Genetic conditions of joint Nordic genetic evaluations of lifetime competition performance in Warmblood sport horses

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Summary

Breeding programmes for warmblood sport horses are similar in the Nordic countries Sweden, Denmark, Finland and Norway and stallions of same origin are used. The aim was to investigate if a joint Nordic genetic evaluation based on lifetime competition performance is feasible and beneficial for breeding competitive sport horses in the Nordic countries. Results for almost 45,000 horses in show jumping and 30,000 horses in dressage were available. The larger populations in Sweden and Denmark contributed with 85% of the results. Heritabilities and genetic correlations between performances in the different countries were estimated, and comparisons of accuracies of estimated breeding values (EBVs) and number of stallions with

EBVs based on national or joint data were studied. The heritabilities ranged between 0.25 and 0.42 for show jumping and between 0.14 and 0.55 for dressage. The genetic correlations between competition performances in the Nordic countries were estimated to 0.63-1.00. EBVs based on joint data increased accuracies for EBVs for stallions by 38-81%, and increased the number of available stallions with EBVs by 40-288%, compared to EBVs based on national data only. A joint Nordic genetic evaluation for sport horses is recommended.

Introduction

The production of warmblood sport horses for the Olympic sports dressage, show jumping and eventing has become more international with increased exchange of genetic material between breed organisations (Koenen et al., 2004; Thorén Hellsten et al., 2008). Germany, France and the Netherlands with large sport horse populations are the main exporting countries, whereas countries with small populations such as the Nordic countries often import breeding stock. However, most breeding organisations run their own selection programs, including genetic evaluations, based exclusively on national information (Koenen & Aldridge, 2002). This means that the estimated breeding values (EBVs) are not comparable across countries, which is a prerequisite if breeders would be able to select the best breeding stallions to their brood mares independent of country of evaluation.

Earlier studies on warmblood sport horse populations in Europe concluded that international genetic evaluation would be feasible due to strong genetic connectedness between the included populations (Thorén Hellsten et al., 2008; Ruhlmann et al., 2009a). In the Icelandic horse population an across countries genetic evaluation has been routinely performed for almost 20 years (Albertsdóttir, 2010).

In the Nordic countries the breeding objectives for warmblood sport horses are very similar and aim for internationally competitive sport horses in either dressage or show jumping

(Koenen et al., 2004). All four countries have similar tests for young horses and registration of competition performance. Stallions of the same origin are used to a large extent in the Nordic countries (Furre et al., in manuscript), providing the necessary genetic ties between populations. Moderate to high genetic correlations have been estimated between traits recorded in young-horse-tests in Sweden and Norway (Furre et al., 2013) and between Sweden and Denmark (Thorén Hellsten et al., 2009a). In Sweden and Denmark national genetic evaluations are performed annually, but in Norway and Finland no EBVs are estimated, meaning that a joint Nordic genetic evaluation would have to be based on raw data.

A joint Nordic genetic evaluation with information from all four countries could be expected to benefit the small populations by considerably increased data for estimation of EBVs, and all populations by increased accuracies and number of evaluated stallions (Thorén Hellsten et al., 2009a; Furre et al., 2013). With the dramatic decrease in number of coverings in the last five years, 2009-2013, collaboration between countries has become even more urgent from both a genetic and economic point of view.

The overall aim of this study was to investigate the scientific opportunities for a joint genetic evaluation based on competition data from the four Nordic countries; Sweden, Denmark, Finland and Norway. Genetic correlations between countries, accuracies of EBVs and number of stallions with EBVs based on different number of offspring were studied to evaluate the effects of a joint genetic evaluation compared to within country genetic evaluations.

Materials

Competition and pedigree data was provided from the breeding organisations in Sweden, Denmark, Finland and Norway. The competition data included results from official competitions, from regional to international level. The Swedish competition data included dressage and show jumping results from 1962 to 2011, the Danish data from 1986 to 2011, the Finnish data from 2002 to 2011, and the Norwegian data from 2007 to 2012. Horses born 1970 and onwards that were found in the national pedigree data were included in the analyses. They were not required to be born in a Nordic country.

In this study competition performance was defined as lifetime accumulated points in dressage and show jumping, respectively. In the current genetic evaluation in Denmark placings from individual competitions are used (Bølling, 2011), but the point systems are similar in all four countries which made it possible to create corresponding lifetime records. Points are given to horses that are placed in competitions, i.e. horses that are among the 25% best in a competition. Points reflect both placing and level of competition; a horse receives more points for a better placing and/or at a more advanced level. In the Norwegian data the recorded points were lacking for a major part of the data and horses with placings without points were given calculated points based on level of competition and the Norwegian point table.

Recording of started horses without any placings or achieved points during their lifetime varied over time both between and within countries. To make data comparable over countries and time periods, these horses were excluded. The distributions of lifetime accumulated points were skewed and to normalize it a transformation with 10-logarithm was used. The number of recorded competition horses in each country, means and standard deviations for the transformed competition traits are given in Table 1. Due to heterogeneity in variances the records were standardised to a common mean and standard deviation in all countries before further analyses.

The pedigree data from the different breed organisations were merged into a joint database. The horses were merged on several different criteria; Universal Equine Life Number (UELN), studbook number for approved breeding animals, registration number and the combination of the name of horse, sire, dam and birth year. A pedigree database including seven ancestral generations of competing horses, comprising in total 229,163 horses, was used in the analyses. Pedigree completeness was quantified by computing a pedigree index (PEC) for five ancestral generations as described by MacCluer et al. (1983). For competing horses the average PEC value was 0.90 in Sweden, 0.67 in Denmark, 0.27 in Norway and 0.84 in Finland.

The genetic similarity (GS) between the four countries based on competing offspring have been calculated to 20-60% (Furre et al., in manuscript). The highest GS was between Sweden and Denmark and the lowest between Finland and Norway.

Methods

Statistical analyses

An analysis of variance was initially performed within country to test which effects to consider in the genetic analyses, using the GLM procedure in SAS (SAS Institute Inc., 2007). The effects of sex and birth year were tested. The effect of birth year was highly significant ($p<0.0001$) for both dressage and show jumping in all countries. The effect of sex was also highly significant ($p<0.0001$) for performance in dressage, where stallions and geldings were more successful than mares. For the Norwegian data the level of significance was lower ($p<0.01$). However, the effect of sex was not significant for show jumping performance in any of the Nordic countries.

The joint competition data from all four countries was analysed using the same method. The tested effects of sex, birth year, country of competition, and the combination of country of competition and birth year were all highly significant for both show jumping and dressage ($p<0.0001$). If a horse had competed in more than one country, the country where the horses had received most points was chosen for that horse, while all points were included.

Estimation of genetic parameters and EBVs

Genetic parameters and breeding values were estimated using animal models. For univariate analyses within country the following statistical model was used:

y_{ijk} = birth year_i + sex_j + animal_k + e_{ijk} (Model I)

where y_{ijk} is the lifetime accumulated points in show jumping or dressage transformed with 10-logarithm for *k*th horse; birth year_i is the fixed effect of *i*th birth year; sex_j is the fixed effect of the *j*th sex (*j*=male or female); animal_k is the random effect of the *k*th horse ~ND(0, $\mathbf{A}\sigma^2_a$), and e_{ijk} is the random ~IND(0, σ^2_e) residual effect.

Genetic correlations between corresponding competition traits in different countries were estimated using bivariate analyses with the same effects as in Model I.

For analyses of the joint Nordic data with the competition traits were defined as the same trait across countries, the following model was used:

y_{ijk} =(country*birth year)$_i$ + sex_j + animal_k + e_{ijk} (Model II)

where y_{ijk} is the lifetime accumulated points in show jumping or dressage transformed with 10-logarithm for *k*th horse; (country*birth year)$_i$ is the fixed effect of the *i*th combination competition country and birth year; sex_j is the fixed effect of the *j*th sex (*j*=male or female); animal_k is the random effect of the *k*th horse ~ND(0, $\mathbf{A}\sigma^2_a$), and e_{ijk} is the random ~IND(0, σ^2_e) residual effect.

Estimates were obtained by use of the average information algorithm (Jensen et al., 1997) for restricted maximum likelihood (REML) in the DMU package for analysing multivariate mixed models (Madsen & Jensen, 2012). All analyses met a convergence criterion for the norm vector of <10^{-7}, except for a few bivariate analyses where the genetic correlation was close to unity. These analyses met the convergence criterion for the norm vector of <10^{-5}.

Accuracies defined as the correlation between true and estimated breeding value (r_{TI}) were calculated as

$$r_{TI} = \sqrt{1 - PEV / \sigma_a^2}$$

where PEV is the prediction error variance.

For stallions with competing offspring in more than one Nordic country, accuracies of EBVs based on univariate analyses within country were compared to those from joint Nordic evaluations. This was done within discipline for different groups of stallion with at least 15 competing offspring in total according to following criteria for each country:

I. Stallions with at least 1 competing offspring within country and in total at least 15 competing offspring in the Nordic countries.
II. Stallions with at least 5 competing offspring within country and in total at least 15 competing offspring in the Nordic countries.
III. Stallions with at least 10 competing offspring within country and in total at least 15 competing offspring in the Nordic countries.
IV. Stallions with at least 15 competing offspring in the Nordic countries in total

The minimum of 15 competing offspring was based on the criteria for a stallion to receive an official published EBV in current national genetic evaluation in Sweden and Denmark (Viklund, 2010; Bølling, 2011).

Genetic trends were computed as the average Nordic EBVs by birth year for competing horses in show jumping and dressage in each Nordic country.

Results

Genetic parameters

The genetic parameters estimated in within country univariate analyses (Model I) and in analyses of joint Nordic data (Model II) are presented in Table 2. For show jumping the estimated heritabilities were moderate, ranging from 0.25 to 0.42. Heritabilities estimated for dressage were more variable, from 0.14 to 0.55, with high estimates for Finnish and Norwegian data, and low for Swedish and Danish data. Heritabilities estimated in joint Nordic analyses were at the same level as for Swedish and Danish data.

Estimated genetic correlations between performances in show jumping in the different countries ranged from 0.73 between Denmark and Norway to 1.00 between Sweden and Denmark (Table 3). For dressage performance the genetic correlations ranged from 0.63 between Sweden and Finland to 1.00 between Sweden and Norway. The phenotypic correlations were moderate to high (0.23-0.66) except between Danish and Finnish data for show jumping (-0.02) and between Swedish and Norwegian dressage data (-0.09). The phenotypic correlations were higher for dressage than for show jumping.

Accuracies of EBVs

Accuracies for EBVs for stallions with competing offspring in more than one country estimated within country or in joint Nordic evaluations are presented in Table 4 (show jumping) and Table 5 (dressage). Criterion I included many stallions as at least one competing offspring within country was the limit, but gave rather low average accuracies (0.50-0.65 for show jumping and 0.47-0.53 for dressage) for EBVs estimated within country. When a minimum of 14 offspring competing in the other countries were added, the average accuracies of stallion EBVs increased to 0.89-0.90 (show jumping) and 0.82-0.85 (dressage). The relative gain in accuracy was consequently very high (38-81%). With increasing minimum number of competing offspring within country, the average accuracies for national EBVs increased and the relative gain in accuracies of joint Nordic evaluation decreased. However, very few stallions met criterion III of 10 competing offspring within country and the number of stallions decreased rapidly, especially in Finland and Norway.

Number of stallions with EBVs

With the minimum of 15 competing offspring for a stallion to receive an official published EBV, the number of stallions with official EBVs increased in a joint Nordic genetic evaluation compared to national evaluations. In Table 6 number of stallions with at least 15 competing offspring within country, and number of stallions with less than 15 offspring within a country but with a total of at least 15 offspring in the Nordic countries are presented. Only stallions that are represented by at least one competing offspring within each country were included. All countries had more stallions with official EBVs in a joint evaluation compared with in national evaluations. In the Norwegian data there was no stallion with 15 competing offspring in dressage, but when data was added from the other Nordic countries 105 stallions with competing offspring in Norway passed the limit to receive an official EBV. For the larger populations in Sweden and Denmark the number of stallions with official EBVs increased by 40-73%.

Genetic trends

Genetic trends for competing horses in the Nordic countries based on joint Nordic genetic evaluation are presented for show jumping (Figure 1) and dressage (Figure 2). The larger populations in Sweden and Denmark showed a faster genetic progress and a higher genetic level than the populations in Finland and Norway. However, between birth year 1990 and 1997 the horses competing in show jumping in Finland had almost as high average EBVs as horses competing in Sweden and Denmark. The genetic trends for Swedish and Danish horses were similar throughout the time period, the Swedish horses were on a little higher level in show jumping while the Danish horses were a on a little higher level in dressage. The horses competing in Norway were at the lowest genetic level and showed the slowest genetic progress over the time period.

Discussion

Scientific conditions for joint Nordic EBVs

In dairy cattle, international genetic evaluation of dairy bulls has been conducted for almost 20 years (Philipsson, 2011). Every participating country provides national EBVs and the international EBVs are estimated using Multiple-trait Across Country Evaluation (MACE). In two Interstallion pilot projects, Thorén Hellsten et al. (2009a) and Ruhlmann et al. (2009b) also used national EBVs when estimating genetic correlations across countries for young horse test data and show jumping data, respectively. In Finland and Norway there are no current national genetic evaluations, meaning that a joint Nordic genetic evaluation has to be based on raw data. In the Icelandic horse population, international genetic evaluations based on raw data from breeding field tests have been performed since 1995 (Albertsdóttir, 2010). Back then records from the Nordic countries Iceland, Norway, Denmark and Sweden were included, but since 2005 assessments from eleven countries are included in the evaluations. An advantage for the Icelandic population is that there is a global database (WorldFengur) with unique identification numbers for all Icelandic horses, and the International Federation of Icelandic Horses Associations (FEIF) has a harmonized, common breeding goal and a standard form of evaluating horses (Árnason et al., 2006). In the present study merging pedigree databases from the different countries required a lot of time and manual work. This situation will certainly improve in the future with the Universal Equine Life Number (UELN) system that has been obligatory in Europe since 2009 (EU, 2008). However, it takes time before all horses, including ancestors in the pedigrees, have received UELN and the original number from the birth population must be kept unchanged.

Complete and correct pedigrees are crucial for reliable EBVs. Thorén Hellsten et al. (2009b) showed that if the pedigree information is incomplete the EBVs are regressed towards the mean, and it will affect stallions with very high or very low true breeding values the most. That means that there is a large risk for good stallions to be underestimated and less good stallions to be overestimated if pedigrees are incomplete. In this study the average PEC value for horses competing in Norway was very low. In the study by Furre et al. (2013) the PEC value for horses tested in young horse tests in Norway was 0.47, which was also low but higher than in this study. The young horse tests are open to horses with an approved pedigree that are registered in the breeding organization. Competitions on the other hand are open for all horses of all breeds without any demands on pedigree, therefore the even lower PEC value in this study for the Norwegian data. The recording system in Norway has recently been improved and PEC values are expected to be higher in the coming years. For the Swedish competition data the PEC values were at the same level (0.90) as in the study by Viklund et al. (2010).

Choice of performance trait and model

Denmark and Sweden use different performance traits and models in their current routine national genetic evaluations. In Denmark EBVs for competition performance are based on ranking in each competition with a single trait repeatability model (Bølling, 2011), whereas lifetime accumulated points in competition is used together with information from young horse test data in a multi trait model in Sweden (Viklund et al., 2011). In this study the same performance traits in the different countries were used to harmonize data. Due to the common long tradition of giving points to placed horses in all countries, lifetime accumulated points were used to include as much data as possible.

The statistical models used included the fixed effects of gender and birth year for analyses within country, and gender and birth year*country for analyses for joint Nordic data. It was a large variation in time periods of data, from five years of Norwegian data to almost 50 years of Swedish data. By considering birth year or birth year*country, all horses of the same age have had equal opportunities to compete under same conditions as the sport has developed throughout the years. In Denmark routine national genetic evaluations the random effect of rider is included (Bølling, 2011), but in this study it was not possible to obtain information about rider from all countries. However, including a rider effect can result in a biased decreased genetic variance since there is an anticipated dependency between the quality of the horse and the quality of the rider. Neglecting the rider effect may on the other hand cause an upward bias of the genetic variance.

Genetic parameters for performance

Data from the different countries were first analysed separately. The genetic parameters for the Swedish data were at the same level as in previous study by Viklund et al. (2010). The Danish data showed somewhat lower heritabilities than the Swedish data due to larger residual variances. However, genetic variances were higher than those used in the current Danish genetic evaluation where the genetic variances were 0.0385 and 0.0862 for dressage and show jumping, respectively (Bølling, 2011). This can partly be explained by use of repeated observations instead of one lifetime record per horse as in this study. For Norwegian and Finnish dressage performance the heritabilities were high, but can be misleading due the small data set. In addition, the pedigree information in the Norwegian data was limited with an average PEC-value of 0.27 for competing horses. For the joint data, when the competition trait was considered the same trait across countries, the genetic parameters were at the same level as the Swedish and Danish data because of their large contribution to the joint data.

Is competition performance the same trait in the Nordic countries?

If the performance traits in one country should be informative in another country it is important that the genetic correlations are at a high level. In this study the genetic correlations were very high between all four countries. In a previous Nordic study based on young horse test data in Sweden and Norway the genetic correlations ranged from 0.43 to 0.90, with no correlation significantly different from unity (Furre et al., 2013). In the study by Thorén Hellsten et al. (2009a) the genetic correlation between national EBVs in Swedish Warmblood (SWB) and Danish Warmblood (DWB) for similar phenotypic young horse performance traits ranged from 0.88 to 1.00. For show jumping traits the genetic correlations between national EBVs in five European countries ranged from 0.45 to 0.91 in a study by Ruhlmann et al. (2009b). Between Sweden and Denmark the correlation was 0.86, which was lower than in this study (1.00). The difference can be explained by the lower genetic connectedness in the data in the study by Ruhlmann et al. (2009b). Ruhlmann et al. (2009a) estimated the genetic similarity to 16% between Sweden and Denmark, while the present study was based on the data by Furre et al. (in manuscript) that showed a genetic similarity of 57% between the same countries.

Genetic trend

As expected there was a more rapid genetic progress in the larger populations in Sweden and Denmark than in Finland and Norway. If the smaller populations would have access to more stallions with reliable EBVs the progress could be increased. Another reason for the low genetic progress in Norway is probably the low average PEC value that leads to more regressed EBVs. All trends were positive except for the downward trend for show jumping horses competing in Finland the two last years. This can probably be explained by a very good cohort born in 2003, and followed by an unstable trend with decreasing number of competing horses born 2004 and 2005.

Benefits of a joint Nordic evaluation

A joint Nordic genetic evaluation will dramatically increase the number of stallions with official EBVs that all Nordic countries can make use of. With a larger number of stallions with available and comparable breeding values the selection can be more accurate and more intense, leading to a larger genetic progress in all four countries. For example the number of show jumping stallions with EBV in Sweden increased by 47%, and in Norway where no stallion reached 15 competing offspring in dressage within Norway, 105 stallions received an EBV in a joint evaluation.

Including more offspring in genetic evaluation of stallions increases the accuracy of the EBV. In the study by Furre et al. (2013) of young horse test data from Sweden and Norway it was shown that a joint genetic analysis was beneficial for both the small Norwegian population as well as for the larger population in Sweden. For stallions with tested offspring in both populations, the average accuracy of estimated breeding values increased by 4% for SWB and by 110% for Norwegian Warmblood (NWB). Thorén Hellsten et al. (2009a) compared the reliabilities for national young horse performance EBVs and expected reliabilities for international EBVs estimated with multiple across country evaluation between Sweden and Denmark. For stallions with tested offspring in both countries the reliabilities increased by 0.05-0.16 units. The present study confirms that a joint evaluation can be beneficial to all the Nordic countries. In the national genetic evaluations in Sweden and Denmark there is a minimum of 15 tested offspring for stallions to receive an official EBV (Viklund, 2010; Bølling, 2011). Depending on what criterion was set concerning competing offspring within country and additional competing offspring in the other countries, the relative gain in average accuracy of EBV ranged from 2 to 244 %. All criteria with a total of 15 competing offspring gave a high average accuracy of joint Nordic EBV (0.88-0.93 for show jumping and 0.82-0.87 for dressage).

Future aspects

In the present study it has been shown that a joint Nordic genetic evaluation of riding horses would be beneficial to all Nordic countries. However, there are some aspects that have to be investigated before a routine genetic evaluation can be implemented.

Pre-selection is an important issue dealing with competition data. The selection can be based on pedigree, talent, interest, exports and use in breeding. In the future it would be necessary to investigate if a multi-trait model including also results from young horse tests in the Nordic countries can be used to reduce the effect of pre-selection. The young horse test data is less selected, and both dressage and jumping talent are evaluated for all horses, which should lead to reduced bias in the EBV. Moreover, the heritabilities are often higher for traits at young horse tests and the tests are more standardised than competitions.

In this study we excluded horses that had started at competition but that never had received points in order to make the data more comparable between countries. This increased the pre-selection of horses with results. In a possible future joint genetic evaluation with a multi-trait model these horses should be included again to reduce bias in EBVs.

When horses are imported for competition they are often selected on their talent. It is not possible to estimate an unbiased EBV for a foreign stallion if only the best offspring by the stallion are exported to the Nordic countries. The experiences in the Nordic Warmblood associations confirm that this is a problem that needs to be addressed in future studies.

Conclusions

The high genetic correlations between competition traits in the different countries confirm that competition performance is equally defined in the Nordic countries and can be treated as the same trait in a joint genetic evaluation.

A joint Nordic genetic evaluation for competition is recommended because it would result in many more available stallions with comparable EBVs for all countries. The EBVs could then also be estimated with higher accuracy earlier. For the smaller populations a joint evaluation is the only possibility to get comparable and reliable EBVs and access to those for a much larger population than from within country evaluations.

Additional studies are needed to investigate the effects of pre-selection or importation of horses for competition if an integrated index based on both competition and young horse test data should be implemented in the Nordic countries.

Intensified work to harmonize the ID of horses is needed to increase the pedigree completeness, especially for the Norwegian data.

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Table 1. Number of horses from each country included in the dataset, means, standard deviations (s.d.), minimum (min) and maximum (max) of 10-log transformed accumulated points in dressage and show jumping in Sweden (SWE), Denmark (DEN), Norway (NOR) and Finland (FIN)

Trait	no of horses	mean	s.d.	min	max
Show jumping					
SWE	22992	1.42	0.67	0.30	4.15
DEN	15141	1.57	0.75	0.30	4.41
FIN	3376	1.31	0.67	0.26	3.55
NOR	3094	1.47	0.53	0.70	3.25
Dressage					
SWE	10768	1.38	0.67	0.48	3.75
DEN	14608	1.45	0.71	0.30	4.50
FIN	2112	1.26	0.63	0.30	3.57
NOR	1873	1.27	0.52	0.70	3.39

Table 2. Genetic (σ_a^2) and residual (σ_e^2) variances, and heritabilities (h^2) for show jumping and dressage performance in the Nordic countries Sweden (SWE), Denmark (DEN), Norway (NOR), Finland (FIN) and for the joint Nordic data (Nordic). Standard errors are given in subscripts

	Show jumping			Dressage		
	σ_a^2	σ_e^2	h^2	σ_a^2	σ_e^2	h^2
SWE	$0.14_{0.01}$	$0.31_{0.01}$	$0.32_{0.02}$	$0.09_{0.01}$	$0.37_{0.01}$	$0.19_{0.02}$
DEN	$0.11_{0.01}$	$0.35_{0.01}$	$0.25_{0.02}$	$0.06_{0.01}$	$0.39_{0.01}$	$0.14_{0.02}$
FIN	$0.19_{0.03}$	$0.26_{0.02}$	$0.42_{0.06}$	$0.18_{0.03}$	$0.25_{0.03}$	$0.42_{0.07}$
NOR	$0.14_{0.04}$	$0.32_{0.04}$	$0.31_{0.08}$	$0.24_{0.06}$	$0.20_{0.05}$	$0.55_{0.12}$
Nordic	$0.12_{0.01}$	$0.33_{0.01}$	$0.27_{0.01}$	$0.07_{0.01}$	$0.38_{0.01}$	$0.16_{0.01}$

Table 3. Genetic correlations (r_g) with standard errors as subscripts and phenotypic correlations (r_p) between competition performance traits in the Nordic countries Sweden (SWE), Denmark (DEN), Norway (NOR) and Finland (FIN)

	Show jumping		Dressage	
	r_g	r_p	r_g	r_p
SWE – DEN	$1.00_{0.05}$[a]	0.33[a]	$0.94_{0.10}$	0.26
SWE - FIN	$0.82_{0.09}$	0.23	$0.63_{0.15}$	0.57
DEN - FIN	$0.78_{0.12}$	-0.02	$1.00_{0.14}$[a]	0.54[a]
SWE - NOR	$0.98_{0.21}$	0.35	$1.00_{0.20}$[a]	-0.09[a]
DEN - NOR	$0.73_{0.19}$	0.29	$1.00_{0.16}$[a]	0.44[a]
NOR - FIN	$0.95_{0.25}$	0.53	$1.00_{0.18}$[a]	0.54[a]

[a]lower convergence criteria was used (norm vector of $<10^{-5}$ instead of $<10^{-7}$)

Table 4. Accuracies for breeding values for <u>show jumping</u> estimated with data within country (r_{TI}(national)), with joint Nordic data (r_{TI}(Nordic)) and the relative gain in accuracy (r_{TI}gain) for stallions with different number of competing offspring in show jumping within country (SWE=Sweden, DEN=Denmark, FIN=Finland, NOR=Norway) and in the other Nordic countries

Stallion offspring criteria	N	r_{TI} (national)	r_{TI} (Nordic)	r_{TI} gain (%)
I. ≥1 within country and ≥15 in total in the Nordic countries				
SWE	143	0.65	0.90	38
DEN	117	0.62	0.90	45
FIN	182	0.58	0.89	53
NOR	144	0.50	0.90	80
II. ≥5 within country and ≥15 in total in the Nordic countries				
SWE	92	0.80	0.90	13
DEN	81	0.79	0.90	14
FIN	52	0.75	0.90	20
NOR	32	0.69	0.93	35
III. ≥10 within country and ≥15 in total in the Nordic countries				
SWE	67	0.87	0.92	6
DEN	84	0.84	0.90	7
FIN	18	0.82	0.93	13
NOR	13	0.76	0.93	22
IV. ≥15 in the Nordic countries				
SWE	305	0.73	0.88	21
DEN	305	0.65	0.88	35
FIN	305	0.50	0.88	76
NOR	305	0.36	0.88	244

Table 5. Accuracies for breeding values for dressage estimated with data within country (r_{TI}(national)), with joint Nordic data (r_{TI}(Nordic)) and the relative gain in accuracy (r_{TI}gain) for stallions with different number of competing offspring in dressage within country (SWE=Sweden, DEN=Denmark, FIN=Finland, NOR=Norway) and in the other Nordic countries

Stallion offspring criteria	N	r_{TI} (national)	r_{TI} (Nordic)	r_{TI} gain (%)
I. ≥1 within country and ≥15 in total in the Nordic countries				
SWE	112	0.49	0.83	69
DEN	91	0.47	0.85	81
FIN	146	0.52	0.82	58
NOR	100	0.53	0.84	58
II. ≥5 within country and ≥15 in total in the Nordic countries				
SWE	42	0.71	0.87	23
DEN	36	0.71	0.86	21
FIN	26	0.74	0.86	16
NOR	12	0.74	0.87	18
III. ≥10 within country and ≥15 in total in the Nordic countries				
SWE	38	0.80	0.88	10
DEN	53	0.76	0.84	11
FIN	10	0.80	0.88	10
NOR	3	0.83	0.85	2
IV. ≥15 in the Nordic countries				
SWE	241	0.58	0.82	41
DEN	241	0.58	0.82	41
FIN	241	0.44	0.82	86
NOR	241	0.35	0.82	234

Table 6. Number of stallions with at least 15 competing offspring within country (SWE=Sweden, DEN=Denmark, FIN=Finland, NOR=Norway), number of stallions with 1-14 competing offspring within country but a total of 15 competing offspring in the joint Nordic data and the total sum of stallions with at least 15 competing offspring

Country	≥15 competing offspring within country	1-14 competing offspring within country, ≥15 in total in Nordic countries	Total no of stallions
Show jumping			
SWE	311	146	457
DEN	184	134	318
FIN	20	202	222
NOR	5	144	149
Dressage			
SWE	179	120	299
DEN	199	79	278
FIN	9	151	160
NOR	0	105	105

Captions of figures

Figure 1. Genetic trends for horses competing in show jumping in the Nordic countries (SWE=Sweden, DEN=Denmark, FIN=Finland, NOR=Norway) based on joint Nordic genetic evaluation.

Figure 2. Genetic trends for horses competing in dressage in the Nordic countries (SWE=Sweden, DEN=Denmark, FIN=Finland, NOR=Norway) based on joint Nordic genetic evaluation.