International Sport Horse Data for Genetic Evaluation

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Abstract

The aim of this thesis was to evaluate international sport horse data for use in genetic evaluations both within populations and between populations. An initial review showed that most sport horse producing breed organisations have created young horse testing schemes. Due to moderate to high heritabilities and highly positive genetic correlations with competition results later in life these tests are good tools for selection and suitable for use in genetic evaluations. Efficiency in testing and selection could be improved by including both sexes in young horse tests where this is not yet done, and by shortening tests, where long test periods are practised.

Genetic connectedness among populations is an essential prerequisite for any kind of assessments of data between them. Genetic connectedness among the five investigated sport horse populations in this thesis is at such a level that it would be feasible to use their national breeding values based on young horse data in international genetic evaluations for estimation of genetic correlations among similar phenotypic traits. This is possible if correct and internationally unique IDs of horses can be established.

Genetic correlations were estimated between phenotypically similar traits tested in Danish Warmblood (DWB) and Swedish Warmblood (SWB). They were highly positive for performance traits and reliabilities for the corresponding breeding values generally became higher when using information from both countries. Thus, mutual use of nationally calculated EBVs was considered possible when stallions are evaluated for use across countries. Moreover a joint genetic evaluation using MACE would be feasible and beneficial for both DWB and SWB.

To evaluate how foreign genetic material should be handled in national genetic evaluations, the influence of foreign stallions on the SWB and its genetic evaluation was studied. Origin of stallions has had significant effects on the genetic improvement of jumping traits in SWB. Inclusion of genetic groups in the genetic evaluation resulted in hardly any re-ranking, but less reliable breeding values; hence it was not recommended as a standard procedure. Complete pedigrees of foreign stallions proved to be much more important than genetic grouping to avoid bias in their EBVs.

Keywords: Horse breeding, genetic evaluation, breeding value, performance tests, genetic connectedness, genetic correlations

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List of Publications

This thesis is based on the following papers, referred to by Roman numerals in the text:

I Thorén Hellsten, E., Viklund, Å., Koenen, E.P.C., Ricard, A., Bruns, E. and Philipsson, J. 2006. Review of genetic parameters estimated at stallion and young horse performance tests and their correlations with later results in dressage and show-jumping competition. *Livestock Science* 103, 1-12.

II Thorén Hellsten, E., Jorjani, H., Philipsson, J. 2008. Connectedness among five European sport horse populations. *Livestock Science*, *in press*.

III Thorén Hellsten, E., Jorjani, H., Philipsson, J. 2008. Genetic correlations between similar traits in the Danish and Swedish Warmblood sport horse populations. *Submitted*.

IV Thorén Hellsten, E., Näsholm, A., Jorjani, H., Strandberg, E., Philipsson, J. 2008. Influence of foreign stallions on the Swedish Warmblood breed and its genetic evaluation. *Submitted*.

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Abbreviations

BLUP	best linear unbiased prediction
CEC	correlation between estimates of country effects
CEV	country effects' variance
DWB	Danish Warmblood
EBV	estimated breeding value
Hann	Hannoveraner Verband
Holst	Holsteiner Verband
ISH	Irish Sport Horse
KWPN	Koninklijk Warmbloed Paardenstamboek Nederland
NGE	national genetic evaluation
MACE	multi-trait across country evaluation
SF	Selle Français
SWB	Swedish Warmblood
UELN	universal equine life number

Introduction

Sport horses, as referred to in this thesis, are horses used for mainly three equestrian disciplines, i.e. the Olympic disciplines Show Jumping, Dressage and Eventing. Most European sport horse breeds can be traced back to versatile horses used in agriculture and in the cavalry. As the horses gradually became replaced by machines, the new focus for horse breeders became sport (Hartley Edwards, 1977; Graaf, 2004). The breeding objective for a majority of the sport horse producing organisations aim at production of horses that are competitive at the most advanced levels in sport (Koenen et al., 2004). It takes several years before a sport horse reaches its maximum performance level. Little genetic progress would be achieved if individuals were chosen for breeding only after they have proved themselves in high levels of sport, due to the long generation interval and low selection intensity. The situation is different in horse racing, where horses often perform their best as 3-5 year olds (Ström and Philipsson, 1978). In genetic evaluation systems for multi-purpose sport horse breeds, use of competition results as a base for the genetic evaluation may lead to biased predictions of breeding values. This is because competition horses are pre-selected based on their talent in usually only one sport discipline. Ordinary competitions are therefore completed by performance tests and/or age class competitions for young horses in the testing schemes for most breed organisations. Young horse tests are vital for sport horse breeding programmes and they serve several purposes. In most breed organisations they constitute the base for genetic evaluations. Another purpose is to use these tests as a means to find talented horses for sport (Bruns et al., 2001; Paper I). The variation among countries in methods for testing and genetic evaluation of sport horses is wide and often not clearly defined (Bruns et al., 2004). This thesis aims at investigating some issues of importance for improved evaluation of sport horse stallions across countries and organisations, focusing in particular on results from performance tests of young horses.

Background

Internationalisation of sport horse breeding

Sport horse breeding has experienced an increased exchange of genetic material during many years (Koenen et al., 2004; Paper II). Table 1 shows the relative origin of warmblood stallions (and their sires) used in some important sport horse studbooks in 2002 (Koenen et al., 2004). Only 42 and 54% of the stallions in Denmark and Sweden were born in their respective home countries, the remaining being imported. Germany dominated the origin of the sires of the active stallions in these two countries as well as in the Netherlands. France and Ireland showed a much more national recruitment of stallions. Figure 1 shows the development of foreign influence in the Swedish Warmblood breed (1976-2006), as an example of an organisation with an increasing rate of import of genetic material. The generally increased internationalisation is partly due to trade of horses, but also to the improved techniques to transport chilled horse semen over long distances (Bruns and Schade, 1994). The increased international use of stallions from different countries or studbooks has created an increased demand for objective information among breeders and licensing committees. They need objective information about foreign stallions and genetic evaluation systems when assessing breeding values of stallions. Those animals are usually very valuable and it is essential that the judges' evaluations are independent of the origin of stallions and in accordance with official regulations.

Table 1. *Relative (%) geographic origin of warmblood stallions (and their sires) used in different studbooks in 2002. From Koenen et al., 2004*

	n[1]	Country of birth[2]						
		NLD	DNK	SWE	FRA	IRL	DEU	Other
KWPN (NLD)	195	**75(32)**	-(-)	-(-)	5(12)	-(-)	18(49)	2(7)
DWB (DNK)	102	7(6)	**42(11)**	-(2)	1(6)	-(-)	50(75)	-(-)
SWB (SWE)	154	12(9)	3(2)	**54(38)**	2(6)	-(-)	27(44)	2(1)
SF (FRA)	765	2(1)	-(-)	-(1)	**92(87)**	-(-)	4(4)	2(8)
ISH (IRL)	200	4(2)	1(-)	1(-)	5(7)	**82(81)**	6(9)	2(2)

[1]Number of warmblood stallions active in breeding.

[2]ISO codes are used as country codes

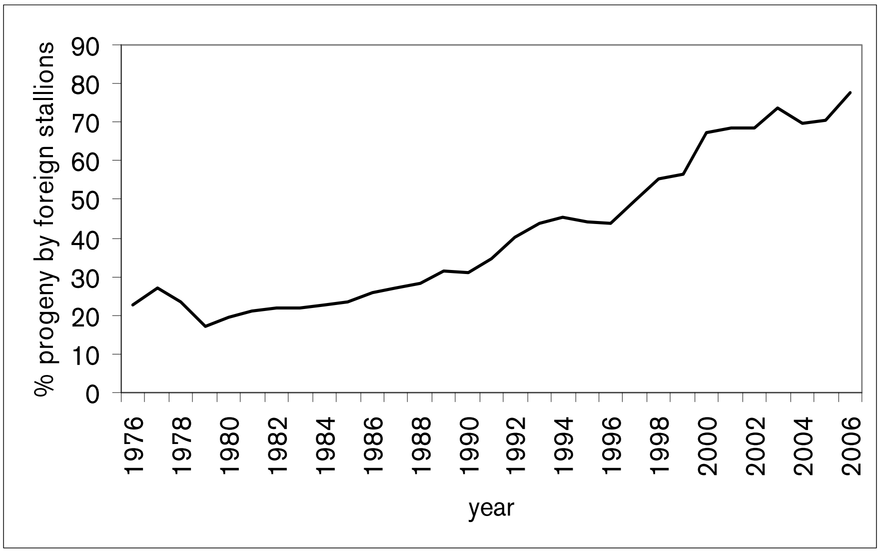

Figure 1. Development of foreign influence in the Swedish warmblood breed 1976-2006. Source: The Swedish Warmblood Association.

Interstallion and the pilot projects

The demand for objective information about foreign stallions and foreign genetic evaluation systems encouraged European Association for Animal

Production (EAAP) to set up a working group called Interstallion Committee in 1998. After initial work on compiling information, as well as reviewing and discussing methods practised for genetic evaluation (Árnason and Ricard, 2001; Bruns et al., 2001; Bruns et al., 2004) the two organisations World Breeding Federation for Sport Horses (WBFSH) and the International Committee for Animal Recording (ICAR) joined the working group. The committee has consisted of researchers and representatives of breed organisations from a number of European countries.

The ambition of Interstallion was to:

- describe breeding goals, performance test procedures and genetic evaluation methods, and make descriptions and their results easily accessible for a broad audience of breeders and professionals in the breeding industry
- make international competition results accessible for the breed organisations. The results from international competitions are often not reported back to the country of birth of a horse, irrespective of whether the horse is competing in international events or was exported. This is a major drawback since the horses competing on an international level potentially are the best horses produced from each country
- be able to recommend improvements of national genetic evaluation systems based on scientific studies and exchanged experiences between countries
- study methods for use of international sport horse data in genetic evaluation of stallions. The existing breeding values were not comparable across countries because they were based on different materials, scales and reference populations

In 2001 the Interstallion committee took the initiative to start two pilot projects working on the use of international sport horse data in genetic evaluations. Two PhD students were subsequently assigned to the projects and this thesis is the result of pilot project one, where the information from tests of young horses is the main source of information. Pilot project two, which uses results from jumping competitions instead of young horse tests, is being performed at l'Institut National de la Recherche Agronomique (INRA) in France. Continuous collaboration has taken place between the two studies.

Genetic evaluation of sport horses

Information on the genetic evaluation of 19 sport horse producing organisations has been readily available at the Interstallion website since 2004. This information includes population structures, breeding goals, testing schemes (stallion performance tests, young horse performance tests, competitions) and evaluation methods.

All major sport horse producing organisations estimate breeding values with the purpose of providing their breeders with as objective information as possible about the breeding stock. Performance traits recorded at the specific young horse tests, such as gaits, jumping ability and rideability are included in the genetic evaluations in Denmark, Germany, the Netherlands and Sweden. Competition results from dressage and show jumping competitions are included in Belgium, Denmark, France, Germany, Ireland, the Netherlands and Sweden. France also includes competition results from eventing. Age class competitions for young horses are included in Belgium, France and Germany. Moreover, some organisations in Belgium, Denmark, Germany, the Netherlands and Sweden estimate breeding values for conformation traits recorded at young horse performance tests, mare shows and/or stallion pre-selections (Interstallion, 2008a).

BLUP animal model is generally used for the genetic evaluations. The animal model has great advantages for genetic evaluation of horses; the important performance traits are not sex limited, i.e. both sexes can be tested and competed on equal terms, and pedigrees are generally deep and complete. Further, the animal model handles the effects of non-random mating which is one of the characteristics of horse breeding (Philipsson, 1989). In a few countries (Germany, the Netherlands, Sweden) the multiple trait BLUP animal model has been introduced to better handle information originating from different tests and competitions (Jaitner and Reinhardt, 2003; ASVH, 2007; Interstallion 2008a). Organisations in other countries use bi- or trivariate models (Belgium, France, Ireland) for performance traits and single trait models for conformation traits (Belgium, Denmark, France, Germany, the Netherlands) to calculate the breeding values. Additionally, traits are sometimes weighted in the calculations of indexes, and sub-indexes weighted in calculations of total merit indexes (Interstallion, 2008a).

Publication scales and reference bases are important information that sometimes differ between countries/organisations (Table 2). In most countries, however, the publication scale with 100 as the mean and 20 as the genetic standard deviation for performance traits has been implemented, although in some cases the standard deviation refers to the variation among estimated breeding values (EBVs). A moving reference base, with respect to birth year of the horses, or a reference base including all evaluated horses or stallions of certain ages with an EBV, are the most common alternatives.

Table 2. *Mean and standard deviation (σ) of the publication scale of indexes, definition of the reference population in Belgium, Germany, Denmark, France, Ireland, The Netherlands and Sweden for performance traits of sport horses*

Country	Trait[1]	Mean	σ	Definition reference population
Belgium	J	100	20	horses having an estimated breeding value
Germany	D, J	100	20	stallions born 11-15 years before year of evaluation that have passed a stallion performance test or having ≥5 tested progeny
Denmark	D, J	100	20	stallions with ≥15 tested progeny
France	J	0	11.2	horses born 5 years before the year of evaluation
	D	0	11.2	horses born 4-6 years before the year of evaluation with a reliability ≥34%
	E	0	11.2	horses born 4-6 years before the year of evaluation with a reliability ≥14%
Ireland	J	100	20	horses having an estimated breeding value
The Netherlands	D, J	100	20	horses having an estimated breeding value
Sweden	D, J	100	20	tested horses born 4-18 years before the year of evaluation

[1]D = dressage, J = show jumping and E = eventing.

International evaluation systems

Because of differences in data recording, testing schemes and genetic evaluations, EBVs are not easily compared across countries/organisations. In dairy cattle, similar comparison problems are handled by Interbull, which has been the driving force in developing international genetic evaluation systems for cattle. The multi-trait across country evaluation (MACE) system (Schaeffer, 1994) is used on a routine basis to estimate genetic correlations between traits in different countries and to estimate international breeding values for bulls (Mark, 2005). Data are merged from different countries for the analyses. This assumes that individual bulls have daughters in many countries, and that nationally used ID numbers of bulls are transformed to internationally unique ID numbers. MACE uses the animals' performance in different countries or populations as different but genetically well correlated traits. Sigurdsson et al. (1996) showed that the best variable to use in the MACE estimations is either progeny performance deviation of sires or de-regressed genetic proofs of sires. Those variables are presumably independent of non-genetic and non-additive genetic effects which would normally affect phenotypic records from each population. The residual correlations between progeny groups are assumed to be zero because each individual progeny of a sire is assumed to be tested in one country only. Since genetic correlations are less than one between countries, MACE evaluations produce breeding values on each country's own publication scale and hence make separate national rankings of bulls possible. In this way, it becomes possible to determine which bulls are best suited for each country (Fikse and Philipsson, 2007).

The most important prerequisites for meaningful international comparisons using MACE are correct and unique ID numbers of animals, validated national breeding values and good genetic connectedness among included populations (Árnason and Ricard, 2001). Validations of national proofs for horse breeding have so far only been published for the Swedish Standardbred trotters (Árnason, 1999) and the Icelandic Horse (Árnason and Sigurdsson, 2004). Genetic connectedness depends on the exchange of genetic material between populations and can be measured in a number of ways. A pragmatic but rough measure is the number of common sires among populations. More sophisticated statistical measures include the prediction error variance of differences in EBVs between countries (Kennedy and Trus, 1993) and derivations from this measure. The genetic connectedness among sport horse populations was expected to be lower than among for example dairy cattle populations. Among the reasons were the smaller progeny groups for stallions, expected large variations in breeding objectives and definition of traits and possible genotype by environment interactions between countries (Bruns et al., 2004).

Problems anticipated in across country evaluation of stallions, as outlined by Bruns et al. (2004) were:

- Differently and insufficiently defined and communicated breeding objectives among countries
- Discrepancies in breeding objectives as practised by breeders and as theoretically calculated
- Differences in methods for the important performance testing of stallions with respect to type and length of test, traits measured and age of tested horses
- Biased national breeding values because of small and selected progeny groups of stallions (as compared to dairy bulls)
- No fully implemented unique identification system for horses
- Incomplete publication of information on test results, breeding values and their reliabilities

- Ignorance among breed organisation about methods and models for estimating breeding values

Furthermore, AI has not been practised in sport horse breeding as long as in dairy cattle breeding, where bulls through the use of frozen semen produce many more progeny than stallions, widely spread in many countries. Consequently it has been considered unlikely to reach as far as in dairy cattle with sport horses in implementation of effective methods for across country evaluations of males. However, a number of improvements of the genetic evaluation systems would be possible.

Aims of the thesis

The overall aim was to evaluate international sport horse data for use in genetic evaluations both within populations and between populations. More specifically, the aims were to:

- produce an overview of genetic parameters estimated for various young horse tests used in genetic evaluations for different European sport horse populations for an assessment of their efficiency in selection for dressage and show jumping
- estimate the genetic connectedness between sport horse populations with similar testing schemes for young horses in order to clarify essential prerequisites for international genetic evaluation
- estimate genetic correlations between phenotypically similar traits tested and evaluated in a pair of genetically connected sport horse populations
- investigate the influence of foreign stallions on the Swedish Warmblood and its genetic evaluation

The overall hypothesis of the thesis, based on these studies, was that the globalisation of sport horse breeding is increasingly important to consider in genetic evaluations of sport horses, and that there are opportunities for improved across country or joint international genetic evaluations of stallions.

Summary of the investigations presented

Materials

A summary of materials used in Paper I-IV is shown in Table 3.

Paper I, which is a review of young horse performance testing systems in Europe, was based on inquiries to 19 European breed organisations and on 17 scientific publications available, in which the genetic parameters for young horse performance tests had been studied in seven European countries.

For Paper II, five breed organisations with similar types of performance data for young horses and a presumed overlapping use of stallions were chosen: the Danish Warmblood Society from Denmark (DWB), the Hannoveraner Verband (Hann) and the Holsteiner Verband (Holst) from Germany, the Royal Warmblood Studbook of the Netherlands (KWPN) from the Netherlands, and the Swedish Warmblood Association (SWB) from Sweden. Each organisation was asked to provide information on stallions with at least one tested progeny. The progeny had to be tested in performance tests of young horses included in national genetic evaluations. It was essential for the stallions to have tested progeny to ensure that they were active contributors of genetic material to the populations being evaluated. The requested data included name, date of birth of the stallion together with ID number of the stallion and its sire, dam, maternal grandsire and paternal grandsire in the organisations sending the data, the ID number of the sire in the organisation of birth, the Unique Equine Life Number (UELN), if available, and the number of tested progeny in tests included in national genetic evaluations. Information was requested on all stallions that had been in use over a time period corresponding to at least two full generations, but no fixed limitation on birth years of stallions was set. The stallions were all born between 1952 and 1997 and there was little variation between organisations. From the DWB information was sent on 624 stallions which on average had 16 tested progeny. Corresponding figures for the other four organisations were 761/20 (Hann), 300/17 (Holst), 453/7 (KWPN) and 748/22 (SWB).

For Paper III, two out of the five organisations from Paper II provided material, DWB and SWB. Information was used on stallions with an EBV and at least 10 progeny tested in young horse tests included in the national genetic evaluations. The higher demand on number of tested progeny compared to Paper II was to ensure a minimum level of reliability for the stallions' EBVs, as the individual values of rather few stallions constituted the major source of information for estimation of genetic correlations. Same requirements on identification and pedigree data as for Paper II applied also for Paper III. Additionally, national EBVs for traits tested at young horse performance tests, their reliabilities, the number of tested progeny and the heritability for each trait were required. The DWB data included 349 stallions with an EBV and 531 ancestor stallions. Corresponding numbers for SWB were 426 stallions with an EBV and 452 ancestor stallions. Out of those stallions, 28 were common to both DWB and SWB. Additionally 151 ancestral stallions were also common to the two organisations.

In Paper IV only data provided by the SWB were used, including 189,330 horses of which 50,907 had results from young horse performance tests and/or competitions included in the national genetic evaluation. For the analysis of variance, stallions with an EBV and at least five progeny tested in young horse performance tests and/or competition included in the national genetic evaluation in Sweden were selected for the analysis. In total the selected group included 757 stallions which together had 116,505 progeny registered as SWB, whereof 47,550 had results in young horse performance test and/or competition. The number of at least five tested progeny was chosen to ensure a minimum level of reliability of the stallions' EBV. To evaluate the impact of genetic group effects in the genetic evaluation of SWB horses, a material including all horses with results in young horse tests, and/or competition (50,907 horses) plus six generations of pedigree information was used, altogether 95,385 horses. The genetic groups were based on year of birth and origin (studbook or breed). To analyse the effects of missing pedigree information on EBVs of foreign stallions, a group of foreign stallions with at least five progeny were selected. In this group there were 393 stallions which together had 17,276 progeny registered by the Swedish Warmblood Association. A coefficient for Pedigree Completeness (PEC), based on five ancestor generations, was calculated for each horse in the data (MacCluer et al., 1983). For the whole data (189,330 horses) PEC was found to be 0.662 on average. The corresponding value for horses with own performance was 0.845 and for stallions with at least 15 tested progeny 0.907. For the group of foreign stallions the average PEC was 0.858.

Table 3. *Summary of materials used in Paper I-IV*

Paper	Countries[1]	
I	BEL, DEU, DNK, FRA, IRL, NLD, SWE	Completed inquiries from 19 breed organisations, 17 scientific publications on young horse performance test data
II	DEU[2], DNK, NLD, SWE	ID information on stallions with at least one progeny tested in young horse test included in the national genetic evaluation, pedigree for two generations and number of tested progeny of those stallions
III	DNK, SWE	Stallions with at least 10 progeny tested in young horse tests included in the national genetic evaluations and their pedigree for two generations. The stallions' EBVs for traits tested at young horse performance tests, the reliability for each EBV, the number of tested progeny and the heritability for each trait
IV	SWE	EBVs of stallions with at least five progeny tested in young horse tests included in the national genetic evaluations, ID information, full pedigree and number of tested progeny of those stallions

[1]ISO codes are used as country codes

[2]the Hannoveraner Verband and the Holsteiner Verband

Methods

For Paper I, available information on testing schemes and genetic parameters in some European breed organisations was compiled and compared in order to assess their efficiency in selection for dressage and show jumping. Measures on efficiency used were the heritabilities for traits tested at specific young horse tests and age-class competitions, their genetic correlations with the breeding goal, i.e. competition results and the proportion of tested horses in relation to foals born.

The number of stallions in common (NSC), genetic similarity (GS) (Rekaya et al.,1999), variance of the differences between estimated country effects (CEV) in two organisations and correlation between estimates of country effects (CEC) (Kennedy and Trus, 1993) were used as measures of the genetic connectedness between organisations in Paper II.

In Paper III, simple product moment (Pearson) correlations were estimated between the breeding values for phenotypically similar or related traits in the DWB and the SWB as indicators of the relationships between the traits evaluated in the two countries. Genetic correlations were estimated between the same phenotypically similar or related traits in the DWB and the SWB. For estimation of genetic correlations, multiple across country evaluation (MACE) methodology was used (Schaeffer, 1994). The dependent variable used in the analysis was national genetic evaluation results of stallions born 1980 or thereafter with at least 10 tested offspring in tests included in the national genetic evaluations. Expected reliabilities for international breeding values were approximated with MACE and compared to the reliabilities reported from the national genetic evaluations in each country.

In Paper IV an analysis of variance of the impact of origin of stallion and time period on the Swedish EBVs for dressage and show jumping was performed using proc GLM in SAS (SAS, 1999). To evaluate the impact of genetic group effects in the genetic evaluation of SWB horses, BLUP breeding values were estimated for dressage and show jumping, with and without genetic group effects in the model. Finally, EBVs were estimated without any pedigree information at all for foreign stallions with at least five tested progeny, while all other horses had their complete pedigree information. This was done in order to evaluate the impact of missing pedigree information on EBVs for foreign stallions. EBVs for the stallions without pedigree were compared to their EBVs when estimated with full pedigrees as in the routine national genetic evaluation for SWB. In all breeding value estimations the DMU package of Madsen and Jensen (2000) was used.

Main results

Despite differences between countries in testing methods of young horses, genetic parameters estimated for populations in Belgium, Denmark, France, Germany, the Netherlands and Sweden were in good agreement. Traits scored at specially designed young horse performance tests, including stallion tests, and age-class competitions, showed moderate to high heritabilities, on average 0.4 for station performance tests and 0.3 for field performance tests. Moreover genetic correlations with later competition results were highly positive, on average about 0.8 for jumping traits and about 0.60-0.70 for dressage related traits. Within tests the genetic correlations were highly positive between gaits, between gaits and rideability and between free jumping and jumping with rider. Between dressage related traits and jumping the genetic correlations varied from moderately negative to moderately positive. However, canter was generally the individual gait most positively correlated to jumping. Even though the figures used for calculation of the proportion of horses tested per year were rough, the results clearly indicated differences between populations, ranging between 10 and 45%.

Estimating genetic connectedness was feasible, despite differences in the choice of materials and models used in the national genetic evaluations of the participating breeding organisations and the lack of uniform identification system of animals (Paper II). Problems with identification of common stallions and ancestors due to the differences in national ID number and name-giving systems required much time to solve. The implementation of a uniform identification system such as the Universal Equine Life Number (UELN) (Haras Nationaux, 2007) was therefore recommended. Genetic connectedness was found between all participating organisations in all birth-year groups of stallions and grew stronger over time. The results were on a similar level to or better than comparable results for Icelandic horses and dairy cattle. Out of the four measures used, the CEV, complemented by the CEC showed to be the most suitable ones because they make full use of the number of stallions in common, their pedigrees and the distribution of their progeny among organizations. The genetic connectedness between the five breeding organisations was at such a level that estimation of genetic correlations between similar traits tested within them would be realistic.

The genetic correlations estimated between DWB and SWB were very high (>0.99) for jumping traits and highly positive (0.879-0.966) for dressage related traits (Paper III). For conformation traits genetic correlations were moderately to highly positive (0.384-0.756) with exception for the correlation between the DWB trait "Hind legs" and the SWB "Legs", which was low (0.104). An increase in reliabilities for performance trait EBVs could be noticed when using information from both DWB and SWB, in particular for stallions with progeny in both countries. High genetic correlations between important traits in DWB and SWB and frequent use of the same or closely related foreign stallions means that mutual utilization of each other's information would be beneficial for both DWB and SWB.

The foreign influence on the SWB had increased from about 20% before 1980 to about 80% in 2007, measured in number of mares covered by foreign stallions (Paper IV). Stallions from some of the foreign populations, e.g. Holstein, Selle Francais and KWPN, had significantly affected the show jumping performance level of the SWB breed in the past although the difference to SWB stallions had become smaller over time. Regarding dressage, no particular foreign population had consistently shown such an impact on the performance. When ignoring pedigree information available for foreign stallions, the EBVs of these stallions changed on average about 20 index units, which corresponds to one genetic standard deviation. Including genetic groups in the genetic evaluation of the SWB resulted in hardly any re-ranking of horses but larger standard errors of the EBVs. Thus, complete pedigree information showed to be the most important factor in estimation of reliable breeding values for foreign stallions in the SWB breed.

General Discussion

It is evident from the studies presented that the internationalisation of sport horse breeding is a continuously increasing process, and that this development needs to be given more and more attention by breeders and their organisations as regards evaluation of breeding stock and exchange of information across countries. In the present study factors influencing the usefulness of international sport horse data in the evaluation of foreign stallions have been investigated. Particular emphasis has been given to data from performance tests of young horses.

Testing schemes

For sport horses, unlike most other livestock species, both some of the breeding goal traits (competition results in dressage) and the traits tested at performance tests for young horses, are subjectively scored. Despite this, heritabilities have shown to be moderate to high for most traits tested at young horse tests (Paper I) while they generally are low for dressage competition (Bruns, 1981; Huizinga and van der Meij, 1989; van Veldhuizen, 1997; Wikström et al., 2005). As shown in Paper I each of the populations studied have found testing schemes suitable for their breeding purposes regarding heritabilities and genetic correlations with the breeding goal. However, in some populations, testing resources could be more effectively used by an increased utilisation of the field tests. For example already established field tests for mares could be extended to also include geldings. Another measure to make selection programmes more effective would be to reduce the length of long station performance tests, in particular for stallions, based on the finding that shorter versions of those tests show equally high genetic parameters as the longer ones. It would potentially reduce costs and also allow for more stallions to be tested, which would increase the selection intensity. Still, it should be kept in mind that the longer tests might have other values for breeders than assessment of performance qualities. For example, some tests include breaking in and initial training of the young horse.

For organisations that include more than one discipline in their breeding goal it is very important to use results from multidisciplinary young horse performance tests as a base in the genetic evaluation. It is necessary in order to correct for the selection that usually takes place before the horses begin their competition career. If not, it could result in biased breeding values for the horses themselves and even more important for their ancestors. Some traditionally multipurpose breeds (KWPN, DWB) are now taking a step towards specialisation within the population; stallions intended for dressage will no longer be tested for jumping in the stallion performance tests, while the stallions intended for show-jumping will still get a basic score for their gaits (KWPN, 2008; Dansk Varmblod, 2008). If those organisations do not intend to separate their populations entirely, it will become even more important to test the progeny for both dressage related traits and jumping traits to avoid bias in their breeding value estimations.

Identification of horses

The lack of unique identification numbers for horses across countries is a major concern when using international sport horse data. Not only does each country or organisation have different identification number systems, but also names of horses are changed or spelled differently in different countries and sponsors' names are added or removed. This makes it difficult and time-consuming to retrieve common individuals among studbooks, be they common stallions, as for the studies in this thesis, or exported competition horses whose results are important for the statistics and genetic evaluation in their respective organisation of birth. The implementation of the UELN number system from 2004 and onwards (Haras Nationaux, 2007) may certainly improve the situation in the future. The UELN is not only a serial number, but it also contains information on the country and organisation of birth. Much could be gained by implementing the UELN also retroactively, to older animals and pedigree animals. However, this work has to be done very carefully. The risk is otherwise that animals present in more than one studbook, which is frequently the case for successful stallions, get registered as more than one animal and that subsequently potential errors become permanent. To facilitate exchange of data between organisations a UELN website has been constructed and hosted by the French National Stud organisation (Haras Nationaux, 2007).

Connectedness

Estimations using data from populations with very weak or no genetic ties, i.e. genetic connectedness, are more or less meaningless because the accuracy and reliability of the estimates will be very low. For example Hanocq et al. (1996) showed that lack of connectedness introduces bias to the estimation of the genetic levels of subpopulations, because without connectedness, their genetic level is not estimable and therefore assumed to be zero. The four measures of connectedness in Paper II (number of common sires, GS, CEV, CEC) have all been used previously for cattle (Kennedy and Trus, 1993; Rekaya et al., 1999; Jorjani, 2000; Weigel et al., 2000) and for Icelandic horses (CEV, CEC) by Árnason and Ricard (2001) and Árnason and Sigurdsson (2004). Both for dairy cattle and Icelandic horses, genetic connectedness have been considered good enough for use of the data in genetic evaluations across countries and international genetic evaluations for these species are now performed on a routine basis. There were differences in the materials provided from the organisations for Paper II, which may have had a negative effect on the connectedness. Such differences were range of birth years for stallions, source of data (type of progeny test) and time period during which the progeny had been tested. Despite this, the connectedness among the studied populations in Paper II were in level with or better than for dairy cattle and Icelandic horses, which implied that it would be technically feasible to proceed with the estimation of genetic correlations between those studbooks. These results may be somewhat surprising due to the rather late introduction of AI, especially across countries, but the trade of live stallions with German pedigrees has been extensive among countries. Thereby genetic linkages have been established between studbooks also outside Germany.

Correlations between similar traits

For sport horse breeders acting on an international market and for licensing committees in sport horse breeding organisations it is of great interest to know how much confidence they should have in test results from other countries/organisations. In Paper I it was concluded that tested traits in the studied young horse performance tests were almost equally heritable and equally predictive for later competition performance. If a) the genetic connectedness between any pair of sport horse populations is good enough and b) the genetic correlations between phenotypically similar traits are high, breeders and licensing committees can be reasonably confident that the results from one population are informative also in the other.

The DWB and the SWB were the best connected populations in Paper II. In Paper III, compared to paper II, the demand on number of tested progeny for inclusion in the data was increased to at least 10, in order to have stallions with reasonable reliable breeding values. Ten tested progeny corresponds to an R_{TI} of 0.67 when the heritability is 0.3, which is an approximate average of the heritabilities for traits tested at young horse tests. Ten tested progeny from each country is also the Interbull recommendation for estimations of genetic correlations between countries (Interbull, 2008). The reliability itself was not used as restriction criteria, because of the differences in national breeding value estimations in DWB and SWB; in DWB the stallion performance test results are included in the breeding value estimations, whereas the SWB breeding values are estimated with ancestor and progeny information only. Inclusion of the stallions' own performance automatically generates higher reliability when the number of tested progeny is low; hence the DWB reliabilities in general are higher than the SWB ones. When MACE was used to approximate the difference in reliability, including data from both populations as was done in Paper III, only progeny information was used and therefore number of progeny was a better restriction criterion.

The genetic correlations between phenotypically similar traits in Paper III were highly positive for dressage related traits and very high for jumping traits. For conformation traits, however, the correlations varied considerably, from low to high. These results indicate that judges in DWB and SWB have very similar opinions for performance traits, but that opinions diverge for the body and leg constitution of the horse. Different definitions of traits as well as different test types providing information to the EBVs are other probable explanations for the lower correlations between conformation traits. Dressage and show jumping competitions provide opportunities for continuous comparison of horses of different origins on national and international levels. Since 1992, there have also been specific international young horse competitions, called World Breeding Championships for Sport Horses (WBFSH, 2008). Seminars and courses for judges about assessing performance traits are regularly arranged in connection to these international young horse competitions. These competitions and courses naturally contribute to a certain consensus among judges with respect to performance traits. However, there are no international conformation shows or courses for judges. Additionally, the type of the horse could be considered a brand, the characteristic of a breed, and as such something to mark the uniqueness of a breed organisation. Hence, a uniform type might not be desired among breed organisations.

Methods and information sources

In Paper III, the different test types providing information to the EBVs is suggested as a potential cause of reduction in genetic correlation between the two breed organisations. The genetic parameters for young horse tests may be similar among countries and the genetic correlations between traits tested may be high, but there are still differences in national genetic evaluation systems that are potential sources for genetic correlations being different from unity. An example is the difference in how these sources of information are combined in the national genetic evaluations, especially if the descriptions of the national genetic evaluations are unclear at this point. As mentioned earlier there is a wide variation in models and weightings among the sport horse breeding organisations (Interstallion, 2008a). Moreover, the treatment of the stallions' own performances in tests and sports is unclear. It is an advantage in genetic evaluation of horses that traits are measurable on both sexes. However, if there is a potential bias caused by preferential treatment of certain stallions, it is important that influence of individual performance on the breeding value is limited compared to that of progeny performance, which after all is more important for coming generations. All organisations could benefit from discussions and international workshops on these subjects in order to improve national genetic evaluations and the international comprehension of genetic evaluations. Efforts should also be made to educate breeders and licensing committees in these subjects to avoid misinterpretations or misuse of breeding values both nationally and internationally. A good example of such international collaboration was the Interstallion workshop on publication scales and reference populations in Warendorf in September 2005, which resulted in common recommendations and some harmonisation of reference bases and scales for national genetic evaluations (Interstallion, 2008b).

Genetic groups

None of the information in Paper II and III has yet been applied in practice. One of the aims in Paper IV was to investigate how a population with substantial influence of foreign stallions – the SWB – can best assess the breeding values of those stallions without knowledge about the connectedness and the correlations with other sport horse populations. It was concluded that the most important factor was to keep as complete pedigrees as possible. Inclusion of genetic groups in the model in fact generated a better fit of the model, but still less accurate EBVs than when no genetic groups were included. One of the reasons might have been that the groups formed became too small. Probably the contributions from other populations, in terms of number of imported animals, are still too low for formation of meaningful genetic groups. The alternative was larger, but much more heterogeneous groups with respect to birth year and/or origin of horses, which was tested but with worse result.

Requirements in the equestrian sports as well as the definition of traits change over time; hence the genetic correlation between apparently the same traits may be less than unity in different time periods. The pedigrees of today's sport horses are often heterogeneous in terms of origin of pedigree horses. This makes it difficult to correctly assign origin to foreign horses and their ancestors, especially since the origin of ancestors seldom is specified. As sport horse breeding grows even more international, it will further complicate the situation. Again, this problem would be almost solved with a correct implementation of the UELN numbers, also retroactively.

Current status

Out of the problems anticipated in across country evaluation of stallions by Bruns et al. (2004), some have been solved and some remain to be dealt with. The breeding objectives of a large amount of important breeding organisations have been described and analysed (Koenen et al., 2004; Teegen et al., 2008) on a scientific level and some of the results have been communicated through the Interstallion website. Differences in testing methods of young horses and stallions have been clarified and the effectiveness for selection of tests has been assessed (Árnason and Ricard, 2001; Bruns et al., 2001; Bruns et al., 2004; Paper I). A unique identification system for horses has been gradually implemented and the process is still running (Haras Nationaux, 2007). A serious problem is still that the pedigree information and reporting systems for internationally competing horses in the equestrian sport are far from the standards kept by the racing horse industry. The remaining problems are not just technical problems that can be solved with more research but most of them could be handled with better communication and cooperation within and among breed organisations.

Conclusions

Most sport horse producing breed organisations have created young horse testing schemes. Due to moderate to high heritabilities and highly positive genetic correlations with competition results later in life they are efficient tools for selection and suitable for use in genetic evaluations. Efficiency in testing and selection could be improved by including both genders in young horse tests where this is not yet done, and by shortening tests, where long test periods are practised.

Genetic connectedness among the five investigated sport horse populations is at such a level that it would be feasible to use their national breeding values based on young horse data in international genetic evaluations for estimation of genetic correlations among similar phenotypic traits. This is provided that correct and internationally unique IDs of horses can be established.

Genetic correlations between phenotypically similar traits tested in Danish Warmblood and Swedish Warmblood are highly positive for performance traits. Reliabilities for the corresponding breeding values became generally higher when using information from both countries. Thus, mutual use of nationally calculated EBVs is possible when stallions are evaluated for use across countries. Moreover a joint genetic evaluation using MACE would be feasible and beneficial for both DWB and SWB.

The origin of stallions had a significant effect on the genetic improvement of jumping traits in SWB. The inclusion of genetic groups according to studbook origin in the genetic evaluation resulted in hardly any re-ranking, but less reliable breeding values; hence inclusion of genetic groups in the national genetic evaluations was not recommended. It proved more important to make sure that foreign stallions have complete pedigrees reported to the national data bases used for national genetic evaluations. Otherwise EBVs of foreign stallions may be seriously biased.

Future research

Validation of national genetic evaluation systems would be an important area for testing the accuracy of evaluation methods practised. It could be done, e.g. by analysing the genetic trends according to relevant tests practised by Interbull. This is specifically important for the comparison of horses born in different time periods and belonging to different populations.

EBVs in different countries contain various amounts of information, of which especially inclusion of the performance test results of individual stallions may have great impact on the EBVs. Hence it would be important to develop a system to partition the EBVs so that it becomes clear how much of the index variation that is due to effects of pedigree, own results and progeny results.

International exchange of genetic material increases each year. For that reason it would be interesting to repeat studies II and III in a couple of years and include more breed organisations and traits. Thereby it would be possible to get a better picture of the possibilities for use of international sport horse data in a broader perspective.

It would be interesting to perform an international genetic evaluation with interested breed organisations.

Soundness and durability are of major importance next to the performance traits. Paper III showed a certain disagreement in opinions about scoring leg conformation. The relation between leg conformation and soundness/durability should be investigated in order to find out whether certain deviations from so-called normal conformation have worse consequences than others.

Trade of semen across countries has become more and more common as part of the globalization of sport horse breeding. Research on fertility to improve the duration for use of transported semen is therefore important. The documentation of semen quality, pregnancy rates or foaling rates of individual stallions seems initially to be an important area for development of transparent information.

Another trait of major importance for the usability of the horse is the temperament. Standardised characterisation of the temperament of horses is needed as are validated temperament test procedures. Heritabilities should be calculated when possible and in the future it will hopefully be possible to estimate breeding values for temperament.

Internationella sporthästdata för avelsvärdering

Bakgrund

I dag är aveln av sporthästar för ridsportgrenarna dressyr, hoppning och fälttävlan i högsta grad internationell genom ett allt större utbyte av avelsmaterial mellan avelsorganisationer. I Sverige var andelen avkommor efter utlandsfödda hingstar ca 80 % år 2006. För 20 år sedan var motsvarande siffra bara 20 %. En viss internationell handel med hingstar har förekommit länge, men under senare år har användningen av importerad sperma blivit allt vanligare. Över 90 % av svenska varmblodsston insemineras numera, de flesta med sperma som transporterats långa sträckor inom landet men också från andra länder. En liknande internationalisering av varmblodsaveln har skett i flera europeiska länder, t.ex. Danmark och Holland. Oftast har man importerat hingstar och sperma från Tyskland. Internationaliseringen av varmblodsaveln innebär att det ställs stora krav på avelsvärderingsnämnderna och de använda metoderna för avelsvärdering i respektive land för att en korrekt bedömning av hingstars avelsvärde ska kunna göras. Testsystem och avelsvärderingsmetoder varierar mellan länder och är ofta inte tydligt beskrivna någonstans. Skillnader i testsystem, avelsvärderingsmetoder och vilka resultat som ingår i beräkningen av avelsvärden, gör att det är svårt att jämföra avelsvärden mellan länder.

Inom nötkreatursaveln har liknande problem hanterats av Interbull, som har varit en drivande kraft i utvecklingen av internationell avelsvärdering för tjurar. Erfarenheter från nötkreatursaveln har visat att de viktigaste förutsättningarna för meningsfulla internationella jämförelser är: a) att varje djur har ett korrekt och unikt ID-nummer, b) att varje lands avelsvärderingssystem ger korrekta och jämförbara avelsvärden över tiden, samt c) att det finns tillräckliga släktskapsband mellan inblandade populationer. Höga genetiska samband mellan liknande egenskaper är också önskvärt, eftersom det visar att man bedömer dessa egenskaper på samma sätt.

I den här avhandlingen har unghästtester i ett antal europeiska länder granskats med avseende på deras effektivitet för avelsarbetet. Släktskapsband mellan ett antal utvalda populationer med liknande testsystem har undersökts, liksom de genetiska sambanden mellan egenskaper i ett par av de mest besläktade populationerna. Slutligen har det utländska inflytandet på den svenska varmblodspopulationen och dess avelsvärderingssystem studerats. Vid genomförandet av undersökningarna har beprövad metodik från liknande studier på nötkreatur använts.

Syftet med avhandlingen var att undersöka förutsättningarna för att använda resultat från framförallt unghästtester i ett internationellt sammanhang. Detta ville vi undersöka genom att granska ovan nämnda faktorer som har betydelse vid jämförelse och avelsvärdering av hingstar i ett internationellt perspektiv.

Resultat

Om urvalet av avelsdjur baserades enbart på tävlingsresultat från fullvuxna sporthästar skulle avelsframsteget bli knappt märkbart på grund av långt generationsintervall och låg urvalsintensitet. Tester av unghästar har därför blivit en av de viktigaste delarna i avelsprogram för sporthästar i hela Europa. För att omvandla resultaten till avelsvärden, så kallade index, används generellt BLUP-metodiken. Medelhöga arvbarheter och medel-höga till höga genetiska samband med tävlingsresultat visade att testsystemen för unga hästar i de flesta större sporthästorganisationerna var tillräckligt bra för att ligga till grund för internationella jämförelser. Avelsprogram för vissa organisationer skulle dock kunna effektiviseras om båda könen testades i de unghästtester som ligger till grund för avelsvärdesberäkningar samt om man i högre grad använde sig av de förhållandevis enkla och billiga endagstesten (motsvarande 3-årstest och kvalitetsbedömning). När det gällde bruksprov skulle de i flera fall kunna kortas betydligt, då kortare test, som det svenska bruksprovet, visade sig vara lika effektiva ur selektionssynpunkt som de längre testen.

För att resultaten från ett land/organisation ska vara av något värde i ett annat krävs att det finns genetiska band, släktskap, mellan populationerna i fråga och att samma egenskaper bedöms på samma sätt. Släktskapsbanden mellan sporthästpopulationerna Danskt varmblod (DVB), de tyska avelsorganisationerna Hannoveranerförbundet (Hannover) och Holsteinerförbundet (Holstein), det holländska avelsförbundet KWPN och Svensk varmblodig ridhäst (SVB) visade sig vara tillräckligt starka för att avelsvärden skattade i respektive land skulle gå att använda vid internationella studier och jämförelser. De starkaste banden fanns mellan DVB och SVB, vilka båda i stor utsträckning importerat avelsmaterial från framförallt Hannover och Holstein. DVB och SVB skulle kunna använda sig av varandras information från unghästtester när det gäller prestationsegenskaper, eftersom det visade sig vara i princip samma egenskaper som bedöms och de bedöms på samma sätt. Det skulle leda till säkrare avelsvärden för prestations-egenskaper, särskilt för de hingstar som har avkommor i båda länderna. På sikt skulle man också kunna tänka sig internationell avelsvärdering för DVB och SVB. Då skulle varje land få avelsvärden som inkluderade information från båda länderna, men på respektive lands egen skala, så att alla hingstar blev jämförbara. Sambanden mellan DVB och SVB varierade mer när det gällde exteriör än när det gällde prestationsegenskaper. Högst var sambanden mellan olika typbetyg och lägst mellan olika betyg som beskriver extremiteter. Variationen och de lägre sambanden kan dels bero på att det skiljer en del mellan DVB och SVB i definitionen av exteriöra egenskaper, men också på att det kan finnas olikheter i vad som anses vara en god exteriör i de båda avelsorganisationerna.

ID-problem

Ett pålitligt system för jämförelse av olika testresultat och avelsvärden mellan länder bygger bland annat på att avelshingstar och hästar som har resultat från flera länder går att identifiera som samma häst, oavsett var resultaten har uppnåtts. I de studier som ligger till grund för avhandlingen har just detta visat sig vara ett av de största problemen, på grund av att hästar ofta byter ID-nummer och ibland även namn när de registreras i andra organisationer än sin födelseorganisation. Förhoppningsvis kan ID-problemen minskas i framtiden eftersom ett nytt system för unik identifiering av hästar börjat införas över hela världen, det så kallade UELN-systemet (Universal Equine Life Number).

Hur påverkar internationaliseringen den svenska varmblodsaveln?

Genom en analys av data från SVB undersöktes om hingstars ursprung hade någon signifikant effekt på utvecklingen av hoppegenskaper respektive dressyregenskaper i svensk varmblodsavel och om hingstar från några särskilda populationer haft speciellt positivt eller negativt inflytande på hoppning respektive dressyr i SVB. Analysen visade att det för svensk varmblodsavels del varit hingstar som härstammar från Holstein, KWPN och Selle Français som fört hoppaveln framåt, men när det gäller dressyr har man snarare fått se till den enskilda individen. Beträffande avelsvärdeberäkning är korrekta ID-uppgifter och härstamningens fullständighet de vikigaste faktorerna för att utländska hingstar ska kunna få ett rättvisande och säkert avelsindex.

Slutsatser i korthet

Förutsättningarna för internationellt användande av resultat från unghästtester är goda med avseende på testsystem i respektive land, släktskap mellan olika sporthästpopulationer och samsynen i bedömningen av prestationsegenskaper. En springande punkt är dock identifieringen av hästar och hur man använder ID-nummer när hästar byter land eller används i avel i andra länder än ursprungslandet.

Framtidsfrågor

Framöver vore det intressant att:

- forska vidare på hur stor andel av variationen i hästars index som beror på härstamningen, egna resultat och avkommeresultat, beroende på i vilket land de avelsvärderas
- utöka de studier som gjorts i den här avhandlingen till fler länder och organisationer
- genomföra internationell avelsvärdering för de organisationer som är intresserade
- forska mer på fertilitet, framförallt spermakvalité, dräktighetsprocent och fölningsprocent, vilka är viktiga faktorer att ta hänsyn till vid internationell handel med hingstsperma
- undersöka exteriörens, framförallt olika benställningars, betydelse för hästars hållbarhet
- ta fram standardiserade beskrivningar av hästens temperament och utveckla validerade temperamentstest. Ärftlighet när det gäller temperament borde undersökas liksom möjligheten att ta fram avelsvärden för temperament

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