have given a broader range of opinions and may also have allowed for a statistical analysis of the results. By speaking directly to the respondents it was possible to get a range of comprehensive answers to each question, however, although every effort was made not to lead respondents in any way, it can be a problem in all surveys of this kind. More clearly objective results could be obtained in an anonymous postal or internet survey with perhaps better defined questions. Again, due to time constraints this was not possible but should be considered for future surveys of this kind.

The results of this survey have given an indication of the views of the sport horse industry. In some cases the different individuals and organisations have conflicting views, however on most aspects they are in agreement. The opinions tend to depend on which discipline is represented; different disciplines require different qualities in their horses.

The opinions expressed in this survey show that conformation and temperament are considered important traits by all involved in the sport horse industry, breeders and handlers alike. This concurs with other surveys; Koenen *et al.* (2004) found that out of 19 European breeding organisations 17 cited conformation as one of their top breeding objectives and 11 cited temperament. For overall importance average scores of 8.4 and 8.0 out of 10 were given to conformation and temperament, respectively. Another survey carried out by Crossman (2005) shows that both breeders and buyers rank temperament and static conformation as their top priorities. However, the research carried out here shows that the relative importance of each varies depending on the discipline involved. Although all respondents said that conformation was important to them, representatives from the BSJA, BR and an international event rider (also a breeder) said that as long as a horse was a good performer then they would overlook some conformational faults.

Temperament is more complicated. Representatives from BD, BEV and BR all said that temperament was more important than conformation. These disciplines, dressage, vaulting and reining, all require a horse that is calm and obedient. However, it is the view of representatives from BE, SEA, BHDTA and a number of individuals that although temperament is important, good management and a skilled rider can mean that a spirited horse is not a problem. The representatives from the BSJA and EGB feel that if a horse performs well then temperament is not important, one individual event rider also said that some riders prefer a horse with some spirit. All of this leads to the question of how to define good or bad temperament? It appears to depend on the discipline involved and makes temperament a difficult term to define. A good temperament for a dressage horse is one that is calm and obedient, one that will behave as asked in a dressage arena, where the behaviour of a horse is marked just as much as its performance. Similarly for vaulting an ideal horse is one that will not misbehave because it is required to carry people balancing in gymnastic poses as its moves. However, for disciplines such as showjumping or endurance, where only performance and not behaviour is scored, it is likely that the preferred temperament is slightly more 'spirited' with an animal keen to go forward. Although this type of horse can be slightly harder to handle, the horse may perform better than less spirited competitors. From the answers gathered in this survey it appears that most people in the sport horse industry define a good temperament as calm and obedient. However, because different disciplines require different temperaments it is necessary for the industry to agree on a clear definition if temperament is to be used as a trait in breeding programs.

The abilities required from a horse also differ between disciplines. There are, however, some common abilities that many of the respondents looked for in a horse: bravery, trainability and athleticism. For showjumping and eventing horses the respondents also looked for jumping ability. It was agreed by most respondents that the best measure of a horse's ability was a combination of assessment at a young age, conformation and performance in competition, although a number of respondents put most emphasis on performance in competition and the representatives from EGB and BR believe that the only way to measure a horse's ability is performance in competition. This is likely due to the nature of reining and endurance as sports. It is hard to assess future performance in endurance in the way future performance in dressage, showjumping and eventing is assessed because the sport is about stamina and competitiveness. Conformation was cited as less important for reining than performance so the use of performance as the sole measure of ability is to be expected. Koenen *et al.* (2004) found that a popular breeding objective is performance in competition, particularly showjumping and dressage, although the one British breeding society that participated in their survey felt that performance in eventing was more important than performance in the other two disciplines. Although in this survey respondents were not directly asked about performance as a breeding objective, all respondents agreed that performance in competition was important in measuring a horse's ability and this suggests that performance in competition is a breeding objective for British sport horse breeders.

One of the more unexpected results from this survey was the answers given on coat colour. It had been expected that none of the respondents would have any preference, and although this was true of some, it was found that a number of respondents preferred specific colours for a number of reasons. For example dark colours are preferred for both eventing and dressage because they can look 'flashier' in the dressage arena. This is a subjective opinion, based more on the impression the horse gives, rather than its performance. However, light colours are preferred for endurance because apparently they are better for dissipating heat. If this is indeed the case it may be that colour could be linked objectively to the performance of endurance horses.

All the respondents fully agreed on the importance of heath and soundness. All of them stated that they would not breed from a horse that they knew to have a heritable muscoskeletal disorder. Although health and soundness is undoubtedly an important trait to breed for, it does not always come out on top in surveys of breeding objectives; Crossman (2005) found that soundness came fifth in a list of 7 breeding objectives and Koenen *et al.* (2004) found that only 9 of 19 breeding organisations cited health as a breeding objective. This is contradicted, however, by the average score of importance given in the same paper of 8.3 out of 10. This indicates that breeders will often take for granted the health and soundness of the animals they are breeding and do not immediately see the importance of using health as a trait in a breeding program until questioned directly on the subject. This may be because often animal breeders do not associate health and genetics and do not see health issues as sufficiently heritable (J A Woolliams, personal communication, 2007).

Gathering opinions on breeding objectives for sport horses is important in considering how to set up genetic evaluations, however, the opinions on the evaluations themselves are very important. All respondents agree that the use of genetic evaluations will help improve British sport horses. Currently the approximate price range for a 3 or 4 year old sport horse is £2000-6000, although some respondents said that if a horse was exceptional they would pay £10,000-£50,000 for it. This gives an indication of the potential economic value of the sport horse industry as it stands now. Many of our respondents said that they would pay more for an animal with a breeding value, because of the comfort in the reliability of knowing that a horse had come from proven stock. This could greatly increase the potential for economic growth of the sport horse industry in Britain. In other species economic weights can be used to show the value of a unit of improvement in traits such as birth litter size in pigs (Quinton *et al.*, 2006), carcass weight in sheep (Conington *et al.*, 2006) and milk content in dairy cattle (Stott *et al.*, 2005), all of which are easily quantified. However, the difficulty of using economic weights in sport horse breeding lies in (1) the subjectivity of the potential traits which can make them difficult to define and quantify and (2) the fact that many sport horse breeders do not breed for financial gain but as a hobby.

3.5 Conclusion

This survey has shown that some of the most important breeding objectives for the British sport horse industry are conformation, temperament and performance in competition. All of these traits are heritable (Huizinga & van der Meij, 1989; Huizinga *et al.*, 1991a; 1991b; Koenen *et al.*, 1995; Ducro *et al.*, 2005). Health and soundness is also important to the sport horse industry, and because some muscoskeletal disorders are also known to be heritable (Dolvik & Klemetsdal, 1994; Bjornsdottir *et al.*, 2000; Árnason & Bjornsdottir, 2003; Stock *et al.*, 2004a, 2004b) care needs to be taken when selecting breeding animals to ensure soundness in future generations.

3.6 Summary

The sport horse breeding industry in Britain needs to examine its policies in order to persuade people to buy British bred horses and to be able to compete on a world stage with other top sport horse breeding nations. One of the strategies to be implemented is the development of genetic evaluations of British bred sport horses. Before this research can begin it is important to understand the objectives of sport horse breeders. Eight individuals and nine organisations were questioned on subjects such as: what they look for in a horse, the discipline they represent, what they believe measures a horse's quality and ability and how they felt they would benefit from the production of estimated breeding values (EBVs). The results of the questionnaire showed that the most important breeding objectives for the British sport horse industry are conformation, temperament, performance in competition and health and soundness. All respondents agreed that the use of genetic evaluations would help to improve British bred sport horses.

4 Analysis of Young Horse Evaluation data for use in the genetic evaluation of British sport horses

4.1 Introduction

Genetic evaluation systems are well established in sheep and cattle breeding, and result in a substantial improvement in economically important traits (Simm, 1998). The use of genetic evaluations in sport horse breeding is becoming more common, with quantitative research established in Sweden, The Netherlands, Ireland, France and Germany. Research into the genetic evaluation of British bred sport horses is now underway, with initial investigations focussing on assessment of youngstock. Data on young British bred horses have been collected from two schemes (1) the Young Horse Evaluation Series (YHE), a group of events open to all 4 year old British bred horses, in which the animals are evaluated on health status (medical and orthopaedic), conformation, paces (in hand and under rider) and jumping (loose and ridden) and (2) the *British Breeding* Futurity Scheme, which assesses horses from foals to six year olds, although the dataset for this study was taken from the first year in which the scheme was held and only includes foals to 3 year olds. Animals are tested on conformation, paces and suitability for type.

The aims of this study were (1) to carry out a preliminary investigation into the genetic parameters of each YHE trait and the phenotypic correlations between traits, (2) to estimate the phenotypic correlations between the Futurity Scheme traits and (3) to determine whether data collected from the YHE could be of use in the genetic evaluation of sport horses.

4.2 Materials and methods

Data collection

Data was collected from one day YHE tests for 4 year old mares, stallions and geldings held across Britain in the summers of 2003-2005. Each test was a one day field test in which horses were examined, first by a veterinarian to confirm the animal was in good health, to check for signs of unsoundness and to assess the conformation for faults that may lead to unsoundness in the future. Horses were then assessed by a panel of three judges on their performance. The traits tested were: conformation, paces, loose jumping ability and ridden jumping ability (see Appendix A for definitions of each trait). Temperament was not measured directly, but is included in the performance scores for paces and jumping ability. Each horse could be entered to be assessed as a potential dressage, showjumping or eventing horse and was scored in each performance trait according to its preferred discipline. Horses could be entered as both dressage and showjumping horses, but any horses entered as an eventing horse could not take part in assessments for the other 2 disciplines. Scores were given subjectively by three judges. The total scores for each discipline were given as an unweighted average of the scores for the veterinary examination, conformation and the relevant performance traits. Scores are on a scale of 0 to 10, in which zero equates to poor and 10 to excellent.

Data was collected from the one day Futurity Scheme event held in the summer of 2005 for foals to 3 year olds. Similarly to the YHE, horses were assessed according to the discipline for which they were entered – dressage, showjumping or eventing. The horses were assessed on conformation (see Appendix A); athleticism – the horse's ability to move and perform easily and 'athletically'; general impression – the judge's overall impression of the horse; paces (see Appendix A) and type – the judges opinion on how well suited each horse would be for its chosen discipline. As with the YHE, scores are given subjectively by three judges and are on a scale of 0 to 10, in which zero equates to poor and 10 to excellent.

The YHE, and to some extent, the Futurity Scheme are based on the Swedish Riding Horse Quality Tests (RHQT). The RHQT is a one day field test which assesses the same traits as the YHE but also includes a separate score for temperament. Horses are scored subjectively on these traits, with scores ranging from 1 to 10 where 1 is poor and 10 is excellent (Olsson *et al.,* 2000). One day tests of this kind are also held in Denmark, Germany and The Netherlands (Thorén Hellsten *et al.,* 2006).

Young Horse Evaluation Series (YHE)

Dataset

Data from the YHE (2003-2005) were provided by *British Breeding* (http://www.bef.co.uk/britishbreeding/yhe.htm). Eleven traits were measured – veterinary examination (V Exam), conformation (Conf), showjumping loose jumping (SJ Loose), showjumping ridden jumping (SJ Ridden), showjumping total score (SJ Total), dressage paces (D Paces), dressage total score (D Total), eventing paces (E Paces), eventing loose jumping (E Loose), eventing ridden jumping (E Ridden) and eventing total score (E Total).

The dataset consisted of 294 records on 248 individual horses. There were more records than horses because some horses were tested more than once. The animals were categorised into 3 sexes (gelding, mare or stallion) and records were collected on 30 different evaluation dates. Pedigree information was available for these data and comprised sires (187), dams (235) and dam's sires (191).

Genetic analysis

The data was analysed with an animal model using ASReml (Gilmour *et al.*, 2002).

$$y_{ijk} = \mu + \alpha_i + \beta_j + u_k + w_k + e_{ijk}$$

Where y_{ijk} is the trait value for the kth animal of sex i evaluated on the jth date, μ is the overall mean, α_i is the fixed effect of sex i, β_j is the fixed effect of date of evaluation j, u_k is the random genetic effect of animal k, w_k is the random permanent environmental effect of animal k and e_{ijk} is the residual error. u_k was assumed to be normally distributed with a variance/covariance matrix of the form $\sigma^2_a \mathbf{A}$ where $\mathbf{A}$ is the numerator relationship matrix, w_k was assumed to be normally distributed with a variance/covariance matrix of the form $\sigma^2_c \mathbf{I}$ and e_{ijk} was assumed to be normally distributed with a variance/covariance matrix of the form $\sigma^2_e \mathbf{I}$. The effect of year of evaluation, location and judges are confounded with date of evaluation. Age is not included in the model because all of the horses taking part in YHE are 4 years old.

Futurity Scheme

Dataset

Data from the *British Breeding* Futurity Scheme for 2005 were provided by *British Breeding* (http://www.bef.co.uk/britishbreeding.htm). Six traits were measured – athleticism (Athl), conformation (Conf), general impression (GI), paces, type and average score (AS). The dataset consisted of 72 records all collected on the same day at the same location. The animals were categorised into 3 sexes (mare, stallion and gelding). There were 4 years of birth – 2002, 2003, 2004 and 2005. All traits were recorded on all animals.

Phenotypic analysis

The data was analysed using ASReml (Gilmour *et al.,* 2002).

$$y_{ijk} = \mu + \alpha_i + \beta_j + e_{ijk}$$

Where y_{ijk} is the trait value for the kth animal of sex i born in the year j, μ is the overall mean, α_i is the effect of sex, β_j is the effect of the year of birth and e_{ijk} is the residual error.

4.3 Results

YHE Summary Statistics

Summary statistics for the YHE traits are shown in Table 4.1. The number of observations for the YHE traits varied depending on the trait. All horses apart from one were scored for V Exam, but only 68 of the 294 horses were scored for SJ Ridden.

Table 4.1 YHE Summary statistics and repeatabilities

Summary statistics				
Trait	No. Observations	Mean	SD	Repeatability±SE
V Exam	293	7.38	1.09	0.56±0.11
Conf	291	6.67	0.87	0.66±0.09
SJ Loose	94	7.21	1.39	0.85±0.09
SJ Ridden	68	6.91	1.32	0.00†
SJ Total	127	7.08	0.90	0.75±0.13
D Paces	171	6.54	1.10	0.22±0.21
D Total	171	6.75	0.83	0.68±0.12
E Paces	158	6.84	0.88	0.60±0.14
E Loose	107	7.16	1.30	0.39±0.29
E Ridden	122	7.05	1.05	0.28±0.26
E Total	159	6.98	0.74	0.57±0.15

V Exam: veterinary exam; Conf.: conformation; SJ Loose: showjumping loose jumping, SJ Ridden: showjumping ridden jumping; SJ Total: showjumping total score; D Paces: dressage paces; D Total: dressage total score; E Paces: eventing paces; E Loose: eventing loose jumping; E Ridden: eventing ridden jumping; E total: eventing total score

† inestimable

YHE Fixed effects

Table 4.2 shows the predicted means of the scores for each sex and the significance of sex and date of evaluation. Significant differences ($P<0.05$) were observed between the sexes in the scoring of V Exam, Conf, SJ Total, D Paces and D Total, with a general pattern of stallions having the highest mean scores. The mean scores for V Exam, Conf, D Paces, D Total, E Paces and E Total differed significantly ($P<0.05$) over the dates of evaluation.

Table 4.2 Predicted means for geldings, stallions and mares for all YHE traits together with significance of fixed effects

Trait	Gelding	Stallion	Mare	Sex	Date of Evaluation
V Exam	7.39±0.11^{a}	7.80±0.17^{b}	7.22±0.10^{a}	$P<0.01$	$P<0.001$
Conf	6.67±0.09^{a}	6.77±0.13^{a}	6.43±0.08^{b}	$P<0.05$	$P<0.001$
SJ Loose	6.89±0.29^{a}	7.73±0.39^{a}	7.12±0.22^{a}	NS	NS
SJ Ridden	7.20±0.34^{a}	7.33±0.34^{a}	6.71±0.25^{a}	NS	NS
SJ Total	6.89±0.15^{a}	7.45±0.18^{b}	6.93±0.12^{a}	$P<0.05$	NS
D Paces	6.54±0.15^{ab}	6.78±0.18^{a}	6.21±0.14^{b}	$P<0.05$	$P<0.01$
D Total	6.74±0.11^{ab}	7.01±0.14^{a}	6.49±0.10^{b}	$P<0.05$	$P<0.001$
E Paces	6.84±0.11^{a}	6.88±0.21^{a}	6.57±0.11^{a}	NS	$P<0.001$
E Loose	7.27±0.23^{a}	7.26±0.47^{a}	6.97±0.21^{a}	NS	NS
E Ridden	7.04±0.15^{a}	6.70±0.28^{a}	6.88±0.15^{a}	NS	NS
E Total	6.99±0.09^{a}	7.05±0.19^{a}	6.76±0.09^{a}	NS	$P<0.01$

a, b, c in the same row: means not sharing a subscript are significantly different ($P<0.05$) when compared using a t-test

NS not significant

V Exam: veterinary exam; Conf.: conformation; SJ Loose: showjumping loose jumping, SJ Ridden: showjumping ridden jumping; SJ Total: showjumping total score; D Paces: dressage paces; D Total: dressage total score; E Paces: eventing paces; E Loose: eventing loose jumping; E Ridden: eventing ridden jumping; E total: eventing total score

YHE Repeatabilities

Table 4.1 shows the estimated repeatabilities for the YHE traits. The repeatabilities for V Exam, Conf, SJ Loose, SJ Total, D Total, E Paces and E Total were significantly different from zero ($P<0.05$) ranging from 0.56 to 0.85. Data for the heritabilities is not presented, none were significantly different from zero and were not meaningful to the study.

YHE Phenotypic Correlations

Table 4.3 shows the phenotypic correlations between YHE traits. Moderate phenotypic correlations were observed between V Exam and Conf, D Paces and E Paces (0.20-0.30). Moderate to high correlations were seen between Conf and SJ Loose, SJ Ridden, D Paces, E Paces and E Loose (0.37-0.65), SJ Loose and

SJ Ridden (0.86), E Loose and E Ridden (0.46), SJ Ridden and D Paces (0.65) and E Paces and E Loose and E Ridden (0.38-0.46).

Table 4.3 Phenotypic correlations between YHE traits

	V Exam	Conf	SJ Loose	SJ Ridden	E Paces	E Loose
Conf	0.20±0.06					
SJ Loose	-0.07±0.13	0.65±0.07				
SJ Ridden	-0.02±0.14	0.37±0.11	0.86±0.06			
D Paces	0.30±0.08	0.46±0.07	0.28±0.16	0.65±0.12	†	
E Paces	0.21±0.09	0.41±0.08	†	†		
E Loose	0.14±0.12	0.54±0.05	†	†	0.46±0.09	
E Ridden	0.14±0.10	0.15±0.11	†	†	0.38±0.09	0.46±0.12

†Horses entered for eventing assessment are not eligible for assessment in dressage or showjumping

V Exam: veterinary exam; Conf.: conformation; SJ Loose: showjumping loose jumping, SJ Ridden: showjumping ridden jumping; SJ Total: showjumping total score; D Paces: dressage paces; D Total: dressage total score; E Paces: eventing paces; E Loose: eventing loose jumping; E Ridden: eventing ridden jumping; E total: eventing total score

Futurity Scheme Fixed Effects

Summary statistics for the Futurity Scheme traits are shown in Table 4.4. Table 4.5 shows the predicted means of the scores for each sex and each year of birth, and the significance of sex and year of birth. Significant differences ($P<0.01$) were found between the sexes in the scoring for Conf, Paces and AS. Conf was the only trait in which the scores differed significantly ($P<0.05$) over the different years of birth.

Table 4.4 Summary statistics for each Futurity Scheme trait

Trait	Mean	SD
Athleticism	7.74	0.71
Conformation	7.80	0.70
General Impression	7.71	0.65
Paces	7.90	0.56
Type	7.96	0.60
Average Score	7.82	0.52

Table 4.5 Predicted means for each sex and each year of birth for all Futurity Scheme traits together with significance of fixed effects

	Sex				Year of birth				
Traits	Mare	Stallion	Gelding	OS	2005	2004	2003	2002	OS
Athleticism	7.73 ± 0.13^{a}	7.88 ± 0.16^{a}	7.40 ± 0.20^{a}	NS	7.69 ± 0.16^{a}	7.66 ± 0.15^{a}	7.78 ± 0.20^{a}	7.54 ± 0.23^{a}	NS
Conformation	8.02 ± 0.12^{a}	7.92 ± 0.14^{a}	7.28 ± 0.19^{b}	$P<0.01$	7.65 ± 0.15^{a}	7.66 ± 0.14^{a}	7.38 ± 0.18^{a}	8.26 ± 0.21^{b}	$P<0.05$
General Impression	7.81 ± 0.12^{a}	7.70 ± 0.14^{ab}	7.33 ± 0.18^{b}	NS	7.79 ± 0.15^{a}	7.59 ± 0.14^{a}	7.45 ± 0.18^{a}	7.63 ± 0.21^{a}	NS
Paces	8.00 ± 0.10^{a}	8.13 ± 0.12^{a}	7.49 ± 0.16^{b}	$P<0.01$	7.69 ± 0.12^{a}	7.74 ± 0.12^{a}	7.85 ± 0.15^{ab}	8.21 ± 0.18^{b}	NS
Type	8.08 ± 0.11^{a}	8.03 ± 0.13^{ab}	7.65 ± 0.17^{b}	NS	7.91 ± 0.14^{a}	7.87 ± 0.13^{a}	7.66 ± 0.16^{ab}	8.24 ± 0.19^{ac}	NS
Average Score	7.92 ± 0.09^{a}	7.95 ± 0.11^{a}	7.43 ± 0.14^{b}	$P<0.05$	7.74 ± 0.11^{a}	7.70 ± 0.11^{a}	7.63 ± 0.14^{a}	7.99 ± 0.16^{a}	NS

OS overall significance

NS not significant

a, b, c in the same row: means not sharing a superscript are significantly different ($P<0.05$) when compared using a t-test

Futurity Scheme Phenotypic Correlations

Table 4.6 shows the phenotypic correlations observed between the Futurity Scheme traits. Moderate to high correlations were observed between all traits, particularly between Athl and GI (0.69) and Conf and GI (0.69). The lowest correlation was observed between Athl and Type (0.37).

Table 4.6 Phenotypic correlations between Futurity Scheme traits

	Athleticism	Conformation	General Impression	Paces
Conformation	0.50±0.09			
General Impression	0.69±0.06	0.69±0.06		
Paces	0.59±0.08	0.42±0.10	0.64±0.07	
Type	0.37±0.11	0.48±0.10	0.55±0.09	0.51±0.09

4.4 Discussion

There were a number of problems with this study, in particular with the small size of both the YHE and Futurity Scheme datasets. The YHE dataset had a total of only 294 records and each trait had different numbers of records. The greatest number of records was observed in V Exam (293) and the lowest in SJ Ridden (68) (Table 4.1). Although pedigree data was available, the low numbers in the dataset meant that there was a lack of genetic links with an average of ~1.3 progeny per sire and ~1 progeny per dam. This lack of genetic links meant that it was impossible to predict meaningful heritabilities for the YHE traits despite the use of a genetic model. Despite heritabilities being inestimable, the repeatabilities (Table 4.1) are sufficient in magnitude and precision to indicate that the YHE is useful as a test of individuals. Since repeatabilities form an upper bound to the heritability they do not rule out the possibility that further data will enable the detection of useful heritabilities for all traits. With just 72 records for the Futurity Scheme it was only possible to use a phenotypic model for analysis.

Another problem with the analysis was the definition and measurement of traits. Despite the aim of V Exam to detect any heritable muscoskeletal problems, the method of assessment can only show if the horse has good conformation and whether or not it is sound on the day of the test. A horse can be unsound at the test as the result of a minor injury sustained *en route* to the event, however it will receive a low score despite the fact that this injury will pass and the horse can return to full soundness. However, a horse can appear sound on the day of the test and receive a high score but be prone to a heritable muscoskeletal disorder such as navicular (Stock *et al.,* 2004a) or joint arthopathies (Stock *et al.,* 2004b) that may not become apparent until later in its life and can only be picked up early in life with the use of X rays. Temperament is not measured as a separate trait, but an assessment of temperament is included in the scoring of paces and jumping ability. This does not allow for an optimum analysis of any of these traits because by combing the scores of two separate traits each may influence other. Some traits from the Futurity Scheme are highly subjective, those such as General Impression and Type cannot be easily defined and rely entirely on the opinion of an individual judge. This could also be the case for traits such as paces and conformation, however these traits have been used in the assessment of youngstock in European systems for a number of years (Bruns *et al.*, 1980; Huizinga *et al.*, 1991a; Huizinga *et al.*, 1991b; Olsson *et al.,* 2000) and have been well defined to reduce subjectivity. Such definitions also need to be applied to all of the Futurity Scheme traits if they are to be used in genetic evaluations in the future.

Judging bias, which can create subjectivity in the scoring of traits, also causes a problem to the analysis of the data in this study. For both the YHE and Futurity Scheme three judges are used, these judges confer amongst themselves and give a single score. Discussion amongst the judges leads to a greater subjectivity because instead of each judge giving their first impression of the horse, they are led by the views of the others. Often the views of a dominant judge are put forward above the views of the other judges. Each should give their own score, with an average of the three taken as the final score. The judges should have no prior knowledge of the horses they are assessing to avoid basing their judgment on previous opinions, this should also help to reduce some bias.

The results of this study have provided an insight into the way in which the sex of an animal can affect the scoring of evaluations. The differences in the V Exam scores for the YHE, in which stallions were given the highest marks, may be explained by pre selection. A stallion would be expected to have sound health, because any young male showing problems is likely to be gelded. The scoring of conformation in the YHE differed between males (stallions and geldings) and females (mares). However, the Futurity Scheme results show that there was a significant difference between the scoring of stallions and geldings for conformation, with the stallions receiving the highest scores. Conformation is the only trait in the Futurity Scheme that shows a significant difference in the scores of animals of different years of birth. Although conformation can be assessed on young foals (Preisinger *et al.,* 1991), a horse's appearance will change as it gets older due to growth and increased muscle tone.

The significance of the date of evaluation for V Exam, Conf, D Paces, D Total, E Paces and E Total may be due to the use of different judges on each evaluation date, establishing differing standards. None of the jumping traits are significantly affected by the date of evaluation, possibly because jumping ability is an easier trait to score objectively compared to V Exam, Conf or paces.

Different conclusions have been drawn about the correlation between ability in dressage and showjumping; that it is correlated (Wallin *et al.*, 2003; Ducro *et al.*, 2005) and that it is not (Bruns, 1981; Huizinga & van der Meij, 1989). The results from the YHE suggest that there is a phenotypic correlation between ability in jumping and ability in paces with moderate to high phenotypic correlations predicted between the paces and jumping traits. The phenotypic correlations from the Futurity Scheme suggest that if a horse is athletic and has good conformation it will generally be judged a good horse.

4.5 Conclusions

There are a number of flaws in the dataset that should be addressed by *British Breeding* before meaningful results can be obtained by analysis of YHE and Futurity Scheme data. However, the repeatabilities shown here are encouraging, suggesting that the tests are assessing individual variation among horses, not simply variation from each evaluation day.

4.6 Summary

A preliminary investigation was carried out into the parameters of veterinary, conformation, showjumping, dressage and eventing traits from the Young Horse Evaluation series. Data on 294 horses was analysed using an animal model with fixed effects of sex and date of evaluation. The repeatabilities for most traits were significantly greater than zero and so are acceptable for developing testing of individuals. Phenotypic correlations between all pairs of traits were moderate to high.

5 Use of competition data for genetic evaluations of eventing horses in Britain: Analysis of the dressage, showjumping and cross country phases of eventing competition

5.1 Introduction

Competition data is widely used in the genetic evaluation of trotting and galloping race horses (Tavernier, 1991; Saastamoinen & Nylander, 1996; Villela *et al.*, 2002; Belhajyahia *et al.*, 2003; Langlois & Vrijenhoek, 2004; Bugislaus *et al.*, 2005; Ekiz & Kocak, 2005) and also showjumping horses (Tavernier, 1990; Reilly *et al.*, 1998; Aldridge *et al.*, 2000; Stallion Genetic Evaluation Project, 2005). The most commonly used traits for the evaluation of racehorses are annual earnings and competition placing. The main problem with this approach is that only horses with winnings or those that are placed can be evaluated, which can introduce selection bias or highly skewed distributions. However, a different approach to the evaluation of showjumping horses, overcoming these problems, has been developed by Reilly *et al.* (1998) which ranks all animals in a competition based on individual performance measures, such as faults and round times, and uses these ranks to create normalised scores for evaluation. This method has been introduced in practice in Ireland (Aldridge *et al.*, 2000; Stallion Genetic Evaluation Project, 2005).

Investigations into eventing data are rare; one such study has investigated the use of both competition placing and annual earnings as a method of evaluation (Ricard & Chanu, 2001), although this approach is not necessarily well suited to the evaluation of eventing horses. Eventing is a combination of three phases (dressage, showjumping and cross country), each of which may have a different heritability. In such circumstances it may be that combining all phases into a single trait prior to evaluation, as would occur when overall competition placing and annual earnings are used, is less effective in identifying genetically superior animals than examining each phase separately. The evaluation of eventing horses may instead benefit from an approach that recognises the different phases of competition.

Genetic analyses allow for the partitioning of variance. An important partition in the context of equestrian events is the relative importance of horse and rider. This has been much speculated upon but little quantified and requires extensive datasets in which both horse and rider are uniquely identified. Such datasets have been rare to date, but a suitable one, holding UK data, has recently been made available.

Using methods based on those developed by Reilly *et al.* (1998) the aims of this study were (1) to develop a genetic model based on normalised competition scores for the analysis of the different phases of eventing competition (dressage, showjumping, cross country and overall competition), (2) to estimate genetic and phenotypic parameters for use in genetic evaluations and (3) to quantify the relative importance of horse and rider.

5.2 Materials and Methods

Within an event, horses compete in classes that differ in degree of challenge and rider experience. Classes are divided into four different grades (pre novice, novice, intermediate and advanced) based on the level of difficulty of each phase as laid out in the rules of British Eventing (www.britisheventing.com). Pre novice is the lowest grade and advanced is the highest. 'Competition' was defined as a group of horses competing at the same event on the same day at the same grade, and this meaning will be used throughout the following text.

Data

The data consisted of penalty records for dressage, showjumping, cross country and overall competition (Table 5.1). Different numbers of horses are observed for each phase because in some cases a horse may drop out of the competition before completing all three phases. The records for overall competition include only those horses that completed all three phases. Whilst there is only one record of a single horse's performance at a single competition, horses can appear in more than one competition and hence in more than one grade. The combination of phase and grade gives sixteen traits for analysis – penalty points in dressage at pre novice (DP), novice (DN), intermediate (DI) and advanced (DA) grade, penalties in showjumping at pre novice (SJP), novice (SJN), intermediate (SJI) and advanced (SJA) grade and penalties in cross country at pre novice (XCP), novice (XCN), intermediate (XCI) and advanced (XCA) grade. In addition, penalty points for each horse in each competition were summed across disciplines to form an overall score at pre novice (OCP), novice (OCN), intermediate (OCI) and advanced (OCA) grade. In a small number of cases the different phases of an event are set at different grades. When this occurs overall competition was treated as equivalent to the grade of the cross country phase.

Table 5.1 Datasets for dressage (D), showjumping (SJ), cross country (XC) and overall competition (OC)

Phase	Total Records	Horses	Sires	Competitions	Riders
D	179967	14550	4772	3170	2703
SJ	169721	14291	4712	3161	2684
XC	149362	13784	4599	3158	2667
OC	148246	13751	4595	3146	2664

Due to low subgroup numbers, the youngest horses (4, 5 and 6 years of age) were grouped together as one age group, as were horses over 19 years of age. Records with missing penalty points were removed, as were any records with no recorded rider. Rider was routinely recorded in all records from 1999 to the present, but sporadically before this time, therefore all records taken before 1999 were removed from the dataset, providing data for analysis from 1999-2005 inclusive. A summary of the dataset editing process is given in Appendix C.

Within phase model

For each competition, the penalty points for dressage, showjumping, cross country and overall competition were converted to normal scores by reference to the horse's ranking for that phase within a competition, using a method adapted from Royston

(1982). Preliminary univariate analyses indicated that including rider in the models as an additional effect significantly improved the fit of the model to the data, with the value of the log likelihood ratio test exceeding 81 (c.f χ^2_1) in all phases. Therefore the following model was analysed.

$$y_{ghijklm} = \mu_g + \alpha_{gh} + \beta_{gi} + \gamma_{gj} + u_{gk} + v_{gkl} + w_{gm} + e_{ghijklm}$$

Where $y_{ghijklm}$ is the trait value for horse l, with sire k, of sex h and age i, competing at grade g in competition j with rider m. For each grade μ_g is the overall mean, α_{gh} is the effect of sex, β_{gi} is the effect of age, γ_{gj} is the effect of competition, u_{gk} is the effect of sire, v_{gkl} is the effect of the residual horse, w_{gm} is the effect of the rider and $e_{ghijklm}$ is the residual error. No sire pedigree was available, they were therefore assumed to be unrelated. The effects of sex, age and competition were considered fixed; the effects of sire, horse and rider were considered random. u_{gk}, v_{gl}, w_{gkm} and $e_{ghijklm}$ were normally distributed with variance/covariance matrices of the form $\mathbf{\Sigma_u \otimes I}$, $\mathbf{\Sigma_v \otimes I}$, $\mathbf{\Sigma_w \otimes I}$ and $\mathbf{\Sigma_e \otimes I}$, respectively.

The variance/covariance matrices $\mathbf{\Sigma_u \otimes I}$, $\mathbf{\Sigma_v \otimes I}$ and $\mathbf{\Sigma_w \otimes I}$ were given further structure with the use of an antedependence model of order 1 to describe the relationship between the progressive grades. An antedependence model is characterised by modelling correlations over time (Horgan, 1996), using previous performances to explain performance at time t (Jaffrézic *et al.*, 2004). For example, in this study, where an antedependence model of order one is used, the performance of a horse at advanced grade is based on that horse's performance at intermediate level, which in turn was based on its performance at novice and before that pre novice level. The model therefore allows for serial correlations but does not assume (1) that the variance is constant over time, (2) that the ordered sequences are not overlapping in time or (3) that correlations between equally spaced measurements are equal. The constrained iterations were carried out in ASReml which has a specific function (ANTE1) for fitting an antedependence model. Algebraically this implies fitting a model of the inverse of the matrices of the form $\Sigma^{-1} = UDU'$ where Σ is the variance/covariance matrix, D is a diagonal matrix, U is an upper triangular matrix and U' is the transpose of the upper triangular matrix. An antedependence model of order 1 implies that only one diagonal above the leading diagonal in U (or below the leading diagonal in U') is above zero (Gilmour *et al.*, 2002).

The antedependence structure was used for the analysis of all traits. Sire models were fitted for each phase using ASReml (Gilmour *et al.*, 2002). The antedependence model allowed identification of very highly correlated grades and an iterative process of combining grades was carried out to allow proper convergence of ASReml. In the final model, sire effects for SJN/SJI, XCN/XCI/XCA and OCN/OCI/OCA were merged. The horse and rider components did not require such grouping of grades.

The following equations were used to calculate a number of parameters from the variance components.

$$\text{Heritability} = (4 \times \sigma^2_u) / \sigma^2_p$$

$$\text{Permanent Environment} = (\sigma^2_v - 3 \times \sigma^2_u) / \sigma^2_p$$

$$\text{Rider} = \sigma^2_w / \sigma^2_p$$

$$\text{Repeatability} = (\sigma^2_u + \sigma^2_v) / \sigma^2_p$$

where σ^2_p is the total phenotypic variance, σ^2_u is the sire variance, $\sigma^2_{v,}$ is the residual horse variance, σ^2_w is the rider variance and σ^2_e is the residual variance for the trait. Age trends were plotted from fitted values contained within the ASReml solution files, with the solutions defined relative to the mean solution for horses aged 4 to 8. ASReml performs a test on fixed effects by dividing the Wald test by the number of degrees of freedom. It is possible to perform an approximate F test if the denominator degrees of freedom can be determined. In ASReml 1.0, as was used in this study, the denominator degrees of freedom were assumed to be infinite (Kenward & Roger, 1997).

Between phase model

To determine the correlations between the dressage, showjumping and cross country phases of eventing competition the data was re arranged into grade groups

(Table 5.2) and analysed with an unstructured trivariate sire model. To avoid problems with confounding, the correlations between overall competition and the three phases were determined using a series of bivariate models. All models were run in ASReml (Gilmour *et al.*, 2002).

$$y_{phijklm} = \mu_p + \alpha_{ph} + \beta_{pi} + \gamma_{pj} + u_{pk} + v_{pkl} + w_{pm} + e_{phijklm}$$

Where $y_{phijklm}$ is the trait value for horse l, with sire k, of sex h and age i, competing at phase p in competition j with rider m. For each phase μ_p is the overall mean, α_{ph} is the effect of sex, β_{pi} is the effect of age, γ_{pj} is the effect of competition, u_{pk} is the effect of sire, v_{pkl} is the effect of the residual horse, w_{pm} is the effect of the rider and $e_{phijklm}$ is the residual error. The fixed and random effects were the same as those in the within phase model. To reduce the running time of the model with minimal loss of accuracy of the results, the pre novice and novice datasets were reduced to include only sires with 30 or more offspring.

Table 5.2 Datasets for pre novice (P), novice (N), intermediate (I) and advanced (A)

Grade	Total Records	Horses	Sires	Competitions	Riders
P	116532	6296	595	901	2254
N	100246	3802	475	1111	1644
I	105120	4097	1926	1106	1296
A	29261	1430	915	313	578

5.3 Results

Fixed Effects

The inclusion of age in the model significantly reduced variation for dressage, showjumping, cross country and overall competition. The age effects are presented as deviations from the average performance of horses aged 4 to 8 years old. As the grades progress, age has a greater effect on performance in all of the phases, although this effect is particularly clear in dressage and overall competition. Beyond the ages 4 to 8, the impact of age on dressage peaked early and remained fairly constant across the age groups (Figure 5.1a), although a slight drop in scores can be seen at around 18 years old for horses at pre novice and novice level. The showjumping (Figure 5.1b), cross country (Figure 5.1c) and overall competition scores (Figure 5.1d) showed an increase with age, peaking at around 16-18 years before dropping as age increased further.

Figure 5.1a Age trend of mean scores (±SE) for dressage scores compared to the average performance of horses aged 4 to 8

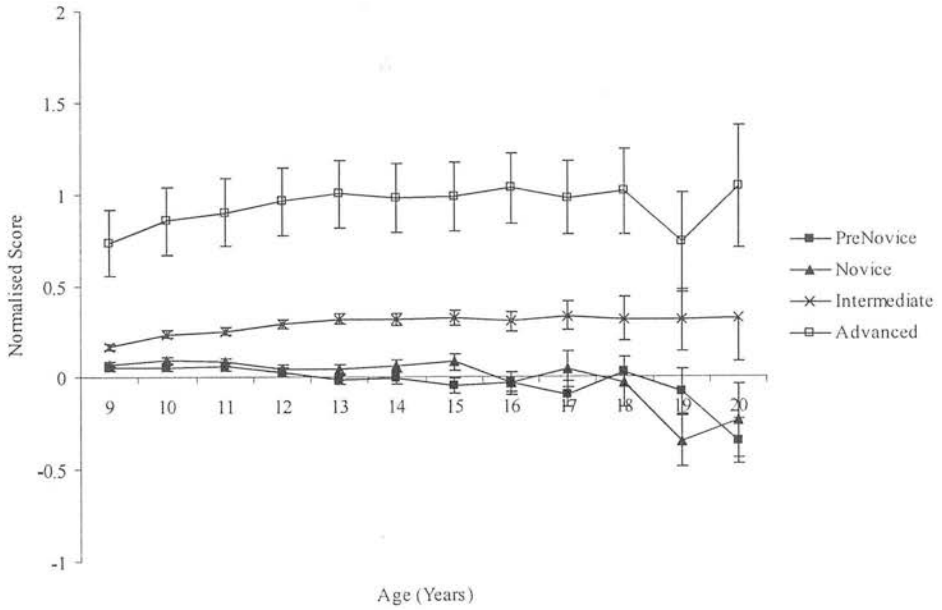


Figure 5.1b Age trend of mean scores (±SE) for showjumping scores compared to the average performance of horses aged 4 to 8

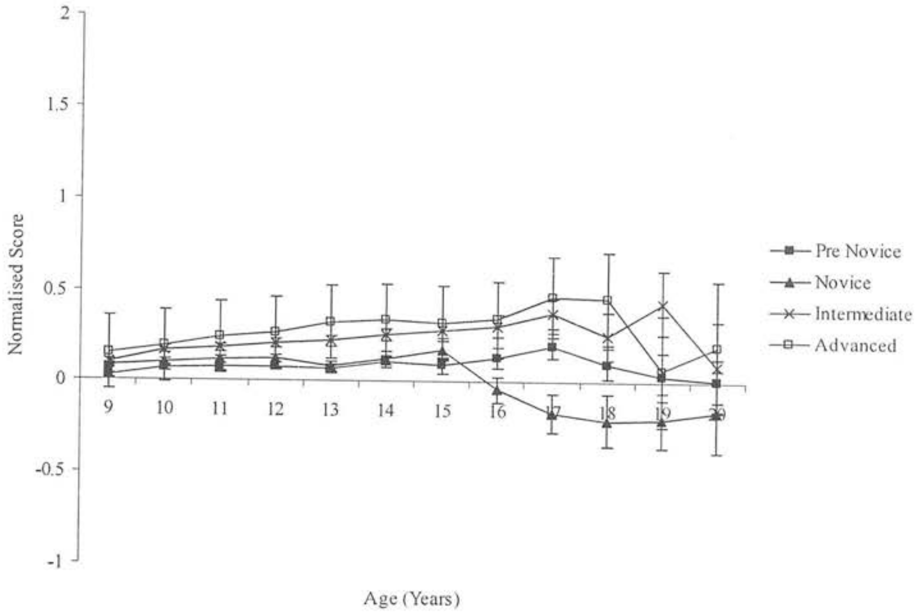


Figure 5.1c Age trend of mean scores (±SE) for cross country scores compared to the average performance of horses aged 4 to 8

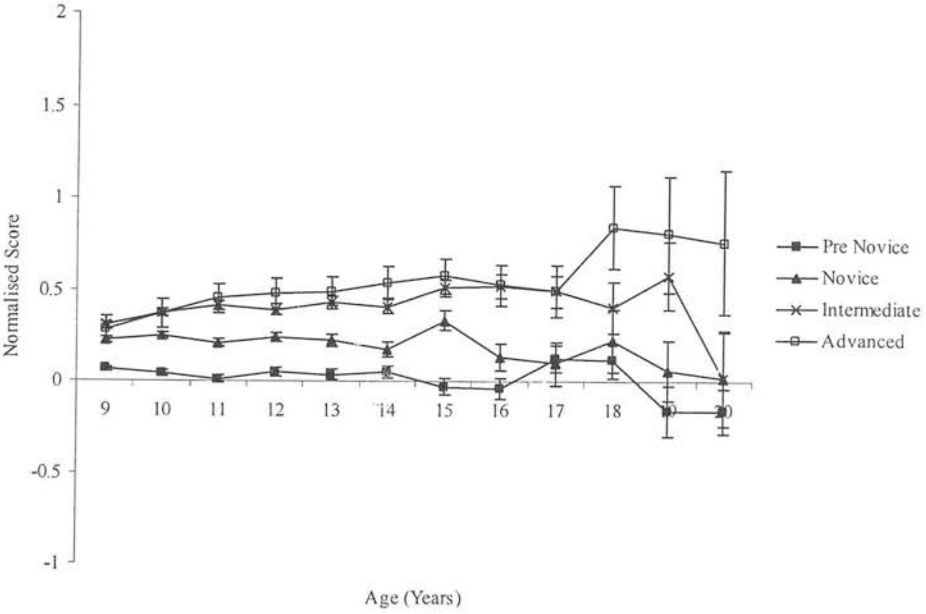
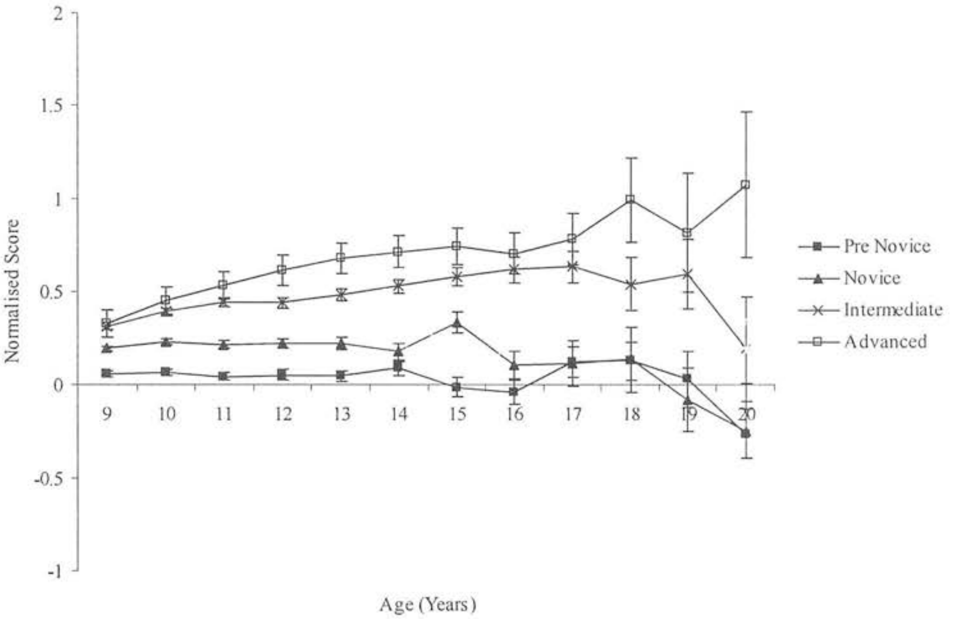


Figure 5.1d Age trend of mean scores (±SE) for overall competition scores compared to the average performance of horses aged 4 to 8



Sex was not significant for cross country but removed a significant amount of variation from dressage, showjumping and overall competition with stallions receiving the highest scores. This pattern was observed for all grades (Table 5.3).

Table 5.3 Sex effects with scores given relative to gelding scores

Phase	Sex	Significance	Score			
			Pre Novice	Novice	Intermediate	Advanced
Dressage	Gelding	P<0.05	0	0	0	0
	Mare		-0.15±0.01	-0.20±0.02	-0.21±0.02	-0.30±0.04
	Stallion		0.21±0.07	0.19±0.07	0.26±0.08	0.21±0.1
Showjumping	Gelding	P<0.05	0	0	0	0
	Mare		0.06±0.01	0.03±0.02	0.02±0.02	-0.004±0.03
	Stallion		0.06±0.05	0.05±0.06	0.16±0.07	0.21±0.1
Cross Country	Gelding	NS	0	0	0	0
	Mare		0.02±0.01	-0.01±0.02	-0.01±0.02	-0.12±0.05
	Stallion		0.05±0.06	-0.04±0.07	-0.003±0.08	0.07±0.1
Overall Competition	Gelding	P<0.05	0	0	0	0
	Mare		-0.03±0.01	-0.07±0.02	-0.07±0.02	-0.17±0.05
	Stallion		0.21±0.07	0.06±0.07	0.12±0.08	0.17±0.1

Heritabilities

The heritabilities estimated for dressage, showjumping, cross country and overall competition were all significantly greater than zero (Table 5.4). With the exception of SJA (0.23), the estimated heritabilities for dressage (0.09-0.11) and showjumping (0.08-0.23) were similar in magnitude. The heritabilities estimated for cross country (0.02-0.03) were notably lower. The heritabilities for overall competition (0.05) were intermediate between cross country and the other phases. These heritabilities are relevant to a single competition.

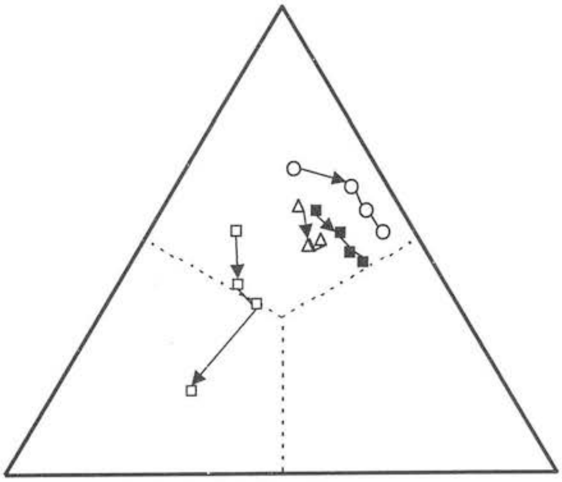
Table 5.4 Heritabilities (±SE) for dressage, showjumping, cross country and overall competition at all grades

	Dressage	Showjumping	Cross Country	Overall Competition
Pre Novice	0.09±0.01	0.08±0.01	0.03±0.01	0.05±0.01
Novice	0.10±0.02	0.12±0.02	0.02±0.01	0.05±0.01
Intermediate	0.11±0.02	0.12±0.02	0.02±0.01	0.05±0.01
Advanced	0.10±0.04	0.23±0.05	0.02±0.01	0.05±0.01

Partition of Variance

The partition of genetic, rider and permanent environmental variances can be observed in Figure 5.2, which shows that the most important single component is the permanent environment (i.e. non genetic, but repeatable, influences on the individual horse). However, as the grades progress the rider becomes more important, particularly for cross country and overall competition, and the genetic effect becomes more important for showjumping. The components for permanent environment and rider are shown in Table 5.5, together with the phenotypic variance (note the genetic components are the heritabilities shown in Table 5.3). The dressage phase had the highest permanent environmental (0.24-0.28) and rider (0.12-0.18) influences compared to the other phases.

Figure 5.2 Partition of genetic, rider and permanent environmental variances using barycentric co-ordinates.



Δ: Dressage; □: Showjumping; ○: Cross country; ■: Overall competition

The points represent the balance point of the triangle when weights corresponding to the magnitudes of the variance components are placed at appropriate vertices. The dashed lines indicate the sectors of the triangle in which the source of variance at the corresponding vertex is the source of greatest magnitude. Arrows point from pre novice towards the higher grade

Each point was plotted at the centre of mass of an equilateral triangle. Weights were placed on the vertices with coordinates of:

- Genetic: (0,0)
- Rider: (0,1)
- Permanent environment: (0, √3/2)

The centre of mass was calculated where the weights of each vertices were considered to be the variances of each effect:

- w_1 = variance of genetic effect
- w_2 = variance of rider effect
- w_3 = variance of permanent environmental effect

For each point the centre of mass was calculated using the equations:

$$x = \frac{w_1x_1 + w_2x_2 + w_3x_3}{w_1 + w_2 + w_3}$$

$$y = \frac{w_1y_1 + w_2y_2 + w_3y_3}{w_1 + w_2 + w_3}$$

where x and y are the coordinates

Table 5.5 Variance components (±SE) for all phases expressed as a ratio of the phenotypic variance (σ^2_p)

	Permanent Environment	Rider	σ^2_p
DP	0.28±0.01	0.12±0.005	1.03±0.01
DN	0.24±0.02	0.15±0.006	1.04±0.01
DI	0.26±0.02	0.16±0.008	1.11±0.02
DA	0.28±0.04	0.18±0.01	1.20±0.03
SJP	0.13±0.01	0.04±0.003	0.86±0.01
SJN	0.13±0.02	0.07±0.005	0.91±0.01
SJI	0.12±0.02	0.09±0.007	0.91±0.01
SJA	0.07±0.05	0.10±0.01	1.00±0.02
XCP	0.13±0.01	0.04±0.003	0.85±0.01
XCN	0.19±0.01	0.10±0.006	1.00±0.01
XCI	0.18±0.01	0.12±0.009	0.98±0.01
XCA	0.18±0.02	0.15±0.02	1.02±0.03
OCP	0.18±0.01	0.09±0.004	1.02±0.01
OCN	0.19±0.01	0.13±0.006	1.09±0.01
OCI	0.17±0.01	0.14±0.009	1.07±0.02
OCA	0.18±0.02	0.17±0.01	1.15±0.03

DP: dressage pre novice, DN: dressage novice, DI: dressage intermediate, DA: dressage advanced

SJP: showjumping pre novice, SJN: showjumping novice, SJI: showjumping intermediate, SJA: showjumping advanced

XCP: cross country pre novice, XCN: cross country novice, XCI: cross country intermediate, XCA: cross country advanced

OCP: overall competition pre novice, OCN: overall competition novice, OCI: overall competition intermediate, OCA: overall competition advanced

Within Phase Genetic Correlations

The within phase genetic correlations are shown in Table 5.6. Estimated genetic correlations were all positive and were consistently high between novice, intermediate and advanced grades, where many were constrained to be 1.00. The genetic correlations between pre novice and the other grades were more variable, with high correlations for the showjumping and dressage phases, but moderate correlations, in comparison, for cross country (0.45) and overall competition (0.68).

Table 5.6 Genetic correlations (±SE) between each grade for dressage, showjumping, cross country and overall competition

	DP	DN	DI		SJP	SJN	SJI
DN	0.91±0.05			SJN	0.90±0.06		
DI	0.85±0.09	0.93±0.05		SJI	0.90±0.06	*1.00*	
DA	0.79±0.16	0.86±0.13	0.93±0.08	SJA	0.86±0.10	0.96±0.05	0.96±0.05
	XCP	XCN	XCI		OCP	OCN	OCI
XCN	0.45±0.24			OCN	0.68±0.14		
XCI	0.45±0.24	*1.00*		OCI	0.68±0.14	*1.00*	
XCP	0.45±0.24	*1.00*	*1.00*	OCA	0.68±0.14	*1.00*	*1.00*

DP: dressage pre novice, DN: dressage novice, DI: dressage intermediate, DA: dressage advanced

SJP: showjumping pre novice, SJN: showjumping novice, SJI: showjumping intermediate, SJA: showjumping advanced

XCP: cross country pre novice, XCN: cross country novice, XCI: cross country intermediate, XCA: cross country advanced

OCP: overall competition pre novice, OCN: overall competition novice, OCI: overall competition intermediate, OCA: overall competition advanced

Within Phase Horse and Rider Correlations

High correlations between horses (Table 5.7), derived from the residual variance/covariance matrix for horses, were observed between all grades for dressage (0.80-0.97) and showjumping (0.73-0.99). A similar pattern was observed between the riders (Table 5.8), derived from the variance/covariance matrix for riders, at each grade in dressage (0.86-0.97) and showjumping (0.81-0.96). A greater spread of correlations is observed for cross country and overall competition, for both the residual horse components and riders, where the highest correlations between horses (0.83 and 0.93, respectively) and the highest correlations between riders (0.87 and 0.93, respectively) are between intermediate and advanced grade, and the lowest correlations between horses (0.29 and 0.45, respectively) and riders (0.56 and 0.72, respectively) are between pre novice and advanced grade.

Table 5.7 Phenotypic correlations (±SE) between horses at each grade for dressage, showjumping, cross country and overall competition derived from the residual horse component

	DP	DN	DI		SJP	SJN	SJI
DN	0.90±0.01			SJN	0.84±0.02		
DI	0.83±0.02	0.92±0.01		SJI	0.74±0.04	0.88±0.02	
DA	0.80±0.04	0.89±0.02	0.97±0.01	SJA	0.73±0.09	0.88±0.04	0.99±0.02
	XCP	XCN	XCI		OCP	OCN	OCI
XCN	0.47±0.03			OCN	0.61±0.02		
XCI	0.35±0.06	0.73±0.03		OCI	0.48±0.05	0.79±0.02	
XCA	0.29±0.17	0.60±0.07	0.83±0.03	OCA	0.45±0.12	0.73±0.05	0.93±0.02

Table 5.8 Phenotypic correlations (±SE) between riders at each grade for dressage, showjumping, cross country and overall competition

	DP	DN	DI		SJP	SJN	SJI
DN	0.92±0.01			SJN	0.88±0.03		
DI	0.88±0.02	0.95±0.01		SJI	0.84±0.04	0.96±0.02	
DA	0.86±0.02	0.93±0.02	0.97±0.01	SJA	0.81±0.06	0.91±0.04	0.96±0.03
	XCP	XCN	XCI		OCP	OCN	OCI
XCN	0.75±0.04			OCN	0.85±0.02		
XCI	0.65±0.05	0.87±0.03		OCI	0.78±0.03	0.92±0.02	
XCA	0.56±0.07	0.75±0.05	0.87±0.04	OCA	0.72±0.04	0.85±0.03	0.93±0.03

DP: dressage pre novice, DN: dressage novice, DI: dressage intermediate, DA: dressage advanced

SJP: showjumping pre novice, SJN: showjumping novice, SJI: showjumping intermediate, SJA: showjumping advanced

XCP: cross country pre novice, XCN: cross country novice, XCI: cross country intermediate, XCA: cross country advanced

OCP: overall competition pre novice, OCN: overall competition novice, OCI: overall competition intermediate, OCA: overall competition advanced

Between Phase Genetic Correlations

Moderate genetic correlations of a similar range (Table 5.9) were estimated between all three phases at pre novice grade (0.36-0.46). More variation is observed in the genetic correlations at novice grade, with a fairly high correlation between the cross country and showjumping phases (0.57), a moderate correlation between the cross country and dressage phases (0.33) and a low correlation between the showjumping and dressage phases (0.13). However, the standard errors are large so the differences in the correlations between grades may be due to sampling error. For both pre novice and novice grade, high correlations are observed between overall competition and dressage (0.60-0.80) and showjumping (0.74). Due to problems with convergence I was unable to estimate reliable correlations between cross country and overall competition. Convergence problems during analysis of the intermediate and advanced datasets meant that I was also unable to provide accurate results for correlations between any phases for these grades.

Table 5.9 Genetic, residual horse and rider correlations (±SE) between each phase at pre novice and novice grade

Genetic	XCP	DP	SJP	Genetic	XCN	DN	SJN
DP	0.46±0.17			DN	0.33±0.21		
SJP	0.44±0.15	0.36±0.12		SJN	0.57±0.15	0.13±0.16	
OCP	†	0.80±0.07	0.74±0.07	OCN	†	0.60±0.13	0.74±0.09
Horse	XCP	DP	SJP	Horse	XCN	DN	SJN
DP	0.30±0.02			DN	0.30±0.03		
SJP	0.52±0.02	0.28±0.02		SJN	0.53±0.02	0.22±0.03	
OCP	†	0.82±0.01	0.86±0.14	OCN	†	0.68±0.02	0.81±0.01
Rider	XCP	DP	SJP	Rider	XCN	DN	SJN
DP	0.59±0.04			DN	0.55±0.04		
SJP	0.77±0.04	0.64±0.04		SJN	0.79±0.03	0.71±0.04	
OCP	†	0.92±0.01	0.93±0.02	OCN	†	0.87±0.02	0.95±0.02

† inestimable due to convergence problems

DP: dressage pre novice, DN: dressage novice

SJP: showjumping pre novice, SJN: showjumping novice

XCP: cross country pre novice, XCN: cross country novice

OCP: overall competition pre novice, OCN: overall competition novice

Between Phase Horse and Rider Correlations

Patterns of correlations observed for both horses and riders (derived from the variance/covariance matrices for residual horse and riders, respectively) between the dressage, showjumping and cross country phases (Table 5.9) at pre novice and novice grades were broadly similar. All of the correlations were positive, the corresponding correlations were consistently higher for riders than for horses. The strongest correlations were observed between the jumping phases – showjumping and cross country – 0.53 for horses and 0.78 for riders. Strong correlations were also observed for both the residual horse component and riders between overall competition and the dressage (0.68-0.82 and 0.87-0.92, respectively) and showjumping (0.81-0.86 and 0.93-0.95, respectively) phases. Again, convergence problems meant I could not reliably predict correlations between overall competition and cross country.

5.4 Discussion

Overall eventing competition is a composite of three phases and this is the first time that the variance components for each of the phases have been estimated. Breeding values for overall competition analysed as a composite trait take no account of differences in the heritability of the phases and so may be less accurate than breeding values derived from recognising the individual phases in the model. The model used also allowed separation of the horses and riders for each phase, making it possible to analyse their effect along with that of the genetics, something that is rarely achieved.

The use of normalised scores in this study was advantageous for a number of reasons. Firstly, it is possible to include all horses in the analysis, because unlike annual earnings or competition placing, where only the top horses have records, all horses have records of penalties received in a competition. Secondly, by definition the scores are normally distributed, therefore there is no need for any further complicated data transformation to better meet normality assumptions implicit in mixed model procedures. Lastly, conversion of penalty points to normal scores allowed for easy comparison of horses within competition and removed much of the variation in the model caused by competition. Competition was included as a fixed effect in the model, however, to allow for correct estimates of age effects because if competition is not included the slope of the regression of normal scores on age is biased towards zero by the between competition component.

The use of antedependence structures took advantage of the progressive nature of the grades to simplify the computational burden. Antedependence models have been shown to be useful for modelling cumulative traits, as suggested by Jaffrézic *et al* (2004) for the analysis of growth. The use of an antedependence model was suitable for this analysis because the grade trait can be thought of as being progressive – horses must start at pre novice and move up through the grades as skill levels increase. The use of an antedependence model allowed identification and management of consecutive grades with very high genetic correlations and adjustment of the genetic model accordingly. Given the high genetic correlations observed between consecutive grades the additional gain from increasing the antedependence model from order 1 to order 2 would be limited. This, coupled with the progressive nature of the grade trait, means that an antedependence model of order 1 was the appropriate method of analysis for this dataset.

The heritabilities (Table 5.4) estimated here correspond to performance at a single competition. For the dressage and showjumping phases estimates were in a similar range to those estimated by Reilly *et al.* (1998) (0.08) and Aldridge *et al.* (2000) (0.07-0.08) in their analyses of horses in specialised showjumping competitions using normal scores. The exception is the heritability for SJA (0.23), which is notably higher than those obtained by these authors and higher than all the other heritabilities estimated in this study. The heritabilities for the cross country phase and overall competition are slightly lower than those estimated for the other phases and those given by Reilly *et al.* (1998) and Aldridge *et al.* (2000). The heritability of 0.07 estimated by Ricard & Chanu (2001) for overall competition placing in a single eventing competition is also of a similar magnitude to the heritabilities for overall competition estimated here.

When mean performances over a number of competitions are used for analysis, rather than a single performance, an increase in the predicted heritability may be expected. Ricard & Chanu (2001) estimated heritabilities of 0.11-0.17 when annual earnings (equivalent to an aggregation over a number of competitions) were used for analysis. Similarly, Reilly *et al.* (1998) reported an increase in heritability from 0.08 to 0.31 when the mean performance over 14 competitions was used for evaluation. The information given in this study allows the estimation of benefits from increased records, for example, the heritability for OCP would be increased to approximately 0.14 if mean performances over 12 competitions (which is the mean number of competitions in this dataset (Table 5.1)) were considered. However, the estimates developed here, based on performance in a single competition, are far more informative; providing (1) a basis for comparison across countries that is independent of frequency of performance, (2) separation of horse and rider, hence improving accuracy and (3) the means to properly account for the variable number of competitions among horses, improving both accuracy and flexibility.

This is the first study to quantify the relative importance of horse and rider across the different phases of eventing competition. The addition of horse and rider as random effects in the model allowed separation of the proportions of variance attributed to the rider and the permanent environmental effect of the horse. The proportions of phenotypic variance shown in Table 5.5, and the clustering in the upper portion of Figure 5.2, show that the permanent environmental variance accounts for a large proportion of the phenotypic variance. The permanent environmental effect represents life history events and may reflect the temperament of the horse, training, nutrition and other such factors. Temperament is a factor that may be influenced by environmental factors, which could explain why the permanent environmental variance is higher in dressage than the other phases, because the scores in the dressage phase will be most affected by temperament in comparison to the other phases. The rider variance is also greatest for dressage, suggesting that for this phase the ability of the rider has the biggest influence on the performance of the horse. The lowest rider variances are observed for showjumping, suggesting the reverse for this phase. For all four phases the highest rider variances are observed for the advanced grade, suggesting that at such a high level the ability of the rider is more important to the horse's performance than at pre novice where the lowest rider variances were observed.

The genetic correlations observed between all grades for all phases (Table 5.6) were of a similar range to those estimated by Aldridge *et al.* (2000) (0.69-0.97) between the different grades of specialised showjumping competitions. These correlations are also consistent with the correlation of 0.99 predicted between high and low levels of eventing competitions by Ricard & Chanu (2001) although here there appears to be some distinction between pre novice and the higher levels. The strong genetic correlations between all grades above pre novice, and those between horses (Table 5.7), nevertheless suggest that it should be possible to predict how a horse will perform in advanced competition based on its performance at novice or even pre novice grade, despite more moderate correlations with the other grades. This should allow for accurate predictions of the future performance of young horses as they progress through the grades.

A number of the genetic correlations presented between the phases for pre novice and novice grade (Table 5.9) have high standard errors, however, they do make structural sense. A high genetic correlation is observed between cross country and showjumping, which is to be expected because they both demand jumping ability. Similarly the correlations between horses and correlations between riders are highest between showjumping and cross country. The lower genetic correlation between showjumping and dressage was not wholly unexpected as studies into the correlations between ability in specialised dressage and showjumping competitions have shown little to no genetic correlation (Bruns, 1981; Huizinga & van der Meij, 1989). High genetic correlations were also observed between overall competition and dressage and showjumping, for both pre novice and novice grade. This would be expected because both the dressage and showjumping phases are important factors in the final outcome of the overall competition, therefore for a horse to do well in the dressage or showjumping phases, it would also be expected to do well in the overall competition. I was unable to estimate the correlation between the cross country phase and overall competition because the bivariate model repeatedly failed to converge. This was probably due to multidimensional high correlations making it difficult to stay within the parameter space. It could be possible to overcome this problem with better data structure, or with the use of a computer intensive iterative method for fitting REML models. I was also unable to estimate correlations between the phases at intermediate and advanced level due to a lack of genetic links. This is clearly illustrated in Table 5.2 where it can be observed that there is an average of approximately 2 horses per sire for the intermediate dataset and an average of approximately one horse per sire for the advanced dataset.

The patterns of normalised scores as age increases (Figures 5.1a-5.1d), whilst novel, conform to prior perceptions of the phases, that experience is important for showjumping and cross country but less so for dressage. For dressage, scores increase until 9 years old then remain fairly constant, consistent with the idea that much of the score will depend on the horse's paces which will not change as the horse ages. However, the scores for the jumping phases, showjumping and cross country, increase with age, peaking at 16-18 years before decreasing. This pattern might be predicted because a horse's jumping ability will increase with skill as age increases but eventually athleticism decreases as the horse passes the peak age.

The long term aim of this project is to use the results from the evaluation of competition data in conjunction with data from assessment of youngstock, from which heritabilities are expected (Chapter 4), to create a model for the prediction of breeding values of British sport horses. Even with the low heritabilities found in this study, this is a feasible aim; heritabilities of a similar level (0.018-0.035) have been estimated for fertility traits in dairy cattle and subsequently used in genetic evaluation (Wall *et al.*2003; 2005).

5.5 Conclusion

The results of this study show that the genetic variances are sufficient to create a genetic model for eventing evaluations based on normalised competition scores. Although the heritabilities are low they are all significantly different from zero. The estimated correlations between grades are high and suggest that it should be possible to predict the performance of a horse at advanced level based on its performance at novice or even pre novice level. Permanent environment is the most important single repeatable source of variance for most grade and phase combinations, although it does decrease in importance as the grades progress.

5.6 Summary

Competition data on UK eventing horses was used to estimate genetic and phenotypic parameters. Penalty points from each of the three phases – dressage, showjumping and cross country – and overall competition were converted to normal scores for analysis. Because horses compete at different levels each phase was separated into 4 different grades of competition – pre novice, novice, intermediate and advanced, where pre novice is the lowest grade and advanced the highest. Data were analysed with an antedependence model of order 1 using ASReml. Fixed effects were sex, age and competition and the random effects were sire, horse and rider. Results showed heritabilities significantly different from zero for dressage (0.09-0.11), showjumping (0.08-0.23), cross country (0.02-0.03) and overall competition (0.05). Correlations between the grades for each phase were high, suggesting that it should be possible to predict a horse's performance at advanced level by its performance at novice and pre novice level. Correlations between each phase were highest between the showjumping and cross country phases. For the first time, the proportions of variance attributed to the rider, permanent environmental effect and genetics of the horse were estimated separately. These estimates showed that for most grades and phases the most important component was the permanent environmental effect, with the rider and genetics becoming more important as the grades become more challenging. The rider effect was greatest for dressage and the genetic effect was greatest for showjumping.

6 Selection of sires, individual horses and riders in the dressage, showjumping and cross country phases of eventing competition

6.1 Introduction

Selection intensity allows the level of selection pressure imposed on a population by a breeder to be described. Across generations the genetic gain achieved is directly proportional to the intensity applied but it is also associated with more rapid inbreeding (Bijma *et al.,* 2000). Reports on the selection intensity achieved in practice are often for sheep or cattle populations (Woolliams & Mäntysaari, 1995; Avendaño *et al.*, 2003), but are rare in horse populations. Selection, however, does not just occur across generations, it is also possible for selection to occur within the same generation of animals as may occur when sport horses progress from low to high levels of competitions. Horses can be selected as breeding or competition animals on the basis of performance in riding horse and stallion tests and on performance in competition (Bruns, 1981; Tavernier, 1991; Olsson *et al.,* 2000; Ricard & Chanu, 2001; Wallin *et al.,* 2003; Thorén Hellsten *et al.,* 2006), however, the extent of this selection has never been measured.

In Chapter 5 the use of competition results for genetic evaluation of eventing horses across four grades – pre novice, novice, intermediate and advanced – was examined. The analysis provided estimated breeding values (EBVs) for sires and solutions for both horses and riders. Historically, this information has not been available in the UK, but even in its absence selection will have taken place. The degree of selection occurring when sport horses progress from low to high grades may provide an insight into the selection intensity applied to the breeding population because individuals with a large impact on the gene pool of the next generation are likely to have been preferentially selected from individuals identified as high performers in the higher grades. The analysis of selection of eventing horses across grades is important both for interpreting genetic evaluation procedures and the competition structure of the sport. By examining the selection pressures on sires, horses and riders we can begin to take stock of how much selection bias may be introduced in analyses of performance. Information from selection amongst the horses and riders indicates the pattern of progression through the grades. This is of interest to the equine industry because it may indicate whether the challenges set for both horses and riders at each of the grades are as effective as intended.

The aims of this study were (1) to investigate the observed selection intensity for sires, horses and riders as progression is made from the pre novice to advanced grades and (2) to determine the proportion of sires, horses and riders progressing through the grades.

6.2 Materials and methods

Derivation of EBVs, HVs and RVs

The estimated breeding values (EBVs), horse values (HVs) and rider values (RVs) used in this investigation were taken from Chapter 5 in which eventing competition was analysed in its 3 component phases – dressage, showjumping and cross country – as well as overall competition. For simplicity, overall competition will be referred to as a phase. Each phase was separated into 4 grades, based on the rules of British Eventing (www.britisheventing.com) - pre novice, novice, intermediate and advanced, where pre novice is the lowest grade and advanced the highest.

Using the data for each phase separately, a multivariate sire model was used to simultaneously derive the estimated breeding values (EBVs), horse values (HVs) and rider values (RVs) for each grade. This was achieved by considering performance at each of the four grades as separate traits so that the output from the analysis provided a distinct EBV, HV and RV for all four grades for every sire, horse and rider appearing in the dataset. The use of the multivariate mixed model ensured that such predicted values were present even when there were no directly relevant records in the dataset. For example even a rider that only rode in the novice grade has a predicted RV for advanced. Mrode (2005) gives further details on the predictive properties of mixed models.

The following multivariate sire model was fitted using ASReml (Gilmour *et al.*, 2002).

$$y_{ghijklm} = \mu_g + \alpha_{gh} + \beta_{gi} + \gamma_{gj} + u_{gk} + v_{gkl} + w_{gm} + e_{ghijklm}$$

Where $y_{ghijklm}$ is the trait value for horse *l*, with sire *k*, of sex *h* and age *i*, competing at grade *g* in competition *j* with rider *m*. For each grade μ_g is the overall mean, α_{gh} is the effect of sex, β_{gi} is the effect of age, γ_{gj} is the effect of competition, u_{gk} is the effect of sire, v_{gkl} is the effect of the individual horse, w_{gm} is the effect of the rider and $e_{ghijklm}$ is the residual error. No sire pedigree was available, they were therefore assumed to be unrelated. The effects of sex, age and competition were considered fixed; the effects of sire, horse and rider were considered random. In the final model, sire effects for novice and intermediate showjumping, novice, intermediate and advanced cross country and novice, intermediate and advanced overall competition were merged because the genetic correlations between these merged grades were equivalent to 1.0. The horse and rider components did not require such grouping of grades.

The output from this model gave the predicted transmitting ability (u_{gk}) for each sire, the residual genetic and permanent environmental effect (v_{gkl}) for each horse and the rider value (w_{gm}) for each rider at each grade. The following calculations were carried out to give the EBVs and HVs for each horse at each grade.

$$\text{EBV} = u_{gk} \times 2$$

$$\text{HV} = u_{gk} + v_{gk}$$

No additional calculation was required to derive the rider values which are denoted RV in the remainder of the text.

Calculation of selected fractions and intensity

In the remainder of this chapter 'subjects' will refer to sires, horses or rider, depending on whether EBVs, HVs or RVs are being considered and 'full dataset' refers to the EBVs/HVs/RVs for all individuals, irrespective of whether they have records in that grade. Selection was considered for each of the three transitions in which subjects move from one grade to the next, e.g. from pre novice to novice. The proportion selected, P, of subjects moving up from each grade to the next was calculated as the fraction of subjects that had performance records in the lower grade of the transition that also had records in the higher grade of the transition.

The selection intensity for the different subjects was calculated using the following procedure. Firstly, the mean of the EBVs, HVs and RVs for the individual subjects represented at the lower of the two grades was calculated. The selection differential is the difference between the mean EBV/HV/RV at the lower grade for those appearing in the higher grade and the mean of the full dataset at the lower grade. The selection intensities (i) were obtained by dividing the calculated selection differential by the standard deviation of the EBV/HV/RV for the full dataset at the lower grade. The empirical standard errors of the selection intensity were also derived directly from the selected EBV/HV/RV data by dividing the standard deviation of the selected subjects at the lower grade by the square root of the number of selected individuals.

Due to the properties of the linear mixed model the EBVs and RVs had means of zero for the full dataset for each grade and phase. However, the means for the full HV datasets are slightly different from zero since they involve the addition of the sire and residual individual effects, with the former being unequally represented among individual horses.

To place the calculated intensities into perspective, theoretical selection intensities (i_t) were calculated, for comparison with the actual selection intensities, with the following equation:

$$i_t = \psi_{(x)} / \mathrm{P}$$

where $\psi_{(x)}$ is the standardised normal probability density at the truncation point x yielding an upper tail probability (P), where P is the proportion of animals progressing to the next grade as described earlier.

To give an indication of selection at the extreme end of the distribution, the progress of the 100 top ranked sires, horses and riders at novice grade was followed through to intermediate and advanced grade. Novice was chosen as a starting point rather than pre novice because it appears to be the starting grade for committed development to advanced grade. Evidence for this comes from the consistently high genetic correlations between novice, intermediate and advanced grade estimated in Chapter 5, whereas the correlations between these grades and pre novice were notably lower.

6.3 Results

EBVs, HVs and RVs

Summary statistics for the EBVs for dressage, showjumping, cross country and overall competition are shown in Table 6.1, with the exception of the means which were all zero. All of the phases show a high degree of symmetry in the distribution of EBVs. The widest range of EBVs is seen for showjumping at pre novice level; the lowest range is observed for the cross country phase. This is largely due to the low heritability of cross country compared to the other phases, which results in the EBVs being derived from mean performance scores that are regressed more strongly towards the mean. Because there are unequal numbers of offspring per sire and the HVs are calculated by adding together u_{gk} and v_{gkl} the means are not zero (Table 6.2), although they are close to zero, ranging from 0.012-0.015 for dressage; -0.001-0.0002 for showjumping; 0.003-0.004 for cross country and 0.007-0.009 for overall competition. A wide distribution of HVs is observed for all phases, particularly dressage. The RVs (Table 6.3) have a high degree of symmetry in the distribution, with a mean of zero. All phases have a wide RV distribution, with the widest distributions observed for advanced level at all phases, particularly dressage.

Normality was not tested for because it was not expected. A normal distribution would be observed if the data used was a random sample and if all accuracies were equal, which is not the case with the EBVs, RVs and HVs.

Table 6.1 Summary statistics for estimated breeding values (EBV) for dressage, showjumping, cross county and overall competition at pre novice (P), novice (N), intermediate (I) and advanced level (A)

Dressage	Min	Lower quartile	Upper quartile	Max	SD
P_EBV	-0.480	-0.052	0.053	0.617	0.093
N_EBV	-0.546	-0.058	0.057	0.692	0.103
I_EBV	-0.534	-0.058	0.056	0.705	0.103
A_EBV	-0.504	-0.055	0.053	0.655	0.098
Showjumping					
P_EBV	-0.648	-0.051	0.054	0.559	0.091
NI_EBV	-0.727	-0.067	0.068	0.739	0.119
A_EBV	-1.063	-0.096	0.096	1.121	0.170
Cross country					
P_EBV	-0.231	-0.015	0.015	0.186	0.032
NIA_EBV	-0.167	-0.013	0.011	0.273	0.026
Overall					
P_EBV	-0.444	-0.031	0.030	0.479	0.060
NIA_EBV	-0.414	-0.030	0.026	0.502	0.059

Table 6.2 Summary statistics for horse values (HV) for dressage, showjumping, cross country and overall competition at pre novice (P), novice (N), intermediate (I) and advanced (A) level

Dressage	Mean	Min	Lower quartile	Upper quartile	Max	SD
P_HV	0.012	-2.422	-0.326	0.363	1.99	0.509
N_HV	0.015	-2.205	-0.314	0.343	1.962	0.490
I_HV	0.015	-2.167	-0.311	0.334	2.090	0.487
A_HV	0.014	-2.210	-0.327	0.344	2.102	0.507
Showjumping						
P_HV	-0.001	-1.313	-0.211	0.222	0.874	0.311
N_HV	0.0002	-1.387	-0.239	0.237	1.153	0.348
I_HV	0.0002	-1.246	-0.221	0.215	1.215	0.325
A_HV	-0.001	-1.471	-0.257	0.250	1.330	0.377
Cross country						
P_HV	0.003	-1.087	-0.127	0.152	0.682	0.220
N_HV	0.004	-1.165	-0.152	0.140	1.328	0.268
I_HV	0.004	-1.109	-0.120	0.099	1.349	0.226
A_HV	0.004	-1.125	-0.105	0.086	1.285	0.201
Overall						
P_HV	0.007	-1.577	-0.208	0.221	1.327	0.333
N_HV	0.009	-1.271	-0.205	0.196	1.532	0.329
I_HV	0.009	-1.217	-0.167	0.151	1.561	0.282
A_HV	0.009	-1.204	-0.166	0.148	1.640	0.282

Table 6.3 Summary statistics for rider values (RV) for dressage, showjumping, cross country and overall competition at pre novice (P), novice (N), intermediate (I) and advanced (A) level

Dressage	Min	Lower quartile	Upper quartile	Max	SD
P_RV	-0.823	-0.196	0.170	1.141	0.282
N_RV	-0.942	-0.208	0.181	1.190	0.303
I_RV	-0.969	-0.220	0.185	1.463	0.318
A_RV	-1.047	-0.238	0.197	1.737	0.345
Showjumping					
P_RV	-0.400	-0.077	0.071	0.477	0.121
N_RV	-0.563	-0.104	0.095	0.686	0.166
I_RV	-0.594	-0.111	0.099	0.802	0.179
A_RV	-0.627	-0.117	0.104	0.875	0.190
Cross country					
P_RV	-0.439	-0.072	0.066	0.763	0.117
N_RV	-0.753	-0.127	0.104	0.885	0.206
I_RV	-0.839	-0.130	0.097	0.854	0.211
A_RV	-0.811	-0.130	0.091	0.926	0.210
Overall					
P_RV	-0.636	-0.148	0.122	0.939	0.215
N_RV	-0.714	-0.181	0.144	1.168	0.268
I_RV	-0.733	-0.178	0.138	1.180	0.266
A_RV	-0.760	-0.186	0.141	1.415	0.279

Proportion of sires, horses and riders progressing through the grades

The percentage of sires, horses and riders progressing through the grades is similar for all phases. This is because each phase is part of the same competition. Approximately 60% of sires are represented in both pre novice and novice, 65% are represented in novice and intermediate and 55% are represented in intermediate and advanced (Table 6.4). Approximately 45% of horses move from pre novice to novice, 55% move from novice to intermediate and 45% move from intermediate to advanced (Table 6.5). There is more variation in the progression of riders through the grades with approximately 75% of riders moving from pre novice to novice, 60%

moving from novice to intermediate and 45% moving from intermediate to advanced (Table 6.6).

Table 6.4 Percentage of sires represented at the next grade and actual and calculated sire selection intensities for dressage, showjumping, cross country and overall competition

Phase		Pre Novice to Novice	Novice to Intermediate	Intermediate to Advanced
Dressage	% Progressing	60	64	54
	i	0.018±0.024	0.149±0.033	0.395±0.048
	$i_{(t)}$	0.64	0.58	0.74
Showjumping	% Progressing	60	64	55
	i	0.059±0.024	0.203±0.033	0.321±0.048
	$i_{(t)}$	0.64	0.58	0.72
Cross Country	% Progressing	59	63	53
	i	0.127±0.026	0.276±0.039	0.570±0.059
	$i_{(t)}$	0.66	0.60	0.75
Overall	% Progressing	59	63	53
	i	0.119±0.026	0.303±0.037	0.634±0.053
	$i_{(t)}$	0.66	0.60	0.75

i: selection intensity

$i_{(t)}$: theoretical selection intensity

Table 6.5 Percentage of horses progressing to the next grade and actual and calculated horse selection intensities for dressage, showjumping, cross country and overall competition

Phase		Pre Novice to Novice	Novice to Intermediate	Intermediate to Advanced
Dressage	% Progressing	46	55	47
	i	0.139±0.014	0.328±0.019	0.617±0.03
	$i_{(t)}$	0.86	0.72	0.85
Showjumping	% Progressing	45	55	47
	i	0.222±0.014	0.521±0.019	0.662±0.03
	$i_{(t)}$	0.88	0.72	0.85
Cross Country	% Progressing	44	54	45
	i	0.297±0.015	0.711±0.023	1.021±0.042
	$i_{(t)}$	0.90	0.74	0.88
Overall	% Progressing	44	54	45
	i	0.352±0.015	0.764±0.022	1.163±0.039
	$i_{(t)}$	0.90	0.74	0.88

Table 6.6 Percentage of riders progressing to the next grade and actual and calculated rider selection intensities for dressage, showjumping, cross country and overall competition

Phase		Pre Novice to Novice	Novice to Intermediate	Intermediate to Advanced
Dressage	% Progressing	76	61	45
	i	0.117±0.024	0.436±0.03	0.967±0.044
	$i_{(t)}$	0.41	0.63	0.88
Showjumping	% Progressing	76	62	44
	i	0.073±0.024	0.327±0.033	0.838±0.05
	$i_{(t)}$	0.41	0.61	0.90
Cross Country	% Progressing	74	59	43
	i	0.051±0.024	0.380±0.035	0.881±0.056
	$i_{(t)}$	0.44	0.66	0.91
Overall	% Progressing	74	58	43
	i	0.135±0.024	0.503±0.033	1.146±0.051
	$i_{(t)}$	0.44	0.67	0.91

i: selection intensity

$i_{(t)}$: theoretical selection intensity

Selection intensities

Similar patterns of selection are observed for the sires, horses and riders (Tables 6.4-6.6). In all cases the lowest level of selection is between pre novice and novice and the highest level of selection is between intermediate and advanced, particularly for cross country and overall competition. Horses are more highly selected than the riders for the cross country phase and overall competition, for all phase transitions; however, for the transition from intermediate to advanced the riders were more highly selected than the horses for dressage and showjumping. The horses and riders are more highly selected than the sires for all phases. The selection intensities for sires (Table 6.4) are 0.018-0.127 between pre novice and novice, increasing between novice and intermediate level to 0.149-0.303. The highest selection intensities are observed in sires whose progeny move from intermediate to advanced level (0.321-0.634). The lowest selection intensities for horses (Table 6.5) are 0.139-0.352 between pre novice and novice and the highest are 0.617-1.163 between intermediate and advanced grade, whilst the selection intensities from novice to intermediate lie between these (0.328-0.764). The selection intensities for riders (Table 6.6) are 0.051-0.135 between pre novice and novice with the highest selection of riders occurring in those moving from intermediate to advanced level (0.838-1.146) and selection intensities of those moving from novice to intermediate lying in between (0.327-0.503). The theoretical selection intensities are shown in Tables 6.4-6.6 and range from 0.41-0.91.

Top 100 Ranked Novice

When each of the different phases was analysed, 92-97% of the top 100 sires represented at novice were also represented at intermediate, of these sires 80-88% were then represented at advanced. Similarly for the riders, 92-97% progressed from novice to intermediate, and then 80-92% of these riders went on to compete at advanced. Lower percentages were observed for individual horses moving through the grades; 52-78% progressed from novice to intermediate and of these horses only 33-52% then went onto advanced level.

6.4 Discussion

The percentages of sires represented in each of the grades are strikingly similar for each of the phases, which is due to competition structure. The general rule is that if an individual competes in one phase they will complete all phases of the competition. This similarity is also observed in the selection of horses and riders. Although a slightly lower percentage of sires are represented at pre novice and novice grade (~60%) than are represented at novice and intermediate grade (~65%), selection is more prominent between novice and intermediate. Only ~10% less sires are represented at intermediate and advanced (~55%), however, the higher selection intensities suggest that many of the animals represented at intermediate and advanced are the top animals, but with the lower selection intensities between pre novice and novice it would seem that animals moving to the next grade is a far more random process. This also appears to be the case for selection of horses, approximately the same percentage of animals move from pre novice to novice as move from intermediate to advanced (~45%). However, the selection intensities for animals moving from intermediate to advanced are far higher, suggesting that, as with sires, the top animals are progressing at the higher grades and the progression from pre novice to novice is a more random process. The selection of riders is more obvious, with lower percentages of riders progressing as the grades increase. Around 75% of those competing at pre novice move on to novice but only ~45% of those competing at intermediate progress to advanced level. This is reflected in the selection intensities.

The observed selection intensities and the theoretical selection intensities, calculated using the proportion of animals progressing through the grades, indicate a fairly strong selection with the top horses moving up through the grades. Theoretical selection intensities are in general higher than or of the same magnitude as the actual selection intensities. However, for horses and riders progressing from intermediate to advanced in dressage (riders only), cross country (horses only) and overall competition (both horses and riders) the theoretical selection intensities are lower than the actual selection intensities because of the assumptions made in the model. The data has a highly symmetric distribution, however within the data there are a mixture of animals with high and low accuracies giving a range of different distributions of EBVs contributing to the overall distribution. The theoretical selection intensity, however, does assume a true normal distribution. Even without the issue of distribution, the theoretical selection intensity can be lower than the actual selection intensity because of a bias in the methods by which they have been calculated. For example, the advanced theoretical selection intensity is only compared to the intermediate dataset which has already been subject to selection in itself. However, the advanced actual selection intensity is compared to all of the data. This can lead to a bias. The use of cumulative selection intensities may have reduced this bias, however this method was not used because not all animals competed at all grades and assessing each grade separately provided a preferable method of analyses for this dataset. In doing this I was also able to calculate the proportion of animals moving between the grades.

Given the results of this study, which show increased selection intensities as individuals progress through the grades and actual selection intensities which are high in relation to theoretical selection intensities, it can be concluded that a progression in the grades does pose the intended challenges for both horses and riders. Most particularly so for the riders, as illustrated by the proportion of riders progressing from one grade to the next. Far fewer are able to take on the challenges of advanced than are able to progress to novice and intermediate.

The high percentages of sires and riders from the top 100 novice individuals progressing to advanced suggests that the novice EBVs and RVs estimated in Chapter 5 are a consistent predictor of performance over higher grades. The low percentages of horses progressing to advanced is surprising when compared to sires and riders. However, many horses that compete, even those that show promise, will not progress for any number of reasons including injury or lack of a competent rider. It appears initially that there is a discrepancy between the high selection intensities for the horses and the low percentages of horses progressing to advanced (~0.45). However, if selection were random the selection intensity for horses progressing to advanced in overall competition would be much lower (Table 6.5, N-I x I-A = 0.54 x 0.45 = 0.24).

6.5 Conclusion

Selection can be observed in the different phases of eventing competition, increasing as the grades progress for the sires, horses and riders. The greatest selection pressure appears to be on the riders, with the least selection pressure on the sires. The methodology presented in this study has not previously been used in sport horse research and although I have encountered problems and biases with the methods used, the patterns of selection that I have identified were not surprising and make sense in the context of the sport of eventing.

6.6 Summary

The intensity of selection on sires, horses and riders progressing from the pre novice to advanced grades in each of the phases of eventing competition – dressage, showjumping, cross country and overall competition - was investigated. Estimated breeding values (EBVs), horse values (HVs) and rider values (RVs) derived from Chapter 5 were used to calculate the observed selection intensity, which is the standardised difference between the mean EBV/HV/RV at the lower grade for those appearing in the higher grade and the overall mean at the lower grade. For sires, horses and riders the highest selection intensities were observed between intermediate and advanced grade (0.634-1.163), particularly for cross country and overall competition. The lowest selection intensities were observed between pre novice and novice (0.018-0.352). Horses were more highly selected than the riders for the cross country phase and overall competition, for all phase transitions; however, for the transition from intermediate to advanced the riders were more highly selected than the horses for dressage and showjumping. In all cases the horses and riders were more highly selected than the sires. The patterns of selection identified in this study were not surprising and make sense in the context of the sport of eventing.

7 Reconciling estimated breeding values and penalty points

7.1 Introduction

Penalty points can be received in all three phases of eventing competition. In the dressage phase a score is given for the horse's performance, which is then converted to penalty points so that the best performing horses are those with the lowest number of penalty points. In the cross country phase penalty points are given for refusals, taking the wrong course and exceeding the time limit, and in the showjumping phase penalty points are given for knocking down poles, refusals and exceeding the time limit. At the end of the competition the horse and rider combination with the lowest number of penalty points is the winner. The analysis of eventing competition for this thesis has been carried out using normal scores derived from the penalty points given to horses in a competition (Chapter 5). This means that the estimated breeding values (EBVs) for each sire and rider values (RVs) for each rider are shown in terms of the normal scores with which they were predicted. The method used to derive EBVs and RVs assumes that the data is normally distributed. Penalty points follow a skewed distribution (Figure 7.1a), however, when penalty points are transformed to normal scores (Figure 7.1b) the actual data distribution matches the assumed normal data distribution which leads to an essentially symmetrical distribution of EBVs (Figure 7.1c) and RVs. However, this difference between penalty points and EBVs/RVs raises a problem by giving no indication of how a sire's EBV or rider's RV will affect the number of penalty points a horse gains in a competition. This can cause a problem when it comes to the public release of EBVs because there is no obvious way of converting EBVs to penalty points. It is important to understand the relationship between penalty points and EBVs/RVs because it is useful in helping breeders relate EBVs to penalty points, and is also important in educating people who have not used EBVs before. EBVs will be released publicly, however the RVs and HVs will not be. RVs are included in this analysis because it was necessary to include them in the model as a fixed effect. However, horse values (HVs) were not included in the analysis because the correlation between HVs and EBVs would result in partial regression coefficients that do not properly predict the outcome of changing EBVs in the absence of information on the HVs.

Figure 7.1a Distribution of overall competition penalty points at advanced grade as an example of how penalty points are distributed

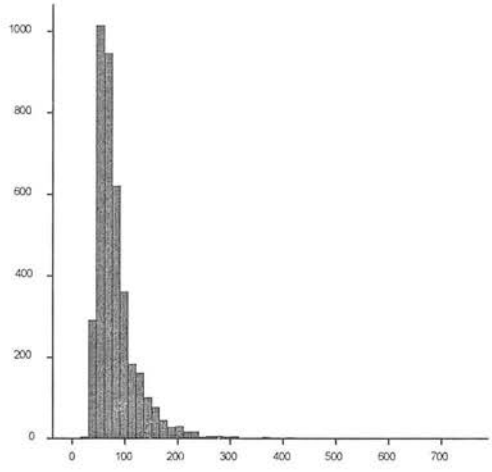


Figure 7.2b Distribution of overall competition normal scores at advanced grade as an example of how converted penalty points are distributed

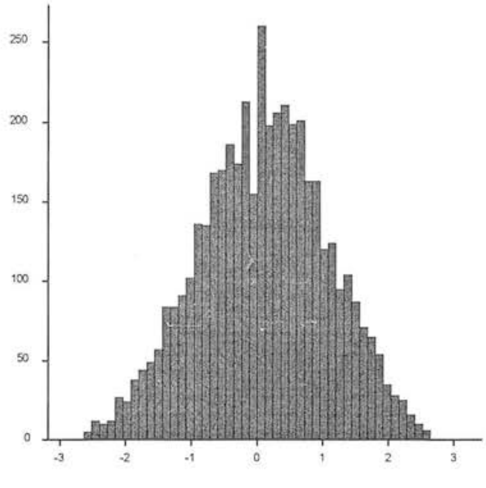
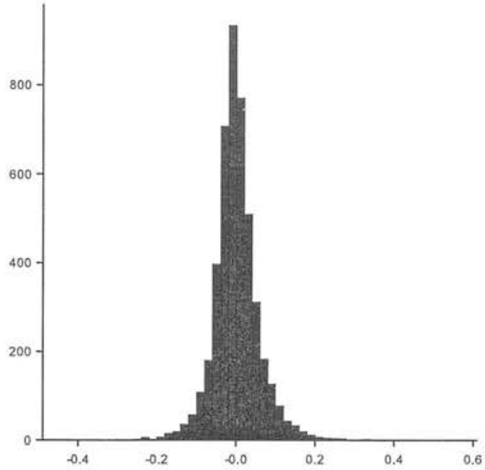


Figure 7.1c Distribution of overall competition estimated breeding values (EBV) at advanced grade as an example of how EBVs derived from converted penalty points are distributed



The aim of this study was to determine the expected penalty points to one unit on the EBV and RV distributions using a regression analysis.

7.2 Materials and Methods

Data

The datasets used in this study were taken from the within phase analysis in Chapter 5 in which datasets were reduced to include only sires with 30 or more offspring. In Chapter 5 eventing competition was analysed in its 3 component phases – dressage, showjumping and cross country – as well as overall competition. Each phase was separated into 4 grades, based on the rules of British Eventing (www.britisheventing.com) - pre novice, novice, intermediate and advanced, where pre novice is the lowest grade and advanced the highest. The datasets were rearranged to include the estimated breeding values (EBVs) for each sire and the rider values (RVs) for each rider. The EBVs and RVs were derived from the multivariate sire model used in Chapter 5. The output from this model gave the predicted transmitting ability (u_{gk}) for each sire and the rider value for each rider at each grade. The following calculation was carried out to give the EBVs for each sire at each grade: EBV = u_{gk} x 2. No additional calculation was required to derive the rider values. Summary statistics for penalty points, EBVs and RVs were calculated with GenStat 9th Edition.

Regression Analysis

Regression analysis was carried out in ASReml (Gilmour *et al.*, 2002) using the following model.

$$y_{hijklm} = \mu + \alpha_h + \beta_i + \gamma_j + \delta_k + \rho_l + e_{hijklm}$$

Where y_{hijklm} is the penalty points accumulated by horse m, of sex h and age i, competing in competition j with a sire of EBV k, and a rider with RV l. μ is the overall mean, α_h is the effect of sex, β_i is the effect of age, γ_j is the effect of competition, δ_k is the sire's EBV, ρ_l is the rider's RV and e_{hijklm} is the residual error. All effects are fixed, however the residual is random. Penalty points for each phase at each grade were regressed on the corresponding EBVs and RVs for that phase and grade. The penalty points for the dressage, showjumping and cross country phases at each grade were also regressed on the EBVs and RVs for overall competition. Analyses were carried out on: (1) EBVs and RVs for all sires and riders and (2) EBVs and RVs with a calculated accuracy of 0.5 or over.

7.3 Results

Summary statistics for penalty points, EBVs and RVs for each horse for dressage, showjumping, cross country and overall competition at all grades are given in Tables 7.1-7.4. The coefficients of variance (cv) are particularly high for the showjumping (1.25 – 1.46) and cross country (1.19-1.90) phases which shows a large variation in the distribution. The cv's for the dressage (0.18 – 0.36) phase and overall competition (0.48 – 0.54) are lower. The summary statistics for EBVs and RVs differ from those presented in Chapter 6 because in this dataset the EBV's and RV's are shown for each horse's sire and rider and in some cases these sires and riders may appear in the list more than once.

Table 7.1 Summary statistics for penalty points (PP), estimated breeding values (EBV) and rider values (RV) for dressage at pre novice, novice, intermediate and advanced grade

		DP	DN	DI	DA
Total No. Values		42904	36058	22764	8325
No. Values with Accuracy >0.5		33647	30367	19156	5021
Penalty Points	Mean	37.64	38.23	40.51	45.27
	Min	0	0	0	0
	Max	147	146	144	162
	SD	6.82	9.21	11.74	16.29
	cv	0.18	0.24	0.30	0.36
EBV	Mean	0.044	0.084	0.11	0.11
	Min	-0.47	-0.54	-0.42	-0.41
	Max	0.61	0.69	0.70	0.62
	SD	0.19	0.21	0.22	0.19
RV	Mean	0.12	0.23	0.41	0.67
	Min	-0.82	-0.94	-0.88	-0.58
	Max	1.14	1.19	1.46	1.73
	SD	0.32	0.35	0.37	0.38

DP: dressage pre novice, DN: dressage novice, DI: dressage intermediate, DA: dressage advanced

SD: standard deviation

cv: coefficient of variance

Table 7.2 Summary statistics for penalty points (PP), estimated breeding values (EBV) and rider values (RV) for showjumping at pre novice, novice, intermediate and advanced grade

		SJP	SJN	SJI	SJA
Total No Values		39831	33578	21004	7129
No. Values with Accuracy >0.5		33296	30742	19510	5924
PP	Mean	6.22	6.83	6.26	6.81
	Min	0	0	0	0
	Max	107	164	122	120
	SD	9.10	8.94	8.52	8.48
	cv	1.46	1.31	1.36	1.25
EBV	Mean	-0.01	0.03	0.06	0.10
	Min	-0.007	-0.72	-0.72	-1.06
	Max	0.55	0.73	0.73	1.12
	SD	0.18	0.24	0.23	0.31
RV	Mean	0.04	0.12	0.22	0.36
	Min	-0.40	-0.56	-0.54	-0.45
	Max	0.47	0.68	0.80	0.87
	SD	0.15	0.20	0.21	0.24

SJP: showjumping pre novice, SJN: showjumping novice, SJI: showjumping intermediate, SJA: showjumping advanced

SD: standard deviation
cv: coefficient of variance

Table 7.3 Summary statistics for penalty points (PP), estimated breeding values (EBV) and rider values (RV) for cross country at pre novice, novice, intermediate and advanced grade

		XCP	XCN	XCI	XCA
Total No Values		33797	30610	15997	4046
No. Values with Accuracy >0.5		11202	10874	7288	1586
PP	Mean	13.2	19.0	21.1	30.0
	Min	0	0	0	0
	Max	308	251	407	579
	SD	25.0	26.6	27.2	35.7
	cv	1.90	1.40	1.29	1.19
EBV	Mean	0.01	0.02	0.04	0.03
	Min	-0.23	-0.16	-0.16	-0.08
	Max	0.18	0.27	0.27	0.27
	SD	0.07	0.07	0.07	0.06
RV	Mean	0.02	0.15	0.27	0.39
	Min	-0.43	-0.75	-0.83	-0.44
	Max	0.76	0.88	0.85	0.92
	SD	0.13	0.26	0.27	0.31

XCP: cross country pre novice, XCN: cross country novice, XCI: cross country intermediate, XCA: cross country advanced

SD: standard deviation

cv: coefficient of variance

Table 7.4 Summary statistics for penalty points (PP), estimated breeding values (EBV) and rider values (RV) for overall competition at pre novice, novice, intermediate and advanced grade

		OCP	OCN	OCI	OCA
Total No Values		34805	31498	16471	3948
No. Values with Accuracy >0.5		22488	21891	5329	2670
PP	Mean	56.3	63.3	66.8	82.6
	Min	0	16	0	28
	Max	359	311	522	749
	SD	28.7	30.6	32.6	44.4
	cv	0.51	0.48	0.49	0.54
EBV	Mean	0.02	0.06	0.09	0.09
	Min	-0.44	-0.41	-0.34	-0.34
	Max	0.47	0.50	0.50	0.50
	SD	0.13	0.14	0.13	0.11
RV	Mean	0.10	0.25	0.43	0.65
	Min	-0.63	-0.71	-0.73	-0.37
	Max	0.93	1.16	1.18	1.41
	SD	0.26	0.34	0.34	0.41

OCP: overall competition pre novice, OCN: overall competition novice, OCI: overall competition intermediate, OCA: overall competition advanced

SD: standard deviation
cv: coefficient of variance

Table 7.5 gives the regression coefficients of penalty points on EBVs and RVs for all phases at all grades. All of the regression coefficients are shown as negative, because in this analysis a higher EBV means lower penalty points. It is striking how much larger the regression coefficients of penalty points on EBVs are for cross country (-18.29 to -44.69) when compared with dressage (-4.56 to -6.27) and showjumping (-4.57 to -6.38). The cross country regression coefficients of penalty points on EBVs are also larger than those for overall competition (-14.84 to -33.56) but by a much smaller margin (~ -10). For all phases the lowest coefficients, when penalty points are regressed on EBVs, are observed at intermediate and the highest at advanced, with the exception of showjumping which has the highest coefficient at pre novice.

Table 7.5 Regression coefficients of penalty points on estimated breeding values (EBV) and rider values (RV) for dressage, showjumping, cross country and overall competition at pre novice, novice, intermediate and advanced grade

Grade	EBV	RV	Scaled EBV†
DP	-5.35±0.14	-6.09±0.08	-0.08
DN	-4.68±0.13	-6.05±0.08	-0.07
DI	-4.56±0.17	-6.80±0.11	-0.08
DA	-6.27±0.39	-8.69±0.19	-0.11
SJP	-6.38±0.24	-12.63±0.32	-0.08
SJN	-5.16±0.20	-9.61±0.24	-0.09
SJI	-4.57±0.25	-8.85±0.28	-0.08
SJA	-5.61±0.30	-8.94±0.40	-0.13
XCP	-44.01±1.88	-4.13±1.07	-0.35
XCN	-36.67±2.10	-22.77±0.60	-0.26
XCI	-18.29±3.04	-21.52±0.81	-0.13
XCA	-44.69±8.16	-30.52±1.65	-0.31
OCP	-28.29±1.12	-26.34±0.61	-0.33
OCN	-27.00±1.20	-24.70±0.52	-0.31
OCI	-14.84±1.80	-25.16±0.72	-0.17
OCA	-33.56±5.08	-34.30±1.38	-0.40

† EBV scaled to a standard deviation of 20 for comparison with publicly presented EBVs which have a mean of 100 and a standard deviation of 20.

DP: dressage pre novice, DN: dressage novice, DI: dressage intermediate, DA: dressage advanced; SJP: showjumping pre novice, SJN: showjumping novice, SJI: showjumping intermediate, SJA: showjumping advanced; XCP: cross country pre novice, XCN: cross country novice, XCI: cross country intermediate, XCA: cross country advanced; OCP: overall competition pre novice, OCN: overall competition novice, OCI: overall competition intermediate, OCA: overall competition advanced

When penalty points are regressed on RVs the largest coefficients are observed for overall competition (-24.70 to -34.30) and cross country (with the exception of pre novice) (-4.13 to -30.52). The regression coefficients for dressage (-6.05 to -8.69) and showjumping (-8.85 to -12.63) are lower. As with regression of penalty points on EBVs, when penalty points are regressed on RVs the highest coefficients are observed at advanced grade, with the exception of showjumping which, again, has the highest coefficient at pre novice.

When the penalty points for the dressage, showjumping and cross country phases are regressed on the EBVs and RVs for overall competition (Table 7.6), the highest regression coefficient is again observed for cross country (-16.76 to -19.73 and -15.03 to -22.71, respectively). Those for dressage (-3.81 to -7.36 and -4.88 to -6.91, respectively) and showjumping (-3.17 to -6.10 and -4.02 to -5.37, respectively) are in a similar range to each other.

Table 7.6 Regression coefficients of penalty points from the dressage, showjumping and cross country phases on estimated breeding values (EBV) and rider values (RV) for overall competition at pre novice, novice, intermediate and advanced grade

Grade	EBV	RV	Scaled EBV†
DP	-4.76±0.20	-5.77±0.11	-0.07
DN	-3.90±0.21	-4.88±0.09	-0.06
DI	-3.81±0.31	-5.77±0.12	-0.07
DA	-7.36±0.73	-6.91±0.19	-0.13
SJP	-6.10±0.34	-5.37±0.19	-0.08
SJN	-5.43±0.35	-4.20±0.15	-0.09
SJI	-3.17±0.46	-4.18±0.18	-0.05
SJA	-6.01±0.92	-4.02±0.25	-0.14
XCP	-16.76±1.01	-15.32±0.56	-0.13
XCN	-17.17±1.10	-15.62±0.48	-0.12
XCI	-7.73±1.68	-15.03±0.67	-0.05
XCA	-19.73±4.73	-22.71±1.27	-0.14

† EBV scaled to a standard deviation of 20 for comparison with publicly presented EBVs which have a mean of 100 and a standard deviation of 20.

DP: dressage pre novice, DN: dressage novice, DI: dressage intermediate, DA: dressage advanced; SJP: showjumping pre novice, SJN: showjumping novice, SJI: showjumping intermediate, SJA: showjumping advanced; XCP: cross country pre novice, XCN: cross country novice, XCI: cross country intermediate, XCA: cross country advanced

When penalty points were regressed on EBVs and RVs with accuracies of 0.5 or greater (Table 7.7), a similar pattern to that seen when they were regressed on all EBVs and RVs was observed for each trait. The highest regression coefficients when penalty points were regressed on EBVs were observed for cross country (-10.83 to -32.37) and overall competition (-15.72 to -21.56) and the lowest for dressage (-4.10 to -4.89) and showjumping (-4.43 to -5.91). The highest regression coefficients were no longer observed at advanced grade but at pre novice. Similarly when penalty points are regressed on RV the highest regression coefficients are observed for overall competition (-23.15 to -36.87) and cross country (with the exception of pre novice) (-2.74 to -33.44) and the lowest observed for dressage (-6.06 to -8.99) and showjumping (-8.70 to -11.82).

Table 7.7 Regression coefficients of penalty points on estimated breeding values (EBV) and rider values (RV) for dressage, showjumping, cross country and overall competition at pre novice, novice, intermediate and advanced grade when only sires and riders with accuracies over 0.5 are analysed

Grade	EBV	RV	Scaled EBV†
DP	-4.89±0.15	-6.22±0.10	-0.07
DN	-4.10±0.14	-6.06±0.09	-0.07
DI	-4.17±0.18	-6.84±0.12	-0.07
DA	-4.26±0.43	-8.99±0.25	-0.07
SJP	-5.91±0.26	-11.82±0.34	-0.08
SJN	-4.96±0.20	-9.24±0.25	-0.08
SJI	-4.43±0.25	-8.90±0.29	-0.07
SJA	-4.86±0.31	-8.70±0.45	-0.12
XCP	-32.37±2.74	-2.74±1.86	-0.26
XCN	-22.49±2.71	-22.21±1.01	-0.16
XCI	-10.83±3.80	-23.05±1.28	-0.08
XCA	-28.30±11.77	-33.44±2.91	-0.20
OCP	-21.56±1.22	25.51±0.76	-0.25
OCN	-20.99±1.32	-23.15±0.62	-0.24
OCI	-15.72±3.65	-36.87±2.85	-0.18
OCA	-19.65±5.54	-32.09±1.69	-0.24

† EBV scaled to a standard deviation of 20 for comparison with publicly presented EBVs which have a mean of 100 and a standard deviation of 20.

DP: dressage pre novice, DN: dressage novice, DI: dressage intermediate, DA: dressage advanced; SJP: showjumping pre novice, SJN: showjumping novice, SJI: showjumping intermediate, SJA: showjumping advanced; XCP: cross country pre novice, XCN: cross country novice, XCI: cross country intermediate, XCA: cross country advanced; OCP: overall competition pre novice, OCN: overall competition novice, OCI: overall competition intermediate, OCA: overall competition advanced

Similarly, when penalty points for dressage, showjumping and cross country are regressed on EBVs and RVs for overall competition with accuracies of 0.5 or over (Table 7.8) the same pattern is observed as when all EBVs and RVs are used in the analysis. A similar range of values is also observed with the highest coefficients at cross country (-9.64 to -18.19 and -15.20 to -26.27, respectively) whilst dressage (-1.92 to -5.38 and -4.88 to -7.42, respectively) and showjumping (-3.32 to -5.58 and -4.13 to -6.70, respectively) are lower. Figures 7.2a-7.2d show the regression lines for each phase at advanced.

Table 7.8 Regression coefficients of penalty points from the dressage, showjumping and cross country phases on estimated breeding values (EBV) and rider values (RV) for overall competition at pre novice, novice, intermediate and advanced grade when only sires and riders with accuracies over 0.5 are analysed

Grade	EBV	RV	Scaled EBV[†]
DP	-2.97±0.23	-6.13±0.14	-0.04
DN	-2.92±0.24	-4.88±0.12	-0.05
DI	-1.92±0.56	-6.04±0.44	-0.03
DA	-5.38±0.89	-7.42±0.27	-0.09
SJP	-4.90±0.38	-5.07±0.24	-0.06
SJN	-5.28±0.40	-4.13±0.19	-0.09
SJI	-3.32±0.95	-6.70±0.75	-0.05
SJA	-5.58±1.11	-4.42±0.34	-0.13
XCP	-13.94±1.14	-15.37±0.70	-0.11
XCN	-13.92±1.24	-15.20±0.59	-0.10
XCI	-9.64±3.71	-26.27±2.87	-0.07
XCA	-18.19±5.60	-22.52±1.64	-0.13

† EBV scaled to a standard deviation of 20 for comparison with publicly presented EBVs which have a mean of 100 and a standard deviation of 20.

DP: dressage pre novice, DN: dressage novice, DI: dressage intermediate, DA: dressage advanced; SJP: showjumping pre novice, SJN: showjumping novice, SJI: showjumping intermediate, SJA: showjumping advanced; XCP: cross country pre novice, XCN: cross country novice, XCI: cross country intermediate, XCA: cross country advanced

Figure 7.2a Regression of advanced dressage penalty points on advanced dressage estimated breeding values

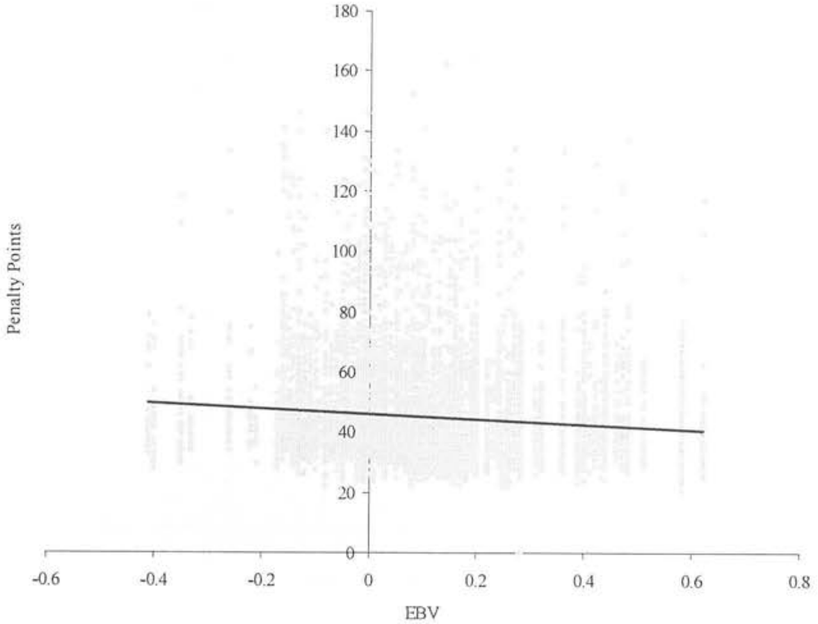


Figure 7.2b Regression of advanced showjumping penalty points on advanced showjumping estimated breeding values

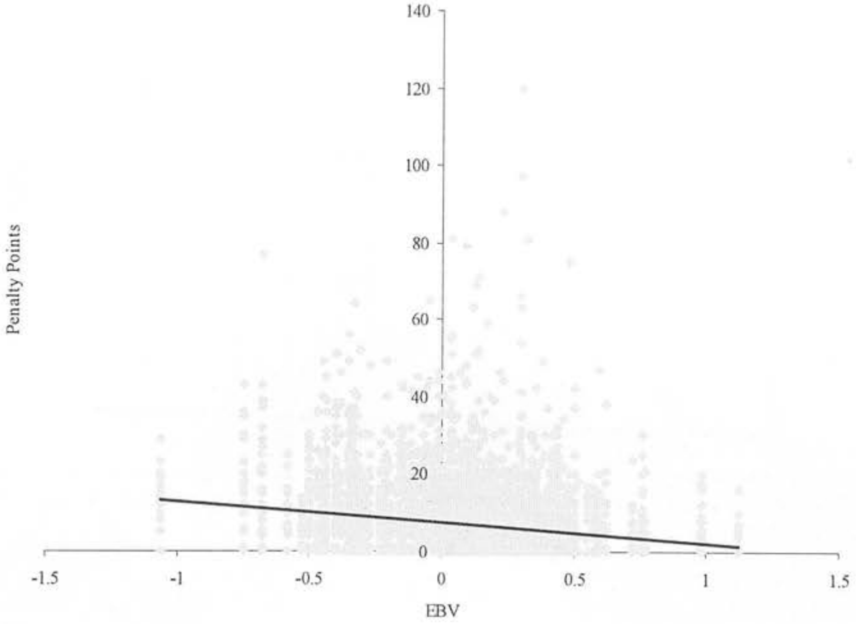


Figure 7.2c Regression of advanced cross country penalty points on advanced cross country estimated breeding values

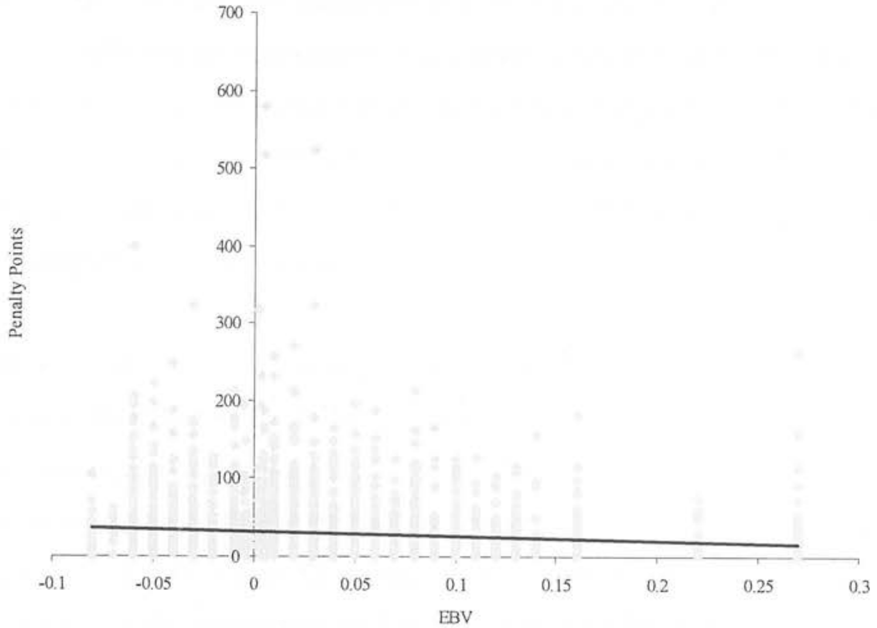
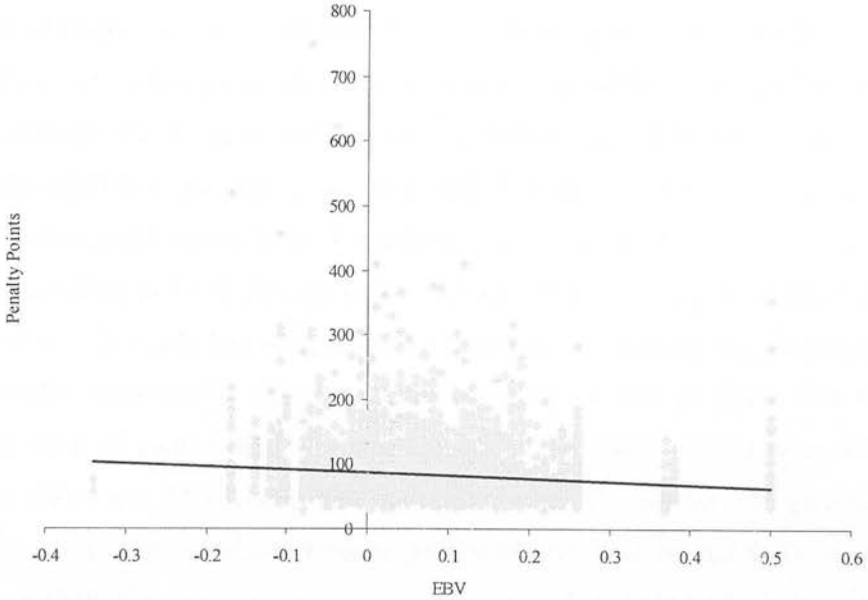


Figure 7.2d Regression of advanced overall competition penalty points on advanced overall competition estimated breeding values



7.4 Discussion

Regressing penalty points on EBVs and RVs allowed the expectant penalty points to one unit on the EBV and RV distributions to be determined. This was given by the regression coefficient and indicates how important changes to the EBVs and RVs are to the number of expected penalty points earned in a competition. For example, the regression coefficient of -44.01 for XCP means that when a sire's EBV increases by one unit, its progeny might be expected to receive 44.01 less penalty points in the cross country phase of a competition.

The penalty points for cross country are most affected by changes to the EBVs and RVs. When an EBV or RV for cross country changes by one unit the number of penalty points gained or lost by the horse is ~20 to40, whereas in the dressage and showjumping phases a change of one unit for the EBV or RV means a change in penalty points of only ~5 to 12 points. A large change in penalty points is also observed for overall competition (~15 to 30) when the EBV and RV change by one unit but this is likely due to the effect of the cross country phase on the overall competition. When cross country penalty points were regressed on the overall competition EBVs and RVs the results showed that a change of one unit in the overall EBV or RV meant a change in penalty points of ~7 to 20 compared to a change of ~3 to 7 points for dressage and showjumping. This pattern of many more penalty points being gained due to a change in one unit of the EBVs and RVs in cross country compared to dressage and showjumping may be due to the standard deviations of the penalty points datasets, in which those for cross country are much higher (25.0 to 35.7) than those for dressage (6.82 to 16.29) and showjumping (8.48 to 9.10). The data has gone through a series of transformations. Penalty points were initially converted to normal scores for analysis, and in doing this the standard deviation of each dataset was equal to one. The normal scores were used to derive the EBVs and RVs which then underwent regression analysis to give the results of this study, the expectant penalty points to one unit on the EBV and RV scale. Essentially the data transformations have come full circle back to the penalty points, and for this reason it is to be expected that the phase with the highest standard deviation for penalty points would also have the highest regression coefficient.

After completion of this study a decision was made on the format for the publicly released EBVs. They are to be presented with a mean of 100 and a genetic standard deviation of 20 (Chapter 8). The results in this study give the regression coefficients for untransformed EBVs. To be of use of the industry these need to be scaled in line with publicly presented EBVs. This can be done with the following equation:

$$\text{Transformed EBV regression} = \frac{\text{EBV regression x genetic standard deviation of trait}}{20}$$

For example, using this equation, the regression coefficient for the EBV for overall competition at advanced grade (-33.56) would be transformed to -0.40. EBV regression coefficients for all traits, scaled to a genetic standard deviation of 20, are given in Tables 7.5-7.8.

7.5 Conclusion

This study provides the key to relating penalty points to EBVs which is necessary for the education of breeders on the use of EBVs. The number of penalty points gained due to changes in one unit of a sire's EBV or a rider's RV varies between phases and shows a difference between cross country and the other phases of competition.

7.6 Summary

The expected penalty points to one unit on the EBV and RV distributions was investigated. This is important for understanding how EBVs/RVs relate to penalty points for educating breeders who use penalty points gained in a competition as their currency. A regression analysis of penalty points on EBVs/RVs was carried out with the regression coefficient indicating how changes to the EBVs and RVs affect the number of expected penalty points earned in a competition. The number of penalty points gained due to changes in one unit of the sire's EBV or rider's RV varies between phases and shows a difference between cross country and the other phases of competition.

8 General Discussion

8.1 Introduction

The aim of this project was to derive models for predicting breeding values for British bred sport horses and to estimate the necessary variance components and develop procedures for their evaluation, an aim which was achieved. Genetic evaluations for sport horses have been used in Ireland, The Netherlands, France, Germany and Sweden for a number of years but this was the first project of its kind to be undertaken in the UK. Evaluations in the afore mentioned countries tend be restricted to showjumping and dressage horses; only France has carried out evaluation on eventing horses until now (Ricard & Chanu, 2001). This project has predominantly focussed on eventing horses, in itself a novelty, but was also the first project to evaluate eventing competition by separating out its component phases for analysis. It was also the first study to separate out the horse, rider and genetic components in the model, allowing not only the prediction of estimated breeding values (EBVs) but also horse values (HVs) and rider values (RVs), which are of use to the industry. This method of analysis allowed quantification of selection intensities between each of the grades. Most selection studies focus on between generation selection, whereas here the focus has been on within generation selection, when horses move through the different grades of competition. This has important practical implications for the sport of eventing because it allows British Eventing to identify potential selection biases when analysing sporting performance, which can help to interpret genetic evaluation procedures and the grading structure of the sport.

As with all new projects there were problems to overcome. Because the data for this project was obtained from outside sources, this is where the major problems lay. The Young Horse Evaluation Series (YHE) has only been running since 2002 and the Futurity Scheme since 2005 and the main problem for both was a lack of data because so few horses are taking part. If the YHE and Futurity Scheme are going to be a source of data for genetic evaluations, as was originally intended, then the number of horses being evaluated needs to increase for meaningful results to be generated (see Recommendations for the industry). Lack of data was not a problem encountered with the data received on eventing horses from British Eventing. However, the database was not designed for the purpose of genetic evaluations so much of the data was not verified and full pedigree data could not be trusted (see Recommendations for the industry). The sires had been identified by name only and had not been assigned identification numbers; therefore the list of sires was subject to some error. I carried out a number of verifications on the data, which included manually checking through the list of sires for spelling mistakes and entry errors and correcting them. It was necessary to carry out evaluations with a sire model, but it would be desirable in the future to use verified pedigree data in the evaluations.

8.2 Breeding values

The major deliverable of this project was a set of EBVs for sport horse stallions, to be provided to *British Breeding* for public release. As shown in Chapter 6, EBVs for all phases at all grades were derived from the model developed in Chapter 5, which gave a total of 16 different breeding values for eventing sires. It is important to first establish the major breeding goals of sport horse breeders in order to make any decisions about which EBVs to publish and how they should be presented. The aim for all event horse breeders is success in overall competition at the highest grade and the aim of *British Breeding* when commissioning this study was to use EBVs in helping to produce horses of the highest calibre; those capable of winning medals at the Olympics. This focused the breeding goal on performance at advanced grade. Because of these breeding goals, and to avoid confusion at the initial release of EBVs, the EBVs provided for public release were those for overall competition at advanced grade. With the strong correlations between advanced and the lower grades (Chapter 5) these EBVs will still give an indication of performance at the lower levels of the sport and because of the multitrait model every sire in the dataset has an advanced EBV, even those that had no progeny competing at advanced grade.

The EBVs for overall competition were available from the solutions of the model in Chapter 5, however, to allow for future allocation of different weights to each of the phases of eventing competition, publicly available EBVs have been calculated by adding together the advanced EBVs for dressage, showjumping and cross country taken from the solutions of the model in Chapter 5. At present all phases are given the same weight. Results presented in this thesis provide a number of methods for weighting each phase, such as the use of the genetic variances of the traits, correlations between each trait or the number of penalty points gained in each phase. However, the decision on how each phase is weighted lies with the BEF.

The next step was to decide on the method of presentation of the EBVs. Penalty points converted to normal scores were used for the prediction of EBVs (Chapter 5), which helped to overcome problems such as the penalty points not being normally distributed. However, these EBVs are difficult to interpret. Other international sport horse evaluations present scaled and transformed EBVs which are relative to the mean. Both Ireland and the Netherlands present their performance EBVs with a mean of 100 and a standard deviation of 20, and each EBV is given an accuracy (Genetic Evaluation of Showjumping Horses in Ireland, 2005; KWPN Stallion Statistics, 2005-2006). British EBVs have been presented in the same format (1) to simplify the interpretation and (2) be consistent with other international evaluations to simplify any possible future collaborations through Interstallion (see Recommendations for the industry). The standard errors for each EBV were taken from the solutions to the model in Chapter 5 and converted to an accuracy. The calculations used to convert the EBVs for presentation are given in Appendix D. It is important for breeders to understand how these scaled EBVs can be interpreted as penalty points. Using the same method of regression analysis shown in Chapter 7, one unit on the published EBV scale is equivalent to 0.36 penalty points. The EBVs and accuracies for the top 20 sires at advanced grade for overall competition are given in Table 8.1.

Table 8.1 Estimated breeding values (EBV) and accuracies for the top 20 sires for overall competition at advanced grade

Sire No.	EBV	Accuracy
1516	126.50	0.84
8780	126.40	0.63
7494	125.19	0.69
3080	123.42	0.75
2628	122.11	0.60
8524	121.24	0.57
7941	120.45	0.67
8465	119.77	0.67
875	119.05	0.73
4594	118.83	0.87
522	118.33	0.46
9697	118.12	0.88
8557	117.15	0.84
4567	117.00	0.61
5673	116.56	0.81
8501	116.07	0.67
2248	115.87	0.57
4604	115.66	0.73
5836	115.47	0.61
6714	115.13	0.36

8.3 Future of genetic research in horses

This project is the first of its kind in Britain and, as has already been discussed, has fulfilled the desired aims with the successful development of a BLUP model to predict breeding values for eventing sires. By using a BLUP model I was able, not only to predict breeding values and separate out the horse and rider components, but also to investigate the fixed effects, in particular the age trends of performance in the different phases of eventing competition (Chapter 5). There is, however, further work that could be carried out to expand upon the methods and results presented in this thesis. This work could include: (1) refinement of accurate components of variance (genetic, residual horse and rider) to improve the models developed in this thesis, both for the analysis of eventing sires and horses taking part in the YHE and

Futurity Scheme; (2) clarifying the definition of temperament (see Recommendations for the Industry) and estimating a heritability; this is an important trait for horse breeders and should not be overlooked; (3) sourcing full pedigrees for horses in the British evening database and re running the sire evaluations with this pedigree in place and (4) plotting genetic trends with the further information gained with access to a full pedigree. Further research on British bred horses should include investigations into evaluations of dressage and showjumping, which would make Britain the only country, other than France, to evaluate all three Olympic disciplines and into the possible combination of data from evaluations of youngstock and competition data to give fully comprehensive breeding values.

The future of equine genetics holds many other exciting prospects, particularly with the completion of the first draft of the horse genome sequence in 2007 (www.animalgenome.org; www.avma.org). The horse genome sequence will be useful for many research projects and its completion will save much time and money in future genetic research projects because a starting point is already available (Bailey, 2007). It is anticipated that one of the main uses of the completed sequence will be in the research of complex equine diseases, such as muscoskeletal and respiratory disorders (Bailey, 2007; www.animalgenome.org). A map of around 1 million single nucleotide polymorphisms (SNPs) has also been developed and this will help, not only in veterinary research, but also research into the genetics of physical attributes and behaviour (www.animalgenome.org; www.avma.org). A 60, 000 SNP chip for horses is due to be released in 2008 (Blott, personal communication). Using this density of markers should allow prediction of breeding values using 'whole genome selection' (Meuwissen, Hayes & Goddard, 2001) which will allow for greater accuracy of breeding values and means that it could be possible to predict breeding values for new born animals and animals with no recorded pedigree. Studies have already begun in cattle which use whole genome technology (Sonstegard *et al.*,2008). The use of the genome may not fully replace genetic evaluations as described in this thesis, but a combination of the traditional BLUP method and whole genome selection could provide a method for successfully breeding sport horses by giving access to both an animal's genotype and its phenotype.

8.4 Recommendations for the industry

Whilst carrying out the work for this thesis I found that in some areas changes to industry procedure could help to improve the genetic evaluation procedure. My recommendations to the sport horse breeding industry are as follows.

Source full, verified pedigrees for all animals to be evaluated

Pedigree information is essential to genetic evaluations and needs to be accurate and trace back at least 2 generations if possible, although the further back a pedigree goes the better. A comprehensive pedigree gives rise to greater genetic links and therefore more accurate breeding values. It also provides information on dams. The now compulsory passport system for all British equines and the development of the National Equine Database (NED) will help to secure this information over time, as will the introduction of the Universal Equine Life Number (UELN) which is assigned to a horse at birth and never changes no matter how many times that horse is registered with different breed societies under a different name. It must be ensured, however, that all information is accurate and readily available to researchers.

Clearly record competition data

A system needs to be put in place for the clear and precise recording of competition data by the governing bodies of each discipline. A clearly set out database, with all possible information recorded in the correct places and not repeated in a number of different tables will allow greater ease of processing in the future.

Join Interstallion with full technical participation

Interstallion is an organisation whose aim is to improve the understanding of the genetic evaluation of sport horses, including methods of evaluation and breeding goals. It also aims to help improve the evaluation systems of its participants and compare genetic evaluations across different countries (www.interstallion.org). The breeding industry in Britain would benefit if the BEF were to participate actively in Interstallion. Each country uses its own traits and measurements in genetic evaluations. By becoming part of Interstallion it will be possible to identify relationships between similar traits which can help to standardise the recording of traits internationally. With traits standardised across countries British breeders would benefit from access to international information and be able to interpret this information in relation to British bred horses. By comparing information on British horses with those in other countries the potential is there to examine and develop international genetic links. A pilot study commissioned by Interstallion has shown that genetic connectedness between breed societies in Denmark, Germany, The Netherlands and Sweden is at a high level, which means that it should be possible to estimate genetic correlations between traits measured on horses within these different societies (Koenen & Philipsson, 2007). It would be hoped that Britain could, in the future, be included in international studies such as this. An examination of the top 100 eventing sires in Britain shows that 31% also appear in Irish evaluation lists, 5% in the KWPN lists and 1% in the evaluation lists of Swedish stallions. The lower percentages of stallions observed in the KWPN and Swedish lists may be because Warmbloods are less commonly used in eventing than in showjumping and dressage. Britain joining Interstallion could also be of benefit to other countries because, at present, Britain tends to be an importer of horses and therefore a number of horses in Britain are of interest to the countries in which they were bred. In participating in Interstallion and allowing the sport horse industry to enjoy these benefits, increased international links for research are also created which can only improve genetic evaluations.

Investigations into why so few of the top novice eventing horses progress to advanced should be carried out

When the movement of the 100 horses with the highest horse values (HVs) at novice grade was investigated in Chapter 6 the results showed that only 33-52% of these horses progressed to advanced level. In contrast 80-92% of the top 100 novice riders and 80-88% of the top 100 sires went on to be represented at advanced grade.

Similar percentages are observed when the top 500 novice horses are tracked through the grades, with only 30-41% moving up to advanced grade. There are a number of possible reasons for so few promising novice horses progressing to advanced, including injury or lack of competent rider, however, investigations should be carried out to find the exact reasons and from there solutions to this problem can be proposed.

Increase number of horses assessed in the YHE and Futurity Scheme

Many more horses need to be assessed via the YHE and Futurity Scheme in order to estimate variance components and predict breeding values, as the results in Chapter 4 show. At present too few 4 year olds are being assessed with a total of ~50 four year olds being put forward for evaluation in the 2 year period of 2006 - 2007 and a total of ~450 since the scheme began in 2002. The YHE has now become part of the Futurity Scheme and although more horses in total (100 in 2005, 200 in 2006 and 320 in 2007) are involved, each age group needs to contain more animals for meaningful evaluations. More animals need to be attracted to these events if evaluation of youngstock is going to be a part of the genetic evaluations of British bred sport horses. Another advantage of increasing the numbers assessed is the reduction in pre selection; by testing a larger number of horses it is more likely that those entering will be of a wide range of abilities and not only those that have been selected for testing because they show promise.

Guidelines for the number of horses that should be taking part in the YHE/Futurity Scheme can be given using predicted sampling variances for the heritability ($V(h^2)$) from Hill (1971). Hill (1971) estimates the minimum $V(h^2)$ as a function of the method of estimation and the number of individuals recorded (T). This equation is presented as:

$$T = v/100V(h^2)$$

Where v is a tabulated coefficient in Hill (1971).

In the YHE data the primary source of information comes from half sibs. Therefore, using the information provided by Hill (1971), it can be shown that a heritability of 0.4 ($v = 1037$), achieving a standard error of 0.04 requires:

$$T = 1037/(100 \times 0.04^2) = 6481$$

Given these values, in order to estimate heritabilities with standard errors with a small margin of error, a good target for the number of horses to bring to the YHE/Futurity Scheme is ~5000. With 5000 individuals, a trait with a heritability of 0.1 ($v = 304$) would have a standard error (se) of:

$$se = \sqrt{V(h^2)} = \sqrt{(v/100T)} = \sqrt{[304/(100 \times 5000)]} = 0.02$$

The majority of animals being evaluated need to be included in the breeding stock so that EBVs are being predicted for horses that will be bred from. It is understood that attracting 5000 horses to the YHE/Futurity Scheme is not an easy task and it is obvious that this increase in numbers would have to take place over a number of years. If this number of horses cannot be attracted then collaboration with other breed societies should be considered to allow more horses to be included in genetic evaluations.

Temperament needs to be clearly defined if it is to be used as part of a breeding program

The results from Chapter 3 show that those involved in different disciplines have different opinions of what a good temperament is. It is difficult to define a good temperament so that the description fits, for example, both a dressage horse and a showjumping horse. This needs to be addressed because a trait needs to be clearly defined if it is to be assessed as part of a breeding program. Possible options are an overall definition that allows for the fact that different disciplines require different temperaments, or different descriptions depending on which discipline a horse is being assessed for. At present, temperament is not measured separately at the YHE but is given as a combined score with the paces and jumping traits. This needs to be addressed if temperament is to be part of a breeding program. By combining the scores of two traits each may influence the other and this may not allow for optimum treatment of either trait. However, the viability of assessing temperament at one day field tests needs to be determined, in this respect a collaboration with Interstallion could be very useful.

The method of veterinary examination needs to be reconsidered if it is to be used for genetic evaluation

The way in which the veterinary exam is carried out at the YHE at present can only show if the horse has good conformation and if it is sound at the time of examination. A horse may be unsound at the time of examination for something as simple as the result of a minor injury sustained *en route* to the event, yet it will receive a low score. Heritable muscoskeletal problems, such as navicular disease (Stock *et al.*, 2004a) and joint arthropathies (Stock *et al.*, 2004b), that will not become apparent until later in the horse's life, cannot be detected by the veterinary exam as it is carried out at present, and horses that may develop these problems may receive high scores. The best solution to this problem is to make X rays compulsory for all horses taking part in the YHE and Futurity Scheme to detect early signs of disease. The use of X rays will also help provide information for research into whole genome selection which will allow for even earlier detection of disease. It is understood that this may deter some owners from participating in the evaluations, because they do not want to alert buyers to the fact that a potential sport horse or breeding stallion has a heritable muscoskeletal disorder. However, in the long run early detection of these problems will improve the quality of sport horse stocks in Britain because they will be reduced if horses with these problems are removed from breeding stock

Loose showjumping should not be dropped from the YHE

Loose jumping has been dropped as a trait from the 2007 YHE. It is recommended that this decision is reconsidered. Loose jumping has been shown to have a higher heritability than ridden jumping (Olsson *et al.*, 2000), because, by removing the rider, one of the many environmental influences is removed and this helps to focus the genetic analysis without so much environmental noise. Results from Chapter 5 show that rider influence does have an effect on performance in eventing competition. As shown in Chapter 4, the highest repeatability was observed for loose jumping, and with repeatabilities forming an upper bound to the heritability, it is possible, that with more data a moderate to high heritability could be estimated for loose jumping. In contrast, the repeatability could be estimated for ridden jumping.

The potential for judging bias needs to be reduced in evaluation of youngstock

It is essential that any potential judging bias is reduced in the evaluation of young horses. Three judges are used in the assessment of horses at the YHE and Futurity Scheme. At present they are able to confer and give a single score. To reduce any bias and create more accurate and objective scoring, the three judges should be unable to confer when giving scores for an animal, each should give their own score, with the three scores combined after judging has taken place. Discussion amongst the judges can lead to a dominant judge influencing the views of the other judges and also means that often scoring is subjective because the different points of a horse are discussed instead of each judge giving their own first impression. Ideally judges should have no prior knowledge of the horses they are judging, because this can also lead to a bias in their scores. This can be achieved by assigning each horse a number and giving the judges this number, but no name, to distinguish each horse. To create further anonymity it may also be advisable to use experienced handlers to show each horse, rather than their owners, who may be known to the judges.

8.5 Summary

All of the objectives of this study were fulfilled. A model to predict breeding values for eventing sires was produced, and the resultant breeding values were passed to the British Equestrian Federation. Genetic and phenotypic parameters were estimated for the traits analysed and these were consistent with those contained in the literature. There were a number of novel aspects to this study, such as the separation of horse and rider in the model, allowing us to assign values to each. This led on to another novel aspect of the research which was the analysis of within generation selection of sires, horses and riders moving through the grades of eventing competition. This study has met its objectives and also provided a platform for the launch of further research into sport horse breeding in Britain.

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10 Appendix A Glossary of equine terms

- **Conformation** – the shape of a horse and the way it is 'put together'. Conformation can affect many things about a horse, including its appearance, movement and soundness.
- **Field test** – a performance test which lasts only for a day. It is more accessible than a station test and commonly stallions, mares and geldings are tested. The Young Horse Evaluation Series and the Futurity Scheme are field tests
- **Loose jumping** – a test of the horse's ability to jump obstacles without a rider.
- **Paces** – a horse's locomotory movement. Includes walk, trot, canter and gallop.
- **Penalty points** – points given for mistakes in performance in each phase of eventing competition. The lower the number of points received the better the performance
- **Performance test** – a test taken by young horses in which they are judged and scored on traits such as conformation, paces, jumping ability and temperament. From these tests potential breeding stock and performance horses can be identified
- **Ridden jumping** – a test of the horse's ability to jump obstacles whilst carrying a rider.
- **Rideability** – how a horse responds to and accepts a rider
- **Station test** – a performance test carried out over a period of time. Horses are kept at the same location and examined repeatedly by the same judges. Can range from 9 days to 100 days and is most commonly used for the selection of young stallions, but is used for mares in some countries.
- **Temperament** – the behaviour of a horse. This is a difficult trait to define – see section 8.5.

11 Appendix B Survey questions

1. **What do you look for in a horse – what are your breeding objectives?**
    a. How important is conformation as a breeding objective?
    b. How important is temperament as a breeding objective?
    c. What kind of abilities do you want from a horse?
    d. How important is health and soundness as a breeding objective?
    e. What traits would you want to eradicate?
    f. What is the general age range of horses competing in this discipline?
    g. Do you feel that the sex of the animal is important for competition?
    h. Do you have any preference for coat colour?
    i. Which breeds do you most often use?
2. **Do you think that a horse should be bred for one specific discipline, or do you feel that the discipline a horse enters can be determined by training and ability?**
3. **Within this discipline:**
    a. How many horses enter competitions each year?
    b. What are the main reasons for horses retiring?
    c. How much influence do you feel the rider has on the performance of a horse in this discipline?
4. **What do you feel is the best measure of a horses quality and ability?**
    a. Conformation?
    b. Assessment at a young age?
    c. Performance in competition?
    d. A combination of these?
5. **What would be the first step in improving the recorded information on health?**
6. **What does this organisation hope to gain from the use of genetic evaluations?**
    a. Do you think that the use of genetic evaluations for breeding will help improve sport horses in the UK through easier access to the genetic merit of breeding stock?

b. How much would you expect to pay for a young horse?

c. Would you be prepared to pay more if an animal had a breeding value?

12 Appendix C Summary of edits made to British Eventing database in preparation for use in analyses

The original database showing all British bred horses registered with British Eventing contained 526696 records. When the decision was made to analyse each phase separately, these records were broken down into:

Phase	No. Records[†]
Dressage	526696
Showjumping	366480
Cross Country	314614
Overall Competition	NA[‡]

[†] These records do not add up to the total records in the dataset (526696) because individual horses appear in more than one phase.

[‡] At this stage in the editing process a dataset had not been created for overall competition

These datasets were further reduced by removing all animals in a competition that had no record of sire or dam. Records of horses that were eliminated, retired, withdrawn, had not started or competed *hors concours* (entered in the event, but running only for practice and not to take any prizes or points) in a competition were removed. Records with missing penalty points and no recorded rider were also removed. The number of records remaining was:

Phase	No. Records
Dressage	283560
Showjumping	264575
Cross Country	227396
Overall Competition	166159

Because, in the original database, sires were identified by name rather than an identification number, the sire records were subject to some error. It was necessary to edit this list manually to ensure that it was correct. This editing process highlighted further null values for sires and therefore when the corrected sire list was added into the datasets the record numbers changed:

Phase	No. Records
Dressage	179967
Showjumping	169721
Cross Country	149362
Overall Competition	148246

These were the finalised record numbers analysed in Chapter 5.

13 Appendix D Calculations for the presentation of EBVs

To convert EBVs to a mean of 100 and a standard deviation of 20 the following equation was used:

$$\frac{[(\mathrm{uEBV} - \mu) \times 20]}{\sqrt{\sigma^2_A}} + 100$$

Where uEBV is the unscaled sire EBV, μ is the mean of the EBVs and σ^2_A is the genetic variance.

Because the EBV for overall competition at advanced level was calculated by adding together the EBVs for dressage showjumping and cross country at advanced level the genetic variance for overall competition at advanced level was calculated using the following equation:

$$\mathrm{var}_{(OC)} = \mathrm{var}_{(SJ)} + \mathrm{var}_{(D)} + \mathrm{var}_{(XC)} + 2\mathrm{cov}_{(SJ,D)} + 2\mathrm{cov}_{(SJ,XC)} + 2\mathrm{cov}_{(D,XC)}$$

Where OC is overall competition, SJ is showjumping, D is dressage and XC is cross country.

Covariances were estimated for pre novice and novice only. For this calculation the advanced variances (calculated using information from Chapter 5) were used and, because there is a high genetic correlation between novice and advanced for all phases, the novice covariances were used.

The accuracy of each EBV was calculated from the standard errors (se) of the sire EBVs with the following equation:

$$\sqrt{(1 - [\mathrm{se}^2 / 0.25\, \sigma^2_A])}$$

Where σ^2_A is the genetic variance.