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1 **Genetic variation in competition traits at different ages and time periods**
2 **and correlations with traits at field tests of 4-year-old Swedish Warmblood**
3 **horses**

4
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10

11 **Running head**

12 Competition and young horse test results in Sweden

13

14 **Abstract**

15

16 For many years, the breeding value estimation for Swedish riding horses has been
17 based on results from Riding Horse Quality Tests (RHQT) of 4-year-olds only. Traits
18 tested are conformation, gaits and jumping ability. An integrated index including
19 competition results is under development to both get as reliable proofs as possible and
20 increase the credibility of the indexes among breeders, trainers and riders. The
21 objectives of this study were to investigate the suitability of competition data for use in
22 genetic evaluations of horses and to examine how well young horse performance
23 agrees with performance later in life. Competition results in dressage and show

1 jumping for almost 40,000 horses from the beginning of the 1960s until 2006 were
2 available. For RHQT data of 14,000 horses judged between 1988-2007 were used.
3 Genetic parameters were estimated for accumulated competition results defined for
4 different age groups (four to six years of age, four to nine years of age and lifetime),
5 and for different birth year groups. Genetic correlations were estimated between
6 results at RHQT and competitions with a multi-trait animal model.

7

8 Heritabilities were higher for show jumping than dressage and increased with
9 increasing age of the horse and amount of information. For dressage, heritabilities
10 increased from 0.11 for the youngest group to 0.16 for lifetime results. For show
11 jumping corresponding values increased from 0.24 to 0.28. Genetic correlations
12 between competition results for the different age groups were highly positive (0.84-
13 1.00), as were those between jumping traits at RHQT and competition results in show
14 jumping (0.87-0.89). For dressage-related traits as 4-year-olds and dressage
15 competition results the estimated genetic correlations were between 0.47 and 0.77.
16 We suggest that lifetime results from competitions should be integrated into the
17 genetic evaluation system. However, genetic parameters showed that traits had
18 changed during the over 35-year period covered due to the development of the sport,
19 which needs to be considered in future genetic evaluations.

20

21

22 **Keywords:** Riding horses, Dressage, Show jumping, Performance test, Genetic
23 parameters

1

2

3 **Implications**

4

5 To estimate reliable breeding values of Swedish Warmblood horses and to
6 reduce bias due to pre-selection of horses for competition, it is important to
7 integrate all available information from both young horse tests and competitions.

8 Lifetime competition results are recommended and high genetic correlations were
9 estimated between results in competition and results from tests of 4-year-olds.

10 The equestrian sport has changed during the 20th century, and this study shows
11 that competition results do not mean the same throughout the 35-year-long
12 period of recording. Future studies will investigate how to handle competition
13 data from different time periods in genetic evaluations.

14

15

16 **Introduction**

17

18 For many years, the genetic evaluation for Swedish riding horses has been based on
19 results from Riding Horse Quality Tests (RHQT) only (Árnason, 1987). This one-day
20 field test was introduced in 1973 and about 18,000, i.e., about one-third of all 4-year-
21 old horses, have participated so far. The aim of the test is to evaluate the overall
22 quality of young sport horses. The major advantages of using young horse test data
23 for genetic evaluations are that they include many and rather unselected horses and

1 the traits show moderately high heritabilities. Therefore, breeding values for traits
2 reflecting the breeding goal can be provided for both stallions and mares early in life,
3 contributing to opportunities for faster genetic progress (Thorén Hellsten *et al.*, 2006).
4 An issue is the correlation with competition results. Thus, if the correlations are not
5 high enough it may be inefficient or even counterproductive that selection is based on
6 indirect traits rather than directly on competitions results in dressage and show
7 jumping at advanced levels, which constitute the real breeding objective as stated by
8 the Swedish Warmblood Association (SWB, 2008).

9

10 Since the 1970s, competition data for Swedish riding horses have been computerized.
11 About 40,000 horses are now included in this database, which corresponds to about
12 30% of horses born. Because the breeding objective of the Swedish Warmblood is to
13 produce internationally competitive horses in dressage and show jumping, it is of
14 interest to investigate the suitability of competition data for genetic evaluation. In
15 Germany, France, Ireland, Belgium and the Netherlands competition results are used
16 to estimate breeding values (Koenen and Aldridge, 2002). The disadvantages of using
17 competition data are the pre-selection of horses before entering competition, the often
18 long time before competition results become available, that competition data are more
19 affected by training conditions, resulting in the generally low heritabilities of
20 competition traits (Ricard *et al.*, 2000).

21

22 In Sweden, horses can start to compete in dressage and show jumping at the age of
23 four years. Still, only few horses compete before the age of five years, and they do not

1 reach more advanced levels until several years later. One question is whether early
2 performances in competition express the same, or genetically correlated, traits as later
3 performance at mature age. If they do, selection on early competition is possible and
4 breeding value estimation can be made already at lower ages. Studies on other horse
5 populations have shown that young horse performance in competition is highly
6 correlated to later performance (Thorén Hellsten *et al.*, 2006).

7

8 In a recent study of RHQT data, Viklund *et al.* (2008) found differences in genetic
9 parameters between time periods of testing horses indicating a change of the horse
10 population by time. The competition data come from the early 1960s. Since then, both
11 the sport and horse population has expanded considerably. Competition has also
12 evolved through time due to technical changes of competition. Therefore it could be
13 hypothesized that competition traits have not been the same throughout the whole
14 period.

15

16 To integrate all information into an overall index it is necessary to know the
17 correlations between early performance at RHQT and competition results. Earlier
18 studies on limited data of horses that participated in RHQT between 1973 and 1986
19 have indicated clearly positive correlations between RHQT and lifetime performance in
20 dressage and show jumping (Wallin *et al.*, 2003). In other European Warmblood horse
21 populations, strong positive genetic correlations between young horse test and
22 competition have been estimated as well (Thorén Hellsten *et al.*, 2006; Lühns-Behnke
23 *et al.*, 2006a and 2006b; Ducro *et al.*, 2007). The question is what the effects are of

1 the changes both in the genetically constitution of the population, and in the sport
2 during the last few decades.

3

4 The objectives of this study were to investigate the suitability of competition data,
5 collected during four decades, for genetic evaluation of riding horses, and to examine
6 how well young horse performance, both at RHQT and early competitions, agree with
7 competition performance later in life.

8

9

10 **Materials**

11

12 *Competition data*

13 The Swedish Horse Board and the Swedish Equestrian Federation supplied the
14 competition data. Results from Swedish riding horse competitions from 1961 to 2006
15 were available. The data comprised 38,707 horses born between 1953 and 2002
16 which had competed in dressage or show jumping. Of these, 29,564 horses were in
17 show jumping and 15,396 horses in dressage. Thus, more than 6000 horses had
18 competed in both disciplines. The distribution between males and females were
19 22,428 and 16,279, respectively. The sex distributions differed in the two disciplines;
20 in dressage 34% were females and in show jumping 45% were females.

21

22 Horses that are placed, i.e. are among the 20% best in each competition, receive
23 “upgrading” points. A horse receives more points either for a better placing or at a

1 more advanced level, or both. The purpose of this point system is to rank horses and
2 exclude those with a certain number of points from participating at that same level
3 again, and this is regulated by the Swedish Equestrian Federation. The number of
4 starts was not recorded before 1983 for regional competitions, and the routines
5 changed again in 1991, when only starts at the national level were recorded. Horses
6 that had started in a competition, but had neither been placed nor received points,
7 were given a zero result (24% of the dressage horses and 18% of the horses in show
8 jumping). The data for this study consisted of summarised annual records and thus
9 not results of individual competitions.

10

11 The expansion of the sport is illustrated by the average proportion of horses born in
12 different periods that were placed in competition. During the period up to 1983 on
13 average 2200 horses were born per year of which 16% were placed in competition
14 during their lifetime. Between 1984 and 1991, 4000 horses were born annually of
15 which 29% had achieved at least one placing in competition. Almost 3500 horses were
16 born per year during 1991 and 2002, of which 30% had been placed in competition
17 until 2006. Of horses aged 7 years or older at the end of data collection in the last birth
18 year period (horses born between 1992 and 1999), 37% had been placed in
19 competition.

20

21 Performance traits were in this study defined as accumulated number of points and
22 accumulated placings across all years, and the ratio between those traits (points per

1 placing). The last trait indicates the level of successful performance of the horses but
2 does not give credits for longevity in competition.

3

4 The results for each discipline were divided into three different age groups:
5 accumulated results until aged six years, nine years, and lifetime results, i.e. including
6 all results until 2006. The distribution of the competition traits was skewed and the
7 traits were transformed with a 10-logarithm to an almost normal distribution, but with a
8 slight excess of low and high values (Gelinder, 1999). To make it possible to calculate
9 the log value for horses with a zero value the number 1 was added to the result before
10 transformation. The number of horses in each age group, and means and standard
11 deviations for the competition traits transformed with 10-logarithm are presented in
12 Table 1.

13

14 *Competition data divided into groups by birth year*

15 To investigate whether the competition traits changed during the long period of
16 recording, the data were grouped according to the birth year of the horses. The same
17 grouping criteria as in an earlier study on RHQT data were used (Viklund *et al.*, 2008).
18 The breaking points refer to periods of certain changes, i.e. a strongly increased
19 genetic progress, and the use of imported stallions or imported semen. Group 1
20 included horses born until 1983, resulting in 13,245 horses in show jumping and 7467
21 in dressage. Group 2 included horses born between 1984 and 1991 (7285 in show
22 jumping and 4219 in dressage). Group 3 included horses born between 1992 and
23 2002 (9034 in show jumping and 3710 in dressage). The horses were sired by

1 stallions that had offspring in the different birth year groups. For example, 86 stallions
2 had offspring in all three groups and 358 stallions had offspring in two groups ensuring
3 genetic connectedness across the groups (Table 2).

4

5 *Riding Horse Quality Test data*

6 Data on horses scored in the RHQT were supplied from the Swedish Horse Board and
7 the Swedish Warmblood Association. Results for 14,006 horses that had participated
8 in RHQT from 1988 to 2007 were used. Most of the horses were 4 years old, but also
9 792 5-year-old mares that had foaled as 4-year-olds were included. In total, 6497
10 mares and 7509 stallions and geldings were judged. Conformation consisted of five
11 subtraits: type, head-neck-body, correctness of legs, walk and trot at hand. The
12 horses also got a total conformation score which was the sum of the five subtraits. In a
13 riding test, individual gaits were judged. The score for jumping consisted of either free
14 jumping, jumping under rider or an average of both whenever both were registered
15 (changes were made over the 20-year period of recording). For both gaits and jumping
16 the horses also received a temperament score. All traits were scored between 1 (very
17 poor) and 10 (excellent). Viklund *et al.* (2008) give a detailed description of the traits.
18 Means, standard deviations, minimum and maximum values for the different traits
19 scored in RHQT are given in Table 3.

20

21 *Competition results and Riding Horse Quality Test*

22 To estimate the genetic correlations between competition traits and traits judged at
23 RHQT the above described two datasets were merged. Only lifetime results in

1 competition were considered when estimating correlations with results in RHQT.
2 Almost 50% of the horses that were judged in RHQT, i.e., 6671 horses, had
3 competition results in dressage or showing jumping.

4

5

6 **Methods**

7

8 *Statistical analysis*

9 *Analysis of variance for competition traits.* An analysis of variance was initially
10 performed to test which effects to consider in the final genetic analyses, by using the
11 GLM procedure in SAS (SAS Institute Inc., 2008). The effects of sex and birth year
12 were tested. By considering birth year, all horses of the same age are given equal
13 opportunities in the sport although the sport has developed considerably during the
14 time period covered. The effect of rider was not tested because rider and horse were
15 confounded as most riders only compete with one or few horses.

16

17 The analysis of variance showed that the effect of birth year was highly significant for
18 all competition traits ($P < 0.001$). The effect of sex was significant for all dressage traits
19 ($P < 0.001$). For show jumping, the effect of sex was highly significant ($P < 0.001$) for
20 lifetime results and for points per placing in the age group up to nine years of age. The
21 effect of sex was less significant ($P < 0.05$) for accumulated placings in the age group
22 up to six years. For the other show jumping traits, the effect of sex was not significant.
23 The coefficients of determination (R^2 -values) for competition data showed that 10-37%

1 of the variation could be ascribed to the model including both tested effects. Clearly
2 the effect of birth year had the greatest influence for all traits.

3

4 *Estimation of genetic parameters.* In accordance with results from the analysis of
5 variances, the following animal model was used for competition traits:

6

$$7 \quad y_{ijk} = \text{birth year}_i + \text{sex}_j + \text{animal}_k + e_{ijk} \quad (\text{Model I})$$

8

9 where y_{ijk} is the score transformed with 10-logarithm of each trait for k th horse; birth
10 year $_i$ is the fixed effect of i th birth year ($i=1953, \dots, 2002$); sex $_j$ is the fixed effect of the
11 j th sex ($j=\text{male or female}$); animal $_k$ is the random effect of the k th horse $\sim \text{ND}(0, \mathbf{A}\sigma_a^2)$,
12 and e_{ijk} is the random $\sim \text{IND}(0, \sigma_e^2)$ residual effect.

13

14 The following model developed by Viklund *et al.* (2008) was used for RHQT traits:

15

$$16 \quad y_{ijkl} = \text{event}_i + \text{sex}_j + \text{age}_k + \text{animal}_l + e_{ijkl} \quad (\text{Model II})$$

17

18 where y_{ijkl} is the score of each trait for l th horse; event $_i$ is the fixed effect of the i th
19 combination of year and place of test ($i=1, \dots, 305$); sex $_j$ is the fixed effect of the j th sex
20 ($j=\text{mare, gelding/stallion}$); age $_k$ is the fixed effect of the k th age ($k=4$ or 5 years of age);
21 animal $_l$ is the random effect of the l th horse $\sim \text{ND}(0, \mathbf{A}\sigma_a^2)$, and e_{ijkl} is the random
22 $\sim \text{IND}(0, \sigma_e^2)$ residual effect.

23

1 The models included the additive relationship matrix (**A**) with sire and dam
2 information. The pedigree of each horse with an observation was traced back seven
3 generations. In total, the pedigree file included 81,103 animals for analyses of
4 competition data, and 91,329 for the joint analyses of competition and RHQT data.
5 Genetic parameters and their standard errors were estimated by use of the average
6 information algorithm (Jensen *et al.*, 1997) for restricted maximum likelihood included
7 in the DMU package (Jensen and Madsen, 1994; Madsen and Jensen, 2000).

8

9 Genetic parameters for competition results obtained for horses four to six years of
10 age, horses four to nine years of age, and lifetime results were estimated in trivariate
11 analyses. Correlations between results from the three birth year groups were also
12 estimated in trivariate analyses. In the analyses with birth year groups the residual
13 covariances were set to zero. Correlations between competition traits and traits in
14 RHQT were estimated in bivariate analyses including one competition trait and one
15 RHQT trait.

16

17 The pedigree completeness in the pedigree file was quantified by computing the
18 pedigree completeness index (PEC) of MacCluer *et al.* (1983). For competition horses
19 the average PEC value was 0.82. The average PEC values were 0.73 for horses in
20 birth year group 1, 0.85 for horses in group 2, and 0.90 for horses in group 3. The
21 average PEC value for horses participating in RHQT was 0.96.

22

23

1 **Results**

2

3 *Effect of sex*

4 The fixed effects solutions from the genetic analyses of competition data showed that
5 males (stallions and geldings) were more successful in competition than mares, and
6 more so for dressage than for show jumping. The differences between the sexes were
7 0.65 (accumulated points) for lifetime results in dressage, and 0.13 (accumulated
8 points) for lifetime results in show jumping (not shown in a table).

9

10 *Genetic parameters for competition traits*

11 Heritabilities for dressage traits were low for all age groups, between 0.07 and 0.16
12 (Table 4). For show jumping the heritabilities were low to moderate, 0.12 to 0.28. For
13 both disciplines, higher heritabilities were estimated for competition results of horses
14 up to nine years of age and lifetime results than for the youngest group. In each age
15 group, accumulated points and accumulated placings showed higher heritabilities than
16 points per placing. The additive genetic variances were in general two to three times
17 higher for lifetime results compared to results of the youngest group.

18

19 Very high genetic correlations (0.84-1.00) were estimated between all age groups in
20 both disciplines (Table 5). The phenotypic correlations were also high, especially
21 between results from four to nine years of age and lifetime results (0.90-0.94). The
22 genetic and phenotypic correlations between the different lifetime competition traits
23 within discipline were very high, 0.91-0.98 and 0.97-1.00, respectively (Table 6). The

1 highest correlations were estimated between accumulated placings and accumulated
2 points.

3

4 For dressage traits the highest heritabilities were estimated for horses born between
5 1953 and 1983 (0.15-0.18), and for show jumping the highest heritabilities were
6 estimated for horses born 1992 and onwards (0.28-0.34) (Table 7). In both disciplines
7 the genetic variances were highest for horses born 1953-1983.

8

9 For dressage, the highest correlations (0.85-0.98) were estimated between birth year
10 group 1 and 2 (Table 8). The lowest correlations were estimated between group 1 and
11 3, except for accumulated placings where the lowest correlation was estimated
12 between group 2 and 3. For show jumping the highest genetic correlations were
13 between group 2 and 3 (0.97-0.98), and the lowest between group 1 and 3 (0.54-
14 0.71).

15

16 *Correlations between competition and RHQT traits*

17 In Table 9 and 10, genetic and phenotypic correlations between competition results
18 and traits at RHQT are presented. Overall, the phenotypic correlations were, as
19 expected, lower than the genetic correlations. Gait traits judged under rider at RHQT
20 were positively genetically correlated to dressage competition (0.47-0.77). Genetic
21 correlations between dressage competition and conformation traits were also highly
22 positive (0.45-0.71), except for correctness of legs (0.15-0.22). There were slightly
23 negative to slightly positive genetic correlations between jumping traits at RHQT and

1 dressage competition results. Those traits were in general also phenotypically
2 unrelated.

3

4 Very high positive genetic correlations were estimated between jumping traits at
5 RHQT and show jumping (0.80-0.89). Between RHQT gait traits and show jumping the
6 genetic correlation was moderate for canter (0.33-0.39), but low for the other traits (-
7 0.01-0.23). Genetic correlations between conformation traits and show jumping were
8 moderate (0.19-0.34). Phenotypically, conformation and gaits at RHQT were largely
9 unrelated to show jumping results.

10

11

12 **Discussion**

13

14 *Choice of trait*

15

16 The competition data included mostly results from horses that had been placed in
17 competition (76% of the dressage horses and 83% of the show jumping horses). This
18 leads to a selection of the data because some horses compete but never or seldom
19 achieve a placing. To get as unselected data as possible, all horses in each
20 competition could be reported in a complete ranking, from the best to the worst horse.
21 Then all horses contribute with information and the level of the competition can be
22 determined. In Belgium, Germany and Ireland the trait rank in competition has been
23 used in genetic analyses for riding horses (Janssens *et al.*, 1997; Hassenstein, 1998;

1 Reilly *et al.*, 1998). These authors used different transformations to handle the trait,
2 e.g. the Blom score or the square root of placing. Ranking methodology is probably a
3 good approach although it may be anticipated that ranking in the top of a competition
4 is more accurate than among the bottom placed horses.

5

6 The heritabilities in this study were slightly higher than those of others (e.g. Huizinga
7 and van der Meij, 1989; Aldridge *et al.*, 2000; Brockmann and Bruns, 2000; Lührs-
8 Behnke *et al.*, 2006a and 2006b) and may be explained by the use of accumulated
9 results up to different ages. However, the comparison of results from different studies
10 is difficult because of the use of different definition of traits, transformations, age
11 groups and statistical models. In general, heritabilities for competition traits are low to
12 moderate. This is mainly because the traits are influenced by several non-genetic
13 factors as training and rider. The heritabilities for lifetime results in competition were in
14 the same range as earlier estimated by Wallin *et al.* (2003).

15

16 Between the different traits within discipline, the genetic correlations were very high.
17 The highest correlations were between accumulated points and accumulated placings.
18 These traits are both measurements of how much and how well a horse has
19 competed. The trait points per placing, instead, is a measurement of what level the
20 horse has successfully competed at. If a single measurement were used, the
21 heritabilities and additive genetic variances estimated indicating the log transformed
22 accumulated points would be preferable.

23

1 *Statistical model*

2 Data used in the present study covered a long period, during which opportunities for
3 competitions changed considerably and the effect of birth year was shown to
4 considerably affect the competition results. The horses born the first 20 years, 1953 to
5 1973, only corresponded to 10% of the horses in the competition data. Thereafter, the
6 sport expanded, and the number of competing horses and competitions increased.
7 Age at performance is often considered when analyzing competition traits (e.g.
8 Huizinga and van der Meij, 1989; Reilly *et al.*, 1998; Ricard and Chanu, 2001; Lührs-
9 Behnke *et al.*, 2006a and 2006b). In the present study accumulated results are used,
10 which in combination with birth year leads to a comparison of horses with the same
11 opportunity period for competition.

12

13 When using accumulated competition results, a horse could have results both as
14 stallion and gelding. Therefore, only males and females were considered in the fixed
15 effect of sex. Males were superior to females, which agrees with findings of Árnason
16 (1987) and Reilly *et al.* (1998) in their studies of Swedish RHQT data and Irish show
17 jumping competition, respectively. The heat cycles of the mares can influence the
18 willingness to cooperate with the rider. The sex difference was larger for dressage
19 than for show jumping indicating that the more uneven temperament anticipated for
20 mares may influence the dressage results more. Moreover, the sex distribution in the
21 dressage competition data (66% males) shows that riders prefer a stallion or gelding
22 for this discipline.

23

1 *Pre-selection*

2 Approximately 30% of the registered foals have competition records. This percentage
3 was considerably higher than earlier reported by Wallin *et al.* (2003). The selection of
4 competition horses is due to talent, interest, exportation, and use in breeding.
5 Considering that the data mostly only included horses that had been placed in
6 competition (i.e. among the 20% best in each competition), the percentage is probably
7 comparable to the Dutch competition data, where 30% of registered foals were
8 brought into dressage competition and 20% into jumping competition (Huizinga and
9 van der Meij, 1989).

10

11 The pre-selection of horses for competition, and that the records largely refer to
12 horses with placings, probably leads to a reduced additive genetic variance, which
13 results in lower and underestimated heritabilities. Janssens *et al.* (1997) estimated
14 genetic parameters for different datasets; one including all available horses in young
15 horse jumping competitions (4 to 7 years of age) and another including only the 25%
16 best ranked horses. The additive genetic variance and heritability were very low for
17 the reduced material, 0.0018 and 0.0243 compared to 0.0902 and 0.0979 for the
18 whole material respectively. The authors concluded that use of the reduced material
19 for genetic improvement would be inadequate because of both lower genetic variance
20 and fewer horses evaluated. However, in the present study the heritabilities for show
21 jumping for horses up to six years of age were considerable higher than those
22 estimated by Janssens *et al.* (1997) for the dataset with complete records (0.14-0.24

1 compared with 0.10). This indicates that the selection of the Swedish material may not
2 be as strong as in the Belgian data.

3

4 *Differences between dressage and show jumping*

5 The higher heritabilities and additive genetic variances for show jumping than for
6 dressage may partly be explained by more information from more horses that had
7 competed in show jumping. Furthermore, dressage riders may influence the horses
8 more by training for competition in dressage than show jumping riders, as Kearsley *et*
9 *al.* (2008) have shown for eventing horses. The results in dressage competition also
10 depend on subjective judgments from one or several judges, which increase the
11 residual variance, leading to lower heritabilities. The results from show jumping
12 competitions are considered to be more objective even though the influence from the
13 rider is also important. Higher heritabilities for show jumping than for dressage have
14 been estimated in some studies (Huizinga and van der Meij, 1989; van Veldhuizen,
15 1997; Wallin *et al.*, 2003). However, in other studies where genetic parameters have
16 been estimated for both dressage and show jumping, the heritability estimates have
17 been higher for dressage (Hassenstein, 1998; Brockmann and Bruns, 2000; Lührs-
18 Behnke *et al.*, 2006a and 2006b) or disciplines did not differ (Schade, 1996; Ducro *et*
19 *al.*, 2007).

20

21 *Changes in competition traits*

22 When dividing the horses in the competition data into birth year groups, the
23 heritabilities for dressage were highest for the group of horses born in the earliest

1 group (1953-1983) and lowest for the group of horses born in the last group (1992-
2 2002). The low heritability in the last group could be because these horses were
3 young, and for dressage horses the results at advanced levels come late in life. For
4 show jumpers, on the other hand, the results in competition are often achieved earlier
5 in life, and for these traits the highest heritabilities were estimated for the last birth
6 year group.

7
8 The genetic correlations between birth year groups showed that the competition traits
9 were not the same throughout the recording period. The sport has developed
10 considerably and the proportion of competing horses out of born horses has increased
11 continuously. In contrast to an earlier study of RHQT data (Viklund *et al.*, 2008) the
12 genetic parameters for competition results were less consistent over time. Thus, it is
13 necessary to investigate the differences in heritabilities and variances between the
14 different birth year groups for their impact on the genetic evaluations.

15 16 *Performance for different age groups*

17 In this study, heritabilities increased with increasing age of the horses because
18 accumulated results were used and an older age group therefore contained more
19 information on the horses. Lower heritabilities are often estimated with increasing age
20 because environmental factors, such as training and rider, may have influenced the
21 horses more (Tavernier, 1992; van Veldhuizen, 1997). On the other hand, Ricard and
22 Chanu (2001) estimated higher heritabilities with increasing age for annual
23 performances in eventing horses. Most likely the genetic potential and variance is

1 better expressed at more advanced competition levels than at lower competition
2 levels.

3

4 Estimated genetic correlations between competition results for the different age
5 groups were positive and very high. This indicates that results from young horses, and
6 consequently at low levels of competition, can be used when estimating breeding
7 values although the heritabilities were lower. When horses start to compete and get
8 results, some selection takes place. Horses that perform well are likely to get more
9 and better training than horses that do not perform well. This selection may contribute
10 to the high levels of the correlations. Other studies confirm that genetic correlations
11 between different age groups are very high (Huizinga and van der Meij, 1989;
12 Tavernier, 1992; van Veldhuizen, 1997; Ricard and Chanu, 2001).

13

14 The heritabilities for lifetime show jumping traits (0.18-0.27) were in the same range as
15 heritabilities estimated for jumping traits judged at young horse test for 4-year-olds
16 (0.17-0.23), and for jumping traits at young horse test for 3-year-olds (0.23-0.33)
17 (Viklund *et al.*, 2008). The young horse should be less influenced by rider and trainer,
18 but horses that compete in show jumping compete often and consequently have more
19 information from competition than from the one-day field test as a 4-year-old. For
20 dressage heritabilities for lifetime competition traits (0.12-0.16) were lower than for
21 gaits judged at young horse tests (0.38-0.48) (Viklund *et al.*, 2008). The dressage
22 horses compete less, especially at young ages, and they are probably more
23 influenced by rider and trainer than the show jumping horses.

1

2 In comparison with the study by Wallin *et al.* (2003), the genetic correlations between
3 lifetime competition traits and traits judged at RHQT were in the same range or lower.
4 Only the correlations between total conformation and dressage competition were
5 higher in this study. A possible explanation for the differences between the studies is
6 that the RHQT data in the study by Wallin *et al.* (2003) only included 3708 horses that
7 had been judged in RHQT between 1973 and 1986, compared to 14,006 horses
8 judged between 1988 and 2007 in this study. Furthermore, the competition data in the
9 study by Wallin *et al.* (2003) comprised data to 1999, which means that the horses
10 from RHQT had a chance to be at least 17 years old in 1999. In the present study
11 lifetime results in the last birth group could be the result for horses as young as four
12 years because the lifetime result was defined as all competition results until 2006.

13

14 The highly positive genetic correlations found between performance in dressage
15 competition and gait traits at RHQT, and even higher for show jumping and jumping
16 traits at RHQT (Table 6 and 7), indicate that results from RHQT are very good
17 predictors of later performance at competitions. Other studies confirm that young
18 horse tests are valuable for prediction of future performance. Lührs-Behnke *et al.*
19 (2006a) found genetic correlations of 0.88 for rideability at mare tests and dressage
20 competition but only 0.36 for free jumping at mare tests and show jumping. Ducro *et*
21 *al.* (2007) estimated correlations to 0.69 between movements at studbook entry
22 inspection and dressage competition and 0.87 between jumping test and show
23 jumping.

1

2 Considering individual gaits, trot and canter are most important for becoming a
3 successful dressage horse. This could be explained by more movements performed in
4 trot and canter in the more advanced classes in dressage. Lührs-Behnke *et al.*
5 (2006b) showed also that trot and canter were the most important gaits for dressage
6 competition at the highest level, but at the lower levels all gaits seemed to have equal
7 importance. In the study by Ducro *et al.* (2007), trot judged at studbook entry
8 inspection was the gait most highly correlated to dressage competition results. In that
9 study there were three to four different subtraits for each gait, and the genetic
10 correlations with dressage varied from 0.05 (correctness in walk) to 0.67 (elasticity in
11 trot). Huizinga *et al.* (1990) estimated genetic correlations between field performance
12 test of mares and competition and found canter to be the gait highest correlated to
13 dressage (0.36). Yet, this correlation was low compared to other studies. Good gaits
14 are probably not enough to succeed at higher classes in dressage. The trait
15 temperament for gaits scored in RHQT, an expression for rideability, in this study was
16 more strongly correlated genetically to performance in dressage competition than any
17 of the individual gaits (0.77). In general our study shows comparatively high
18 correlations between test results of 4-year-olds and later competition results in the
19 same discipline.

20

21 Between gaits judged at RHQT and show jumping, the genetic correlations were
22 moderate for canter (0.33-0.39), but low for the other RHQT traits. The importance of
23 canter for show jumping is also reported by Huizinga *et al.* (1990), Lührs-Behnke *et al.*

1 (2006a) and Ducro *et al.* (2007). They estimated genetic correlations to 0.36, 0.32 and
2 0.28-0.43, respectively.

3

4 Genetic correlations between jumping traits at RHQT and dressage competition
5 results were low negative to low positive. In the study by Wallin *et al.* (2003) the
6 genetic correlations were low, but positive. Ducro *et al.* (2007) estimated weak to
7 moderate and unfavourable genetic correlations between free jumping traits at
8 studbook entry inspection and results from dressage competition (-0.34 – -0.09). In the
9 study by Lührs-Behnke *et al.* (2006a) the genetic correlations were almost zero (0.01)
10 between free jumping at mare performance test and dressage competition. On the
11 other hand, Huizinga *et al.* (1990) found a positive correlation between jumping ability
12 at field performance test for mares and dressage (0.17). Thus, our study confirms the
13 low relationships between dressage traits and show jumping, with the generally
14 accepted exception of the positive correlation between canter and jumping traits.

15

16 *Suitability for genetic evaluations*

17 A great advantage for competition traits is that they directly reflect the breeding
18 objective, and for show jumping traits the results from the present study show
19 moderate heritabilities. For dressage traits the heritabilities were low and much lower
20 than for the gait traits recorded at RHQT (Viklund *et al.*, 2008). Drawbacks for
21 competition results are that the horses are pre-selected for competition and that
22 results come late in life, especially in dressage. Use of competition results in genetic

1 evaluation of sport horses therefore leads to long generation intervals if selection has
2 to wait for those results.

3

4 Competition performance can be measured in different ways. In this study,
5 accumulated points, accumulated placings and the ratio between those have been
6 analyzed for three different stages in life of the horse. The heritabilities, and genetic
7 variances, were highest for accumulated points. Thus, this trait would be of most
8 interest to use in genetic evaluations. For the different stages in the horses' life,
9 lifetime performance showed the highest heritabilities and genetic variances, and
10 therefore it seems to be the most suitable approach. The lifetime performance in this
11 study was defined as all results the horses had achieved until the end of data
12 collection. This means that young horses also have a lifetime result even though they
13 have not yet finished competing. Clearly young horses have fewer results, but this is
14 corrected for in the analyses by including birth year as a fixed effect.

15

16 The present research aims ultimately at integrating the results from the test of 3-year-
17 olds (Viklund *et al.*, 2008) and the competition data into the BLUP index system. It is
18 considered important to make use of all data sources to both get as reliable proofs as
19 possible and for the credibility of the indexes among breeders, trainers and riders.
20 When results from tests of 3- and 4-year-olds are included in a multi-trait mixed model
21 analysis, the effects of selected data for competitions are reduced because many
22 more horses are evaluated as 3- and 4-year-olds, and at these occasions for both
23 dressage and jumping traits. In constructing the indexes it is important to note that the

1 initially described breeding objective is kept, i.e. competition results at advanced levels
2 in dressage and show jumping respectively. The young horse test results should then
3 be used as indicator traits. However, in the indexes most weight will be put on results
4 from RHQT because the horses are tested for both disciplines, while they often only
5 compete in one discipline. Moreover, the heritabilities for traits at RHQT are often
6 higher than for competition traits (dressage) and the tests are more standardized than
7 the competitions.

8

9

10 **Conclusions**

11

12 Lifetime competition results are recommended to be used in genetic evaluation of
13 Swedish Warmblood horses because higher heritabilities were estimated when all
14 competition results were included compared with only results from young horses. The
15 accuracy increases when results from more years are added as more information of
16 the horse is obtained.

17

18 Accumulated lifetime performance allows competition results to be available early in
19 life for genetic evaluation as horses are compared within birth year.

20

21 The high genetic correlations between traits tested at RHQT for 4-year-olds and
22 competition imply that results from the RHQT are desired to continuously be included

1 in the genetic evaluation because they are highly correlated with the breeding
2 objectives and results appear early in life.

3

4 Due to pre-selection of horses for competition, integrated breeding values with results
5 from young horse test and competition results would be preferable to indexes only
6 including competition results.

7

8 Additional studies are needed to investigate how to handle competition data from
9 different time periods in genetic evaluations because the equestrian sport has
10 expanded and competition results do not mean the same throughout the 35-year-long
11 period of recording. Such studies should comprise e.g. studies of heterogeneity of the
12 variances over time and comparison of breeding values and their variation, estimated
13 with competition data from different birth year groups.

14

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21

22

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1 **Table 1.** Means, standard deviations (s.d.) and maximum (Max) of 10-log transformed competition traits in different age
 2 groups

	No. of horses	<u>Points</u>			<u>Placings</u>			<u>Points/placing</u>		
		Mean	s.d.	Max	Mean	s.d.	Max	Mean	s.d.	Max
Dressage										
4-6 years	5806	0.77	0.62	2.66	0.45	0.37	1.76	0.49	0.33	1.35
4-9 years	11,988	0.94	0.74	3.44	0.56	0.46	1.98	0.53	0.35	1.76
Lifetime	15,396	0.99	0.81	4.10	0.59	0.50	2.23	0.54	0.37	1.91
Show jumping										
4-6 years	15,908	0.97	0.63	2.79	0.63	0.42	2.09	0.51	0.26	1.49
4-9 years	25,715	1.07	0.74	3.49	0.72	0.51	2.21	0.52	0.28	1.59
Lifetime	29,564	1.11	0.80	4.08	0.75	0.55	2.55	0.52	0.29	1.72

3

1 **Table 2.** Number of sires and number of offspring in different birth year group
 2 (B1, B2, B3)^a with results in show jumping and/or dressage

	B1 only	B2 only	B3 only	B1 & B2	B2 & B3	B1 & B3	B1, B2 & B3
Stallions ^b (2218)	246	365	1163	100	253	5	86
Offspring ^c (37,227)	5991	733	5666	6340	8723	302	9472

3 ^aBirth year group 1: 1953-1983, Birth year group 2: 1984-1991, Birth year group
 4 3: 1992-2002.

5 ^bEach sire is only represented once.

6 ^cOffspring with results in competition. 1480 of the horses in competition had no
 7 information of sire and were not included.

8

9

1 **Table 3.** Means, standard deviations (s.d.), minimum (Min.) and maximum (Max.)
 2 values for traits in RHQT 1988-2007^a

Trait	Mean	s.d.	Min	Max
Conformation traits				
Type	7.80	0.61	4	10
Head-neck-body	7.70	0.57	5	10
Correctness of legs	7.34	0.66	4	9
Total conformation	37.4	1.90	27	44
Gaits under rider				
Walk	6.69	0.96	1	10
Trot	6.32	0.98	1	10
Canter	6.69	0.97	1	10
Average for gaits	6.57	0.78	1	9.67
Temperaments for gaits	6.56	0.96	1	10
Jumping traits				
Technique and ability ^b	6.67	1.39	1	10
Temperament for jumping ^b	6.75	1.53	1	10

3 ^aNumber of records varied for the various traits between 12,988 and 14,006.

4 ^bA mix of free jumping and jumping under rider.

5

6

1 **Table 4.** Heritabilities and additive genetic variances with standard errors as
 2 subscripts for competition traits

	Heritability			Genetic variance		
	Points	Placings	Points/plac.	Points	Placings	Points/plac.
Dressage						
4-6 years	0.11 _{.02}	0.11 _{.02}	0.07 _{.01}	0.03 _{.005}	0.01 _{.002}	0.01 _{.001}
4-9 years	0.15 _{.02}	0.15 _{.02}	0.11 _{.02}	0.07 _{.008}	0.02 _{.003}	0.01 _{.002}
Lifetime	0.16 _{.02}	0.15 _{.02}	0.12 _{.02}	0.09 _{.01}	0.03 _{.004}	0.01 _{.002}
Show jumping						
4-6 years	0.24 _{.02}	0.23 _{.02}	0.12 _{.01}	0.07 _{.005}	0.03 _{.002}	0.01 _{.001}
4-9 years	0.28 _{.02}	0.26 _{.02}	0.17 _{.01}	0.13 _{.008}	0.06 _{.004}	0.01 _{.001}
Lifetime	0.27 _{.01}	0.26 _{.02}	0.18 _{.01}	0.15 _{.009}	0.07 _{.004}	0.01 _{.001}

3

4

1 **Table 5.** Genetic (r_g) and phenotypic correlations (r_p) between competition traits
 2 in different age groups

Traits	r_g^a	r_p
Dressage		
4-6 years - 4-9 years	0.92-0.95	0.74-0.76
4-6 years - Lifetime	0.84-0.93	0.60-0.68
4-9 years - Lifetime	0.98-0.99	0.90-0.91
Show jumping		
4-6 years - 4-9 years	0.96-1.00	0.79-0.81
4-6 years - Lifetime	0.92-0.99	0.69-0.72
4-9 years - Lifetime	0.99-1.00	0.93-0.94

3 ^aStandard errors for genetic correlations were 0.03-0.04 for dressage traits and
 4 0.001-0.01 for show jumping traits.

5
 6
 7

- 1 **Table 6.** Genetic correlations (r_g) with standard errors as subscripts and
- 2 phenotypic correlations (r_p) between different competition traits

Traits	r_g	r_p
Dressage		
Placings - Points	0.98 _{.004}	0.97
Placings - Points per placing	0.91 _{.022}	0.74
Points - Points per placing	0.97 _{.009}	0.87
Show jumping		
Placings - Points	1.00 _{.001}	0.97
Placings - Points per placing	0.97 _{.007}	0.73
Points - Points per placing	0.99 _{.004}	0.84

3

1 **Table 7.** Heritabilities and genetic variances with standard errors as subscripts
 2 for competition traits divided into three groups by birth year (B1, B2, B3)^a

	Heritability			Genetic variance			
	No. of horses	Points	Placings	Points/ plac.	Points	Placings	Points/ plac.
Dressage							
B1	7467	0.18 _{.03}	0.18 _{.03}	0.15 _{.02}	0.11 _{.02}	0.05 _{.01}	0.02 _{.003}
B2	4219	0.17 _{.03}	0.16 _{.03}	0.14 _{.03}	0.09 _{.02}	0.03 _{.01}	0.01 _{.003}
B3	3710	0.14 _{.04}	0.12 _{.03}	0.14 _{.04}	0.07 _{.02}	0.02 _{.01}	0.01 _{.003}
Show jumping							
B1	13245	0.31 _{.02}	0.30 _{.02}	0.20 _{.02}	0.19 _{.02}	0.09 _{.01}	0.02 _{.002}
B2	7285	0.29 _{.03}	0.26 _{.03}	0.25 _{.03}	0.17 _{.02}	0.07 _{.01}	0.02 _{.002}
B3	9034	0.34 _{.03}	0.30 _{.03}	0.28 _{.03}	0.16 _{.01}	0.07 _{.01}	0.01 _{.001}

3 ^aBirth year group 1: 1953-1983, Birth year group 2: 1984-1991, Birth year group
 4 3: 1992-2002.

5

6

1 **Table 8.** Genetic correlations, with standard errors as subscripts, between
 2 corresponding traits for different birth year groups (B1, B2, B3)^a

	Points	Placings	Points per placing
Dressage			
B1 – B2	0.95 _{.07}	0.98 _{.06}	0.85 _{.11}
B2 – B3	0.75 _{.13}	0.77 _{.14}	0.80 _{.13}
B1 – B3	0.71 _{.14}	0.85 _{.13}	0.40 _{.19}
Show jumping			
B1 – B2	0.81 _{.06}	0.85 _{.06}	0.69 _{.07}
B2 – B3	0.98 _{.04}	0.98 _{.05}	0.97 _{.05}
B1 – B3	0.66 _{.07}	0.71 _{.07}	0.54 _{.09}

3 ^aBirth year group 1: 1953-1983, Birth year group 2: 1984-1991, Birth year group
 4 3: 1992-2002.

5

6

7

1 **Table 9.** Genetic correlations (r_g) with standard errors as subscripts and
 2 phenotypic correlations (r_p) between traits at RHQT and dressage competition
 3 traits

Trait at RHQT	<u>Dressage competition traits</u>					
	<u>r_g</u>			<u>r_p</u>		
	Points	Placings	Points/ placing	Points	Placings	Points/ placing
Conformation traits						
Type	0.50 _{.07}	0.45 _{.07}	0.58 _{.07}	0.12	0.10	0.14
Head-neck-body	0.52 _{.07}	0.46 _{.08}	0.59 _{.07}	0.09	0.06	0.13
Correctness of legs	0.17 _{.11}	0.15 _{.11}	0.22 _{.11}	0.05	0.05	0.06
Total conformation	0.65 _{.05}	0.60 _{.06}	0.71 _{.05}	0.23	0.21	0.23
Gaits under rider						
Walk	0.50 _{.06}	0.47 _{.07}	0.51 _{.07}	0.19	0.19	0.16
Trot	0.73 _{.05}	0.70 _{.05}	0.72 _{.05}	0.25	0.23	0.21
Canter	0.64 _{.06}	0.58 _{.06}	0.70 _{.06}	0.24	0.22	0.21
Average for gaits	0.73 _{.05}	0.68 _{.05}	0.75 _{.05}	0.27	0.26	0.23
Temp. for gaits	0.76 _{.05}	0.72 _{.05}	0.77 _{.05}	0.25	0.22	0.22
Jumping traits						
Technique and ability	0.02 _{.09}	-0.05 _{.08}	0.17 _{.09}	0.05	0.03	0.07
Temp. for jumping	-0.19 _{.09}	-0.13 _{.09}	0.03 _{.10}	0.03	0.04	0.06

4

5

1 **Table 10.** Genetic correlations (r_g) with standard errors as subscripts and
 2 phenotypic correlations (r_p) between traits at RHQT and show jumping
 3 competition traits

Trait at RHQT	<u>Show jumping traits</u>					
	<u>r_g</u>			<u>r_p</u>		
	Points	Placings	Points/ Placings	Points	Placings	Points/ Placings
Conformation traits						
Type	0.24 _{.06}	0.20 _{.06}	0.34 _{.06}	0.10	0.09	0.11
Head-neck-body	0.22 _{.06}	0.20 _{.07}	0.26 _{.06}	0.08	0.07	0.08
Correctness of legs	0.23 _{.09}	0.22 _{.09}	0.25 _{.09}	0.03	0.04	0.01
Total conformation	0.22 _{.03}	0.19 _{.05}	0.31 _{.06}	0.10	0.09	0.10
Gaits under rider						
Walk	-0.01 _{.06}	-0.01 _{.06}	0.02 _{.06}	-0.01	-0.01	0.01
Trot	0.15 _{.05}	0.12 _{.05}	0.18 _{.06}	0.05	0.04	0.06
Canter	0.34 _{.05}	0.33 _{.05}	0.39 _{.06}	0.11	0.10	0.11
Average for gaits	0.19 _{.05}	0.18 _{.05}	0.23 _{.08}	0.07	0.05	0.08
Temp. for gaits	0.17 _{.06}	0.16 _{.06}	0.22 _{.06}	0.07	0.06	0.08
Jumping traits						
Technique and ability	0.88 _{.03}	0.87 _{.03}	0.88 _{.03}	0.30	0.29	0.25
Temp. for jumping	0.88 _{.03}	0.88 _{.03}	0.89 _{.03}	0.28	0.27	0.24

4

5

6