Genetic analysis of competition traits in Icelandic Horses

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Licentiate thesis

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Abstract

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The aim of this thesis was to explore the basis for including competition traits in the genetic evaluations of the Icelandic horse. This evaluation is currently based on breeding field-test traits. For this purpose knowledge about genetic parameters of the competition traits, and of genetic relationships between competition traits and the breeding field-test traits was required.

A data-set including 18 982 records of 3790 horses competing in Iceland and Sweden 1998 – 2004 were analysed using linear animal models. The traits analysed were two different measures of four-gait, five-gait and tölt, and one pace trait. Additionally, new combined traits were formed and analysed in order to describe the competition traits in simpler manner. The estimated heritabilities were low to moderately high (0.18 – 0.35) for all competition traits. The genetic correlations estimated among competition traits (-0.42 – 1.00) were generally strong and favourable with a few exceptions.

Genetic relationships were estimated between breeding field-test traits and combined competition traits, along with one original competition trait (pace). The breeding field-test data included 16 401 individual records of Icelandic horses evaluated in 11 countries during 1990–2005. Furthermore, genetic parameters of the breeding field-test traits were reanalysed and confirmed earlier results. Moderate genetic correlations were estimated between most of the competition traits and some of the conformation traits judged in breeding field-tests. High genetic correlations were generally estimated between the competition traits and most of the riding ability traits recorded in breeding field-tests.

It was concluded that competition traits can be added to current genetic evaluations of the Icelandic horse. Heritability estimates and results from statistical analyses for the combined traits, indicated that these traits were the most promising kind to use to complement the genetic evaluation. The original competition trait, pace test, should also be included in the genetic evaluation. Relationships between competition traits and breeding field-test traits showed that information on competition traits could improve the accuracy of the genetic evaluation of the breeding field-test traits if the data are used simultaneously. However, a sufficient quantity of competition data needs to be made available in the future, and data collections should be standardized.

Keywords: Horse; Genetic evaluation; Breeding field-test; Competition; Genetic correlations; Iceland; Sweden.

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Contents

Appendix

Papers included in the thesis

The present thesis is based on the following publications, which will be referred to by their Roman numerals.

I. Albertsdottir, E., Eriksson, S., Näsholm, A., Strandberg, E., Árnason, Th. 2006. Genetic analysis of competition data on Icelandic horses. Livest. Sci., In press.

II. Albertsdottir, E., Eriksson, S., Näsholm, A., Strandberg, E., Árnason, Th. 2007. Genetic correlations between competition traits and traits scored at breeding field-tests in Icelandic horses. Submitted for publication.

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Introduction

Competitions for Icelandic horses are popular. Good competition horses, along with high-quality breeding horses, are the most valuable kinds of Icelandic horses.

The Icelandic horse breeding goal describes the horse as a multi-gaited riding horse for pleasure riding and sport competitions, suitable for adults and children. The breeding objectives include detailed definitions of the goal traits specifying eight conformation traits and eight riding ability traits that are measured in breeding field-tests. The selection of breeding horses is based on estimated breeding values calculated from records prepared in the course of these field-tests. However, the breeding objectives include no specifications of competition competence or the competition traits that define it, and no direct selection criterion is applied in the selection of competition horses.

According to animal breeding theory, it is important in obtaining the maximum genetic response, for breeding objectives to be well defined and to include details of all the traits that breeders wish to improve by genetic selection (Koenen, Aldridge & Philipsson, 2004). Given how popular and valuable competition horses are, and given statements in the general breeding goal concerning competition ability, competition traits should be included among the goal traits. Assuming that they are suitable, competition data should then be added to the genetic evaluations, thereby improving the selection criterion for breeding competition horses.

The inclusion of competition results in the genetic evaluation would make it possible to utilise very helpful source of information containing records on many new individuals, as a large proportion of competing horses are geldings which are never presented at breeding field-tests. The inclusion could give increased genetic response in these traits and bring economic benefits for people that are breeding competition horses

Background

The Icelandic horse is a unique and purebred horse. It is assumed that no horses have been imported into Iceland since the human habitation of the country in the late ninth century (Adalsteinsson, 1981). The selection of Icelandic horses has been driven for centuries by nature and more recently through extensive interference of humans. The rough Icelandic environment chiselled the horse's spirit and body and made it independent and robust with a strong and compact body. The multi-gaiting ability of the horse was then appreciated by humans as the horse's main purpose less than century ago, was to provide comfortable transportation in a country of sparse roads. Today, Icelandic horses are kept as riding horses in Europe and North-America, where the fine virtues of gaiting ability and temperament have made them favourites. In Sweden, for example the Icelandic horse has in few years become the third most common horse breed. The number of Icelandic horses worldwide is estimated to be around 200 000; about

75 000 of these are in Iceland. Every year horses are exported from Iceland, but all import of livestock to Iceland, including horses, are forbidden. This is a long-standing policy.

Most known horse colours and markings can be observed in the Icelandic horse. Individuals measured at the highest point of withers range from 125–145 cm. The horse's life span is up to 30 years. Overall good health and high fertility are recognised. The horse matures slowly and generally attains full size at the age of six years. The training (riding) of horses starts from four years of age. At that age, initial assessments at breeding field-tests can be carried out.

Almost all Icelandic horses have four gaits: walk, tölt, trot and gallop. A fifth gait is pace. Many individuals show this in addition to the other four gaits. Horses that only show walk, tölt, trot and gallop are called 'four-gaiters' but those that also show pace are called 'five-gaiters'. Pacing ability is considered to be a threshold trait: horses that do not surpass the genetic threshold for pacing ability do not show pace (Árnason & Sigurdsson, 2004). On the other hand, many horses with the genetic ability to pace are not trained to pace. This is mainly for two reasons. First it is believed that pace training may impair the valuable tölt gait; and second, four-gaiters are considered easier to ride and for this reason they are often preferred as riding horses for beginners and amateur riders. Good temperamental qualities are sought after in the breed; the horse ought to be suitable for riders of all ages and skills.

The Breeding organisation

Breeding goal

In 1891 organised breeding of Icelandic horses was officially established when first law covering breeding in Iceland was introduced on the Althingi. In 1902 the Agricultural Society of Iceland began to offer advisory service in animal breeding and since 1904 numerous horse breeding associations have operated in the country. A unique breeding assessment system was established in 1950 with a scoring index for registration of individual traits on a linear scale; the traits are judged in breeding field-tests (Árnason et al, 1994; Hugason, 1994). Ever since, this system has undergone continuous development where marketing objectives, among other things, are considered; affecting what traits are included in the breeding objectives and their weighting proportions. The assessment system became international with a 2004 declaration in which Iceland was recognised as the country of origin of the Icelandic horse. At this point the 18 member nations of FEIF (The International Federation of Icelandic Horse Associations) outside Iceland agreed to follow Iceland's lead in carrying out the official breeding goal that is described in *Icelandic horse breeding* (FEIF, 2004a).

The official overall breeding goal states the Icelandic horse should have five good gaits and an excellent temperament. Conformation should be well suited for riding and aesthetically appealing. Traits such as health, fertility, and size are also defined in the breeding goal. In the breeding objectives, where a detailed description of conformation and riding ability traits is included, strong emphasis is put on performance ability. The traits, tölt, general impression, spirit and pace are underlined. By contrast, competition competence is not specified.

Selection programme

There are very few limits, in the international breeding assessment system, on which animals can be used in breeding. The only requirement is that animals should be purebred Icelandic horses all of whose registered pedigree paths are traceable back to Icelandic ancestors. Different FEIF member nation's can, however, place special constraints on their own breeding. In Sweden, for instance, only approved stallions may be used in breeding; Breeding stallions of five years and older need to have attained a certain minimum total score in breeding field-tests, and stallions younger than this must have a certain minimum estimated breeding value. In Iceland, however, no requirement of this sort is made on breeding horses. Instead, marketing objectives and the shared extensive knowledge of horse people associated with the breeding organisation, together ensure that horses are used sensibly in breeding.

The first selection indices were constructed in 1975 for mass selection and progeny testing; they were based on estimated genetic parameters from genetic analyses, initially on body measurements and later on records from breeding field-test (Árnason, 1979). Since then records from breeding field-tests have been re-analysed number of times and a practical procedure for BLUP multi-trait animal model (MT-AM) evaluation of the breeding stock has been developed (Árnason, 1982, 1984).

Optimal selection strategies for the Icelandic horse population were studied by Hugason, Árnason & Norell (1987) who consider three-stage selection of stallions. The main conclusions from this study were as follows. Approximately 25% of breeding mares should be covered by young stallions with an outstanding pedigree index based on the performance of parents, 50% by performance-tested stallions selected on an index combining parental and own records, and the remaining 25% by the very best progeny tested stallions selected on an index combining records of parents, of the individual itself and of progeny average. Hugason, Árnason & Norell also concluded that selection on the basis of estimated breeding values using the BLUP method across stallion age classes would result in genetic gain close to the maximum. Therefore breeders have been encouraged to make use of the estimated breeding values (BLUP) in their selection decisions. The distribution across the three stages in the population has, furthermore, been found to be very satisfactory in practice (Hugason, 1994); and according to Árnason, Sigurdsson & Lorange (2006) the genetic response in the total score over the last fifteen years is equal to one additive genetic standard deviation. Every year a guideline on the selection of breeding horses is published on the Internet and presented at several educational meetings. Here horses are ranked according to estimated breeding values from a total score that reflects the overall breeding goal. The total score comprises of fifteen traits judged at breeding field-tests with relative weightings. Breeding values are also presented for each of the fifteen traits, along with height at withers, which gives breeders an opportunity to emphasise traits of their own choice. Breeders are urged to have a large number of probable breeding horses evaluated at breeding field-tests when the horses are as young as possible. This ensures that genetic variance in the population is reflected as well as it can be, which in turn gives more reliable estimates of breeding values.

Genetic evaluation

The Icelandic horse was the first animal on which a multivariate BLUP animal model was used for the estimation of breeding values (Árnason, 1984). The breeding values have been computed annually with this method since 1983. Until 1995, it was only records from breeding field-tests run in Iceland that were used. From that point on, records from breeding horses evaluated in Denmark, Sweden and Norway were also included, and since 2005 genetic evaluations have been based on records from breeding field-tests run in 11 countries: Iceland, Austria, Denmark, Finland, Germany, Great Britain, Norway, Sweden, Switzerland, The Netherlands, and The United States of America. International genetic evaluation of this sort requires unique identification numbers, good genetic connectedness among countries and a properly synchronised cross-border assessment system carried out by qualified judges who have been authorised to operate (Árnason & Ricard, 2001; Bruns, Ricard & Koenen, 2004).

The latest breeding values for Icelandic horses can be accessed on the Internet database at www.worldfengur.com. There, information is connected to unique ID-numbers which have been assigned to each horse. Additional information about records from breeding field-tests (since 1961), pedigree and progeny information, colour of horse, breeder, owner's history, DNA sequences, identification marks (microchip and/or freeze mark) and records of certain health features is also covered by the database (Árnason, Sigurdsson & Lorange, 2006).

Breeding field-tests

To date more than 25 000 Icelandic horses have been evaluated in breeding field-tests. Three authorised judges evaluate stallions, geldings and mares in separate age-classes (4, 5, 6 and >6 years old) in field-tests done over the course of 1–2 days (FEIF, 2005). There is no limit on how many times a horse can participate at breeding field-tests (also within a year), but only the highest age-corrected total score of each individual is used in the prediction of breeding values. All horses presented at breeding field-tests have to be both registered in the WorldFengur database and individually marked (micro-chipped or freeze-marked). Additional identification rules apply to stallions where parental proof, either by blood type or DNA analysis, is required. All horses must pass a general veterinary examination before they can be presented at international breeding field-tests. Additional health tests are performed on stallions. In connection with fertility, the testicles are palpated and measured, and in order to detect bone spavin a radiographic examination is required before stallions (of five years and older) are assessed for the first time in field-tests. To provide information for breeders, records from both these tests are registered in WorldFengur (FEIF, 2004a).

The breeding field-tests begin by measuring various body parts of the horse (e.g. height of withers in cm). Following this the horse's conformation is assessed, and lastly, riding ability traits shown on a straight track are scored. A second assessment (an overview show) of the riding ability traits is available. This assessment is optional and is rarely made on the same day as the first assessment. The purpose here is to give the riders an opportunity to highlight the good qualities of their horses or to improve any unsuccessful performance from the previous demonstration. Scores are never reduced to a level below that given on the first assessment. There are no requirements on which riders show horses at breeding field-tests, but breeding horses are commonly shown by professional riders in order to secure the best possible results. Only minimal riding equipment is allowed in the breeding field-tests. In total eight conformation traits (head; neck, withers and shoulders; back and hindquarters; proportions; leg quality; leg stance; hooves; mane and tail), and eight riding ability traits (slow tölt; tölt; trot; pace; gallop (and canter); spirit; general impression; walk) are scored (FEIF, 2005). All traits are judged on a rising scale of 5–10, and if a trait is not shown it is awarded the minimum score of five.

The individual breeding field-test traits are goal traits. They are weighted and joined to produce a total score – except, that is, for slow tölt and canter, which only indirectly influence judgment of the tölt and the gallop. Conformation traits weigh 40% and riding ability traits weigh 60%. This demonstrates the strong emphasis that is placed on performance ability in the breeding goal. In Table 1 the weighting proportions on the different traits measured in breeding field-tests are presented. The table indicates the significance of each trait in the overall breeding goal.

Table 1. Weighting proportions of traits measured in breeding field-tests

Conformation traits		Riding abilities	
Head	3%	Tölt	15%
Neck, withers and shoulders	10%	Trot	7.5%
Back and hindquarters	3%	Pace	9%
Proportions	7.5%	Canter/gallop	4.5%
Leg quality	6%	Spirit	12.5%
Leg stance	3%	General impression	10%
Hooves	6%	Walk	1.5%
Mane and tail	1.5%		

Competitions for Icelandic horses

Special competitions for Icelandic horses are popular in Western Europe. The two main types of competition are sport and gæðinga competitions. The former one follows the standardized international rules (FIPO) described in *Rules for Icelandic Horse Competitions* (FEIF, 2005). The latter is practised mostly in Iceland and follows the Icelandic rules *Gæðingakeppni competition* (FEIF, 2004b). Three or five authorized officials judge the sport and gæðinga competitions. Horses of five years or older registered in the WorldFengur database are allowed to compete.

The competitions involve several disciplines in which the horses are ridden in the various gaits (tölt, the four-gaits or the five-gaits) on an oval track. One sport discipline (pace test) takes place on a straight track, however. In gæðinga competitions, which are becoming increasingly popular in European countries outside Iceland, general impression and spirit are judged in addition to the quality of gaits. In sport competitions the quality of the gaits, and also various technical features of the performance, are important. Otherwise these two forms of competition do not differ from each other. In sport competition disciplines, three levels of participation are available. Some of these are open to anyone to compete in, whereas others require the equipage to have achieved a certain minimum score at the open levels. Upgrading rules are applied that prohibit equipages fulfilling the given requirements several times, to compete at the open levels. Special "light" (i.e. easier) disciplines in sport competitions are practised in Sweden. They are designed for beginners in the Icelandic horse sport, and they do not follow international sport rules. However, the upgrading rules that apply in "light" disciplines are similar to those applying at different levels. One further form of competition exists; the pace racing competition. There horses compete in racing pace on a straight track of different lengths. Time in seconds is measured; the shortest time achieved is the best result.

To gain best possible results in competition, it is necessary to demonstrate a high quality of performance ability with great precision. As a result of this, competition horses are often older and more thoroughly trained than the horses presented at breeding field-tests. Young horses often lack strength and training and are therefore shown with slight imperfections in performance. Such flawed performance (even when accompanied by a high quality of gaiting ability, general impression and spirit) is harshly penalised in competitive scoring. In breeding field-tests, by contrast, the assessors strive to detect the real underlying quality of the horse, and it is recognised that this may be demonstrated with trivial defects. It is to be expected, then, that scoring in competitions involving young, or inexperienced horses will often give skewed results so far as the evaluation of the real quality of horses is concerned. It can also be safely assumed that competition horses are more selected individuals than breeding horses. Competition horses are expected to be potential winners, whereas it is underlying evaluations of gaiting ability, general impression and spirit that are presented at breeding field-tests.

These assumptions about age and selection make competition records less suitable as a basis of genetic evaluation, than records from breeding field-tests. In the former we see longer generation intervals and a biased expression of genetic ability (Tavernier, 1991). However, considering the breeding goal and how valuable good competition horses are, it would seem to be appropriate to include competition data in genetic evaluations, given their suitability; thereby improving the selection criterion for breeding competition horses.

Competition traits in Icelandic horses have not been the subject of genetic analysis besides the genetic analysis made on Icelandic horse competition data presented in Paper I, and a pilot study made by Ragnarsson (2001) on pace racing traits.

Competition traits in other horse breeds

In Europe many breeding organisations run selection programmes for Warmblood riding horses. The aim is to produce high quality competition horses, mainly in dressage and jumping. Competition data have therefore been studied to a great deal in the breeds (Huizinga, Boucamp & Smoulders, 1990; Tavernier, 1991; Tavernier, 1992; Foran et al., 1995; Schade, 1996; Brockmann & Bruns, 1997; Janssens, Geysen & Vandepitte et al., 1997; Van Veldhuizen, 1997; Brockmann, 1998; Bruns & Schade, 1998; Reilly et al., 1998; Ricard, 1998; Hassenstein, Roehe & Kalm, 1999; Ricard, Bruns & Cunningham, 2000; Wallin, Strandberg & Philipsson, 2001; Gelinder et al., 2002; Wallin, Strandberg & Philipsson, 2003; Koenen, Aldridge & Philipsson, 2004; Langlois & Blouin, 2004; Olsson, 2006; Thorén et al., 2006). Belgium, France and Ireland base their genetic evaluation for Warmblood riding horses on competition data, Denmark uses performance test results and Germany and The Netherlands combine competition and test results (Bruns, Ricard & Koenen, 2004). Since 2005 Sweden has included competition results in the genetic evaluation of the Swedish Warmblood breed that was previously based only on performance results (Olsson, 2006).

Koenen, Aldridge & Philipsson (2004) reviewed the current breeding objectives for Warmblood sport horses in a number of countries. They came to the conclusion that breeding organisations sometimes assigned high weightings to traits that were not defined in the breeding objective and the traits in the breeding objectives often lacked detailed definitions. Additionally, the breeding objectives were often deficient in specifying what kinds of performance they included: neither the sport discipline nor the level of competition at which the horse was to compete were defined. Koenen, Aldridge & Philipsson concluded that this was an inadequate approach – if at any rate, the gaining of maximum genetic response was required. According to the authors optimising selection strategies involves clear and well-accepted breeding objectives that include well defined traits of interest with detailed description and relative weightings.

Objectives of the thesis

The aim of this thesis was to explore the basis for including competition traits in the genetic evaluations of the Icelandic horse. For this purpose, knowledge about the genetic parameters of the competition traits was required. Additionally, the relationships between competition traits and the breeding field-test traits that genetic evaluation is currently based on were studied.

Summary of investigations

Material

In Paper I competition data, including data on ten competition traits – both original and combined ones, were analysed. In Paper II competition data and breeding field-test data were analysed. There data related to four competition traits (one original and three combined traits) and seventeen breeding field-test traits.

Competition data

Internationally standardised competition data for Icelandic horses was collected from The National Association of Riding Clubs in Iceland and The Swedish Icelandic Horse Association. The data from the two countries were merged on the basis of strong genetic correlations between similar competition traits in Iceland and Sweden, and similar means and standard deviations in Icelandic and Swedish competition data. The data included competition results from sport and gæðinga competitions from the period 1998 to 2004 with a total of 18 982 records of 3790 horses in 379 different events. An insufficient quantity of data was available from pace racing competitions, so these were not included in the analyses.

Seven original competition traits were studied. These included five disciplines from sport competition: tölt (T1 and T2), four-gait (V1), five-gait (F1) and pace (PP1); and two disciplines from gæðinga competitions: four-gait (B-Class) and five-gait (A-Class). Additionally, three combined competition traits were formed and analysed including: tölt(comp), 4-gait and 5-gait. The combined traits were formed by merging highly correlated and similar traits in order to simplify the competition traits. Tölt(comp) was a combination of the tölting disciplines (T1 and T2), 4-gait was a combination of the four-gaited disciplines (V1 and B-Class) and 5-gait was a combination of the five-gaited disciplines (F1 and A-Class). In the four-gaited tests the traits walk, tölt, trot and gallop are exhibited, and in the five-gaited tests pace is exhibited in addition to the other four gaits. The tölt and the pace disciplines are performances of these single gaits, respectively. Scores that are given for gæðinga competition traits range from 5 to 10. For sport competition traits the range is from 0 to 10. For the combined traits scores from original traits were standardised to approximately 0 mean with a standard deviation of 1. All traits were normally distributed, based on estimated skewness and kurtosis.

Breeding field-test data

Records from breeding field-tests were collected from the global database WorldFengur (www.worldfengur.com). 16 401 individual records from horses tested in 11 countries between 1990 and 2005 were included. For all traits, except the pace, all available records were used in the genetic analysis. For the pace trait two sets of records were used: all records and records ≥ 5.5 (i.e. records equal to 5 were excluded). This decision was made because the aim was to examine possible difference in genetic parameters. It is believed that the score of 5 provides a skewed estimate of pacing ability that may reflect not just a genuine lack of pacing ability but also the decision of the rider not to show the pace despite the horse's ability to pace (Árnason & Sigurdsson, 2004). In the thesis, however, only results from analyses with the latter data-set are presented.

The traits studied were as follows: height of withers; mane and tail; head; neck; withers and shoulders; back and hindquarters; proportions; leg quality; leg stance; hooves; walk; slow tölt; tölt; trot; pace; gallop; general impression and spirit.

Pedigree data

Relevant pedigree information from the international Icelandic horse database included 10 generations. In Paper I a total of 12 324 individuals were included and in Paper II a total of 30 198 individuals were included. Pedigrees for all horses with data in the database can be traced back to Icelandic founders (Árnason, Sigurdsson & Lorange, 2006).

Methods

Statistical models

In Paper I statistical models for the competition traits were evaluated using the GLM procedure in the SAS package (SAS Institute Inc., 2004). The fixed effects of age, sex and event were statistically significant on all competition traits. Level of discipline was statistically significant for four of the original sport traits (T1, T2, V1 and F1). The models used for the genetic analysis also included the random additive genetic effect of the horse, the random permanent environmental effect and the random residual effect.

In Paper II the model that had been used in Paper I was used again for the competition traits. For the breeding field-test traits, the model that is used in the current genetic evaluation, was used (Árnason & Sigurdsson, 2004). This model included two fixed effects: age by sex interaction and year by country interaction. It also included the random additive genetic effect of the horse and the random residual effect.

Estimation of genetic parameters

In both Paper I and Paper II genetic parameters were estimated using the DMU package (Jensen & Madsen, 2000). Analyses were performed with univariate and bivariate models. Variance and covariance components were estimated using the average information (AI) algorithm for restricted maximum likelihood and the asymptotic standard error of (co)variances component was computed from the inverse AI matrix. Heritabilities were calculated as $\sigma^2_a/(\sigma^2_a+\sigma^2_{pe}+\sigma^2_e)$ and repeatabilities were calculated as $(\sigma^2_a+\sigma^2_{pe})/(\sigma^2_a+\sigma^2_{pe}+\sigma^2_e)$. Standard errors of the heritabilities and repeatabilities were computed with a Taylor series expansion. Residual correlations between breeding field-test traits and competition traits were constrained to zero, as almost no horses participated both in breeding field-tests and competitions.

Main findings

The main results on heritabilities and genetic correlations between traits included in the present thesis (originally reported in Paper I and Paper II) are summarised below in Table 2 and Table 3.

Heritabilities and genetic correlations among competition traits

Heritabilities for competition traits in Paper I estimated with univariate and bivariate analyses were very similar (Table 2). Estimated heritabilities for sport competition traits ranged between 0.18 and 0.23, and for gæðinga competition traits between 0.33 and 0.35. Heritabilities estimated for the combined competition traits ranged between 0.19 and 0.22. Standard errors for estimated heritabilities of competition traits ranged between 0.05 and 0.23, where the highest values were observed for the gæðinga competition traits (0.21 and 0.23).

In Paper II heritabilities estimated for competition traits from bivariate runs where one competition trait and one breeding field-test trait were included depended heavily on whether or not the relevant traits were strongly correlated. When the traits were correlated, higher heritability estimates for competition traits were found (Table 2).

Genetic correlations within sport competition traits (T1, T2, V1 and F1) were 0.63 to 0.96. The highest values here were observed between T1 and V1 (0.85), T2 and F1 (0.96) and F1 and PP1 (0.93). Genetic correlation between the gæðinga competition traits (A-Class and B-Class) were estimated at 0.43. Between comparable sport and gæðinga competition traits strong correlations were estimated: B-Class to T1, T2 and V1 (0.93 – 1.00), and A-Class to F1 and PP1 (0.94 – 0.97). Genetic correlations between combined competition traits reflected estimated genetic correlations between original trait pairs, ranging between 0.62 and 0.90. However, genetic correlations estimated among combined traits had lower standard errors, than standard error for genetic correlations estimated among the original traits. The only weak genetic relationships observed within competition traits were between the pace test (PP1) and all original and combined competition traits expressing tölt (T1, T2 and Tölt(comp)) and four-gait (V1, B-Class and 4-gait).

Table 2. Summary of estimated heritabilities on competition traits with standard errors within parentheses in paper I and II

	Heritability	
Competition traits	Paper I	Paper II
T1	0.18 (0.05)	
T2	0.23 (0.14)	
V1	0.19 (0.05)	
F1	0.19 (0.07)	
PP1	0.21 (0.11)	0.17-0.24
B-Class	0.33 (0.21)	
A-Class	0.35 (0.23)	
Tölt(comp)	0.19 (0.05)	0.18-0.37
4-gait	0.22 (0.05)	0.21-0.44
5-gait	0.22 (0.07)	0.20-0.42

Heritabilities and genetic correlations among breeding field-test traits

In Paper II the heritabilities estimated for breeding field-test traits in univariate and bivariate analyses were similar. Estimated heritabilities from univariate analyses for breeding field-test traits ranged between 0.20 and 0.67; the highest estimates here were for height of withers (0.67) and mane and tail (0.46). In Paper II, estimated heritabilities for breeding field-test traits from bivariate analyses with competition traits did not differ much from the results from univariate analysis, although, modest increases were observed in heritability estimates for breeding field-test traits when they were analysed with highly correlated competition traits.

Genetic correlations between conformation traits varied between -0.07 and 0.69, with moderately strong correlations (0.32 – 0.69) being estimated in general among the following conformation traits: height of withers; head; neck, withers and shoulders; back and hindquarters; and proportions. These conformation traits often showed moderately strong genetic correlations (0.17 – 0.54) with the following riding ability traits: slow tölt, tölt, gallop, spirit and general impression. Otherwise genetic correlations between conformation traits and riding ability traits ranged from -0.21 to 0.54. Conformation traits other than those mentioned above did not generally associate among themselves, showing only weak genetic correlations. Genetic correlations among riding ability traits varied between -0.22 and 0.92, but they were estimated between most of the riding ability traits as moderate or strong (0.31 – 0.92). The trait walk, however, showed only weak genetic correlations (-0.22 – 0.29) with other riding ability traits, and a similar pattern was observed between the pace trait and most of the other riding ability traits.

Correlations between breeding field-test traits and competition traits

In Paper II genetic correlations were estimated between the three combined competition traits, tölt(comp), 4-gait and 5-gait, and one original sport competition trait, the pace test (PP1) and the breeding field-test traits (see Table 3). Moderately strong genetic correlations were generally estimated between the competition traits and the following conformation traits recorded in breeding field-tests: neck, withers and shoulders; back and hindquarters; proportions; and hooves. The combined competition traits, tölt(comp), 4-gait and 5-gait, showed high positive genetic correlations with the breeding field-test traits, slow tölt, tölt, trot, gallop, spirit and general impression. The combined traits, 4-gait and 5-gait, showed moderately high genetic correlations with walk. The trait 5-gait at competition was highly genetically correlated with pace recorded in breeding field-tests. Moderately high genetic correlations were estimated between the competition trait, pace test (PP1), and the breeding field-test traits, tölt, pace, spirit and general impression.

Table 3. Genetic correlations (with S.E. in parenthesis) between competition traits and breeding field-test traits from bivariate analyses

Trait	Tölt(comp)	4-gait	5-gait	PP1
Height of withers	0.15 (0.09)	0.15 (0.09)	0.14 (0.10)	0.38 (0.15)
Mane and tail	0.08 (0.10)	0.09 (0.09)	0.22 (0.11)	0.07 (0.15)
Head	0.28 (0.09)	0.23 (0.10)	0.24 (0.11)	-0.05 (0.15)
Neck, withers and shoulders	0.52 (0.08)	0.41 (0.08)	-0.05 (0.18)	0.29 (0.14)
Back and hindquarters	0.41 (0.10)	0.29 (0.10)	0.54 (0.12)	0.26 (0.15)
Proportions	0.39 (0.09)	0.32 (0.09)	0.45 (0.11)	0.17 (0.14)
Leg quality	0.06 (0.09)	0.15 (0.09)	0.03 (0.10)	0.01 (0.14)
Leg stance	-0.03 (0.11)	-0.07 (0.11)	-0.24 (0.12)	0.13 (0.17)
Hooves	0.52 (0.09)	0.45 (0.09)	0.39 (0.11)	0.41 (0.16)
Slow tölt	0.93 (0.06)	0.89 (0.55)	0.73 (0.10)	0.34 (0.18)
Walk	0.23 (0.12)	0.71 (0.08)	0.51 (0.14)	-0.10 (0.18)
Tölt	0.96 (0.03)	0.87 (0.04)	0.84 (0.08)	0.55 (0.15)
Trot	0.91 (0.05)	0.95 (0.04)	0.79 (0.08)	0.16 (0.16)
Pace (records ≥ 5.5)	0.38 (0.11)	0.12 (0.11)	0.86 (0.08)	0.83 (0.15)
Gallop	0.93 (0.06)	0.90 (0.05)	0.65 (0.11)	0.36 (0.17)
Spirit	0.94 (0.04)	0.87 (0.04)	0.79 (0.09)	0.43 (0.15)
General impression	0.88 (0.05)	0.75 (0.06)	0.83 (0.08)	0.68 (0.20)

General discussion

Heritabilities and genetic correlations among competition traits

The combined traits were the most stable in statistical analyses: heritability estimates for them indicate that these traits are the most promising competition traits on which to base genetic evaluation. Furthermore, genetic correlations between the combined traits were estimated with greater precision, thereby giving a more reliable and useful pattern of results. The combined traits may be more readily accepted by the breeders and trainers of Icelandic horses: they describe competition traits in a simpler manner than the original traits, expressing different aptitudes of competing horses, i.e. four-gaited (4-gait), five-gaited (5-gait) or tölting (tölt(comp)) horses. In addition to the combined traits PP1 could be used in the genetic evaluation to describe the competition aptitude of pacing horses.

Problems arising from selection accompany the use of competition traits in genetic evaluations. The alleged selection leads to incomplete expression of the genetic variation of competing horses, which gives biased genetic parameters of competition data such as underestimated heritabilities. However, this study showed that when strongly related breeding field-test traits and competition traits are analysed together, the estimated heritabilities of the competition traits becomes higher. This indicates that less selected breeding field-test data diminish the effect of selection reducing genetic variance in the competition data. Given this, the use of both data-sets simultaneously in prediction of breeding values is supported. Genetic evaluations based on records both from breeding field-tests and competitions would reflect more appropriately the breeding goal of producing good riding horses with performance ability measured in early testing at breeding field-tests and in later competitions. Subsequently, competition traits should be specified and defined as goal traits.

Heritabilities and genetic correlations among breeding field-test traits

Estimated genetic parameters for the breeding field-test data were consistent with earlier results obtained by Árnason & Sigurdsson (2004). In that study, breeding field-test records from 1990–2003 were used. These records comprise data-set that is similar to and overlaps with the one used in the present study.

Correlations between competition traits and breeding field-test traits

Estimated genetic correlations between breeding field-test traits and competition traits confirm that comparable traits are evaluated similarly in field-tests and competition, and that both sets of traits are controlled to a great deal by the same genes.

A similar pattern was observed in genetic correlations between conformation traits recorded at breeding field-tests and performance ability in both competition and breeding field-tests. Conformation traits that reflect beautiful and sound qualities of the horse relate to gaiting ability, spirit and general impression. One conformation trait, hooves, behaved in a different way when it was compared with the performance traits in competition or in breeding field-tests: genetically, hooves correlated more strongly with the competition traits. This perhaps underlines the importance of having good quality hooves in durable competition horses.

Moderate to high favourable genetic correlations were estimated between most of the riding ability traits in breeding field-tests and the competition traits. This, shows that performance ability is evaluated similarly in both breeding field-tests and competitions.

Future genetic evaluations

The use of competition traits in the genetic evaluation of Icelandic horses would involve the utilization of a new information source. This source would include records relating to many new individuals, as a large number of competition horses are geldings, and geldings seldom participate in breeding field-tests. The inclusion of competition traits in the genetic evaluation is expected to increase reliability of the prediction, as competition traits add information relating to the breeding goal. This inclusion could therefore bring considerable economic benefits, because good competition horses are valuable and much sought-after by riders.

Selection in Icelandic horse competition-data is not as big a problem as first believed since its effect decreases considerably when analysed with less selected data – breeding field-test data.

Conclusions

- Competition traits are suitable for genetic selection.
- The results from present study confirm that competition traits and riding ability traits from breeding field-tests are closely genetically correlated.
- Selection bias in the estimation of genetic parameters of competition data diminishes when highly correlated competition traits are analysed simultaneously with breeding field-test traits.
- Including competition traits in the genetic evaluation would be beneficial, because these traits add information related to the breeding goal.
- If competition traits are to be included in the genetic evaluation of the Icelandic horse, a sufficient quantity of competition data needs to be made available in the future, and data collection should be standardized.

Future research

In future, competition traits should be incorporated in the current genetic evaluation where genetic evaluation performed simultaneously on both breeding field-test traits and competition traits is the best option. This will require current computational models and programmes to be developed. It will also require a practical multi-trait animal model procedure that is capable of genetically evaluating 13 correlated breeding field-test traits and 4 correlated competition traits and utilises estimated genetic correlations between the field-test traits and the competition traits.

The possible economic benefits of such genetic evaluation, and its delivery of genetic gain in both breeding field-test traits and competition traits should also be studied.

Records form pace racing competitions should be genetically analysed to find out whether they are suitable to include in the genetic evaluation along with other competition traits.

References

Adalsteinsson, S., 1981. Origin and conservation of farm animal populations in Iceland. J. *Anim. Breed. Genet.* 98, 258–264.

Árnason, Th., 1979. Studies on traits in the Icelandic toelter horses. *J. Agr. Res. Icel.*, 11, 81–102.

Árnason, T., 1982. Prediction of breeding values for multiple traits in small non-random mating (horses) populations. *Acta Agric. Scand*., 32, 171–176.

Árnason, T., 1984. Genetic studies on conformation and performance of Icelandic Toelter horses: IV Best linear unbiased prediction of ten correlated traits by use of an animal model. *Acta Agric. Scand*. 34, 450–462.

Árnason, Th., Jensen, P., Klemetsdal, M., Ojala, J., Philipsson, 1994. Experience from application of animal breeding theory in Nordic horse breeding. *Livest. Prod. Sci*. 40, 9–19.

Árnason, T., Ricard, A., 2001. International genetic evaluations of the Icelandic horse. 55th Annual Meeting of the EAAP, Bled, Slovania, September 5–9. Paper HG5.3.

Árnason, T. and Sigurdsson, A 2004. International genetic evaluations of the Icelandic horse. 55thAnnual Meeting of the EAAP, Bled, Slovania, September 5–9. Paper HG5.3.

Árnason, T., Sigurdsson, Á., Lorange, J.B., 2006. Global genetic evaluations of the Icelandic horse and genetic connectedness between countries. In: Proceedings of the 8th World Congress on Genetics Applied to Livestock Production, Bello Horizonte, MG. Brazil, August 13–18, 2006. Paper 24–16.

Brockmann, A., Bruns, E., 1997. Estimation of genetic parameters with data from competitions for young dressage horses. 48th Annual Meeting of the EAAP. Vienna, 25–28. August. Session V.

Brockmann, A. 1998. Entwicklung einer Eigenleistungsprüfung im Feld für Hengste unter Berücksichtigung der Turniersportprüfung. Dissertation Göttingen, 1998.

Bruns, E and Schade, W., 1998. Genetic value of various performance test schemes of young riding horses. Proc. 6th World Congress Genetic Applied to Livestock Production, Armidale, Australia, 1998. 4pp.

Bruns, E, Ricard, A., Koenen, E., 2004. Interstallion – on the way to an international genetic evaluation of sprot horses. 55th Annual Meeting of the EAAP, Bled, Slovenia, September 5-8, 2004. Paper HS5.

FEIF (The International Federation of Icelandic Horse Associations)a, 2004. Icelandic Horse Breeding – Official definition, rules and approved information 1. / 2000. ((on line) URL: http://www.feif.org/englisch/frameset_englisch.html; 24–11–2004).

FEIF (The International Federation of Icelandic Horse Associations)b, 2004. Gæðingakeppni competition – Icelandic Rules set by LH 2003 (FIPO 9.2). ((on line) URL: http://www.feif.org/englisch/frameset_englisch.html; 24–11–2004).

FEIF (The International Federation of Icelandic Horse Associations), 2005. FIPO – Rules for Icelandic Horse Competitions 6.5 /2005. ((on line) URL: http://www.feif.org/pdf/fipo05e.pdf; 10–10–05)

Foran, M.K., Reilly, M.P., Kelleher, D.L., Langan, K.W., Brophy, P.O. 1995. Genetic evaluation of show jumping horses in Ireland using ranks in competition. 46th Annual meeting of the EAAP. Prague, Czech Republic, 4–7 September. Paper H4.1.

Gelinder, Å., Thorén, E., Näsholm, A., Philipsson, J., 2002. Relationships between test results at 3 and 4 years of age for Swedish riding horses. 53rd Annual Meeting of the EAAP, Montpellier, France, 19–23 August. 4pp.

Hassenstein, C., Roehe, R., Kalm, E., 1999. Genetic statistical analysis of new traits in performance tests of riding horses – 1 communication: Development of traits and estimation of heritability. *Züchtungsk. 71,* 106–117.

Hugason, K., Árnason, Th., Norell, N., 1987. Efficiency of three-stage selection. *J. Anim. Breedg. Genet.* 104, 350–363.

Hugason, K., 1994. Breeding of Icelandic toelter horses: an overview. *Livest. Prod. Sci*. 40, 21–29.

Huizinga, H.A., Boucamp, M. and Smolders, G., 1990. Estimated parameters of field performance testing of mares from the Dutch Warmblood riding horse population. *Livest. Prod. Sci*. 26, 291–299.

Janssens, S., Geysen, D., Vandepitte, W., 1997. Genetic parameters for show jumping in Belgian sporthorses. 48th Annual Meeting of the EAAP, Vienna, 25–28 August. 5pp.

Jensen, J., Madsen, P., 2000. In: A user's guide to DMU. A package for analyzing multivariate mixed models, Danish Institute of Agricultural Sciences. Research Centre Foulum, Denmark, p 18.

Koenen, E.P.C., Aldridge, L.I , Philipsson, J., 2004. An overview of breeding objectives for warmblood sport horses. *Livest. Prod. Sci*. 88, 77–84.

Langlois B. and Blouin C., 2004. Practical efficiency of breeding value estimations based on annual earnings of horses for jumping, trotting, and galloping races in France. *Livest. Prod. Sci*. 87, 99–107.

Olsson, E. 2006. Multi-trait evaluation of Swedish Warmblood stallions at station performance including field and competition records. Publication no. 144 at the Department of Animal Breeding and Genetics, Swedish University of Agricultural Sciences. Licentiate thesis

Ragnarsson, S., 2001. Mat á arfgengi skeiðflýtis og áhrif umhverfisþátta [Estimation of the heritability of pace-racing speed and the effect of environmental factors]. B.Sc thesis, The Agricultural University of Iceland, Hvanneyri, Iceland.

Reilly M., Foran, M.K., Kelleher, D.L., Flanagan, M.J., Brophy, P.O., 1998. Estimation of genetic value of showjumping horses from the ranking of all performances in all competitions. *J. Anim. Breed. Genet*. 115, 17–25.

Ricard, A. 1998. Developments in the genetic evaluation of performance traits in horses. Proceedings of the 6th World congress on genetics applied to Livestock Production, Armidale, NSW, Australia, 11–16 January.

Ricard, A., Bruns, E., Cunningham, E.P., 2000. Genetics of performance traits. In: Bowling, A.T. and Ruvinsky, A., (Eds.), The genetics of the horse. CABI Publishing, Oxon and New York pp. 411–438.

SAS Institute Inc. 2004. SAS OnlineDoc® 9.1.3**.** Cary, NC: SAS Institute Inc.

Schade, W., 1996. Entwicklung eines Besamungszuchtprogramms für die Hannoveranersche Warmblutzucht. Dissertation Göttingen 1996.

Tavernier, A., 1991. Genetic evaluation of horses based on ranks in competitions. *Livest. Prod. Sci*. 23, 159–173.

Tavernier, A., 1992. Is the performance at 4 years in jumping informative for later results? 43rd Annual Meeting of the EAAP, Madrid, Spain, 13–17 September 1992. 4pp.

Thorén Hellsten, E., Viklund, Å, Koenen, E.P.C., Ricard, A., Bruns, E., 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 competitions. *Livest. Sci*. 103, 1–12.

Van Veldhuizen, A.E., 1997. Breeding value estimation for riding horses in the Netherlands. 48th Ann. Meet. EAAP, Vienna, Austria, 25–28 August. 8pp.

Wallin, L., Strandberg, E., Philipsson, J., 2001. Phenotypic relationships between test results of Swedish Warmblood horses at 4-year-olds and longetivety. *Livest. Prod. Sci*. 68, 97–105.

Wallin, L., Strandberg, E., Philipsson, J., 2003. Genetic correlations between field-test results of Swedish Warmblood riding horses as 4-year-olds and lifetime performance results in dressage and show jumping. *Livest. Prod. Sci.* 82, 61–71.

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