Breeding of Swedish Warmblood horses towards specialization in show jumping and dressage

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Abstract

A clear specialization towards show jumping or dressage performance is evident in most European Warmblood studbooks. As a consequence, some breeding organizations have introduced specialized breeding programs. The aim of this thesis was to investigate the specialization towards show jumping and dressage in the Swedish Warmblood (SWB) population, as well as the relationships between linearly scored traits and performance in these disciplines. The proportion of allround horses had decreased considerably from 1980 in favor of show jumping and dressage horses. A decrease was also seen in the average relationship between show jumping and dressage horses over time, while it increased within the subpopulations during the past decade. A future scenario with discipline-specific young horse tests would result in decreased heritability and genetic variance for traits that are not assessed for all horses, but would have only minor impact on the ranking of sires within discipline based on breeding values. Phenotypic relationships between linearly scored traits and competition results showed that few traits except jumping traits were important for performance in show jumping, whereas several conformation and gait traits seemed to be of high importance for performance in dressage. For show jumping performance, most relationships had a linear association, whereas relationships with intermediate optimal scores were common for performance in dressage. The findings confirm the specialization of the SWB population, and that linear assessment of young horses is a valuable tool in sport horse breeding.

Keywords: breeding program, linear scoring, optimum, young horse test

Avel av svenska varmblodshästar mot specialisering i hoppning och dressyr

Sammanfattning

En specialisering mot prestation i hoppning eller dressyr är tydlig i de flesta europeiska stamböcker för varmblodiga ridhästar. Med anledning av detta har flera avelsorganisationer infört specialiserade avelsprogram. Syftet med den här avhandlingen var att undersöka specialiseringen mot hoppning och dressyr hos den svenska varmblodshästen (SWB), samt även sambanden mellan linjära egenskaper och prestation i dessa discipliner. Andelen hästar klassificerade som ”allround” minskade påtagligt från 1980 till förmån för hopp- och dressyrhästar. Även det genomsnittliga släktskapet mellan hopp- och dressyrhästar minskade över tid, medan det ökade inom de olika subpopulationerna under det senaste decenniet. Ett framtidsscenario med disciplinspecifika unghästtest skulle leda till minskad arvbarhet och genetisk variation för de egenskaper som inte skulle bedömas för alla hästar, men det skulle endast ha liten påverkan på rangeringen av hingstar inom deras huvuddisciplin. Fenotypiska samband mellan linjära egenskaper och tävlingsresultat visade att få egenskaper förutom hoppegenskaper var viktiga för prestation i hoppning, medan flertalet exteriör- och gångartsegenskaper var viktiga för prestation i dressyr. För prestation i hoppning var de flesta sambanden linjära, medan samband med intermediära optimum var vanligt för prestation i dressyr. Resultaten bekräftade att det finns en tydlig specialisering inom SWB-populationen, och att linjär bedömning av unga hästar är ett värdefullt verktyg inom sporthästaveln.

Nyckelord: avelsprogram, linjär bedömning, optimum, unghästtest

Till mästerskapet gives blott en bana
ren som solens väg uti det blå,
att syfta uppåt och det högsta ana,
men aldrig tro sig mästare ändå

Clas Adam Ehrengranat

Till mamma, och alla fantastiska hästar vi haft nöjet att lära känna.

Contents

List of publications

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

I. Bonow, S., Eriksson, S., Thorén Hellsten, E. & Gelinder Viklund, Å. (2022). Consequences of specialized breeding in the Swedish Warmblood horse population. Journal of Animal Breeding and Genetics 140 (issue 1), 79-91.

II. Bonow, S., Eriksson, S., Strandberg, E., Thorén Hellsten, E. & Gelinder Viklund, Å. Relationship between linearly scored traits and sport performance in Swedish Warmblood horse population. (Manuscript).

The contribution of Sandra Bonow to the papers included in this thesis was as follows:

I. Planned and designed the study together with co-authors, performed the analyses. Drafted, wrote and reviewed the manuscript in collaboration with all co-authors. Had the responsibility for the final version, submission process, and correspondence with the journal.

II. Planned and designed the study together with the co-authors, performed the analyses. Drafted and wrote the manuscript in collaboration with all co-authors.

Abbreviations

AR	Allround
BLUP	Best Linear Unbiased Prediction
EBV	Estimated Breeding Value
D	Dressage
J	Jumping
KWPN	Koninklijk Warmbloed Paardenstamboek Nederland (Royal Studbook of the Netherlands)
RHT	Riding Horse Test
SWB	Swedish Warmblood
Th	Thoroughbred
YHT	Young Horse Test

1. Introduction

The international equestrian sport is highly competitive. In order to produce horses that can become successful in either show jumping or dressage, a clear specialization towards one or the other discipline is evident in several European Warmblood studbooks (Stock et al., 2015). Also the Swedish Warmblood (SWB) breed is undergoing such specialization, leading to a possible need for separate breeding programs and discipline-specific young horse tests. Assessment of young horses is necessary to achieve fast genetic progress in the population. Because results from young horse tests are highly correlated with performance later in life, they can act as early indicators for the breeding goal trait (Thorén Hellsten et al., 2006). Besides the benefit of shortening the generation interval, the heritability of performance in young horse tests is also considerably higher than for competition results (Ricard et al., 2000). The assessments of young horses are an important part in the routine genetic evaluation of the SWB breed since 1986 (Viklund et al., 2011), but to what extent discipline-specific testing could affect the genetic evaluation has not previously been investigated.

In order to breed horses that can become top athletes in international sport, details have become even more important. To identify important characteristics for successful performance in either show jumping or dressage is of high interest for the breeding organizations. The linear scoring system has been introduced in several studbooks to give a more detailed assessment of the horse (Duensing et al., 2014). In SWB, it was introduced in 2013 and the first age cohorts have thus had time to achieve competition results at advanced level in show jumping or dressage. This makes it for the first time possible to investigate relationships between the linearly scored traits and sport performance in the SWB population.

2. Background

2.1 The Swedish Warmblood

The SWB breed traces its origin back to the eighteenth century, when the main purpose was to produce horses for the royal cavalry (Graaf, 2004). The studbook in its current from was established in 1928 and the aim was to breed a correct warmblood horse suitable for several equestrian purposes. Today, the SWB breed is the most common horse breed in Sweden, with approximately 65 000 registered horses and about 2800 foals born each year (HNS, 2021). Although the SWB breed is a rather small population in comparison to other warmblood studbooks (WBFSH, 2021), many SWB horses have been successful at international level and the studbook has achieved high placings in studbooks rankings in both show jumping and dressage (WBFSH, 2023).

2.2 Breeding goal

The breeding goal for most European warmblood studbooks is to produce competitive horses at an international level in show jumping and/or dressage (Koenen et al., 2004). In SWB, the overall breeding goal is stated as "A noble, correct and sound horse that by its temperament, rideability and good movements and/or jumping ability is internationally competitive" (SWB, 2021*)*. The genetic trend for both show jumping and dressage in the SWB population has increased considerably since the mid 1980´s (Viklund et al., 2011). Several factors may have influenced this development, such as import of high-quality stallions for jumping or dressage, an improved stallion selection and the introduction of the BLUP evaluation in 1986. Since 2002,

the SWB stallion performance test has been specialized and stallions are approved for breeding based on results from only one discipline (Granberg, 2017).

2.3 Assessment of young horses in SWB

The first performance test for young horses in SWB, the Riding Horse Test (RHT), was introduced in 1973 and was a one-day field test for 4-year-old horses (and 5-years-old mares that had foal the previous year), where conformation, health status, jumping ability, gaits and rideability were assessed (Jönsson, 2013). Since 2006 health status is excluded from the test. In 1999 an additional test was introduced, the Young Horse Test (YHT), where 3-year-old horses are assessed for conformation, gaits and free jumping traits (Viklund et al, 2011). In both tests, traits are subjectively scored between 1-10 in relation to the breeding goal.

The aim of the tests for young horses is to give the owners an opportunity to have their horse assessed, to find suitable mares for breeding, and to function as a base for genetic evaluation of the breed (SWB, 2021). The collected horse data is also useful for research purpose. The tests are arranged annually in about 20-25 locations throughout the country from April to September. Approximately 40% of the available 3-year-old horses participate in YHT (Viklund & Eriksson, 2018), whereas the interest for RHT has decreased during the last decades to a participation rate of 6% in 2022 (Gelinder Viklund, pers. comm., 2023). All results from YHT and RHT are registered and published by the breeding organization at https://www.blup.se. At YHT all participating horses are tested as both jumping and dressage talents, whereas it since 2019 is possible to have the horse tested for only one discipline at the RHT, provided that the horse has participated in YHT (SWB, 2018). This requirement was made to ensure that all assessed horses get an overall assessment. However, according to the breeding organization, some owners of dressage horses would like to opt out of having jumping assessed at YHT (Thorén Hellsten, pers. comm., 2022). Similarly, owners of jumping horses often do not pay much attention to the assessment of walk and trot.

2.4 Linear scoring

The linear scoring system has become an important tool in many European studbooks when assessing young horses (Duensing et al., 2014). The aim is to give a detailed and more objective description of the horse, by describing several traits on a scale between two biological extremes. The assessment serves as a complement to the traditional valuating scoring where traits are evaluated according to the breeding goal. The KWPN studbook was one of the first warmblood studbooks to introduce the linear scoring system in 1989 (Koenen et al., 1995). In SWB, the linear scoring was introduced in 2013 at the YHT, and the year after, in 2014, it was introduced at RHT and Stallion Performance Test (Viklund & Eriksson, 2018), The assessment scale for SWB consists of nine scores, A-I, where A and I correspond to the two biological extremes. Before the introduction of the linear profiling protocol, the judges were trained to achieve harmonization in the judging. This is a main factor to achieve quality in the assessment. Also, the judges need to rotate and can only judge at the same location and with the same judge partner for a limited number of times. Since 2017, breeding values for linearly scored traits are officially published by the Swedish Warmblood Association.

2.5 Sport performance

The show jumping sport is the most popular discipline of the equestrian sports world wide. Also in Sweden, show jumping is by far the most common discipline, where 81% of all starts in official competitions belongs to show jumping (Svenska Ridsportförbundet, 2021). The dressage sport is the second most popular discipline in Sweden, with 16% of the starts in official competitions. A clear difference between the disciplines is that show jumping is an objective sport where faults and time are counted, whereas dressage is a judged sport where the performance depends on the subjective evaluation by one or a few judges. In the genetic evaluation in SWB, the sport performance is the breeding goal trait, and it is measured as accumulated lifetime points achieved at official competitions (Viklund et al., 2011). However, how successful a horse will be in the competition ring is due to several factors, including talent, health and temperament of the individual horse, as well as management, training and skills of the rider.

3. Aims of the thesis

The overall aims of the thesis were to investigate the specialization of the Swedish Warmblood horse population towards show jumping and dressage, and to find important characteristics for successful sport performance in these disciplines.

The specific aims were to:

- Investigate the specialization process of Swedish Warmblood horses towards subpopulations of jumping and dressage horses, and the consequences this could have for genetic evaluation in this relatively small population.

- investigate the phenotypic relationships between linearly scored traits in the Swedish Warmblood horse population, assessed at young horse tests, and performance in show jumping and dressage competitions, as well as trait differences between jumping and dressage horses.

4. Summary of performed studies

4.1 Material and methods

4.1.1 Data

A pedigree file with 315 117 horses, data from YHT and RHT, and results from official competitions were provided by the Swedish Warmblood Association. Breeding values (EBVs), estimated according to methods described in Viklund et al. (2011), were obtained from the routine genetic evaluation in 2020. The EBVs were estimated in separate multi-trait models for jumping and dressage including data from YHT, RHT and competition. The competition trait was defined as the accumulated lifetime points in show jumping or dressage competition.

4.1.2 Population

In the first study (I), the studied population consisted of SWB horses born between 1980 and 2020. SWB horses were defined as horses with a SWB id number and no foreign number. Further, only horses sired by a stallion with a SWB studbook number or at least 10 assessed offspring at YHT or RHT were included. According to these criteria, a population of 122 054 horses was set. All sires and grandsires were classified into one of four categories; jumping (J); dressage (D); allround (AR); thoroughbred (Th). Sires approved in stallion performance test from 2002 were easily assigned to a category, because they were assessed for only one discipline at the test (jumping or dressage). Sires approved before 2002 were assigned to the J or the D category according to breeding values, own performance, and offspring

performance. Sires with verified good performance in both jumping and dressage, or sires that had offspring that had demonstrated good performance in both jumping and dressage, were assigned to the AR category. Horses in the population were classified according to the sire's category, except if they had a category J sire and a category D grandsire, or vice versa, in which case they were classified as AR. A majority of the horses were classified as AR (46 262), followed by J (41 279) and D (29 822), whereas few horses were classified as Th (4691). Data on 8713 J horses and 6477 D horses assessed at YHT were used to estimate genetic parameters within and between groups.

In the second study (II), the studied population was restricted to horses with a linear assessment from YHT or RHT between 2013 and 2021. The horses were classified into categories by the same methodology as in the first study. Horses with unknown pedigree or sired by a stallion not approved for SWB or for any other common warmblood studbook, were excluded. In the first part of this study, trait comparisons were made between linearly scored J horses (N=4216) and D horses (N=3152). In the second part, the focus was to investigate important characteristics for subpopulations of J horses with competition results in show jumping (N=2414), and D horses with competition results in dressage (N=1178).

4.1.3 Traits

In study I, eight subjectively assessed valuating traits from YHT were used in the analyzes. The traits were assessed on a scale 1-10, where 10 is the best. One judge assessed conformation, walk and trot, and one judge assessed the two jumping traits. Canter is assessed jointly by the two judge members. Results for 19 621 horses assessed at YHT between 1999 and 2020, and a pedigree file with seven generations from tested horses, were used in the analysis. The data from the YHT were divided into two periods of 11 years each named 'early' (horses assessed 1999-2009) and 'late' (horses assessed 2010-2020).

In study II, the results from the linear assessment at YHT or RHT were used. A total of 48 linearly scored traits, comprising 21 conformation traits, 13 gait traits, 13 jumping traits, and one temperament trait, were analyzed. The scores A-I were transformed to numerical values (1-9) to enable analyses. The competition trait was measured as accumulated lifetime points in show jumping or dressage. Horses received points if they were placed in

an official competition, i.e., are among the 25% best in each competition. More points are given for a better placing, a placing at a more advanced level, or both.

4.1.4 Future scenarios

In the first study (I), future scenarios with discipline-specific YHT were investigated. In the scenarios, it was assumed that approximately 50% of the owners of dressage horses would prefer to not have the two jumping traits assessed. Similarly, it was assumed that approximately 50% of the owners of jumping horses would prefer to not have walk and trot assessed. In both these scenarios, about 50% of the results were thus removed in each group. The omitted results belonged to horses with the lowest scores for respectively traits, in order to simulate that the owner was aware of the weakness of the horse and thereby would prefer the discipline-specific test. Two ranking lists, on the basis of EBVs, were set for jumping sires and dressage sires. The re-ranking of sires, regarding the current situation and future scenarios, were analyzed using Spearman rank correlation. Accuracy of EBVs for the sires was also calculated, both in the current situation and for the future scenarios.

4.1.5 Analyses

In study I, descriptive statistics on the data were analyzed using SAS version 9 (SAS Institute Inc., 2015). The average relationships between and within categories were computed using the software package CFC (Sargolzaei et al., 2006), whereas genetic parameters and EBVs for traits assessed at YHT were estimated using the DMU program package, version 6 (Madsen & Jensen, 2013). Traits from YHT were analyzed with an animal model with the fixed effect of event (location-date) and sex (male or female). Heritability estimates were estimated separately for J and D horses, and for all horses in total. Genetic parameters and EBVs were estimated for all traits using univariate analyses. Genetic correlations between traits assessed for category J and category D horses, and between jumping and dressage traits for all horses, were estimated using bivariate analyses.

In study II, phenotypic relationships between linearly scored traits, assessed at YHT and RHT, and competition results in show jumping and

dressage were investigated by using the GLM procedure in SAS version 9 (SAS Institute Inc., 2015). In the analysis, J and D horses were classified as "competing horses" if they had at least one record from an official competition in its main discipline, regardless of whether they had received points or not. Lifetime accumulated points in show jumping competitions for J horses and in dressage competitions for D horses were analyzed with a linear model with the fixed effect of sex (male or female), birth year (2009, …, 2017), and each linearly scored trait individually as a class variable. Scores with fewer than 15 observations (i.e., observations for extreme values) were merged with the closest score towards E. Because the distribution of competition points was skewed, the results were transformed with a logarithm to the basis of 10 before analyses. For all linearly scored traits that were significant for show jumping or dressage performance, least squares means for scores A-I were plotted to visualize the trend. The trend line shapes were divided into two categories by visual inspection of the relation between the continuous competition trait and the categorical linearly scored trait: linear trend or trend with an optimum. The classification of an optimum was based on the trend line shape in the direction from the population mean towards better competition performance. This part corresponds to the direction of selection and it is important to be aware of an optimum to avoid selection beyond that point.

4.2 Main findings

4.2.1 Specialization

The result from study I showed a clear and increasing specialization in the SWB horse population. About 80% of the horses born 1980-1985 were classified as AR horses, whereas 92% of the horses born 2016-2020 were classified as either J or D horses (Fig. 1). Also, the mean values from YHT showed considerable differences for discipline-specific traits for J and D horses (Table 1). This was also seen for study II, where the differences in mean values for J and D horses were highly significant ($p<0.0001$) for all linearly scored gait and jumping traits.

The average EBV from the routine genetic evaluation for jumping had increased considerably for J horses born between 1980 and 2020, whereas

the increase in EBV for jumping was very modest for D horses during the same period. Similarly, the increase in EBV for dressage was strong for D horses, while only a slight increase in EBV for dressage was seen for J horses. The average relationship coefficient within each subpopulation (J or D horses) was found to increase during the last decade, whereas the relationship between these categories decreased (Fig. 2).

Heritability values were estimated separately for J and D horses and showed clear differences between the groups. For gait traits, heritability estimates were 0.42-0.56 for D horses and 0.25-0.38 for J horses. For jumping traits, heritability estimates were 0.17-0.26 for J horses and 0.10-0.18 for D horses. The genetic correlations between corresponding traits for J and D horses were in the range 0.48-0.81, with a tendency to be lower in the late study period (horses assessed 2010-2020).

Table 1. Mean[1], standard deviation (SD), minimum (Min), and maximum (Max) value of traits in Young Horse Test, assessed for jumping horses (N=8713) and dressage horses (N=6477)

	Jumping horses				Dressage horses			
Trait	**Mean**	**SD**	**Min**	**Max**	**Mean**	**SD**	**Min**	**Max**
Type	7.71[a]	0.62	4.0	10.0	7.87[b]	0.64	4.0	10.0
Head-neck-body	7.53[a]	0.55	4.0	9.0	7.70[b]	0.57	5.0	9.5
Corr. of legs	7.32[a]	0.62	4.0	9.0	7.32[a]	0.65	2.0	9.0
Walk at hand	7.04[a]	0.68	4.0	10.0	7.52[b]	0.75	4.0	10.0
Trot at hand	6.72[a]	0.68	4.0	9.5	7.47[b]	0.84	4.0	10.0
Free canter	7.28[a]	0.75	4.0	10.0	7.35[b]	0.80	3.0	10.0
Free jumping – TA[2]	7.41[a]	1.14	1.0	10.0	6.13[b]	1.09	1.0	10.0
Free jumping – TG[3]	7.32[a]	1.29	1.0	10.0	6.25[b]	1.18	1.0	10.0

[1]Mean values between jumping and dressage horses with different superscripts were significantly different ($p<0.05$)

[2]Technique and ability.

[3]Temperament and general impression.

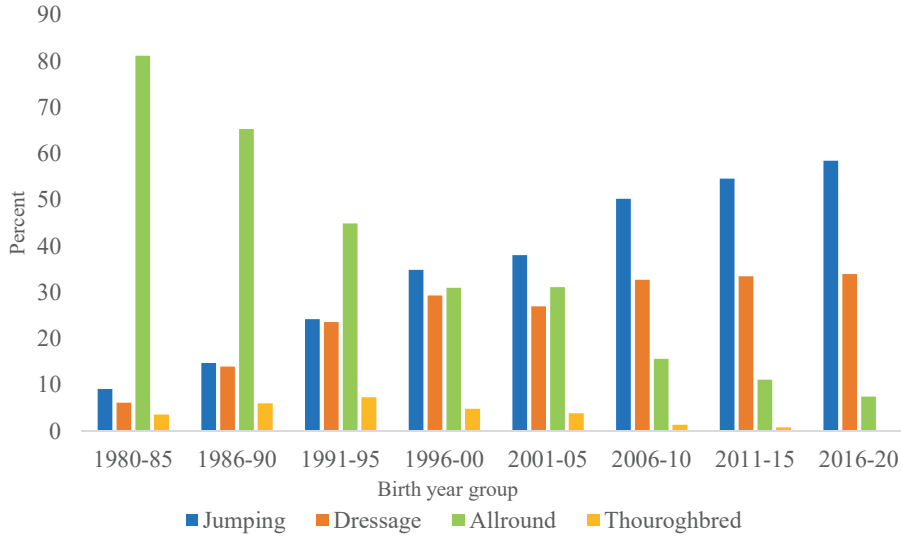

Figure 1. Distribution (%) of horses in the Swedish Warmblood population into different categories (jumping (J), dressage (D), allround (AR), or thoroughbred (Th)) according to birth year group between 1980-2020.

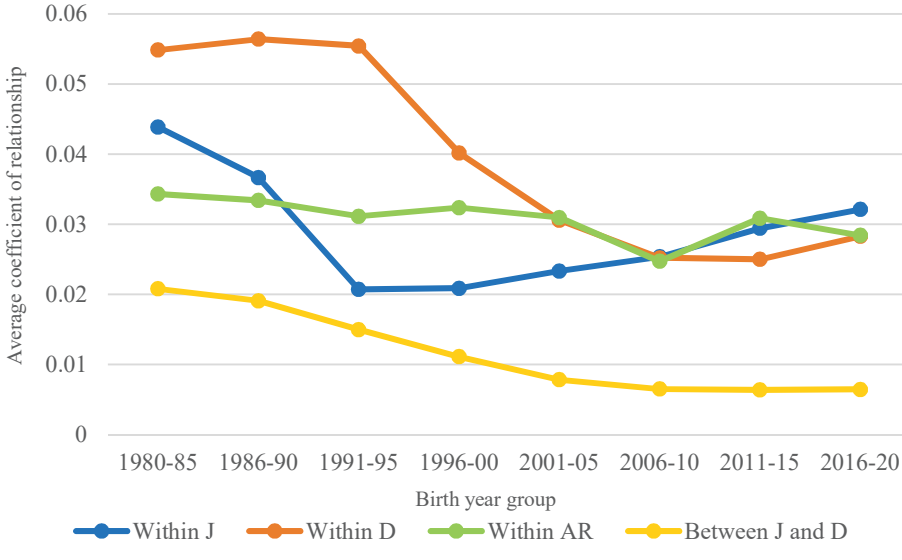

Figure 2. Average coefficient of relationship as a function of birth year group within and between categories of Swedish Warmblood horses classified as jumping (J), dressage (D), or allround (AR).

4.2.2 Discipline-specific Young Horse Test

When investigating the consequences of a discipline-specific YHT in study I, both heritability estimates and genetic variances decreased for traits that were not assessed for all horses. However, the EBVs for stallions' main discipline were still reliable, because the rank correlations between traits in the full data set and the scenario (where some results were omitted) were high (0.93-0.95 and 0.96-0.97 for J and D horses, respectively). Also, the mean accuracy for EBVs was only slightly decreased in the scenario in comparison to the full data set. On the other hand, the EBVs for traits in the other discipline were considerable altered, because the rank correlations between traits in the full data set and in the scenario were considerably lower (0.56-0.60 and 0.19-0.48 for J and D horses, respectively). The mean accuracy for EBVs also decreased noticeably.

4.2.3 Phenotypic relationships

In study II, phenotypic relationships between linearly scored traits and sport performance were investigated. For J horses, 18 linearly scored traits were found to be significant for show jumping performance. A great majority of these traits significant for show jumping performance were jumping traits, whereas just a few were conformation or gaits traits. For D horses, 17 linearly scored traits were significant for dressage performance. Traits associated to trot seemed to be of high importance for competition performance in dressage, as did some conformation and canter traits.

For J horses, most of the significant relationships were linear (14 of 18), indicating that an expression of the linearly scored trait towards one of the extremes was associated with on average better performance in show jumping (Table 2). In all cases, an expression towards the extreme of A was the most favorable. Thus, the more towards A on the assessment scale a horse is scored, the higher the probability of that horse competing on a high level in show jumping. For D horses, on the other hand, several traits showed a relationship with an intermediate optimal score (7 of 17), indicating that breeding for more extreme expression of these specific traits was not associated with better performance in dressage (Table 3).

Table 2. Significant linearly scored traits for show jumping performance by Swedish Warmblood jumping horses and classification of trend line shape (where least squares mean are plotted towards logarithm$_{10}$ of accumulated lifetime points in show jumping)

Significant traits	Extreme values	Trend line class
Conformation		
Type	*refined – heavy*	
Body direction	*uphill – downhill*	
Position of neck	*vertical – horizontal*	
Canter		
Elasticity	*elastic – stiff*	
Gaits: Overall		
Movement: direction	*uphill – downhill*	
Jumping		
Take-off	*powerful – weak*	
Take-off: quickness	*quick – slow*	
Take-off: direction	*upwards – forwards*	
Technique: foreleg	*bent – hanging*	
Technique: back	*rounded – hollow*	
Technique: haunches	*open – tight*	
Scope	*much – little*	
Elasticity	*elastic – stiff*	
Carefulness	*too careful – not careful*	
Balance	*balanced – unbalanced*	
Reaction	*quick – slow*	
Approach to assign.	*focused – unfocused*	
Distance estimation	*secure – insecure*	

Explanation of classification of trend line shape:

 = linear trend  = trend with optimum

Table 3. Significant linearly scored traits for dressage performance by Swedish Warmblood dressage horses and classification of trend line shape (where least squares mean are plotted towards logarithm$_{10}$ of accumulated lifetime points in show jumping)

Significant traits	Extreme values	Trend line class
Conformation		
Body: shape	*long legged – short legged*	
Body direction	*uphill – downhill*	
Length of neck	*long – short*	
Position of neck	*vertical – horizontal*	
Shape of neck	*arched – straight*	
Position of shoulder	*sloping – straight*	
Foreleg	*over at knee – back at knee*	
Hind leg	*sickle – straight*	
Trot		
Stride length	*long – short*	
Elasticity	*elastic – inelastic*	
Foreleg activity	*shoulder free – short*	
Hind leg position	*under the body – behind the body*	
Hind leg activity	*active – inactive*	
Canter		
Stride length	*long – short*	
Action	*round – flat*	
Elasticity	*elastic – stiff*	
Gaits: Overall		
Movement: direction	*uphill – downhill*	

Explanation of classification of trend line shape:

 = linear trend  = trend with optimum

5. General discussion

5.1 Specialization

The results from study I and II showed clear specialization towards either show jumping or dressage horses in the SWB population. The number of AR horses had decreased during the last decades and significant differences between J and D horses in mean values for discipline-specific traits were found. Also the increase in EBV for horses' main discipline (jumping or dressage) were considerably strong in comparison to the other discipline during the time period (1980-2020). In addition, the average relationship within the subpopulations of J and D horses increased during the past decade, whereas the relationship between the subpopulations decreased. It has already been shown that there are genetic differences between SWB horses bred for show jumping or dressage, which was confirmed in a genomic study by Ablondi et al. (2019). Specialization into disciplines has also been investigated in other studbooks, for example Rovere et al. (2014) found that genetic connections between the two subpopulations "jumping" and "dressage" in KWPN decreased markedly after the studbook was divided in 2006, while the relationship within the subpopulations increased. Rovere et al. (2014) concluded that, if the specialization process continues, it will give rise to two unrelated subpopulations in KWPN. This would probably also be seen in SWB if separation into different breeding programs were to be introduced. However, it should be kept in mind that the SWB population is considerably smaller than the KWPN population (WBFSH, 2021), which can influence the effectiveness of breeding in smaller subpopulations.

5.2 Heritability estimates and genetic correlations

In study I, heritability estimates were estimated separately for J and D horses, and for all horses in the data set. The heritability estimates were moderate to high for all traits, except for correctness of legs, in the analysis of the full data set. The results were generally in agreement with the findings by Viklund & Eriksson (2018). D horses had higher heritability for gaits than J horses, whereas the opposite was seen for jumping traits. The genetic variance for these traits showed a similar pattern. This may indicate use of a wider assessment scale for gaits in D horses than in J horses, and for jumping traits in J horses than in D horses. Use of a wider assessment scale in these cases depends primarily on more frequent use of high scores for discipline-specific traits within category.

The genetic correlations between corresponding traits for J and D horses were weaker in the late compared with in the early period for all traits except free canter. The results indicated that there were larger differences between J and D horses for traits in the late period, which could confirm an ongoing specialization process in the population. However, the standard error was very high in most cases, making it difficult to draw any firm conclusions. Similar results were seen in the study by Rovere et al. (2015), in which the genetic correlations between gait traits assessed for J and D horses in the later period (2008-2012) were lower than those in the earlier period (2003-2007) (jumping traits were not included in that study).

5.3 Discipline-specific Young Horse Test

In the first study (I), future scenarios with a discipline-specific YHT were investigated. Two different scenarios were studied, in which scores for walk and trot and jumping traits were omitted for approximately 50% of the poorest performing J and D horses, respectively. This could illustrate a situation where the horse owner is aware that their horse would probably receive a modest score for jumping (or walk and trot), and thus chooses to have their horse assessed as either a jumping horse or a dressage horse. In both these scenarios, the heritability estimates and the genetic variances for discipline-specific traits decreased in comparison with the current situation. Lower heritability could slow down genetic progress in the population, which could be an argument for retaining assessments for all traits. However,

while the genetic variance appeared to be reduced in the scenarios, the consequences may be less severe in practice. If the genetic variance for a trait is large mainly because of weak performance by horses of a different discipline, genetic progress will probably not decline if these horses are not assessed, because they were not intended for that discipline in any case. This assumes that the ranking of selected candidates is not affected.

When investigating the sire ranking (based on EBVs) for jumping and dressage stallions, it was found that the ranking of sires were only slightly altered for the stallions' main discipline in the scenarios. This could be an argument for introducing a discipline-specific YHT, because it is more important to have accurate EBVs for jumping traits for J sires and for walk and trot for D sires. On the other hand, the re-ranking was considerably altered for the opposite traits, i.e., evaluation of jumping traits for D sires and evaluation of walk and trot for J sires. The accuracy of EBVs for these traits also decreased to a larger extent in both scenarios, in comparison with the full dataset where all results were included. This indicate that sire EBVs for these traits would be less reliable and thus could make it more difficult for breeders to produce horses that have talent for both disciplines, such as AR horses or eventing horses.

5.4 Relationships between linearly scored traits and show jumping

In the second study (II), phenotypic relationships between linearly scored traits and sport performance were investigated. For J horses, all linearly scored jumping traits were significant for show jumping performance, as well as elasticity in canter. The importance of these traits was also shown in studies by Ducro et al. (2007) and Rovere et al. (2017), who found high genetic correlations between linearly scored free jumping traits and show jumping, and moderate genetic correlations between linearly scored canter traits and show jumping in KWPN. In our study, direction and power of take-off, balance, scope, and technique of the back were jumping traits that were highly significant ($p<0.0001$) for show jumping performance. These results are in agreement with findings in a study by Stock et al. (2022), where the strongest genetic trends in Oldenburg jumping horses were seen for power of take-off and jumping ability. In our study, only three conformation traits

(type, body direction, and position of neck) were significant for show jumping. This suggests that the conformation of a warmblood show jumping horse has weak association with its competition performance. Also the assessment scores for walk and trot traits were not significant for show jumping, indicating that these gaits are not associated with show jumping performance. This was also seen in a study by Ricard et al. (2020), who concluded that assessing gait traits in order to improve jumping performance is unhelpful, because the genetic correlations are low.

The majority of the linearly scored traits that were significant for show jumping showed a linear or almost linear association, which indicates that expressions towards an extreme is favorable. Only a few traits showed an intermediate optimum score for show jumping performance (Table 2). The optimal score for these traits was D (except for carefulness in jumping with the optimum score C), indicating that breeding for extreme expressions of these traits are not related to better performance in show jumping. However, the mean scores for these traits were close to E, indicating that some improvement is possible in the population. It is worth noting that the show jumping sport is changing over time, likely adding new traits to the most favorable characteristics of a high-performing horse.

5.5 Relationships between linearly scored traits and dressage performance

For D horses, all linearly scored traits associated with trot were significant for performance in dressage, as did some traits associated with canter. Traits associated to walk were not significant for performance. The importance of trot and canter traits for a dressage horse was also identified in studies by Ducro et al. (2007) and Rovere et al. (2017), where linearly scored traits associated with trot and canter had a moderate to strong genetic correlation to dressage performance. Our results indicate that an elastic trot with shoulder free foreleg activity, active hind legs and an uphill direction of movements seems to be of high importance at the phenotypic level. High importance of such traits was reported previously by Stock et al. (2021), who found high correlation between EBVs for linearly scored traits and dressage performance for carrying power and freedom of shoulders in trot and direction of movement in canter in Oldenburg dressage horses. In our study,

several traits associated to conformation were also significant for dressage performance. Based on the results, a long legged and uphill body conformation seem to be of high value for a dressage horse, as well as a long, arched neck and a sloping shoulder. Similarly, in the study by Stock et al. (2022), genetic trends for conformation traits indicated significant development towards a larger frame, longer legs, and a shorter back.

Seven linearly scored traits that were significant for dressage performance showed an association with an intermediate optimal score (Table 3). For example, an optimum was seen for the traits length of neck, position of hind legs in trot, and stride length in canter. The optimal score represents the expression of the trait that probably has the best influence on dressage performance, and thus expressions towards one or the other extreme was not related to better competition performance on average. Because dressage is a subjectively judged sport, the most favorable expressions can change over time. The intermediate optimal score was D for these traits, whereas the mean scores for these traits were close to E, indicating that improvement in these traits is possible still.

5.6 Practical implications for breeding

The result from this thesis highlights the specialization process of the SWB population, as well as the usefulness of linear scoring. Because of the clear specialization towards show jumping and dressage, specialized breeding programs for these disciplines may be developed for the SWB population in the future. If there is a market demand for versatile and/or amateur-friendly horses, breeding programs for such horses may need to be considered as well. However, with specialized breeding in several parallel subpopulations of a small breed such as SWB, there is a risk of slowing down the genetic progress due to insufficient selection intensity.

All linear traits that were found to be significant for show jumping or dressage performance had either a linear relationship or a relationship with an optimal score. In both cases it is important to monitor these traits in the population. Selection beyond an optimal score would probably not result in better sport performance, whereby it is necessary to pay extra attention to these traits when matching stallion and mare. It is also important to take notice to traits that have a linear relationship with performance, because

selection towards more extreme expression of certain traits may have negative consequences on the welfare of the horse. For example, it has been shown that horses that are carriers of the Fragile Foal Syndrome mutation have more elastic trot than non-carriers, indicating that breeding for that trait could increase the prevalence of the deleterious mutation in the population (Ablondi et al., 2022). Thus, monitoring of health and durability in the population is highly recommended, which would require cooperation between the breeding organization, veterinarians, insurance companies, and horse owners.

6. Conclusions

The analyses showed a clear specialization towards show jumping and dressage in the SWB population. The average relationship within the formed discipline-specific subpopulations increased the past decade, whereas the relationship between the groups decreased. When investigating future scenarios with discipline-specific YHT, both heritability estimates and genetic variances decreased. This could have a negative impact on the genetic progress for these traits. However, the sire rankings (based on EBVs) and accuracy of EBVs were only slightly altered for discipline-specific traits, indicating that specialization of the YHT could be a viable option. The analyses of the relationship between linearly scored traits and sport performance showed that few traits except jumping traits were significant for show jumping performance. For dressage performance, traits associated to trot seemed to be of high importance, as did some conformation and canter traits. A majority of the traits that were significant for show jumping showed a linear association, meaning that expression towards one of the extreme of these traits are associated with better competition performance. On the other hand, traits that were significant for dressage performance in several cases showed intermediate optimal scores, indicating that more extreme expression of these specific traits are not associated with better sport performance on average. Because some optima were based on few observations, a re-examination of these relationships when more data is available would be recommended. The results confirm that linear scoring is a valuable tool for finding and monitoring essential traits for sport performance.

7. Future research

In this thesis, phenotypic relationships between linearly scored traits and sport performance were investigated. To get a deeper understanding of how these traits influence performance, it would be of high value to also investigate the genetic relationships between linearly scored traits and competition results in show jumping and dressage. This could add more information on what characteristics are the most important to take into consideration of when breeding horses for international sport.

In order to produce horses that can become competitive at the highest level, it is necessary to select for extraordinary abilities in show jumping or dressage. In our study, many linearly scored traits showed a linear association with performance, meaning that scores towards one of the two extremes on the assessment scale are associated with better sport performance. This may indicate that more extreme expression of these traits will become more common in future, in order to produce horses for high-level sport. However, breeding for extreme expressions of some specific traits may have negative side-effects on health and durability of the horse. For future studies it would be of high interest to investigate the linearly scored traits further, and how these traits are connected to health and durability of the horse. This could for example be done by surveys, where owners of horses that has been linearly assessed answers questions of the horse health status and veterinary treatments. This could possibly also be investigated by using insurance data, if the information from the linear assessment could be linked to registered diagnoses of the horse.

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Popular science summary

The development of the equestrian sport has been remarkable during the last decades, leading to an increased interest and a stronger competition between riders, especially in the disciplines show jumping and dressage. This has contributed to an increased specialization of the breeding, where most horses are bred for either show jumping or dressage. Some breeding organizations for warmblood horses have divided their studbook and young horse test into disciplines, bringing the question to the fore also in the organization for the Swedish warmblood (SWB).

Assessment of young horses is an important tool to early find individuals suitable for breeding and sports, but also for collecting information about the population in order to maintain a reliable genetic evaluation of the breed. As a complement to the traditional scoring, where characteristics are valued in relation to the breeding goal, the linear scoring system was introduced in 2013 at the young horse test in SWB. The aim of the linear scoring system is to give a more objective and detailed picture of the horse, where the characteristics are described on a scale between two biological extremes. The scale has nine values from A to I. The first cohorts with a linear scoring have now come to an age where they have had the opportunity to achieve competition results on a higher level, which makes it possible to investigate the relationships between linearly scored traits and competition performance for the first time.

The aim of this thesis was to investigate the specialization towards show jumping and dressage in the SWB breed, and how a discipline-specific young horse test could affect the genetic evaluation. The aim was also to investigate the relationships between linearly scored traits assessed in young horse tests and competition performance later in life, and whether any traits had an intermediate optimum.

Summary of performed studies

Specialization
In the first study in this thesis, the specialization towards show jumping and dressage was investigated. All SWB horses born between 1980 and 2020 were classified into one of four categories based on their sire's and grandsire's classification; jumping, dressage, allround or Thoroughbred. The results showed that there has been a clear alteration over time, where the number of horses classified as allround has decreased considerably from the early 1980s in favor of horses classified as jumping or dressage horses. Also, the relationship within and between the groups of horses classified as jumping and dressage indicated a clear specialization, where the relationship within the groups increased over the past decade while the relationship between the groups decreased. The results from young horse tests also showed clear differences for discipline-specific traits, both in terms of the traditional assessment and the linearly scored traits.

Discipline-specific young horse test
In this study, future scenarios with discipline-specific young horse tests were investigated, where dressage horses would not get assessed for jumping traits while jumping horses would not get assessed for walk and trot. The results showed that both heritability and genetic variation decreased for the traits that were not assessed for all horses, which in the long run could have a negative impact on genetic evaluation. Furthermore, it was investigated how the ranking of sires, based on breeding values, could be affected by discipline-specific young horse tests. The results showed that the sire ranking for traits connected to stallions' main discipline were only slightly altered, which suggests that it would be possible to introduce a discipline-specific young horse test. However, there was a major re-ranking for the opposite traits (i.e. for jumping traits for dressage sires and for walk and trot for the jumping sires), which could make it more difficult to breed horses that have talent for both show jumping and dressage.

Relationship between linearly scored traits and competition performance
In the second study in this thesis, phenotypic relationships between linearly scored traits and competition results in show jumping and dressage were investigated. Also in this study the classification was used to investigate

subpopulations of horses classified as jumping and dressage horses, respectively. Out of 48 linearly scored traits, 18 traits were significant for performance in jumping. A majority of these were jumping traits, suggesting that few traits besides jumping traits are important for the performance of a show jumping horse. For performance in dressage, 17 linearly scored traits were significant. Of these, all trot traits were of high importance for performance, but also a number of traits associated to conformation and canter.

Traits with intermediate optimum score

For those traits that had a significant effect on performance, the relationship between achieved competition points and the linear assessment was examined by investigating the shape of the trend line for each of these traits. For the show jumping horses, most traits had a linear relationship, meaning that a score towards one of the extremes on the scale was synonymous with higher competition points. For the dressage horses, on the other hand, there were several linearly scored traits that had an intermediate optimum, where the best score for performance was somewhere between the two extremes. In both cases, it is important to follow the progress of these traits. Selection beyond an optimum would probably not result in better sport performance, and a strong selection on traits with a linear relationship may in the long run have negative consequences, e.g. for health traits. Thus, the linear scoring system is an important tool in horse breeding to in detail monitor a population over time.

Conclusions

- The SWB population is clearly specialized into show jumping and dressage, because the proportion of horses classified as "allround" has decreased considerably since 1980. The relationship between groups of show jumping and dressage horses has also decreased over time, while the relationship within these groups has increased over the past decade.

- An introduction of discipline-specific young horse tests is possible, because the breeding values of the sires' main discipline would probably only be slightly altered. However, it could give

less reliable breeding values for traits that are not associated to the sires' main discipline.

- Few linearly scored traits besides jumping traits are important for performance in show jumping. For performance in dressage, trot traits are of high importance, but also several traits associated to conformation and canter.

- Most linearly scored traits had a linear relationship to competition performance, but a number of traits associated to dressage had an intermediate optimum score.

Populärvetenskaplig sammanfattning

Utvecklingen av ridsporten har varit stor under de senaste decennierna och det har lett till både ett ökat intresse och en hårdare konkurrens bland utövarna, framför allt i tävlingsdisciplinerna hoppning och dressyr. Detta har bidragit till en ökad specialisering av aveln, där de allra flesta hästar idag avlas för antingen hoppning eller dressyr. Några avelsorganisationer för varmblodiga ridhästar har därför delat upp sin stambok och sina unghästbedömningar efter disciplin, vilket har lett till att frågan aktualiserats även inom organisationen för det svenska varmblodet (SWB).

Bedömning av unga hästar är viktigt för att tidigt hitta lämpliga individer för avel och sport, men även för att samla in information om populationen för att upprätthålla en tillförlitlig avelsvärdering av rasen. Som ett komplement till den traditionella bedömningen, där egenskaper värderas i förhållande till avelsmålet, infördes 2013 den linjära beskrivningen vid SWBs unghästtest. Syftet med den linjära beskrivningen är att ge en mer objektiv och detaljerad bild av hästen, där egenskaperna beskrivs på en skala mellan två biologiska extremvärden. Skalan har nio värden från A till I. De första årskullarna med linjär beskrivning har nu kommit upp i ålder och haft möjlighet att nå tävlingresultat i högre klasser, vilket gör det möjligt att göra en första utvärdering av sambanden mellan linjära egenskaper och tävlingsprestation.

Syftet med den här avhandlingen var att undersöka specialiseringen mot hoppning och dressyr av SWB-rasen, samt hur ett disciplinspecifikt unghästtest skulle kunna påverka avelsvärderingen. Syftet var också att undersöka sambanden mellan linjära egenskaper bedömda vid unghästtest och tävlingsprestation senare i livet, samt om några egenskaper uppvisade intermediära optimum.

Sammanfattning av studierna

Specialisering
I den första studien i den här avhandlingen undersöktes specialiseringen mot hoppning och dressyr. Alla SWB-hästar födda mellan 1980 och 2020 blev indelade i en av fyra klasser utifrån sin fars och morfars klassificering; hoppning, dressyr, allround eller fullblod. Resultaten visade att det skett en tydlig förändring över tid, där antalet hästar klassade som allround minskat avsevärt sedan början av 1980-talet till fördel för hästar klassade som hoppning eller dressyr. Även släktskapet inom och mellan grupperna av hästar klassade som hoppning och dressyr visade på en tydlig specialisering, då släktskapet inom grupperna ökat under det senaste decenniet medan släktskapet mellan grupperna minskat. Resultaten från unghästest visade också på tydliga skillnader för disciplinspecifika egenskaper, både vad gäller den traditionella och den linjära bedömningen.

Disciplinspecifikt unghästtest
I studien undersöktes framtidsscenarion med grenspecifika unghästtest, där dressyrhästar avstår bedömning i hoppning medan hopphästar inte blir bedömda för skritt och trav. Resultaten visade att både arvbarhet och genetisk variation minskade för de egenskaper som inte blev bedömda för alla hästar, vilket på sikt skulle kunna ha negativ påverkan på avelsvärderingen. Vidare undersöktes hur rankingen av hingstar, baserade på avelsvärden, skulle kunna påverkas av grenspecifika unghästtest. Resultaten visade att rankingen för egenskaper kopplade till hingstarnas huvuddisciplin inte påverkades nämnvärt, vilket talar för att det skulle vara möjligt att införa ett grenspecifikt unghästtest. Däremot blev det en stor omrangering för de motsatta egenskaperna (dvs. för hoppegenskaper för dressyrhingstar och för skritt och trav för hopphingstarna), vilket på sikt skulle kunna göra det svårare att avla hästar med talang för både hoppning och dressyr.

Samband mellan linjära egenskaper och tävlingsprestation
I den andra studien i avhandlingen undersöktes fenotypiska samband mellan linjära egenskaper och tävlingsresultat i hoppning och dressyr. Även här användes klassindelningen för att undersöka grupper av hästar klassade som hopp- respektive dressyrhästar. Av totalt 48 linjära egenskaper var 18

egenskaper signifikanta för prestation i hoppning. De allra flesta av dessa var hoppegenskaper, vilket tyder på att få egenskaper förutom just hoppegenskaper är viktiga för en hopphäst. För prestation i dressyr var 17 egenskaper signifikanta. Av dessa hade samtliga travegenskaper stor betydelse för prestation, men även ett antal egenskaper kopplade till exteriör och galopp.

Egenskaper med intermediära optimum
För de egenskaper med signifikant påverkan på prestation undersöktes förhållandet mellan uppnådda tävlingpoäng och den linjära bedömningen närmare genom att studera trendlinjens form för var och en av dessa egenskaper. För hopphästarna hade de flesta egenskaper ett linjärt samband, där en förflyttning mot A på skalan var synonymt med högre tävlingspoäng. För dressyrhästarna fanns det däremot flera egenskaper som hade ett intermediärt optimum, där det bästa värdet för prestation låg någonstans mellan de två extremerna. I båda fallen är det viktigt att följa utvecklingen för dessa egenskaper. Avel förbi ett optimum leder troligtvis inte till bättre prestation och en alltför stark selektion på egenskaper med linjära samband skulle på sikt kunna ha negativa konsekvenser, t.ex. för hälsoegenskaper. Den linjära beskrivningen är därför ett viktigt verktyg i avelsarbetet och gör det möjligt att i detalj följa populationens utveckling över tid.

Slutsatser i korthet

- SWB-aveln är tydligt specialiserad mot hoppning och dressyr, då andelen hästar klassade som ”allround” har minskat stadigt sedan 1980. Även släktskapet mellan grupper av hopp- respektive dressyrhästar har minskat över tid, medan släktskapen inom dessa grupper har ökat under det senaste decenniet.

- Ett införande av grenspecifika unghästtest är möjligt, eftersom avelsvärdena för hingstarnas huvuddisciplin troligtvis inte kommer att påverkas i någon större utsträckning. Däremot skulle det kunna innebära mindre tillförlitliga avelsvärden för egenskaper som inte är kopplade till hingstens huvuddisciplin.

- Få linjära egenskaper förutom hoppegenskaper är viktiga för prestation i hoppning. För prestation i dressyr är framför allt travegenskaper av stor betydelse, men även flera egenskaper kopplade till exteriör och galopp.

- De flesta linjära egenskaper hade ett linjärt förhållande till tävlingsprestation, men för ett flertal egenskaper kopplade till dressyr fanns det ett intermediärt optimum.

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Consequences of specialized breeding in the Swedish Warmblood horse population

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Abstract

In many European warmblood studbooks, clear specialization toward either jumping or dressage horses is evident. The Swedish Warmblood (SWB) is also undergoing such specialization, creating a possible need for separate breeding programs and a discipline-specific Young Horse Test (YHT). This study investigated how far specialization of the SWB breed has proceeded and the potential consequences. Individuals in a population of 122,054 SWB horses born between 1980 and 2020 were categorized according to pedigree as jumping (J), dressage (D), allround (AR), or thoroughbred (Th). Data on 8,713 J horses and 6,477 D horses assessed for eight traits in YHT 1999–2020 were used to estimate genetic parameters within and between J and D horses and between different periods. Future scenarios in which young horses are assessed for either jumping or dressage traits at YHT were also analyzed. More than 80% of horses born in 1980–1985 were found to be AR horses, while 92% of horses born in 2016–2020 belonged to a specialized category. The average relationship within J or D category was found to increase during the past decade, whereas the relationship between these categories decreased. Heritability estimates for gait traits were 0.42–0.56 for D horses and 0.25–0.38 for J horses. For jumping traits, heritability estimates were 0.17–0.26 for J horses and 0.10–0.18 for D horses. Genetic correlations between corresponding traits assessed in J and D horses were within the range 0.48–0.81, with a tendency to be lower in the late study period. In the future scenarios, heritability and genetic variance both decreased for traits that were not assessed in all horses, indicating that estimation of breeding value and genetic progress for these traits could be affected by a specialized YHT. However, ranking of sires based on estimated breeding values (EBVs) and accuracy of EBVs was only slightly altered for discipline-specific traits. With continued specialization in SWB, specialization of the YHT should thus be considered.

KEYWORDS

breeding value, dressage, genetic parameters, jumping, sport horses, Young Horse Test

1 | INTRODUCTION

The Swedish Warmblood (SWB) is the most common horse breed in Sweden, with approximately 65,000 registered horses and 2,800 foals born per year (HNS, 2021), although SWB is still a small population in comparison with other European warmblood studbooks (WBFSH, 2021). The SWB has its origin in the eighteenth century, when its main purpose was to supply royal cavalry with suitable riding horses (Graaf, 2004). When the studbook was established in 1928, the aim was to breed horses for multiple equestrian purposes. During recent decades, breeding has focused more on sport performance, and the current breeding goal for SWB is to produce competitive horses at international level in show jumping and dressage (Swedish Warmblood Association, 2021). As a result, breeding has become more specialized toward either jumping or dressage as demonstrated by Ablondi et al. (2019) in a study based on high-density single-nucleotide polymorphism (SNP) array data, which found genetic differences between SWB horses bred for show jumping and dressage.

Specialization of breeding for sport disciplines has also occurred in other European warmblood studbooks, for example, it has been reported for the Dutch warmblood (KWPN) (Rovere et al., 2014). In the KWPN studbook, foals have been registered as either jumping or dressage horses since 2006. Another example is the Oldenburg studbook, which was divided into two specialized studbooks (for show jumping and dressage) in 2001 (Oldenburger Pferdezuchtverband, 2022). In the Danish Warmblood studbook, a breeding plan with the focus on separation of the disciplines was initiated in 2004, and young horse assessments are now discipline-specific (Dansk Varmblod, 2022). In SWB, the genetic trend for specialization in show jumping or dressage increased considerably from the mid-1980s, mainly because of strong stallion selection and import of high-quality stallions for either jumping or dressage (Viklund et al., 2011). Since 2002, the SWB stallion performance test has been specialized, and stallions are approved for breeding based on results from only one discipline (Granberg, 2017). Since 2019, it is also possible to choose discipline in the Riding Horse Test for 4-year-olds (RHT), provided that the horse has already participated in the Young Horse Test (YHT), where all traits are assessed, as a 3-year-old (SWB, 2018). However, according to the breeding organization, some owners of dressage horses would like to be able to opt out of having jumping assessed (Thorén Hellsten, 2022). Similarly, owners of jumping horses often do not pay much attention to assessments of walk and trot.

The ongoing specialization of SWB creates a possible need for separate breeding programs, making it necessary to investigate the consequences that this can have for the rather small SWB population. If some horses are not assessed for all traits in YHT, this could affect the estimated genetic variance and heritability as well as estimation of breeding values for these traits. In the long term, a potentially lower heritability and accuracy of breeding values could have a negative impact on genetic improvement of the breed.

The aim of the present study was to investigate how far the specialization process of SWB toward subpopulations of jumping and dressage horses has proceeded, and the consequences this could have for selection strategy and genetic evaluation in this relatively small population. To fulfil this aim, genetic parameters were estimated, relationships within and between SWB subpopulations were compared, and future scenarios in which horse owners could choose to have their young horses assessed for only one discipline in YHT were investigated.

2 | MATERIALS AND METHODS

2.1 | Data

A pedigree file for 315,117 was provided by the Swedish Warmblood Association. In addition, breeding values (EBVs) for show jumping and dressage were obtained from the routine genetic evaluation in 2020. Information about the horse participation in YHT and RHT as well as in official competition was also provided. The study population was restricted to SWB horses born between 1980 and 2020, where SWB horses were defined as horses with a SWB ID number and no foreign number in the database. Furthermore, only horses sired by a stallion with a SWB studbook number or at least 10 assessed offspring at YHT or RHT were included. In total, 122,054 horses met these criteria. The number of sires was 1,581, and the number of grandsires was 1,315, with 1,157 stallions appearing as both sires and grandsires.

2.2 | Classification

Sires and grandsires were assigned to one of four categories: jumping (J), dressage (D), allround (AR), or thoroughbred (Th). The classification was performed by the breeding director for SWB. Sires approved in stallion performance test in or after 2002 were easily assigned to a category because they were assessed for only one discipline at the test (jumping or dressage). Sires approved before 2002 were assigned to the J or the D category according to pedigree, breeding values, own performance, and offspring performance. Sires with verified good performance in both jumping and dressage or sires who had offspring

which had demonstrated good performance in both jumping and dressage were assigned to the AR category. These sires could have either jumping or dressage as their main discipline. Sires used in breeding in the beginning of the study period often had no obvious specialization in either jumping or dressage and were therefore classified as AR. The Th category consisted of English Thoroughbred (xx) and Arabian Thoroughbred (ox). Anglo-Arabian Thoroughbred (x) sires were not classified in the Th category because these horses are mainly bred for riding, whereas the other Thoroughbred breeds are mainly bred for racing. The Anglo-Arabian Thoroughbred sires used in SWB breeding had intermediate breeding values in both jumping and dressage and was therefore classified as AR.

The horses in the population were classified according to the sire's category, except if they had a category J sire and a category D grandsire, or vice versa, in which case they were classified as AR. A majority of the horses were classified as AR (46,262), followed by J (41,279) and D (29,822). Fewer horses were classified as Th (4,691).

2.3 | Traits

The provided EBVs from the 2020 routine genetic evaluation had been estimated in two separate multi-trait models for jumping and dressage including data from competition, YHT, and RHT according to methods described in Viklund et al. (2011). Lifetime accumulated points in show jumping or dressage competition, transformed with a logarithm to the basis of 10, are the breeding goal traits, while evaluating scores from YHT and RHT are early indicator traits that have been shown to be strongly correlated to the breeding goal traits (Viklund et al., 2011). Horses that are placed, that is, are among the 25% best in each competition receive points. A horse receives more points either for a better placing or at a more advanced level or both. EBVs for the breeding goal traits show jumping and dressage from the routine genetic evaluation are considered in this study.

In YHT, eight traits are subjectively assessed by two judges using a scale from 1 to 10, where 10 is the best score (Table 1). One judge assesses conformation, walk, and trot and one judge assesses jumping traits, while canter is assessed jointly by both judges. YHT results for 19,621 horses evaluated between 1999 (when YHT was introduced) and 2020 and a pedigree file with seven generations from tested horses were used in further analysis. The data from the YHT were divided into two 11-year periods named "early" (1999–2009) and "late" (2010–2020), referring to horses born 3 years before that, that is, 1996–2006 and 2007–2017. The traits in the full dataset and in the different time periods were treated as different traits to enable comparisons. Competition data included official results from competitions in show jumping, dressage, and eventing at the regional, national, and international level.

2.4 | Future scenarios

To illustrate a possible future situation where horse owners can choose to have their horse assessed for only one discipline in YHT, two alternative scenarios were created and compared with the current situation. In the first scenario, it was assumed that approximately 50% of D horses (those with the lowest scores for jumping) were not assessed for jumping traits. In the second scenario, it was assumed that approximately 50% of J horses (those with the lowest scores for walk and trot) were not assessed for these traits. The limit for removing observations was set as

TABLE 1 Mean,[1] standard deviation (SD), minimum (Min) and maximum (Max) value of traits in Young Horse Test, assessed for jumping horses ($N = 8713$) and dressage horses ($N = 6477$)

	Jumping horses				Dressage horses			
Trait	**Mean**	**SD**	**Min**	**Max**	**Mean**	**SD**	**Min**	**Max**
Type	7.71[a]	0.62	4.0	10.0	7.87[b]	0.64	4.0	10.0
Head-neck-body	7.53[a]	0.55	4.0	9.0	7.70[b]	0.57	5.0	9.5
Correctness of legs	7.32[a]	0.62	4.0	9.0	7.32[a]	0.65	2.0	9.0
Walk at hand	7.04[a]	0.68	4.0	10.0	7.52[b]	0.75	4.0	10.0
Trot at hand	6.72[a]	0.68	4.0	9.5	7.47[b]	0.84	4.0	10.0
Free canter	7.28[a]	0.75	4.0	10.0	7.35[b]	0.80	3.0	10.0
Free jumping—TA[2]	7.41[a]	1.14	1.0	10.0	6.13[b]	1.09	1.0	10.0
Free jumping—TG[3]	7.32[a]	1.29	1.0	10.0	6.25[b]	1.18	1.0	10.0

[1]Mean values between jumping and dressage horses with different superscripts were significantly different ($p < .05$).

[2]Technique and ability.

[3]Temperament and general impression.

the categorical value closest to the median of each group, which resulted in the following data edits:

D spec: For D horses, scores for the two jumping traits "Technique and ability" (TA) and "Temperament and general impression" (TG) were removed from the dataset if the sum of the two scores was lower than 12.5 points. This eliminated 52% of the D horses.

J spec: For J horses, scores for walk and trot were removed from the dataset if the sum of the two scores was lower than 14 points. This eliminated 42% of the J horses.

Two ranking lists, on the basis of EBVs, were created for sires with at least 10 tested offspring at YHT. The first, named "J sire group", consisted of 217 J sires and AR sires with jumping as their main discipline. The second, named "D sire group", consisted of 182 D sires and AR sires with dressage as their main discipline. Spearman's rank correlations were estimated to quantify re-ranking according to the scenarios compared with the current situation. This was performed separately for the J and D sire groups.

2.5 | Genetic analysis

Descriptive statistics on the data were analyzed using SAS (Statistical Analysis System) (SAS Institute Inc., 2015). The average relationships between and within categories were computed using the software package CFC (Sargolzaei et al., 2006), using an indirect approach as described by Colleau (2002). Trends for relationships were estimated by computing the relationship for each category in eight birth-year periods of 5 years between 1980 and 2020 (with the exception of the first group, which covered 6 years). Genetic parameters and EBVs for traits assessed at YHT were estimated using the DMU program package, version 6 (Madsen & Jensen, 2013). Traits from YHT were analyzed similarly to the routine genetic evaluation (Viklund et al., 2011), with the following animal model:

$$Y_{ijk} = \mu + \text{event}_i + \text{sex}_j + a_k + e_{ijk}$$

where Y_{ijk} is the observed value of horse k; μ is the population mean; event_i is the fixed effect of location-date combination, $i = 1,2...547$; sex_j is the fixed effect of sex, $j =$ male or female; a_k is the additive genetic effect of horse $k \sim \text{ND}(0, \text{A}\sigma_a^2)$ (where A is the relationship matrix; σ_a^2 is the additive genetic variance), and e_{ijk} is the random ~IND $(0, \sigma_e^2)$ residual effect (where σ_e^2 is the residual variance).

Genetic parameters and EBVs were estimated for all YHT traits using univariate analysis. Genetic correlations between corresponding traits assessed for category J and category D horses were estimated using bivariate analysis. Because each horse was assigned to one category, J or D, the residual covariance was then set to 0. Bivariate analyses were also used to estimate the genetic correlations between jumping and gait traits for all horses. Accuracy of EBVs was calculated for the J and D sire groups and for the two scenarios. Accuracy was defined as the correlation between true and estimated breeding value (r_{TI}) and was calculated as

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

where PEV is prediction error variance, calculated as in (Henderson, 1975).

3 | RESULTS

3.1 | Population structure

Of the 1,581 sires included in the analysis, 713 were classified as J, 487 were classified as D, and 288 were classified as AR. The sires in category AR consisted of 141 horses classified as "jumping-dressage", a further 141 classified as "dressage-jumping", and six horses of Anglo-Arabian breed (x). There were 93 sires in category Th (84 English Thoroughbreds and nine Arabian Thoroughbreds).

The majority of the sires born before 1980 were classified as AR (59%) (Figure 1). From the early 1980s, more sires came to be bred for either jumping or dressage, and the number of AR sires started to decline. The proportion of sires classified as AR born 1971–1975 were 63%, and 30 years later, (2001–2005) the number had decreased to 1.8%. In the latest birth year group (2011–2015), a majority of the sires were classified as J (55%), followed by D (45%), while the number of AR sires was close to 0 (Figure 1). The number of Th sires also decreased to become almost nonexistent in 2020. The total number of available sires increased considerably in recent decades, and the number of offspring per sire decreased. Of the 1,581 sires analyzed, a majority had 30 or fewer offspring (Figure 2), with a total range from 1 to 1,386 offspring per sire.

A majority of the 122,054 horses investigated were classified as AR (37.9%), followed by J (33.8%) and D (24.4%). A small number of horses were classified as Th (3.8%). Figure 3 shows changes in the distribution of the categories according to birth year. In the beginning of the study period, AR horses were in the great majority. By 2020, about 58% of the population consisted of J horses, 34% of D horses, and 7.5% of AR horses. Horses in category Th, that is, horses with a Thoroughbred sire were relatively common in the 1990s but declined to close to zero by 2020 (Figure 3).

For J horses, the average EBV from the routine genetic evaluation for jumping increased from 83 to 124 between 1980 and 2020, whereas the increase in average

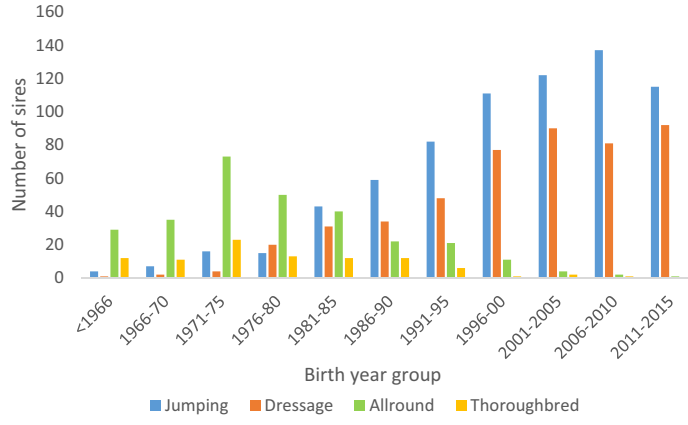

FIGURE 1 Number of sires in Swedish Warmblood breeding by category and birth year group [Colour figure can be viewed at wileyonlinelibrary.com]

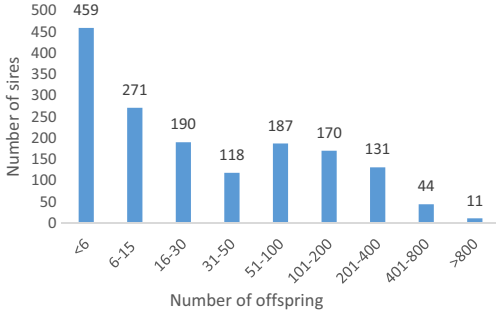

FIGURE 2 Distribution of sires approved for SWB breeding according to number of offspring [Colour figure can be viewed at wileyonlinelibrary.com]

EBV for jumping was very modest for D horses (from 71 to 78) (Figure 4a). On the other hand, the average EBV for dressage increased from 89 to 128 for D horses, while the increase in average EBV for dressage for J horses was smaller, from 80 to 94 (Figure 4b). For AR horses, the increase in average EBV was intermediate (relative to the changes for D and J horses) for both disciplines.

3.2 | Relationship

At the beginning of the study period, D horses had a higher average relationship coefficient within the category (5.5%) compared with J horses (4.4%) (Figure 5). The average relationship among J horses decreased considerably during the 1980s. There was also a drastic decrease for D horses, but starting about 10 years later. By 2020, the average relationship was increasing within both these categories, while the average relationship coefficient between the categories had declined to a very low level (<1%). In contrast, the level of relationship within the category of AR horses remained around 3% from 1980 until 2020.

3.3 | Performance

About 30% of the population born 1980–2017 was assessed in either YHT or RHT, or both. Around 40% of the population competed, with most horses competing in jumping (29%), followed by dressage (17%). Only a small proportion (2.8%) of the population competed in eventing. About 50% of J horses competed in jumping, whereas only 28% of D horses competed in dressage (Figure 6). For AR horses, more competed in jumping (24%) compared with dressage (17%). Category Th had the highest proportion of horses competing in eventing (8.4%) (Figure 6).

Category D horses born in 1996–2017 and assessed at YHT had considerably higher mean values for walk and trot compared with J horses (Table 1). On the other hand, J horses had substantially higher mean values for the two jumping traits (TA and TG). The mean values for type, head–neck-body, and canter were slightly higher for D horses than J horses, whereas the mean value for correctness of legs was similar for both categories. The differences between J and D horses for all mean values of corresponding traits except correctness of legs were statistically significant ($p < 0.05$).

3.4 | Genetic parameters

For the 8,713 J horses assessed in YHT, the heritability of traits was low to moderate (range 0.17–0.38) (Table 2). For the 6,477 D horses, the heritability was moderate to high for conformation and gaits (0.30–0.56) and low for the two

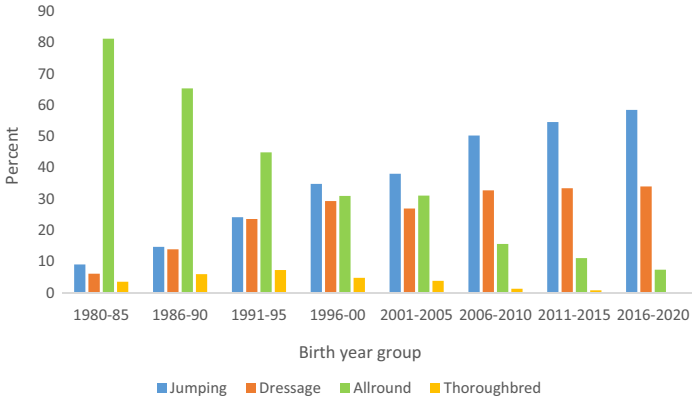

FIGURE 3 Distribution (%) of horses in the Swedish Warmblood population into different categories according to birth year group between 1980 and 2020 [Colour figure can be viewed at wileyonlinelibrary.com]

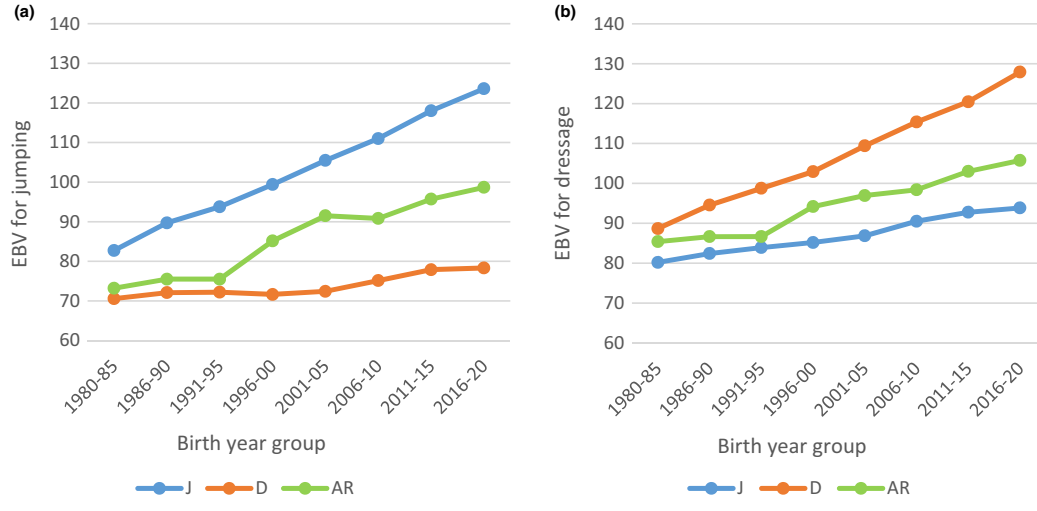

FIGURE 4 Estimated breeding values (EBV) for (a) show jumping and (b) dressage according to birth year group for Swedish Warmblood horses classified as jumping (J), dressage (D), or allround (AR) horses [Colour figure can be viewed at wileyonlinelibrary.com]

jumping traits (0.10–0.18). For all horses in total (19,621), the heritability was moderate to high for all traits (0.23–0.53), except for correctness of legs (0.08). For all horses in total, the genetic variance varied between 0.03 and 0.16 for conformation traits and between 0.18 and 0.41 for gaits and jumping traits. For J and D horses, the genetic variance ranged from 0.07 to 0.36 and was somewhat higher for D horses for all traits, except for the two jumping traits. In comparison with all horses in total, D horses had similar or higher heritability and genetic variance for all traits except jumping traits, while J horses had lower heritability and genetic variance for all traits (Table 2). The genetic correlations between gait traits and jumping traits for all horses were close to zero or low and unfavorable for walk and trot (from 0 to −0.13) and moderate and positive for canter (0.25–0.30). Standard errors for the correlations were between 0.04 and 0.05.

The heritability and genetic variance for YHT traits were estimated for both the early period (1999–2009) and the late period (2010–2020) and compared with the corresponding parameters for all horses in total (1999–2020) (Tables 3 and 4). For J horses, the heritability was lower for head–neck-body and free canter in the late period, whereas the heritability for the other traits was similar for both periods. For D horses, the heritability was higher for type, head–neck-body, and free canter in the late period, whereas the heritability for the other traits remained unchanged over time (Table 3).

In the late period, the genetic variance for J horses was lower for all traits except walk at hand (Table 4). For D

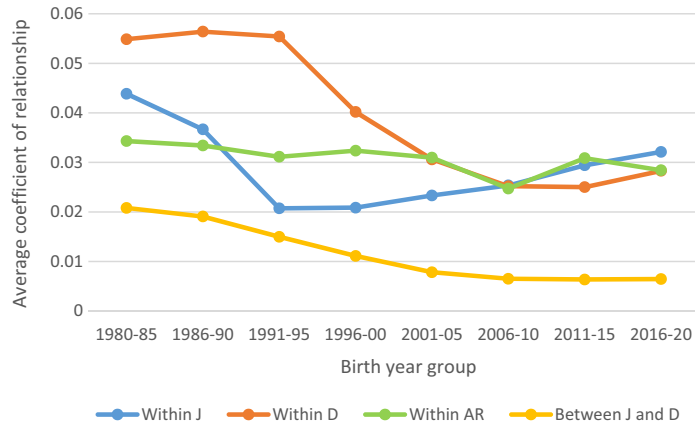

FIGURE 5 Average coefficient of relationship as a function of birth year group within and between categories of Swedish Warmblood horses classified as jumping (J), dressage (D), or allround (AR) [Colour figure can be viewed at wileyonlinelibrary.com]

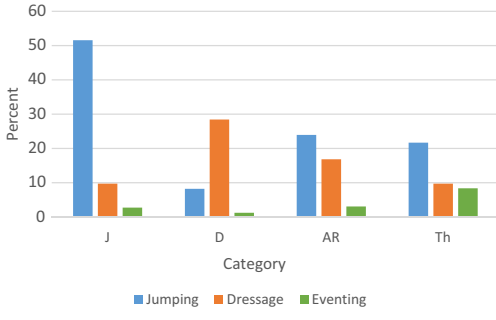

FIGURE 6 Percentage of horses born 1980–2016 competing in show jumping, dressage, or eventing, stratified by their category: Jumping (J), dressage (D), allround (AR), or thoroughbred (Th) [Colour figure can be viewed at wileyonlinelibrary.com]

horses, the genetic variance was lower in the late period or unchanged. The heritability and genetic variance were in general higher for D horses than J horses, except for the two jumping traits.

The genetic correlations between traits at YHT evaluated in J and D horses in the early period, late period, and in total are presented in Table 5. The genetic correlation ranged between 0.48 and 0.81 for the total period but varied between the early and late period, and the values were associated with high standard error and were not significantly different from unity. The results indicated lower genetic correlations between J horses and D horses in the late period than in the early period for all traits except free canter, but none of these correlations were significantly different.

3.5 | Future scenarios

The heritability and genetic variance for traits assessed at YHT and the corresponding parameters for scenario *D spec* and scenario *J spec* are presented in Table 6. When the results of the poorest performing horses were excluded, heritability and genetic variance both decreased. For the jumping traits, also the residual variance decreased. The sire rank correlations between EBVs from analysis of *Full data* (with all results in YHT included) and scenario *D spec* or scenario *J spec* are presented separately for the J and D sire groups in Table 7. For the J sire group, the correlation between *Full data* and scenario *D spec* was very high for jumping traits, while the correlation between *Full data* and scenario *J spec* was moderate for walk and trot. For the D sire group, the opposite was seen, with a very high correlation between *Full data* and scenario *J spec* (walk and trot) and low to moderate correlation between *Full data* and scenario *D spec* (jumping traits). When no results were removed, the ranking was the same, with a correlation equal to 1.00.

The accuracy of EBVs for *Full data* and for scenarios *D spec* and *J spec* is presented separately for the J and D sire group in Table 8. For both scenarios evaluated, the mean accuracy value (r_{TI}) decreased in comparison with when all results were included (*Full data*). The largest differences were seen for jumping traits in the D sire group (18%–25% decrease), while the decrease for walk and trot in the J sire group was smaller (11%–14%).

4 | DISCUSSION

4.1 | Classification

In this study, horses in the SWB population were divided into categories according to the category of their sire and grandsire. The classification of sires was in some cases performed subjectively, which could be regarded as a weakness of the study. However, the results showed clear and logical differences between J and D horses, indicating

TABLE 2 Estimated heritability (h^2) with standard error as subscript, genetic (σ_a^2) and residual (σ_e^2) variances for traits evaluated in young horse test for horses classified as jumping or dressage and for all horses in total

	Jumping horses			Dressage horses			All horses		
Trait	h^2	σ_a^2	σ_e^2	h^2	σ_a^2	σ_e^2	h^2	σ_a^2	σ_e^2
Type	$0.32_{0.03}$	0.12	0.26	$0.48_{0.04}$	0.19	0.21	$0.40_{0.02}$	0.16	0.24
Head–neck-body	$0.23_{0.03}$	0.07	0.22	$0.30_{0.04}$	0.10	0.22	$0.30_{0.02}$	0.09	0.22
Corr. of legs	[a]	[a]	[a]	[a]	[a]	[a]	$0.08_{0.01}$	0.03	0.35
Walk at hand	$0.25_{0.03}$	0.11	0.33	$0.42_{0.04}$	0.23	0.31	$0.36_{0.02}$	0.18	0.32
Trot at hand	$0.38_{0.03}$	0.17	0.28	$0.56_{0.04}$	0.36	0.28	$0.53_{0.02}$	0.29	0.26
Free canter	$0.33_{0.03}$	0.17	0.36	$0.45_{0.04}$	0.27	0.33	$0.35_{0.02}$	0.20	0.37
Free jumping – TA	$0.26_{0.03}$	0.33	0.92	$0.18_{0.03}$	0.20	0.94	$0.31_{0.02}$	0.41	0.90
Free jumping – TG	$0.17_{0.02}$	0.27	1.33	$0.10_{0.02}$	0.13	1.21	$0.23_{0.02}$	0.36	1.23

Note: The horses were born in 1996–2017.

Abbreviations: TA, technique and ability; TG, temperament and general impression.

[a]Did not reach convergence.

TABLE 3 Estimated heritability (with standard error as subscript) in Young Horse Test (YHT) for horses classified as jumping or dressage horses in the early period (1999–2009), late period (2010–2020) and total period (1999–2020) and for all horses in the total period (1999–2020)

	Jumping horses			Dressage horses			All horses
Trait	**Early**	**Late**	**Total**	**Early**	**Late**	**Total**	**Total**
Type	$0.32_{0.05}$	$0.30_{0.04}$	$0.32_{0.03}$	$0.41_{0.06}$	$0.49_{0.06}$	$0.48_{0.04}$	$0.40_{0.02}$
Head-neck-body	$0.31_{0.05}$	$0.15_{0.03}$	$0.23_{0.03}$	$0.19_{0.05}$	$0.31_{0.05}$	$0.30_{0.04}$	$0.30_{0.02}$
Corr. of legs	[a]	[a]	[a]	[a]	[a]	[a]	$0.08_{0.01}$
Walk at hand	$0.19_{0.04}$	$0.22_{0.04}$	$0.25_{0.03}$	$0.46_{0.06}$	$0.43_{0.05}$	$0.42_{0.04}$	$0.36_{0.02}$
Trot at hand	[a]	$0.42_{0.05}$	$0.38_{0.03}$	[a]	$0.64_{0.05}$	$0.56_{0.04}$	$0.53_{0.02}$
Free canter	$0.43_{0.05}$	$0.25_{0.04}$	$0.33_{0.03}$	$0.42_{0.06}$	$0.51_{0.06}$	$0.45_{0.04}$	$0.35_{0.02}$
Free jumping—TA[b]	$0.28_{0.05}$	$0.24_{0.04}$	$0.26_{0.03}$	$0.15_{0.04}$	$0.13_{0.04}$	$0.18_{0.03}$	$0.31_{0.02}$
Free jumping—TG[c]	$0.18_{0.04}$	$0.18_{0.03}$	$0.17_{0.02}$	$0.08_{0.03}$	$0.06_{0.03}$	$0.10_{0.02}$	$0.23_{0.02}$

[a]Did not reach convergence.

[b]Technique and ability.

[c]Temperament and general impression.

TABLE 4 Estimated genetic variance (with standard error as subscript) for traits in Young Horse Test for horses classified as jumping or dressage in the early period (1999–2009), late period (2010–2020) and total period (1999–2020) and for all horses in the total period (1999–2020)

	Jumping horses			Dressage horses			All horses
Trait	**Early**	**Late**	**Total**	**Early**	**Late**	**Total**	**Total**
Type	$0.13_{0.02}$	$0.11_{0.02}$	$0.12_{0.01}$	$0.19_{0.03}$	$0.17_{0.02}$	$0.19_{0.02}$	$0.16_{0.01}$
Head-neck-body	$0.10_{0.02}$	$0.04_{0.01}$	$0.07_{0.01}$	$0.06_{0.02}$	$0.09_{0.02}$	$0.10_{0.01}$	$0.09_{0.01}$
Corr. of legs	[a]	[a]	[a]	[a]	[a]	[a]	$0.03_{<0.01}$
Walk at hand	$0.09_{0.02}$	$0.09_{0.02}$	$0.11_{0.01}$	$0.28_{0.04}$	$0.21_{0.03}$	$0.23_{0.02}$	$0.18_{0.01}$
Trot at hand	[a]	$0.17_{0.02}$	$0.17_{0.02}$	[a]	$0.38_{0.04}$	$0.36_{0.03}$	$0.29_{0.01}$
Free canter	$0.28_{0.04}$	$0.11_{0.02}$	$0.17_{0.02}$	$0.28_{0.05}$	$0.27_{0.04}$	$0.27_{0.03}$	$0.20_{0.01}$
Free jumping—TA[b]	$0.42_{0.07}$	$0.25_{0.04}$	$0.33_{0.04}$	$0.19_{0.06}$	$0.12_{0.04}$	$0.20_{0.04}$	$0.41_{0.03}$
Free jumping—TG[c]	$0.34_{0.07}$	$0.25_{0.05}$	$0.27_{0.04}$	$0.13_{0.05}$	$0.07_{0.03}$	$0.13_{0.03}$	$0.36_{0.03}$

[a]Did not reach convergence.

[b]Technique and ability.

[c]Temperament and general impression.

that the classification was in general correctly performed. In contrast to the study by Rovere et al. (2014), horses in our study were classified not only as J or D but also as AR or Th. This probably made the classification in our study more refined. Additionally, in the present study, J and D horses were classified according to their sire's discipline, meaning that a sire could only have offspring in one of the two categories. In the study by Rovere et al. (2014), 40% of the sires had offspring in both the J and D subpopulations.

4.2 | Discipline specialization

A clear specialization over time toward either J or D horses was evident, with the number of AR sires (Figure 1) and AR horses (Figure 3) declining considerably during the last decade of the study period in favor of J and D horses. Based on the trends in EBVs (Figure 4), there were large differences between J and D horses in terms of average EBVs for jumping and dressage. Similarly, mean values in YHT for walk and trot on one hand and jumping traits on the other showed clear differences between J and D horses (Table 1).

In a previous study, Viklund et al. (2011) investigated genetic trends in SWB for show jumping and dressage and found a considerable increase in EBVs for both disciplines, starting in the mid-1980s. They also found that the 50% best sires in each discipline had noticeably better EBVs in comparison with the mean of all sires. A similar finding was made for the 50% best dams in comparison with the mean of all dams. This indicates that the specialization into disciplines of the SWB breed is a process that has been going on for at least 40 years.

TABLE 5 Estimated genetic correlation (with standard error as subscript) for traits in Young Horse Test between horses classified as jumping or dressage in the early period (1999–2009), late period (2010–2020) and total period (1999–2020)

	Genetic correlation		
Trait	**Early**	**Late**	**Total**
Type	$0.97_{0.20}$	$0.74_{0.22}$	$0.75_{0.14}$
Head-neck-body	$0.89_{0.29}$	$0.65_{0.39}$	$0.78_{0.18}$
Corr. of legs	[a]	[a]	[a]
Walk at hand	$0.55_{0.30}$	$-0.11_{0.41}$	$0.48_{0.20}$
Trot at hand	[a]	$0.70_{0.19}$	$0.81_{0.12}$
Free canter	$0.64_{0.22}$	$0.82_{0.25}$	$0.73_{0.15}$
Free jumping—TA[b]	$0.82_{0.38}$	$0.52_{0.46}$	$0.72_{0.23}$
Free jumping—TG[c]	$0.56_{0.56}$	$0.22_{0.77}$	$0.56_{0.33}$

[a]Did not reach convergence.
[b]Technique and ability.
[c]Temperament and general impression.

4.3 | Relationship

A decrease in relationship between J and D horses and an increase in relationship within the groups of J and D horses were seen in this study (Figure 6). Even so, the average relationship within category was still low (approximately 3% for both categories). Similarly, Rovere et al. (2014) found that genetic connections between the two subpopulations "jumping" and "dressage" in KWPN decreased markedly after the studbook was divided in 2006, while the relationship within the subpopulations increased. The average relationship coefficient they found for KWPN was slightly higher than that in our study (4% for J horses and 5% for D horses, for horses born in 2009). Rovere et al. (2014) concluded that if the specialization process continues, it will give rise to two unrelated subpopulations in KWPN. This would probably also be seen

TABLE 6 Estimated heritability (h^2) and genetic (σ^2_a) and residual (σ^2_e) variance (with standard error as subscript) for traits in Young Horse Test, based on *Full data*[a] and in future scenarios *D spec* and *J spec*[b]

	Full data			Scenario D spec			Scenario J spec		
Trait	h^2	σ^2_a	σ^2_e	h^2	σ^2_a	σ^2_e	h^2	σ^2_a	σ^2_e
Walk at hand	$0.36_{0.02}$	$0.18_{0.01}$	$0.32_{0.01}$	–	–	–	$0.30_{0.02}$	$0.13_{0.01}$	$0.30_{0.01}$
Trot at hand	$0.53_{0.02}$	$0.29_{0.01}$	$0.26_{0.01}$	–	–	–	$0.48_{0.03}$	$0.23_{0.01}$	$0.25_{0.01}$
Free jumping—TA[c]	$0.31_{0.02}$	$0.41_{0.03}$	$0.90_{0.02}$	$0.24_{0.02}$	$0.25_{0.03}$	$0.79_{0.02}$	–	–	–
Free jumping—TG[d]	$0.23_{0.02}$	$0.36_{0.03}$	$1.23_{0.02}$	$0.15_{0.02}$	$0.20_{0.03}$	$1.12_{0.03}$	–	–	–

[a]Full data: including all results for horses evaluated 1999–2020.
[b]D-spec: for D horses with the poorest results for TA and TG, scores for these traits were omitted in the analyses. J-spec: for J horses with the poorest results for walk and trot at hand, scores for these traits were omitted in the analyses.
[c]Technique and ability.
[d]Temperament and general impression.

TABLE 7 Correlations between rankings for *full data*[a] and future scenarios *D spec* and *J spec*[b], shown separately for the jumping sire and dressage sire groups

Trait	Jumping sire group		Dressage sire group	
	Full data - D spec	Full data - J spec	Full data - D spec	Full data - J spec
Walk at hand	1.00	0.56	1.00	0.96
Trot at hand	1.00	0.60	1.00	0.97
Free jumping – TA	0.95	1.00	0.48	1.00
Free jumping – TG	0.93	1.00	0.19	1.00

Abbreviations: TA, technique and ability; TG, temperament and general impression.

[a]Full data: Including all results from horses evaluated 1999–2020.

[b]D-spec: for D horses with the poorest results for TA and TG, score for these traits were omitted in the analyses. J-spec: for J horses with the poorest results for walk and trot at hand, score for these traits were omitted in the analyses.

TABLE 8 Mean accuracy (r_{TI}) for breeding values (with standard deviation as subscript) for *Full data*[a] and for future scenarios *D spec* and *J spec*[b] and difference in accuracy (Diff.) between *Full data* and each scenario, shown separately for the jumping sire and dressage sire groups

Trait	Jumping sire group				Dressage sire group			
	Full data	D spec	J spec	Diff. (%)	Full data	D spec	J spec	Diff. (%)
Walk at hand	$0.87_{0.06}$	–	$0.75_{0.13}$	−13.8	$0.86_{0.08}$	–	$0.80_{0.12}$	−7.0
Trot at hand	$0.91_{0.05}$	–	$0.81_{0.11}$	−11.0	$0.90_{0.07}$	–	$0.85_{0.11}$	−5.6
Free jumping—TA[c]	$0.85_{0.07}$	$0.78_{0.12}$	–	−8.2	$0.84_{0.09}$	$0.69_{0.13}$	–	−17.9
Free jumping—TG[d]	$0.82_{0.08}$	$0.72_{0.13}$	–	−12.2	$0.81_{0.10}$	$0.61_{0.14}$	–	−24.7

[a]Full data: including all results from horses evaluated 1999–2020.

[b]D-spec: for D horses with the poorest results for TA and TG, score for these traits were omitted in the analyses. J-spec: for J horses with the poorest results for walk and trot at hand, score for these traits were omitted in the analyses.

[c]Technique and ability.

[d]Temperament and general impression.

in SWB if separation into different breeding programs was to be introduced.

Our result is a further confirmation of what is reported in Ablondi et al. (2019), where they found genetic differences between SWB horses bred for show jumping or dressage by analyzing high-density SNP array data. The horses in that study were born in 2010–2011, and the authors found signatures of selection in 11 chromosomes. The selected regions included genes with known function in mentality, endogenous reward system, development of connective tissues and muscles, motor control, body growth, and development.

In the beginning of our study period (1980s), the relationship within the groups of J and D horses was higher than in 2020. This could be partly explained by the low number of horses classified as J or D at that time. In the 1980s, there was a drastic decrease in relationship for J horses, and 10 years later, the same was seen for D horses, probably due to importation of stallions with bloodlines that had not been used previously in the SWB breed. Today, those bloodlines are well spread in all European warmblood studbooks (Ruhlmann et al., 2009), which could partly explain the increase in relationship seen for both categories in recent years. In a future scenario with separate breeding programs, the average increase in relationship needs to be monitored carefully to avoid inbreeding.

4.4 | Heritability estimates

The moderate to high heritability estimates, except for correctness of legs (Table 2), in analysis of the full dataset were in agreement with findings by Viklund and Eriksson (2018). In the study by Rovere et al. (2017), the heritability for conformation and gait traits was slightly lower (0.24–0.39) than in the present study (0.35–0.53). The heritability for trot showed the highest value in both studies. The heritability for jumping found by Rovere et al. (2017) (0.33) was slightly higher than in this study (range 0.23–0.31).

Category D horses had higher heritability for gaits than J horses, whereas the opposite was seen for jumping traits. The genetic variance for these traits showed a similar pattern. This may indicate use of a wider assessment scale for gaits in D horses than in J horses and for jumping traits in

J horses than in D horses. Use of a wider assessment scale in these cases depends primarily on more frequent use of higher scores for discipline-specific traits within category. In the study by Rovere et al. (2015), the differences between heritability estimates for J and D horses were smaller, for example, for conformation and gait, heritability ranged from 0.26 to 0.37 for D horses and from 0.21 to 0.39 for J horses.

Compared with all horses, D horses had similar or higher heritability and genetic variance for all traits except jumping traits. This may indicate that division into subpopulations would be favorable for D horses since high heritability and genetic variance are advantageous for genetic progress. On the other hand, the heritability and genetic variance for J horses were lower for all traits, in comparison with all horses, so division into subpopulations might have negative impacts on genetic progress for J horses.

On comparing genetic parameters estimated for the early (1999–2009) and late (2010–2020) periods (Table 3), no clear pattern could be seen. Similarly, Rovere et al. (2015) found no clear trend between different periods (1998–2002, 2003–2007, and 2008–2012) for conformation and gait traits in the KWPN population. In the study of SWB by Viklund et al. (2010b), higher heritability and genetic variance estimates were found in the later period (1988–2007) compared with the earlier period (1973–1987) for horses assessed in RHT. Those authors concluded that the higher heritability in the later period could have been be due to improvements in judging of horses and that the increase in genetic variance could have been due to import of sires and increased specialization into either jumping and dressage. However, the periods studied by Viklund et al. (2010b) were longer than in the present study and thus covered many changes in both sport and breeding, which may explain why those authors found differences between periods that were not detected in this study.

4.5 | Genetic correlations

The genetic correlations between corresponding traits for J and D horses were weaker in the late compared with the early period for all traits except free canter (Table 5). The results indicated that there were larger differences between J and D horses for traits in the late period, which could confirm an ongoing specialization process in the population. However, the standard error was very high in most cases, making it difficult to draw any firm conclusions. Similar results were seen in the study by Rovere et al. (2015), in which the genetic correlations between gait traits assessed for J and D horses in the later period (2008–2012) were lower than those in the earlier period (2003–2007) (jumping traits were not included in that study).

In contrast to other traits, the genetic correlation for free canter between J and D horses was higher in the late period. This could possibly be explained by the cooperation between the two judges when assessing this trait. During the assessment, the judge assessing gaits and the judge assessing jumping discuss and jointly set a score for canter, which may increase the correlation between J and D horses for this trait.

The estimated genetic correlations between gait traits and jumping traits were higher than corresponding estimates in a study by Viklund et al. (2008), where data from YHT between 1999 to 2003 were investigated. Viklund et al. (2008) concluded that walk and trot appeared to have no genetic relationship with jumping traits (−0.05 to 0.03), while the correlations they observed between canter and jumping traits were stronger (0.32–0.33). The weak correlations between disciplines in the SWB population were confirmed in a later study in which Viklund et al. (2010a) found slightly negative to low genetic correlations between jumping traits judged in RHT and dressage competition (−0.19 to 0.17) and walk and trot judged under rider in RHT and show jumping (−0.01 to 0.18). In the KWPN population, Rovere et al. (2017) observed a negative correlation between jumping traits assessed at studbook entry inspection and dressage competition (−0.39), while the assessments of walk and trot were not correlated with show jumping. Their estimated genetic correlation between show jumping and dressage was weak and unfavorable (−0.21), and they concluded that a breeding program under specialization might be most effective if separate breeding goals were defined for each discipline. In the SWB population, there is a need for further investigation of the correlations between YHT results and competition data in order to identify characteristics that are important for successful sport horses in both disciplines.

4.6 | Future scenarios

Two different scenarios were assessed, in which scores for walk and trot and jumping traits were omitted for approximately 50% of the poorest performing J and D horses, respectively. This could illustrate a situation where the horse owner is aware that their horse would probably receive at most a modest score for jumping (or walk and trot) and thus chooses to have their horse assessed as either a jumping horse or a dressage horse. Scenario *D spec*, in which 50% of D horses were not assessed in jumping, is a likely future scenario because some owners of D horses

appear to find free jumping unnecessary. There is also a higher risk of a horse that is not fully trained for free jumping having a bad experience in the test, which would be undesirable from an animal welfare perspective.

Scenario *J spec*, in which 50% of J horses were not assessed for walk and trot, could also represent a future scenario because owners of J horses are often less interested in assessment of gaits other than canter. However, walk and trot are less time-consuming for judges to assess, which could be a reason for retaining these traits in the assessment. This is also the practice in KWPN (Rovere et al., 2015), where all horses are assessed for gaits regardless of discipline. Another argument for assessing all traits at YHT is to encourage horse owners to give their horse a varied training, which is considered to have positive impacts on health and durability (Braam et al., 2011).

In both scenarios, the estimated heritability and genetic variance declined for walk, trot, and jumping traits in comparison with the current situation (Table 6). Lower heritability could slow down genetic progress in the population, which could be an argument for retaining assessments for all traits. However, while the genetic variance appeared to be reduced in the scenarios, the consequences may be less severe in practice. If the genetic variance for a trait is large mainly because of weak performance by horses of a different discipline, genetic progress will probably not decline if these horses are not assessed since they were not intended for that discipline in any case. This assumes that the ranking of selected candidates is not affected.

Our analysis of future scenarios indicated that the ranking of sires on EBVs for jumping traits would only be slightly affected for the J sire group in scenario *D spec*, that is, when some of the D horses were not assessed in free jumping (Table 7). A similar pattern was seen for walk and trot for the D sire group in scenario *J spec*, that is, when some J horses were not assessed for these traits. This could be a reason for allowing horse owners to choose to have their horse assessed as either a jumping horse or a dressage horse since it is more important to have an accurate evaluation for jumping traits for J sires and for walk and trot for D sires. On the other hand, the re-ranking was strongly affected for the opposite traits, that is, evaluation of jumping traits for the D sire group and evaluation of walk and trot for the J sire group. The accuracy of EBVs for these traits also decreased to a larger extent in both scenarios, in comparison with the full dataset (where all results were included) (Table 8). This indicates that genetic evaluation for these traits would be affected and give less certain EBVs if some horses were not assessed for all traits at YHT. This could make it more difficult for breeders aiming to produce horses with high quality in both gaits and jumping traits, such as AR horses and eventers.

5 | CONCLUSIONS

This analysis revealed clear specialization into jumping or dressage horses in the SWB breed. The average relationship within these categories increased in the past decade, while the relationship between horses in different categories decreased. Evaluation of two different future scenarios, in which horse owners could choose to have their young horses assessed as either a jumping horse or a dressage horse in YHT, showed that both estimated heritability and genetic variance decreased for traits that were not assessed in all horses. This could have a negative impact on genetic progress for these traits. The ranking of sires (based on EBVs) was also altered in both scenarios, which could have consequences for estimation of breeding values. However, since there were only minor changes for traits connected to the respective disciplines, that is, jumping traits for J horses and walk and trot for D horses, specialization of the YHT can be a viable option, provided that the number of horses participating in YHT stays at the same level and that interest in producing AR horses remains low.

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DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from Swedish Warmblood Association. Restrictions apply to the availability of these data, which were used under license for this study. Data are available from the author(s) with the permission of Swedish Warmblood Association.

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The overall aims of the thesis were to investigate the specialization of the Swedish Warmblood (SWB) horse population towards show jumping and dressage, and to find important characteristics for successful sport performance in these disciplines. The results provide an overall picture of the specialization process in the SWB breed, as well as the usefulness of linearly scored traits as a tool for improvement of sport horse breeding.

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