Use of field records and competition results in genetic evaluation of station performance tested Swedish Warmblood stallions

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Abstract

The main objective of this study was to investigate possibilities to increase accuracy in the selection and test of Swedish warmblood stallions by combining information from stallion performance tests (SPT) with information from competitions and riding horse quality tests (RHQT). Data on 801 stallions judged at the SPT 1979-2005 were used for the analyses, which also included about 14 900 horses from the RHQT, 26 800 horses with results in show jumping and 14 200 with results in dressage competitions.

Heritability coefficients were on average 0.41 for individual gaits under rider and 0.36-0.65 for jumping traits in SPT. Heritabilities for competition traits were 0.17 for dressage and 0.27 for show jumping. The heritability for overall conformation in SPT was 0.25. Genetic correlations between stallion performance test traits and competition results were 0.44-0.77 for gaits and dressage, and 0.78-0.96 for jumping traits in SPT and show jumping. The genetic correlation between conformation and results in dressage competitions was 0.22.

For stallions participating in SPT in 2004 and 2005 accuracy increased when evaluating stallions by using information from relatives that have taken part in RHQT and competitions. For show jumping accuracy changed from 0.60 to 0.68 for stallions born in Sweden, an increase with 13%, when information from RHQT and competitions in show jumping were used. For stallions born in a foreign country, the corresponding figure was, 5%, lower. For dressage the information from RHQT and competition results in dressage changed the accuracy from 0.41 to 0.55, an increase with 34%, for stallions born in Sweden. The improvement in accuracy for imported stallions was 11%.

Keywords: Riding horses; Performance; Animal model; Correlations; Breeding values

1. Introduction

The breeding goal for the Swedish warmblood horse is "to produce a noble, correct and durable riding horse which through its temperament, rideability, good movements and/or jumping ability is internationally competitive" (ASVH, 2006). Good competition results in dressage and show jumping are the main objectives. The most important part in the breeding program is the selection of stallions. A successful horse breeding programme must have a sustainable well functioning test of young stallions as it takes too many years to achieve competition results at advanced levels. Effective selection has, therefore, to take place at an early stage of life and consider talents for both dressage and show jumping in dual purpose horse population. Today most of the warmblood stallions in Sweden are approved on results gained in the Stallion Performance Test (SPT) and some get approved from doing well in competitions. Approximately 30 to 50 three to five year old stallions per year participate in the SPT and of them about 30% will be approved for breeding. Gelinder *et al*. (2001) concluded that the SPT is a good predictor of the stallion´s breeding value for sport traits. In their preliminary study the genetic correlations between jumping traits in SPT and show jumping at competitions (0.74 to 0.88) were higher than correlations between gaits in SPT and dressage at competitions (0.20 to 0.66).

During the last years great efforts have been made to correct and extend information of identities and pedigree for the Swedish warmblood horse, thus giving better opportunities in genetic analyses and genetic evaluations to combine information from different sources. Information on competition results are today available for approximately 40 000 horses competing from the late seventies until today. Each year approximately one third of all warmblood horses participate in show jumping and dressage competitions. The horses start to compete at four years of age (Wikström *et al*, 2005; Philipsson, 2005). The Riding Horse Quality Test (RHQT) is a field test at four years of age, and provides a unique data base, with information on gaits, jumping, conformation and health comprising approximately 17 000 horses. In an earlier study the correlations between SPT and offspring results in the Riding Horse Quality Test (RHQT) were found to be almost unity for jumping and gaits (Gerber Olsson *et al.*, 2000) and it was concluded that similarly defined traits in the two tests can be regarded as virtually the same genetic traits. Results from the RHQT are used for prediction of breeding values and about 20 to 40% of all four year old horses participate.

The SPT have some limitations as the selection of stallions are only based on phenotypic traits, information from relatives is only subjectively judged by the licensing team in the SPT and its effect has not been studied. Furthermore, only a limited number of stallions participate in the test every year.

The main objective of this study was to investigate the possibilities to increase the accuracy in selection of Swedish warmblood stallions by combining information from SPT with information from competitions and RHQT. For this purpose heritabilities and genetic and environmental correlations, not earlier estimated for traits scored in the SPT and competition results were estimated. The accuracy of the breeding values for stallions participating in SPT were estimated and compared for different combinations of information from SPT, competitions and RHQT.

2. Testing Systems

2.1 Stallion Performance Test

The Swedish stallion performance test is carried out every spring at Flyinge in the southern part of the country. The judging of stallions at the SPT are done by experienced national judges and trainers and by national and international test riders. In the approximately one week long station test three, four and five year old stallions are evaluated for soundness, conformation, gaits under rider, free jumping and jumping under rider. The stallions are also scored for temperament and general appearance in gaits under rider, free jumping and jumping under rider. The Swedish SPT has changed during the years and the development is more precisely described by Gerber Olsson *et al*. (2000) and by ASVH (2006).

A voluntary preselection for participation in SPT takes place in the autumn every year. The stallions are mainly 1.5 or 2.5 years of age and they are preselected for conformation, soundness and free jumping (voluntarily) (Gerber Olsson *et al*., 2000).

Three year old stallions undergo a three-day SPT before the breeding season. It includes a veterinary inspection, judging of conformation, free jumping and gaits under own rider. The stallions that are approved receive a one year breeding permit (ASVH, 2006).

For stallions older than three years the SPT is divided into two phases. Four and five year old stallions enter phase I beginning with the veterinary inspection and judging of conformation. All four year old stallions are to be shown in either free jumping (dressage stallions only) or jumping under rider. Five year old stallions, both dressage and jumping stallions, are shown in jumping under rider. The stallions are shown under own rider in phase I. For phase II the stallion owner decides in what discipline, dressage or jumping or both, the stallion will continue the test. Dressage stallions are shown in gaits under own rider as well as under test rider. Similarly jumping stallions are shown in jumping under own rider as well as under test rider. Approved stallions receive a six year breeding permit (ASVH, 2006).

All stallions entering the SPT have their pedigrees subjectively evaluated by the judges in the SPT and incorporated in the overall score of the horse. The pedigree is evaluated according to ancestor's performance in show jumping and/or dressage. This pedigree evaluation also contributes a small part of a performance index for jumping and dressage, respectively. The index is otherwise based on each stallion's performance in the SPT in dressage (dressage index) and in jumping (jumping index) (ASVH, 2006).

2.2 Competitions

Competition results have been recorded in Sweden since long and annual horse records are computerized since the early 1970-ies (Wikström, 2005). Today about 40 000 horses are included in this database, which corresponds to approximately 30% of born warmblood horses. During the years since the recording started the registration routines have changed. In some periods only horses with placings (20%) were recorded and some years all horses participating in competitions were taken into account. From a certain higher level of competitions, all started horses were recorded during the whole time period. In Sweden, horses that are placed in a competition receive upgrading points, more points for better placing and/or at more advanced level. The aim of this upgrading system is to stop horses to participate at a, for them, too low competition level. This is regulated by the Swedish Equestrian Federation. Wikström *et al.* (2005) analyzed competition data and concluded that the logarithmic accumulated lifetime upgrading points for each horse and discipline (dressage and show jumping) could be used for genetic evaluations and this trait was in 2005 included in the genetic evaluations of Swedish warmblood horses.

2.3 Riding Horse Quality Test

Riding Horse Quality Tests (RHQT), a one day field test for 4-year old horses, has taken place in Sweden since 1973. Annually about one fourth to one third, or 500-1 000, of all the 4-year old riding horses in Sweden participate. The tests take place at about 20 different places every autumn. The aims of this one-day field test are to provide information for genetic evaluation of stallions and mares, and to evaluate overall quality of young sport horses, especially their talents for dressage and show jumping. The traits scored include health status, conformation, gaits under rider and jumping. A temperament and general appearance score is given of the tests of gaits and jumping. The tests are more precisely described by Gelinder *et al.* (2002).

3. Material

3.1. Stallion performance test data

Data comprising 801 stallions judged at the SPT during 1979-2005 were obtained from the Swedish Warmblood Association. The stallions took part in one to three performance tests. Only the last recorded observation per trait was used for the analyses. Jumping traits included in the analyses were free jumping, temperament and general appearance in free jumping, jumping under rider, and temperament and general appearance for jumping under rider. Traits related to dressage were walk, trot, canter, temperament and general appearance in the gait tests, and conformation. All traits were given scores between 1 and 10 (Table 1). The temperament and general appearance scores for the two jumping traits have been recorded since autumn 1985 and the corresponding score for gaits under rider since autumn 1988. The score for conformation was calculated as an average for the scores of type and of head-neck-body. These scores are two of the totally five scores given when conformation is judged in Sweden and they are also included in the official genetic evaluations using RHQT-data. The score for soundness was not included in the analyses as the stallions were pre-selected on these criteria. Performance jumping and dressage indexes, roughly corresponding to indexes set by the SPT judging team since 2003 were created for each stallion. The stallions received an index for both jumping and dressage and this was independent of the age of the stallion, but always based on the stallion's last score in the SPT. The performance index for jumping (PJI) was calculated as the sum of the last score for jumping under rider and temperament and general appearance for jumping under rider multiplied with the heritability for jumping under rider (0.47) estimated in the analysis with information from SPT, competitions and RHQT. For stallions only having results in free jumping, the scores and heritability (0.42) for free jumping (estimated in the analysis) were used.

In the calculation of a performance index for dressage (PDI) for stallions participating in the SPT the last scores for gaits, temperament and general appearance at the gait test, and conformation and the heritabilities for gaits (0.30) and conformation (0.33) were used . The formula was:

$$\text{PDI} = 0.33 \times \left(\frac{\text{conformation} - 15}{2} \right) + 2 \times 0.30 \times \left(\frac{\text{walk} + \text{trot} + \text{canter}}{3} \right)$$

Means and standard deviations for the SPT traits analyzed are given in Table 1.

Table 1. *Description of data used for estimation of genetic parameters for stallion performance test (SPT), competition traits and riding horse quality test (RHQT)*

Trait	No. of records	Mean	SD	Range	Coeff. of variation, %
SPT					
Free jumping	565	6.35	1.75	1 – 10	27.7
Temp.[a] free jumping	514	6.47	1.87	1 – 10	28.9
Mean free jumping[b]	565	6.58	1.78	1 – 10	27.1
Jumping under rider	486	6.56	1.62	1 – 10	24.7
Temp.[a] jumping under rider	462	6.59	1.81	1 – 10	27.5
Means jumping under rider[c]	486	6.79	1.71	1 – 10	25.3
Walk	678	6.98	1.11	4 – 10	15.9
Trot	678	6.65	1.21	4 – 10	18.2
Canter	678	7.21	1.09	5 – 10	13.9
Temp.[a] gaits	360	6.75	1.21	4 – 10	17.9
Mean gaits[d]	678	6.94	0.94	4 – 10	13.5
Conformation[e]	700	8.23	0.60	5 – 10	7.3
Performance index jumping[f]	88	5.99	1.41	2.8 – 9.4	23.5
Performance index gaits[g]	89	9.44	1.12	6.8 – 11.7	11.9
Competition					
Show jumping[h]	26830	1.08	0.85	0 – 4	78.7
Dressage[h]	14272	0.97	0.80	0 – 4	82.9
RHQT					
Jumping[i]	14921	6.93	1.47	1 – 10	21.2
Gaits[j]	14896	6.62	0.93	1 – 10	14.0
Conformation[k]	14896	7.96	0.56	5 – 10	7.0

[a] Temp., temperament and general appearance. [b] Mean for free jumping and temperament free jumping at stallion performance test. [c] Mean for jumping under rider and temperament jumping under rider at stallion performance test.
[d] Mean for walk, trot, canter, and temp. gaits at stallion performance test. [e] Mean for type and head-neck-body at stallion performance test. [f] see text 4.2 [g] see text 4.2 [h] Log_{10} (accumulated lifetime upgrading points) [i] Mean for jumping under rider and free jumping at riding horse quality test. [j] Mean for walk, trot, canter, and temperament gaits at riding horse quality test. [k] Mean value of the scores for type and head-neck-body at riding horse quality test

3.2 Competition results

Competition results in show jumping and dressage were supplied from The Swedish Horse Board and the Swedish Equestrian Federation. Results from Swedish riding horse competitions carried out during the period from 1961 to 2004 were available. The competition trait for show jumping and dressage used in the analyses was the accumulated lifetime upgrading points for each horse and discipline transformed by $\log_{10}$ to approach as normal a distribution as possible (Wikström *et al.*, 2005). This trait is since 2005 included in the official genetic evaluations of Swedish warmblood horses.

The analyses included 26 830 horses that had participated in show jumping; 21 554 of these had upgrading points. In dressage, 14 272 horses had participated and of these 10 525 horses had upgrading points. Among the horses 2 957 had participated in both show jumping and dressage. The number of males and females in show jumping data was 18 870 and 11 960, respectively, and in the dressage data there were 9 429 males and 4 843 females. The horses were born between 1953 and 2000. Means and standard deviations for the competition traits are given in Table 1 and number of observations of jumping related traits in the data from show jumping, SPT and RHQT are given in Table 2. In Table 3 the number of observations per combination of dressage related traits in the data from dressage competitions, SPT and RHQT are shown.

3.3 Riding Horse Quality Test Data

The data for RHQT was supplied from the Swedish Horse Board and the Swedish Warmblood Association and comprised 14 927 horses with a unique identity, participating during 1973-2005. The conformation score was an average of the score for type and the score for head-neck-body. The score for gaits was calculated as the average of the scores for walk, trot, canter, and temperament and general appearance in the gaits test. The score jumping was an average of the scores for jumping and temperament and general appearance in jumping. Means and standard deviations for the RHQT-traits used in the prediction of breeding values are given in Table 1.

Mares are allowed to participate in the RHQT at the age of five years if they had a foal at four years of age. In this study 773 five year old mares were included.

The number of horses participating in RHQT and SPT is shown in Tables 2 and 3 for jumping and dressage, respectively. There were 120 stallions participating in jumping both at the SPT and the RHQT and for gaits there were 155 stallions. Totally 179 stallions from the SPT participated in the RHQT. In show jumping or dressage competitions competed 5 199 of the horses participating in the RHQT.

Table 2. *Number of observations per combination of jumping related traits in the data from competitions, stallion performance test (SPT) and riding horse quality test (RHQT)*

Trait	1	2	3	4
Jumping				
1 Show jumping (competition)	26830			
2 Free jumping mean[a] (SPT)	-	565		
3 Jumping under rider mean[b] (SPT)	-	310	486	
4 Jumping mean[c] (RHQT)	5194	107	120	14921

[a] Mean for free jumping and temperament free jumping at stallion performance test.
[b] Mean for jumping under rider and temperament jumping under rider at stallion performance test.
[c] Mean for jumping under rider and free jumping at riding horse quality test.

Table 3. *Number of observations per combination of dressage related traits in the data from competitions, stallion performance test (SPT) and riding horse quality test (RHQT)*

Trait	1	2	3	4	5
Dressage					
1 Dressage (competition)	14272				
2 Gaits mean[a](SPT)	-	678			
3 Conformation [b](SPT)	-	615	700		
4 Gaits mean[c] (RHQT)	3561	155	154	14896	
5 Conformation mean [d] (RHQT)	3561	155	154	14896	14896

[a] Mean for walk, trot, canter, and temperament gaits at stallion performance test.
[b] Mean value of the scores for type and head-neck-body at stallion performance test.
[c] Mean for walk, trot, canter, and temperament gaits at riding horse quality test.
[d] Mean value of the scores for type and head-neck-body at riding horse quality test.

3.4 Pedigree information

The pedigree files used for analyses of jumping traits contained 71 937 horses and the pedigree file used for analyses of dressage related traits contained 52 875 horses. The pedigree of each individual was, when possible, traced back seven generations. Among the performance tested stallions 93% had complete pedigree information for at least four generations and 26% had complete pedigree information from five generations. Stallions lacking of pedigree information were usually born abroad and imported to Sweden.

The performance tested stallions included in the study had 359 sires, 701 dams and 461 maternal grandsires. Of the sires 162 also appeared as maternal grandsires. Among the sires and maternal grandsires 56 had participated in the SPT. The riding horse quality tested horses had 815 sires, 9 931 dams and 1 042 grandsires. The horses that had competed in show jumping had 1 652 sires and 14 766 dams. Corresponding figures for dressage were 925 and 8 848. Among the horses with show jumping results 2 615 have information about sire but not about dam. For horses participating in dressage competitions, the corresponding figure were 1 048.

4. Methods

4.1 Genetic parameters for stallion performance test traits and competition results

Heritabilities and genetic correlations for results from SPT and competition were estimated separately for jumping traits and traits related to dressage (gaits and conformation).

Of the horses participating in competitions 495 were performance tested. To adjust the competition results of these stallions for a probably better training and treatment, their competition results were attributed to a dummy stallion, afictional fullsib to the original stallion. This adjustment is tested in the Swedish breeding value prediction and is used since 2005. We assumed that the stallions result in RHQT was not too much affected by special treatment of the stallion. The RHQT is a much shorter test, done during one day and the horse is only four years of age.

Owing to computational constraints (co)variance components for jumping traits recorded at SPT and competition were estimated in bi- and trivariate analyses. Parameters for the gaits and conformation at SPT and dressage at competition were estimated in one multivariate analysis. For the traits recorded at SPT the following animal model was used:

$y_{ijk} = testyr_i + testage_j + stallion_k + e_{ijk}$ Model 1

where
y_{ijk} is the score for each SPT trait , $testyr_i$ is the fixed effect of *i*th year of test (1979-2005), $testage_j$ is the fixed effect of *j*th age of tested stallion (3, 4, 5 or >5 years), $stallion_k$ is the random additive genetic effect of *k*th stallion ~ND (0, A σ_a^2), and e_{ijk} is the random environmental effect ~IND (0, σ_e^2).

For show jumping and dressage at competition the following model was used:

$y_{ijk} = birthyr_i + sex_j + horse_k + e_{ijk}$ Model 2

where y_{ijk} is the value of each competition trait, $birthyr_i$ is the fixed effect of *i*th year of birth (1953-2000 for show jumping and 1954-2000 for dressage), sex_j is the fixed effect of *j*th sex of horse (mare or gelding/stallion), $horse_k$ is the random additive genetic effect of the breeding value of the *k*th horse ~ND (0, A σ_a^2), and e_{ijk} is the random environmental effect ~IND (0, σ_e^2).

The model included the additive relationship matrix (A) with information about sires and dams. Parameters were estimated by use of the average information algorithm (Jensen *et al.*, 1997) for restricted maximum likelihood included in the DMU-package of Jensen and Madsen (1994). The convergence criterion was chosen so that the norm of the update vector for the (co)variance components was less than 10^{-5}. Asymptotic standard errors of (co)variance components were computed from the inverse average information matrix. Standard errors of heritabilities and genetic correlations were obtained by Taylor series expansions (Madsen & Jensen, 2000). Covariances between genetic and environmental effects and variances due to dominance and epistatic deviations were assumed to be zero. The total phenotypic variance (σ_p^2) was calculated as $\sigma_a^2 + \sigma_e^2$. Heritabilities and genetic correlations were calculated from the estimated (co)variance components in the standard way. Residual correlations between SPT and competitions were assumed not to.

4.2 Breeding values for show jumping and dressage at competition

To study the value of including relationship information and information from competition and RHQT in the evaluation and selection of young stallions after the performance test correlations between a performance index for jumping (PJI) and dressage (PDI), respectively, and breeding values estimated for stallion performance tested stallions based on different sources of information were calculated. Information from SPT, competitions and RHQT were used when breeding values for performance tested stallions were predicted. The breeding values for stallions in the SPT for show jumping at competition were estimated using information about jumping traits recorded at SPT only; SPT and competition; and SPT, competition, and RHQT in multivariate mixed linear animal models. Similarly, for dressage at competition, breeding values were estimated using information about gaits and conformation recorded at the three different tests. Results of show jumping and dressage at competition as described above were used for these analyses. Accuracies of these breeding values were calculated as

$$\sqrt{1 - \mathrm{PEV} / \sigma_a^2}$$

where PEV is prediction error variance from the multivariate mixed model analyses.

The same SPT dataset that was used for estimation of genetic parameters was used for the prediction of breeding values. Due to the results when estimating genetic parameters between SPT and competition results, the two scores for free jumping from SPT data (free jumping and temperament and general appearance for free jumping) and the two scores for jumping under rider (jumping under rider and temperament and general appearance for jumping under rider) were treated as mean of the two corresponding scores.

For prediction of breeding values for dressage a mean for gaits was calculated as the average of the scores for walk, trot, canter, and temperament and general appearance for gaits. Conformation was a mean of the scores for type and head-neck-body. When one or more of the scores were not recorded, the mean was calculated from available scores. For example, for stallions performance tested before 1988, when the score for temperament and general appearance for gaits was not recorded, the mean for gaits was calculated as the average of the scores for walk, trot and canter. Means and standard deviations for the SPT traits used in the breeding value predictions are given in Table 1.

In the multivariate BLUP-evaluation, for SPT and competition traits models 1 and 2, respectively, were used. For results from the RHQT the following model was used:

y_{ijk} = year-place$_i$ + sex$_j$ + horse$_k$ + e_{ijk} Model 3

where y_{ijk} is the average score of each trait, year-place$_i$ is the fixed effect of *i*th combination of year and place of testing (i= 1, ..., 409), sex$_j$ is *j*th combination of sex and age of horse tested (mare 4 years, mare 5 years or gelding/stallion 4 years), horse$_k$ is the random genetic effect of the *k*th horse ~ND (0, Aσ_a^2), and e_{ijk} is the random environmental effect ~IND (0, σ_e^2).

All models included the additive relationship matrix (A) with information about sires and dams. For all analyses the DMU-package was used (Jensen and Madsen, 1994).

The genetic parameters used in the breeding value predictions were estimated in two multivariate analyses including four and five traits, respectively. The genetic parameters were estimated in the same way as described under 4.1.

The study on effects of using different sources of information on the accuracy of estimated breeding values after the SPT comprised only 89 stallions participating in the SPT during the years 2004 and 2005. This restriction was made because only these stallions could have no advantage or disadvantage from future coming information, which will affect the breeding values of stallions tested in the SPT earlier than 2004. The stallions were divided into two groups depending on birth in Sweden (*n*=42) or in a foreign country (*n*=47). The stallions born abroad were assumed to have less relationship information and less information from Swedish competitions and RHQT.

5. Results and Discussion

5. 1 Stallion performance test and competition results

5.1.1 Means and standard deviations

Table 1 show that the scores for conformation and gaits (coefficient of variation 7.3-18.2%) have smaller variation than the jumping traits (coefficient of variation 24.7 to 28.9). For both gaits and conformation the whole scale was not used. This is due to the fact that a score under five is used by the judges only to indicate that the stallion does not have a "clean" gait. For jumping traits the whole scale was used. The standard deviations presented in the table are higher than the corresponding standard deviations estimated by von Velsen-Zerweck (1998) for German stallion performance tests.

5.1.2 Heritabilities

The heritabilities for the jumping traits in SPT were high, 0.55 for free jumping and 0.65 for jumping under rider (Table 4). In the study by Gerber Olsson *et al.* (2000) the heritability for jumping under rider was much lower (0.32) and the heritability for free jumping was slightly lower (0.47). In the earlier study the number of stallion performance tested horses was only 136, which is much lower than in the present study (484-563 horses). Furthermore, in the present study only the last observation per stallion is taken into account in comparison to all observations in the earlier study. Brockman (1998) almost have the same heritabilities for free jumping and jumping under rider in the German stallion performance test (0.58 and 0.62, respectively) as in this study. Lührs-Behnke (2002) got lower estimates for free jumping and jumping under rider (0.39 and 0.33, respectively) as did Friemel *et al.* (1998) (0.38) in the SPT in Germany. von Velsen-Zerweck (1998) estimated a heritability for jumping under rider and free jumping in the German SPT to 0.47, slightly lower than in this study. Ducro *et al.* (2002) in the Netherlands estimated heritabilities for the jumping traits power, technique and take-off 0.46-0.62.

For the temperament and general appearance score in jumping under rider the heritability (0.51) was higher and the environmental variance (1.51) was lower than the corresponding values for free jumping (heritability 0.36, and environmental variance 2.03) indicating that environmental factors influence the scoring more when the stallion is judged without a rider. This may be an effect of very skilled riders used for testing stallions.

The heritabilities as shown in Table 4 for gaits in the SPT varied slightly between 0.41 and 0.42 and the heritability for temperament and general appearance was 0.38. The heritabilities for the individual gaits were in the same range as the heritabilities estimated by Gerber Olsson *et al.* (2000) (varied between 0.37 and 0.46, respectively). Ducro *et al.* (2002) had similar heritabilities for walk and trot (0.37 and 0.50, respectively). Schade (1996) estimated heritabilities for gaits (0.25-0.37) similar to the ones in the present study as well as the ones by von Velsen-Zerweck (1998) (estimates varied between 0.43 and 0.50), Lührs-Behnke (2002) (estimates varied between 0.34 and 0.51) and Friemel *et al.* (1998) (estimates varied between 0.26 and 0.46) . The heritability for canter (0.42) was higher in our study than in the studies presented by Brockmann (1998) (0.32), and Ducro *et al.* (2002) (0.25).

Table 4. *Estimates[a] of heritabilities (h^2) (S.E. as subscripts) and additive genetic (σ^2_a) and environmental (σ^2_e) variances of traits recorded at competitions and stallion performance tests (SPT)*

Trait[b]	h^2	σ^2_a	σ^2_e
Jumping			
Show jumping (competition)	$0.27_{0.02}$	0.16	0.41
Free jumping (SPT)	$0.55_{0.09}$	1.61	1.30
Temp[c] free jumping (SPT)	$0.36_{0.11}$	1.16	2.03
Jumping under rider (SPT)	$0.65_{0.11}$	1.59	0.94
Temp[c] jumping under rider (SPT)	$0.51_{0.12}$	1.56	1.51
Dressage			
Dressage (competition)	$0.17_{0.02}$	0.10	0.46
Walk (SPT)	$0.42_{0.09}$	0.49	0.68
Trot (SPT)	$0.41_{0.09}$	0.55	0.77
Canter (SPT)	$0.42_{0.10}$	0.45	0.63
Temp[c] gaits (SPT)	$0.38_{0.11}$	0.48	0.79
Conformation (SPT)	$0.25_{0.10}$	0.09	0.26

[a] For jumping, the estimates are means from bivariate analyses and for dressage the values were estimated in a multi-trait analysis.
[b] The traits are described in Table 1.
[c] Temp., Temperament and general appearance

The heritability for the competition traits, show jumping and dressage, was estimated to 0.27 and 0.17, respectively. These results correspond very well to the results from Wallin *et al.* (2003) (0.23-0.27 and 0.16- 0.17 respectively) and Gelinder *et al.* (2001) (0.24 and 0.20, respectively). van Veldhuizen (1997) estimated heritablities for dressage and show jumping to be slightly lower (0.16 and 0.11, respectively) than in the present study, but the trait is differently defined (highest level in sport accomplished during the lifetime of the horse) than in this study. Hassenstein (1998) also showed lower heritabilities for show jumping and dressage varying between 0.05 and 0.11, respectively. This study was based on individual results and not annual records as in the present study. The heritabilities for competition results in show jumping in the Dutch warmblood population were estimated to 0.10-0.20 and for dressage to 0.03-0.10. The study of Huizinga and van der Meij (1989) was based only on competition results from horses younger than nine years of age, which is a difference compared to this study.

5.1.3 Genetic and environmental correlations

The genetic correlations between all traits including jumping were high and positive (Table 5) (0.78 to 1.0). These results are in agreement with those presented by Gerber Olsson *et al.* (2000) except for somewhat higher estimates for the genetic correlations for temperament and general appearance in jumping under rider. Free jumping and temperament and general appearance in free jumping had a genetic correlation close to unit. The situation was the same for jumping under rider and the corresponding temperament and general appearance score. This justifies our decision to analyse a mean of the two scores for free jumping and jumping under rider, respectively, when predicting breeding values.

Table 5. *Genetic correlations (above the diagonal) with S.E. as subscripts and environmental correlations[a] (below the diagonal) estimated in bivariate analyses for jumping traits recorded at stallion performance tests (SPT) and competitions*

Trait[b]	2	3	4	5
1 Show jumping (competition)	$0.86_{0.08}$	$0.96_{0.12}$	$0.80_{0.08}$	$0.78_{0.11}$
2 Free jumping (SPT)		$1.00^{c}_{0.03}$	$0.89_{0.10}$	$0.87_{0.12}$
3 Temp. free jumping (SPT)	0.85		$0.94_{0.12}$	$0.90_{0.14}$
4 Jumping under rider (SPT)	0.11	0.06		$0.99_{0.02}$
5 Temp. jumping under rider (SPT)	0.11	0.15	0.76	

[a] The standard errors of the environmental correlations varied between 0.06 and 0.15.
[b] The traits are described in Table 1.
[c] 0.9996

Lührs-Behnke (2002) estimated similar genetic correlations between jumping under rider at station and show jumping (0.80) as we did (0.78). van Veldhuizen (1997) estimated a genetic correlation between show jumping in the Dutch SPT and show jumping in competitions to 0.90. Wallin *et al*. (2003) estimated a genetic correlation between jumping in RHQT and show jumping in competition to 0.88-0.93 and these figures corresponds very well with the genetic correlations in this study.

All estimated genetic correlations between competition results in dressage and the individual gaits and temperament and general appearance in the gaits test were positive and high varying between 0.43 and 0.68 (Table 6), the highest value was for temperament and general appearance. Lührs-Behnke (2002) also showed high and positive genetic correlations between gaits and results in dressage competitions

Table 6. *Genetic (above the diagonal) with S.E. as subscripts and environmental correlations*[a] *(below the diagonal) estimated in a multi-variate analysis for gaits and conformation recorded at stallion performance tests (SPT) and dressage recorded at competitions*

Trait[b]	2	3	4	5	6
1 Dressage (competition)	$0.44_{0.13}$	$0.62_{0.12}$	$0.53_{0.14}$	$0.77_{0.14}$	$0.22_{0.18}$
2 Walk (SPT)		$0.34_{0.15}$	$0.11_{0.17}$	$0.43_{0.15}$	$-0.03_{0.22}$
3 Trot (SPT)	0.44		$0.67_{0.09}$	$0.84_{0.07}$	$0.35_{0.19}$
4 Canter (SPT)	0.52	0.64		$0.90_{0.08}$	$0.19_{0.22}$
5 Temp. gaits (SPT)	0.68	0.77	0.64		$0.28_{0.23}$
6 Conformation (SPT)	0.16	0.25	0.27	0.31	

[a] The standard errors of the environmental correlations varied between 0.05 and 0.10.
[b] The traits are described in Table 1.

(0.75-0.89). Their results were based only on young horses and the correlations were somewhat higher than in the present study which was based on life-time records in sport. van Veldhuizen (1997) estimated the genetic correlation between competition results in dressage and dressage in the Dutch SPT to 0.68, very similar to the ones in this study. The genetic correlation between results in dressage competitions and gaits was in this study on SPT data higher than the corresponding correlations estimated by Wallin *et al*. (2003) (0.36-0.45) on RHQT data.

Trot and canter are higher genetically correlated (0.68) than walk and canter (0.11). This corresponds to the results presented by Gerber Olsson *et al*. (2000). The correlations between conformation and the gaits were low to moderately high, varying between -0.03 to 0.35. The highest genetic correlation was with trot indicating that the stallions conformation affects the way they trot.

5.2 Breeding values for sport traits

The estimated parameters for jumping related traits scored in SPT, competitions and RHQT that were used for predicting breeding values for show jumping are shown in Table 7. Table 8 gives the estimated parameters in SPT, competitions and RHQT that were used for prediction of breeding values for dressage.

Table 7. *Heritabilities (on the diagonal), genetic correlations (above the diagonal) with S.E. as subscripts and environmental correlations[a] (below the diagonal) estimated in a multi-trait analysis for the traits recorded in SPT, show jumping competitions and RHQT used for prediction of breeding values of show jumping*

Trait[b]	1	2	3	4
1. Show jumping (competition)	**0.25** $_{0.01}$	0.87 $_{0.09}$	0.83 $_{0.10}$	0.88 $_{0.03}$
2. Free jumping mean(SPT)	-[c]	**0.42** $_{0.09}$	0.85 $_{0.13}$	0.72 $_{0.11}$
3. Jumping under rider mean (SPT)	-[c]	0.26	**0.47** $_{0.11}$	0.73 $_{0.11}$
4. Jumping mean (RHQT)	0.10	0.01	0.02	**0.19** $_{0.02}$

[a] The standard errors of the environmental correlations varied between 0.02 and 0.12.
[b] The traits are explained in Table 2.
[c] Residual correlations do not exist and was not estimated.

Table 8. *Heritabilitities (on the diagonal), genetic correlations (above the diagonal) with S.E. as subscripts and environmental correlations*[a] *(below the diagonal) estimated in a multi-trait analysis for the traits recorded in SPT, dressage competitions and RHQT used for prediction of breeding values of dressage*

Trait[b]	1	2	3	4	5
1. Dressage (competition)	**0.17** $_{0.02}$	0.68 $_{0.16}$	0.34 $_{0.16}$	0.73 $_{0.07}$	0.47 $_{0.08}$
2. Gaits mean (SPT)	-[c]	**0.30** $_{0.08}$	0.19 $_{0.19}$	0.90 $_{0.12}$	0.18 $_{0.13}$
3. Conformation mean (SPT)	-[c]	0.29	**0.33** $_{0.09}$	0.37 $_{0.12}$	0.74 $_{0.12}$
4. Gaits mean (RHQT)	0.10	0.01	-0.35	**0.36** $_{0.02}$	0.56 $_{0.04}$
5. Conformation (RHQT)	0.00	-0.15	0.08	0.09	**0.26** $_{0.02}$

[a] The standard errors of the environmental correlations varied between 0.02 and 0.10
[b] The traits are explained in Table 3.
[c] Residual correlations do not exist and was not estimated

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Table 9. *Mean accuracies (r_{TI})[a] of breeding values (BV) for show jumping and dressage of stallions performance tested in 2004 and 2005 and correlations between the breeding value and performance index[b] for show jumping (PJI)/dressage (PDI) (Corr)*

Trait[b]	Information source	Mean r_{TI}	Corr	Mean r_{TI}	Corr
Show jumping		42 Swedish stallions		46 foreign stallions	
(competition)	Only SPT	0.60	0.84	0.57	0.93
	SPT and competition	0.66	0.76	0.59	0.89
	SPT and RHQT	0.65	0.81	0.58	0.91
	SPT, competition and RHQT	0.68	0.76	0.60	0.89
Dressage		42 Swedish stallions		47 foreign stallions	
(competition)	Only SPT	0.41	0.88	0.38	0.84
	SPT and competition	0.49	0.84	0.40	0.82
	SPT and RHQT	0.51	0.83	0.40	0.76
	SPT, competition and RHQT	0.55	0.83	0.42	0.74

[a] Calculated as $\sqrt{1 - \mathrm{PEV} / \sigma_a^2}$, where PEV is prediction error variance.

[b] The performance index and the traits are explained in Table 1.

5.2.1 Accuracy of breeding values for show jumping and dressage at competition

In Table 9 mean accuracies of estimated breeding values for show jumping and dressage are shown for stallions performance tested in the years 2004 and 2005. The accuracy for breeding values of show jumping for stallions born in Sweden varied between 0.60 and 0.68 with the lowest value when only results from SPT were included and the highest value when the analyses were based on information from SPT, competition and RHQT. The difference between the accuracies when only information from the SPT was included and when all available information was included, amounted to an increase of 13%. For stallions imported to Sweden the accuracy varied between 0.57, when only SPT were used in the analyses, and 0.60 when all information sources were included, an increase of 5%.

For the trait dressage competitions the general level of the accuracy was lower. The increase in accuracy for the breeding goal results at dressage competitions for stallions born in Sweden was 34%, a change from 0.41 to 0.55. The accuracy for breeding values for dressage competitions for foreign stallions changed from 0.38 to 0.42, an increase of 11%. From these examples, it is clear that you can gain by adding information from RHQT and competitions to the SPT results when testing and selecting stallions for improvements in show jumping and dressage at competition. It is also clear that the stallions born in Sweden, with more relationship information and information from relatives' results in competitions and RHQT will gain more in accuracy than stallions born abroad. The larger gain for dressage compared to jumping is an effect of the lower correlation between gaits at SPT and in sport.

5.2.2 Correlations between breeding values and performance indexes

The correlations between the performance index for jumping at SPT and the predicted breeding values are variable (Table 9). The lower correlation at maximum use of all information for prediction of the breeding value is also an indication that the final results in the SPT would gain by using information from relative's results in RHQT and competitions. The correlations between the performance index for jumping and the predicted breeding values for the foreign born stallions (0.89-0.93) varied less compared to the correlations for stallions born in Sweden (0.76-0.84). This could again be explained by the fact that the foreign stallions had less opportunity to gain information by adding information from competitions and RHQT.

The overall correlations between the performance index for gaits and the predicted breeding value for results in dressage competitions of stallions born in Sweden were more or less unaffected by adding more information sources. However, the correlations for foreign stallions changed from 0.84 when only SPT data were considered to 0.74 when all information was included. The lower correlation means that the performance index is not utilising all genetic information available. Thus, the final results in the SPT would definitely gain by using information from relative's results in RHQT and competitions. The performance indexes in this study had no information from relatives, in contrast to the indexes given in practise for stallions at the SPT. It therefore seems principally important to consider pedigree information when evaluating the stallions, even if it is done subjectively.

6. Conclusions

The results in free jumping and jumping under rider in the SPT are highly correlated to show jumping results in competitions. The results in gaits in SPT are also highly correlated to results in dressage competitions, although a bit less so than for jumping. All traits showed moderately high heritabilities, usually 0.3-0.5. This indicates that the traits judged in the SPT are well suited to describe genetic properties that are important for future results in sport, which is the over all breeding goal for Swedish warmbloods.

The use of information from RHQT and results from competitions in show jumping will raise the accuracy of the breeding values for show jumping with 13% for stallions born in Sweden and with five percent for stallions born abroad. Higher values are obtained for dressage, 34% for stallions born in Sweden and with 11% for stallions born abroad. This indicates that using information from competitions and RHQT when selecting future breeding stallions is expected to give even more reliable results in the SPT and may therefore contribute to increased genetic progress of the Swedish warmblood sport horses.

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