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Breeding, performance, and health in the Swedish Warmblood horse

- Trait associations and population-level insights

Sandra Bonow

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Sandra Bonow
Faculty of Veterinary Medicine and Animal Science
Department of Animal Biosciences
Uppsala

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Cover: Two SWB horses on a walk. (Photo: Lisa Chröisty/HästSverige, 2024)

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Swedish University of Agricultural Sciences, Department of Animal Biosciences, Uppsala, Sweden

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Abstract

Equestrian sport has made tremendous development during recent decades, requiring athletic and specialized horses that can be competitive at the highest level in show jumping or dressage. Furthermore, horses need to be sound to withstand the physical strain and stay durable in sport. Today, orthopedic diseases are the most common health problem in sport horses, causing negative impact on performance, owners' economy, and the welfare of the horse. This thesis aimed to investigate the specialization towards show jumping and dressage in the Swedish Warmblood (SWB) horse, and to examine assessed traits in young horses and their associations with performance and orthopedic diagnoses from insurance data. The results showed that the proportion of horses classified as 'allround' decreased markedly since 1980 in favor of jumping and dressage horses. The average relationship between jumping and dressage horses decreased over time, whereas it increased within these subpopulations during the past decade. Also, clear differences were seen between discipline-specific traits for jumping and dressage horses, indicating a clear specialization into disciplines in the SWB breed. Several linearly scored traits had a phenotypic association with performance in show jumping or dressage. Most associations were linear, indicating that stronger expression of these traits was in general associated with better performance. However, some traits showed intermediate optimal scores, suggesting that extreme expressions do not correspond to better performance in general for those traits. The prevalence of orthopedic diagnoses was higher in dressage than jumping horses. Also, later cohorts had higher risk of having an orthopedic diagnosis at a young age than earlier cohorts. Height at withers and the assessment score for 'trot at hand' had a significant association with the risk of having an orthopedic diagnosis for both jumping and dressage horses, whereas few linearly scored traits influenced the risk for such diagnosis. These findings highlight the importance of monitoring the orthopedic health status in sport horses, and to find measurements that can be useful for this purpose.

Keywords: dressage, insurance data, lameness, linearly scored traits, orthopedic diagnoses, show jumping, survival analysis, young horse test

Avel, prestation och hälsa hos den svenska varmblodiga ridhästen

Sammanfattning

Ridsporten har gjort en storartad utveckling de senaste årtiondena, vilket har lett till en ökad efterfrågan på talangfulla och specialiserade hästar som kan vara konkurrenskraftiga på den högsta nivån i hoppning eller dressyr. Hästarna behöver också vara sunda, för att klara av den fysiska påfrestningen och förbli varaktiga i sporten. Ortopediska skador är det vanligast hälsoproblemet hos sporthästar idag, vilket orsakar negativa effekter på prestation, ägarens ekonomi och hästens välfärd. Syftet med den här avhandlingen var att undersöka specialiseringen mot hoppning och dressyr hos det svenska varmblodet (SWB), samt att studera bedömda egenskaper hos unghästar och hur dessa kan kopplas till prestation och ortopediska diagnoser från försäkringsdata. Resultaten visade att andelen hästar klassade som 'allround' minskat betydligt sedan 1980, till förmån för hopp- och dressyrhästar. Det genomsnittliga släktskapet mellan hopp- och dressyrhästar minskade över tid, medan det ökat inom dessa grupper under det senaste årtiondet. Vidare fanns tydliga skillnader mellan hopp- och dressyrhästar för grenspecifika egenskaper, vilket pekar på en tydlig disciplinspecialisering inom SWB-rasen. Flertalet linjärt bedömda egenskaper hade ett fenotypiskt samband med hoppning eller dressyr. De flesta samband var linjära, vilket innebär att ett starkare uttryck av en viss egenskap generellt sett var förknippat med bättre prestation. Några egenskaper uppvisade dock ett samband med ett intermediärt optimum, vilket tyder på att ett starkare uttryck inte är kopplat till bättre prestation i genomsnitt för dessa egenskaper. Förekomsten av ortopediska diagnoser var högre hos dressyrhästar än hos hopphästar. Senare årgångar hade också högre risk att drabbas av en ortopedisk diagnos vid ung ålder, jämför med tidigare årgångar. Mankhöjd och bedömningspoäng för 'trav vid hand' hade ett signifikant samband med risken att drabbas av en ortopedisk diagnos för både hopp- och dressyrhästar, medan få linjärt bedömda egenskaper hade någon tydlig koppling till risken för sådana diagnoser. Resultaten understryker vikten av att kontinuerligt följa utvecklingen av ortopedisk hälsa hos sporthästar, samt att hitta lämpliga mätvärden som kan vara användbara för detta ändamål.

Nyckelord: dressyr, försäkringsdata, hoppning, hälta, linjära egenskaper, ortopediska diagnoser, unghästtest, överlevnadsanalys

The aim of breeding is not to create perfection, but to make informed and sustainable progress.

To all wonderful horses, whose partnership inspires both science and passion.

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. (2023). Consequences of specialized breeding in the Swedish Warmblood horse population. Journal of Animal Breeding and Genetics 140 (issue 1), 79-91. https://doi.org/10.1111/jbg.12731

II. Bonow, S., Eriksson, S., Strandberg, E., Thorén Hellsten, E. & Gelinder Viklund, Å. (2024). Phenotypic associations between linearly scored traits and sport performance in the Swedish Warmblood horse population. Livestock Science 282:105438. https://doi.org/10.1016/j.livsci.2024.105438

III. Bonow, S., Hernlund, E., Eriksson, S., Strandberg, E. & Gelinder Viklund, Å. (2025). Prevalence and risk of orthopedic diagnoses in insured Swedish Warmblood horses, Preventive Veterinary Medicine, 242:106596. https://doi.org/10.1016/j.prevetmed.2025.106596

IV. Bonow, S., Hernlund, E., Eriksson, S., Strandberg, E. & Gelinder Viklund, Å. (2025). Phenotypic associations between young horse assessments and orthopedic diagnoses in insured Swedish Warmblood horses. (Submitted).

All published papers are published open access.

This thesis is an extended work of the licentiate thesis ‘Breeding of Swedish Warmblood horses towards specialization in show jumping and dressage’ (Bonow, S., 2023).

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 and performed the analyses together with co-authors. Drafted and wrote the manuscript in collaboration with all co-authors. Had the responsibility for the submission process and the correspondence with the journal.

III. 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.

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

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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

Equestrian sport at the highest level is demanding, requiring athletic and talented horses that can stay sound for many years. Because of the clear differences in characteristics between horses intended for show jumping or dressage, breeding practices have become highly specialized in most warmblood studbooks (Stock et al., 2015). This specialization is apparent also in the Swedish Warmblood (SWB) breed, suggesting a potential need for separate breeding programs and discipline-specific testing of young horses.

Assessments of young horses have a crucial function in most warmblood studbooks, to evaluate and monitor the genetic progress within the population (Thorén Hellsten et al., 2006). Traits assessed in young horses are highly correlated with performance later in life and are thus useful as indicator traits of future sport success. The linear scoring system has become a common tool in many studbooks and was introduced in SWB in 2013 (Viklund & Eriksson, 2018). With linearly scored traits, a more objective and detailed assessment of each horse can be achieved (Deunsing et al., 2014). However, the associations between linearly scored traits and sport performance in show jumping and dressage in the SWB population have not been investigated before.

Orthopedic diseases are the most common health problem in sport horses (Egenvall et al., 2013; Wallin et al., 2000), causing negative impact on sport performance, owners' economy, and the welfare of the horse. Because of the specialization into disciplines, jumping and dressage horses have differences in characteristics and may also be exposed to different training and management. Consequently, they may be predisposed to varying levels of risk and to different types of orthopedic diseases.

Until 2005, a health examination of the extremities and the locomotion was performed at the young horse performance test for 4-year-old horses (Jönsson et al., 2013). These health measurements were found to be correlated with future longevity in sport and gave an overview of the overall health status in the SWB population. Due to the current lack of a standardized health assessment in young SWB horses, possible methods need to be investigated. Whether linearly scored traits assessed at young horse tests can serve as indicator traits of future orthopedic health status has not previously been investigated.

2. Background

2.1 The Swedish Warmblood

The SWB breed originates from the eighteenth century, when the main purpose was to produce horses for the royal cavalry (Graaf, 2004). However, after a successful participation in the Olympic games in 1924, where Sweden won medals in both show jumping and dressage, an interest for suitable horses for equestrian sports arose. The association for the Swedish Warmblood was established in 1928, and the intention was to breed a correct warmblood horse for equestrian purposes. Over the decades, the SWB horse went from a solid cavalry horse to a highly specialized horse bred for either show jumping or dressage. The genetic trend for both show jumping and dressage has increased noticeably in the last decades, mainly because of import of high-quality stallions, improved selection of stallions, and the introduction of BLUP animal model for genetic evaluation in 1986 (Viklund et al., 2011). Today, the 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). Although the SWB breed represents a relatively small population compared with other warmblood studbooks (WBFSH, 2024), many SWB horses have achieved success at the international level, and the studbook has attained high rankings among studbooks in both show jumping and dressage (WBFSH, 2025). In Sweden, the SWB breed is the most common horse breed, with approximately 52,000 registered horses and about 3,000 foals born each year (HNS, 2025).

2.2 Specialization into disciplines

The specialization into disciplines is an ongoing process that is evident in many European studbooks (Stock et al., 2015). Breeding organizations have handled this in different ways, from small adjustments to larger changes such as splitting the studbook. The Dutch Warmblood federation (KWPN) took notice of this specialization already in the 1990's and extended the studbook entry inspection in 1998 by adding a subset of traits for jumping ability

(Rovere et al., 2014). Furthermore, since 2006, breeders have to register their foals as either jumping or dressage horses, which has led to a considerably decrease in genetic relatedness between these groups of horses. The Oldenburg studbook has made major changes because of the specialization and founded a separate studbook in 2001 exclusively for breeding of show jumping horses (Oldenburg Pferdezuchtferband, 2025). Similarly, the breeding organization for the Danish Warmblood (DWB) introduced a special breeding plan for jumping horses in 2004 (Dansk Varmblod, 2025). Also, the young horse performance test for 4-year-old DWB horses has been discipline-specific since 2003.

In SWB, relatively few changes have been implemented by the breeding organization to adapt to the specialization, except for introduction of a discipline-specific stallion performance test in 2002. However, it has been shown that the SWB population consists of two largely genetically differentiated subpopulations of jumping and dressage horses, according to a study based on high-density single-nucleotide polymorphism (SNP) array data (Ablondi et al., 2019).

2.3 Assessment of young horses

Young horse assessments are common in most warmblood studbooks and have several important functions, including to find and select talented horses and to serve as an information source for the genetic evaluation of the breed (Thorén Hellsten et al., 2006). In SWB, two separate performance tests for young horses are held annually: the Young Horse Test (YHT) for 3-year-old horses (and 4-year-old horses that have not participate as 3-year-olds) and the Riding Horse Test (RHT) for 4-year-old horses (and 5-year-old mares that have had a foal) (Viklund et al., 2008). Both tests are one-day field tests held at several places throughout the country. Each horse is evaluated by two judges, where one judge assesses conformation and gaits and one judge assesses jumping ability. The YHT was introduced in 1999, and includes assessment of conformation, gaits and free jumping, and an optional examination under rider. Previously, an accepted examination under rider was a prerequisite to achieve a diploma, but this rule was omitted in 2024. The RHT was introduced already in 1973 and has been remodeled over the years. Today, the test includes assessment of conformation, gaits, and jumping ability. The gaits are assessed under rider, and the jumping ability are assessed either under rider or by free jumping (optional). Since 2019, it is possible to have only one of the disciplines examined, either gaits or jumping, provided that the horse has participated in YHT (SWB, 2018). Approximately 30% of the SWB population participate in YHT, whereas the participation rate at RHT has decreased considerably in the last decades to less than 10% (Gelinder Viklund et al., 2025).

2.4 Linearly scored traits

In the linear assessment, traits are described on a scale between two biological extremes, e.g. long-short, powerful-weak, etc. (Deunsing et al., 2014). The aim is to give a detailed and more objective description of the horse, compared with the traditional evaluation where traits are scored on a scale from 'very bad' to 'excellent' in relation to the breeding goal. A large number of traits are included in the linear assessment, which facilitates the ability to differentiate between traits and contributes to a more uniform and standardized examination of the horse (Koenen et al., 1995).

Linear assessment is common in several species and was first developed in the American Holstein cattle association already in the 1970´s (Mawdsley et al., 1996). However, it took several years until the method was introduced in warmblood horses. The Dutch warmblood federation, KWPN, was the first studbook introducing linear assessment in 1989, where 26 traits describing conformation, walk and trot were assessed on a scale between 1 and 40 (Koenen et al., 1995). Many breeding organizations followed KWPN, and linear assessment was introduced in several studbooks, including Belgian Warmblood (BWP) in 2003, Irish Sport Horse (ISH) in 2008, and the Oldenburg studbooks (OL/OS) in 2012, as summarized by Duensing et al. (2014).

In SWB, the linear assessment was introduced in 2013 at the YHT, and the year after, in 2014, at the RHT (Viklund & Eriksson, 2018). The protocol comprises about 50 traits, and from 2017, breeding values are presented for these traits in the routine genetic evaluation. The assessment scale has nine values from A to I, where E is the center score and A and I represent the biological extremes of the trait. Scores within range D to F can be considered to fall within the normal biological variation. The linear scoring protocol for YHT was slightly modified between 2013 and 2014, and in 2025, four traits related to behavior were added in the protocol.

2.5 Competition records

Because the breeding goal for SWB is to produce highly competitive horses in show jumping or dressage, competition performance is an essential part to evaluate the breed. Accumulated lifetime competition points are used as the breeding goal trait and results from official competitions in show jumping and dressage are registered and used in the routine genetic evaluation (Viklund et al., 2011). Results from **-level (1.10 m jumping and 'Lätt A' dressage) and higher generates in competition points if the horse is placed (i.e., being within the 25% best) (Svenska Ridsportförbundet, 2025a). More points are given for better placings, a placing on a more advanced level, or both. Results from international competitions are registered as well, provided that the rider has a Swedish competition license. Approximately 30,000 horses had an active competition license in Sweden in 2024 (Svenska Ridsportförbundet, 2025b). Show jumping is the predominant discipline, accounting for 78% of all entries in official competitions, whereas dressage is the second most popular discipline, accounting for 19% of all entries.

2.6 Orthopedic health in SWB horses

Lameness is the most common health problem in warmblood horses and the main cause for euthanizing horses. This was shown in a study by Wallin et al. (2000), where the most common cause for death in SWB horses born between 1965 and 1982 was diseases of the musculoskeletal system (56-57%), followed by respiratory diseases (8-9%). While some health problems, like respiratory diseases, have been successfully managed and are now relatively uncommon, lameness is still a major problem in the horse industry. In 2017, the insurance company Agria implemented a project named 'Stoppa hältan' (Stop the lameness), with the aim to increase the knowledge about lameness and common risk factors, in order to improve the horse welfare and decrease the prevalence of orthopedic disease (Agria, 2025; Tidningen Ridsport, 2025). However, since the start of the project, the prevalence of these diagnoses has increased by 34% according to statistics from the insurance company, indicating that efforts for improved orthopedic health continue to be a matter of considerable importance.

Previously, a health examination was conducted at the RHT, including medical health, hoof examination, palpatory orthopedic health, and locomotion examination. In a study by Jönsson et al. (2013), these health records were investigated in 8,238 horses examined at the RHT between 1982 and 2005. The authors found moderate heritability estimates for hooves and palpatory orthopedic health, suggesting that improvement of the health status in the SWB population is feasible. The authors concluded that breeding values for orthopedic health for stallions could possibly be implemented, as a complement to existing breeding values for performance. However, although health measurements in young horses can provide valuable information for genetic evaluation, such traits have not yet been implemented in the SWB breeding program. The health examination at the RHT was omitted in 2006, and no other standardized health assessment of young SWB horses has been conducted since then.

2.7 Insurance data for research

Sweden has a long tradition of insurance policies, and a large proportion of companion animals and horses are insured (Egenvall et al., 2025; VIN News, 2019). Because insurance policies are less common in other countries, the number of studies based on insurance data outside Sweden is scarce (Egenvall et al., 2009). Although insurance data are considered as secondary data, such data has been found to be valuable for research purposes, e.g., for investigating incidence and prevalence of diseases. For example, the database of Agria (the leading insurance company for horses in Sweden) has been used for investigating morbidity and mortality in the Swedish horse population, e.g., in studies by Egenvall et al. (2005; 2006) and Penell et al. (2005). Using insurance databases for research involves some limitations though. For example, there may be differences among owners in their willingness to contact a veterinarian when health issues arise, as well as in their inclination to make use of their insurance coverage. Validation of insurance data is therefore crucial when such data are used for research (Egenvall et al., 2009). Insurance data from Agria was validated to clinical records in a study by Penell et al. (2007), and the agreement was found to be high. The authors concluded that insurance data at least estimates the lower limit of the injury frequency.

3. Aims of the thesis

The overall aims of the thesis were to investigate the specialization of the Swedish Warmblood (SWB) horse population towards show jumping or dressage, and to find important characteristics for successful sport performance in these disciplines. Furthermore, the aim was to investigate the prevalence of orthopedic diagnoses in the SWB population and to find traits associated with these.

The specific aims were to:

- investigate the specialization process of SWB horses towards subpopulations of jumping or dressage horses, and the consequences this could have for genetic evaluation.

- investigate phenotypic associations between linearly scored traits assessed in young SWB horses and later competition performance in show jumping and dressage, and to examine if some linearly scored traits have an intermediate optimal score.

- describe the prevalence and risk of having an orthopedic diagnosis in the SWB horse population, and to investigate the effects of discipline category (jumping or dressage), sex, birth cohort, test status, and competition status.

- investigate the phenotypic associations between traits assessed in young SWB horses and orthopedic diagnoses.

4. Summary of performed studies

4.1 Material

4.1.1 Data and discipline classification

Data were provided by the Swedish Warmblood Association for all studies in this thesis, including a pedigree file and results from YHT, RHT, and official competitions. In study III and IV, insurance data for SWB horses were provided by the insurance company Agria.

In all studies (I-IV), horses were classified into categories according to pedigree. All sires and maternal grandsires of horses included in the studies were classified into one of four categories: jumping (J), dressage (D), allround (AR), and Thoroughbred (Th). Sires approved in the stallion performance test from 2002 onwards were readily assigned to a category, as they were assessed in only one discipline (jumping or dressage) during the test. Sires approved prior to 2002 were classified as J or D based on their breeding values, individual performance, and offspring performance. Sires that had demonstrated verified success in both jumping and dressage, or that had offspring performing well in both disciplines, were assigned to the AR category. Horses in the populations were classified according to the sire's category, except if they had a category J sire and a category D maternal grandsire, or vice versa, in which case they were classified as AR.

4.1.2 Population

The data sets with SWB horses investigated in study I-IV are summarized in Table 1. In the first study (I), the studied population consisted of all 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 created. Most 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 (4,691). Data on 8,713 J horses and 6,477 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 born between 2009 and 2018 and with a linear assessment from YHT or RHT. 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=4,216) and D horses (N=3,152). In the second part, the focus was to investigate important characteristics for subpopulations of J horses with competition results in show jumping (N=2,414), and D horses with competition results in dressage (N=1,178).

In the third study (III), the studied population was restricted to horses registered in SWB, insured in Agria and born between 2010 and 2020. Horses sired by an unlicensed stallion were removed. According to these criteria, a population of 15,619 horses was set. The study mainly considered horses classified as J horses (N=9,034) and D horses (N=5,240). In the fourth study (IV), insured J and D horses from study III, with a linear assessment from YHT or RHT were considered. According to these criteria, a population of 5,991 horses was studied (J: N=3,445 and D: N=2,546).

Table 1. Populations of SWB horses included in study I - IV

	Birth year	**Criteria**	**No of horses**	**Discipline category**		
				J	**D**	**AR/Th**
Study I (a)	1980-2020	All horses	122,054	41,279	29,822	50,953
Study I (b)	1996-2017	J and D horses assessed at Young Horse Test	15,190	8,713	6,477	-
Study II (a)	2009-2018	Linearly assessed J and D horses	7,368	4,216	3,152	-
Study II (b)	2009-2017	Linearly assessed and competed J and D horses	3,592	2,414	1,178	-
Study III	2010-2020	Insured[1] horses	15,619	9,034	5,240	1,345
Study IV	2010-2020	Insured[1] and linearly assessed J and D horses	5,991	3,445	2,546	-

Abbreviations: J=jumping, D=dressage, AR=allround, Th=Thoroughbred

[1]Insured in Agria

4.1.3 Traits

In the first study (I), eight evaluated traits from YHT were used in the analyses. The traits were assessed on a scale 1-10, where 10 is defined as the breeding goal. At each event, one judge assessed conformation (type, head-neck-body, correctness of legs) and gaits, and another judge assessed the two jumping traits. Results for 15,190 J and D 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 the second 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 can participate in competitions from 4 years of age, and they receive points if they are placed in an official competition at **-level and higher, i.e., if they 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.

In the third study (III), different groups of insured SWB horses were investigated, i.e., according to sex (male or female horses), discipline category (J or D), test status (1/0) (i.e., if they had participated at YHT/RHT or not), competition status (1/0) (i.e., if they had competed in an official competition or not), if they had an insurance claim or not (1/0), and if they had an insurance claim connected to an orthopedic diagnosis or not (1/0). The orthopedic diagnoses were classified into eight subgroups, and the horses received a classification (1/0) for each one of these subgroups as well (i.e., whether they have had a diagnosis connected to the specific subgroup or not). The eight subgroups were: orthopedic disease of extremities, orthopedic disease of the axial skeleton, osteochondrosis, developmental disease in limbs or hooves (other than osteochondrosis), traumatic orthopedic disease, neurologic disease, laminitis, and infectious disease in joint or skeleton. Time-to-event data, i.e., the number of days from birth to the first orthopedic diagnosis, was used in the analysis.

In the fourth study (IV), assessed traits from young horse tests were analyzed for insured J and D horses from study III. Eight evaluated traits and height at withers from YHT, and 48 linearly scored traits from YHT or RHT, were analyzed to investigate the association between each trait and the risk of having an orthopedic diagnosis (by using the number of days from birth to the first orthopedic diagnosis as the time scale).

4.2 Analyses

4.2.1 Investigating specialization into disciplines

In the first study (I), descriptive statistics were analyzed using SAS version 9 (SAS Institute Inc., 2015). Mean values from YHT and significant levels between J and D horses for those traits were investigated with t-test (Proc ttest in SAS). Average genetic relationships between and within categories were computed using the software package CFC (Sargolzaei et al., 2006). Genetic parameters and estimated breeding values (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 sex (male or female) and event (location-date). Heritability estimates were estimated separately for J and D horses, and for all horses in total. Genetic parameters and EBVs for all traits were obtained from univariate analyses, whereas genetic correlations between traits assessed in J and D horses, and between jumping and dressage traits in the overall population, were estimated using bivariate analyses.

4.2.2 Future scenarios with discipline-specific Young Horse Test

Future scenarios involving discipline-specific YHT were investigated in study I. In these scenarios, it was assumed that approximately 50% of the owners of D horses would prefer to not have their horses evaluated for the two jumping traits. Likewise, it was assumed that approximately 50% of the owners of jumping horses would opt out of having walk and trot assessed. Consequently, approximately half of the results were removed from each group. The omitted results belonged to horses with the lowest scores for respective traits, simulating a situation in which owners were aware of their horses' weaknesses and therefore preferred a discipline-specific test. Two ranking lists based on EBVs were created - one for jumping sires and one for dressage sires. Re-ranking of sires under the current situation versus the future scenarios was analyzed using Spearman's rank correlation. In addition, the accuracy of sire EBVs was calculated for both the current and the scenario-based datasets.

4.2.3 Trait differences between jumping and dressage horses

In study II, differences between J and D horses regarding the linearly scored traits were analyzed using the GLM procedure in SAS version 9 (SAS Institute Inc., 2015). Each trait was analyzed in a linear model with the fixed effect of sex (male or female), event (year-location), and discipline category (J or D). Least Squares means were estimated for the differences between J and D horses. Also, phenotypic associations between linearly scored traits and competition results in show jumping and dressage were analyzed by using the GLM procedure in SAS version 9. In the analysis, J and D horses were classified as 'competing horses' if they had at least one record from an official competition at **-level and higher in its main discipline, regardless of whether they had received points or not. Each linearly scored trait was analyzed with a linear model with the fixed effect of sex (male or female) and event (year-location) for all J and D horses separately. The resulting residuals, i.e. adjusted trait values, were used as explanatory variables in the model for competition performance. In that model, the competition trait was analyzed in a linear model with the fixed effect of sex (male or female), birth year (2009, …, 2017), and the linear and quadratic regressions of the residual for each linearly scored trait at the time. The squared term was used to detect potential nonlinear associations, i.e., an optimal score for the specific trait. Because the distribution of competition points was skewed, these results were transformed with a 10-logarithm before analyses. For traits for which there was a significant quadratic regression effect, the regression coefficients from the analyses were used to plot graphs to illustrate the association between the linearly scored trait and lifetime accumulated points. A negative regression coefficient would indicate that there is an optimal score for that specific trait. The graphs were plotted using a scale with a mean equal to that of the linearly scored trait within group (J or D) and extended to +/- 2 standard deviations from the mean.

4.2.4 Investigating prevalence and risk of orthopedic diagnoses

In study III, the prevalence of insurance claims for orthopedic diagnoses between different groups of horses were investigated with a multivariate logistic regression, i.e., the PROC LOGISTIC statement in SAS, with sex (male or female), birth year, discipline category (J or D), test status (1/0), and competition status (1/0) as class variables. The estimates were presented as Least Squares means for the overall prevalence of orthopedic diagnosis, and for each specific subgroup of orthopedic diagnoses. Only J and D horses born between 2010 and 2019 that had the possibility to compete were included (N =13,085 horses) in these analyses. Survival analysis was used to investigate the risk of having an orthopedic diagnosis by using the information from 'time to event' i.e., the number of days from birth to the first orthopedic diagnosis. Horses without such diagnosis were censored in the analysis, and the last day with available insurance data (30th of January 2024) was used as the censoring date. Horses were also censored if they were omitted from the data before the end date for other reasons. Survival curves were made by the Kaplan-Meier method (Kaplan and Meier, 1958) using the PROC LIFETEST statement in SAS. To make interpretation easier, these curves were transformed into Cumulative Incidence Function (CIF) curves.

4.2.5 Investigating associations between assessed traits and orthopedic diagnoses

In study IV, phenotypic associations between assessed traits (evaluated traits, linearly scored traits, and height at withers) and orthopedic diagnosis for insured SWB horses were investigated using survival analysis. First, traits were analyzed with the GLM procedure in SAS for all assessed horses to correct for the fixed effects of sex (male or female) and event (location-date) prior to the survival analysis. J and D horses were analyzed separately. The resulting residuals were used as explanatory variables in the model for the risk of having an orthopedic diagnosis. The Cox proportional hazards regression model was fitted using the PHREG procedure in SAS to analyze time-to-event data for insured J and D horses. Categorical variables that had a significant effect on the analysis, i.e., the fixed effect of birth year (2010, …, 2020), sex (male or female), and competition status (1/0), were included in the model together with the linear and quadratic regressions of the residual for each assessed trait at the time. If only the linear regression coefficient was significant, the analysis was rerun without the quadratic term in the model. For traits for which there was a significant linear or quadratic regression effect, the regression coefficients from the analyses were used to plot graphs to illustrate the association between the trait and orthopedic diagnosis, i.e., the hazard ratio of having an orthopedic diagnosis.

4.3 Main findings

4.3.1 Specialization

In study I, the specialization towards show jumping and dressage in the SWB breed was investigated. The results showed a clear and increasing specialization process, where 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 (Figure 1). Also, the mean values from YHT showed considerable differences for discipline-specific traits for J and D horses, with an increase in difference in the late period (Table 2). Similar findings were also seen for the linearly scored traits investigated in study II, where the differences in mean values for J and D horses were highly significant ($p<0.0001$) for all gait and jumping traits. In Figure 2, examples of the distribution of two linearly scored traits assessed in J and D horses are presented.

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. Also, the average relationship coefficient within each subpopulation of J or D horses was found to increase during the last decade, whereas the relationship between these categories decreased (Figure 3).

Heritability estimates were calculated separately for J and D horses and showed clear differences between the groups. For gait traits, heritability estimates were 0.25-0.38 for J horses and 0.42-0.56 for D 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) compared with the early study period (horses assessed 1999-2009).

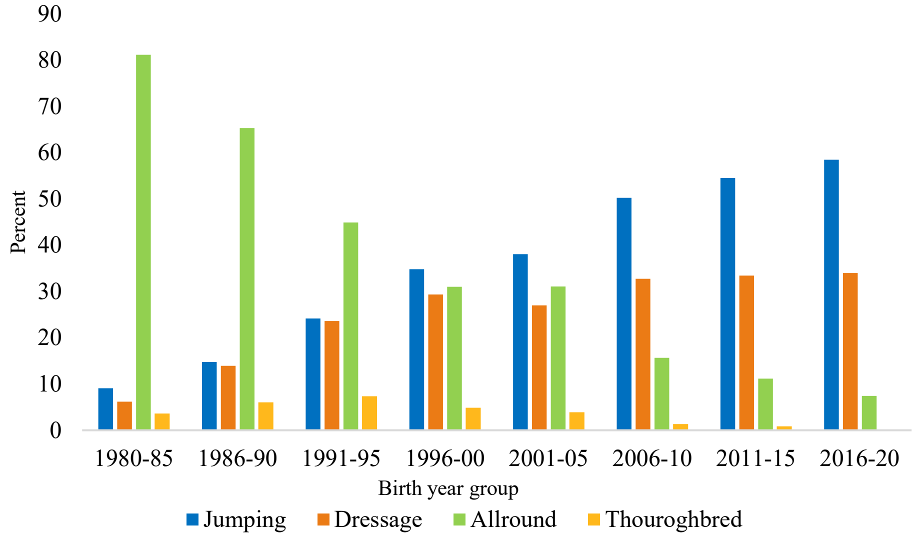

Figure 1. Distribution (%) of horses in the Swedish Warmblood population into different categories (jumping, dressage, allround, or Thoroughbred) according to birth year group between 1980-2020.

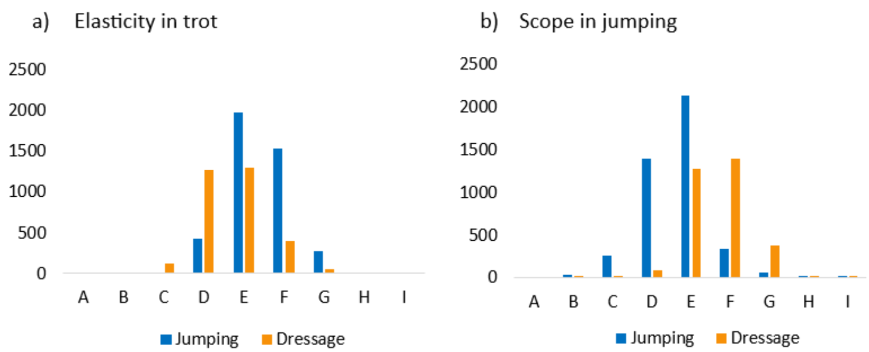

Figure 2. The distribution of linearly scored traits assessed in jumping and dressage horses for 'elasticity in trot' (a) and 'scope in jumping' (b).

Table 2. Mean values of traits in Young Horse Test, assessed for jumping (J) and dressage (D) horses in early (1999-2009) and late (2010-2020) period, and the differences between J and D horses for each period

Trait	J horses		D horses		Diff. J-D horses[1]	
	Early	Late	Early	Late	Early	Late
Type	7.67	7.74	7.78	7.95	-0.11	-0.21
Head-neck-body	7.52	7.54	7.65	7.75	-0.13	-0.21
Corr. of legs	7.34	7.30	7.33	7.31	0.01	-0.01
Walk at hand	7.03	7.04	7.47	7.57	-0.44	-0.53
Trot at hand	6.64	6.79	7.28	7.65	-0.64	-0.73
Free canter	7.17	7.36	7.16	7.52	0.01	-0.16
Free jumping – TA[2]	7.25	7.54	6.16	6.10	1.09	1.44
Free jumping – TG[3]	7.19	7.43	6.27	6.23	0.92	1.20

[1]All differences were significant ($p<0.0001$), except for correctness of legs, and free canter in early period.

[2]Technique and ability.

[3]Temperament and general impression.

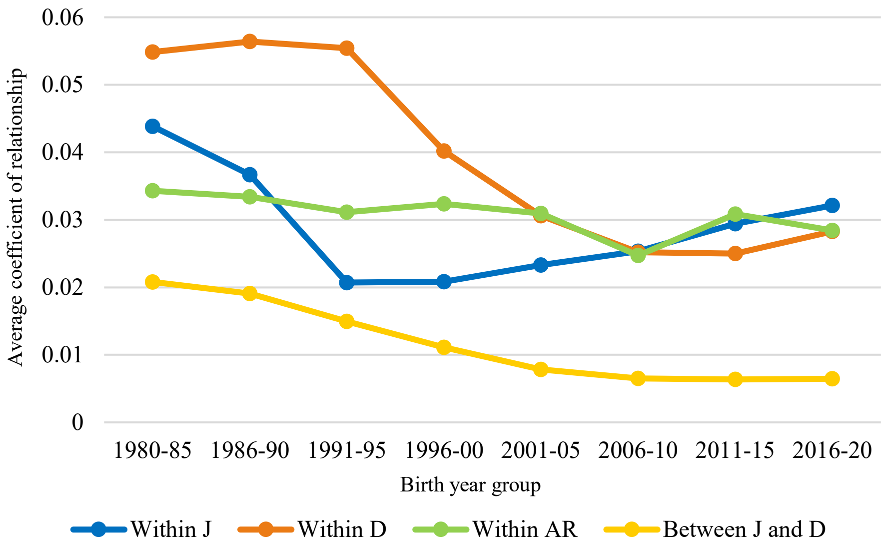

Figure 3. Average coefficient of relationship as a function of birth year group within and between categories of Swedish Warmblood horses classified as jumping (J), dressage (D), or allround (AR).

4.3.2 Discipline-specific Young Horse Test

In study I, the consequences of introducing a discipline-specific YHT were investigated. In the future scenarios, both heritability estimates and genetic variances decreased for traits that were not assessed for all horses. On the other hand, the rank correlations between traits in the full data set and each scenario were high (0.93-0.95 and 0.96-0.97 for J and D sires, respectively) for stallions' main discipline, indicating that these EBVs would still be reliable. Also, the mean accuracy for EBVs was only slightly decreased in the scenario compared with the full data set for stallions' main discipline. However, stallions EBVs for traits in the opposite discipline were clearly changed in the scenario, indicated by the considerably lower rank correlations between traits in the full data set and the scenario (0.56-0.60 and 0.19-0.48 for J and D sires, respectively). The mean accuracy for EBVs decreased noticeably in the scenario for these traits as well.

4.3.3 Phenotypic associations with sport performance

Phenotypic associations between linearly scored traits and sport performance in show jumping and dressage were investigated in study II. For J horses, 25 linearly scored traits (8 conformation traits, 3 gait traits, 13 jumping traits, and 1 behavior trait) were significant for performance in show jumping. For D horses, 21 linearly scored traits (11 conformation traits and 10 gait traits) were significant for performance in dressage competition. For J horses, all traits connected to jumping were significant. For D horses, all traits connected to trot were highly significant, as were three of four traits connected to canter.

For J horses, most of the significant traits (21 out of 25 traits) showed a linear association with performance in show jumping, meaning that scores towards one of the extreme values (score A) were associated with better performance. Four traits had a significant quadratic coefficient, indicating a nonlinear association. However, none of these presented an intermediate optimal score. For D horses, 15 of the 21 significant traits showed a linear association, whereas six traits showed an association with an optimal score: line of back (straight – swayback), foreleg (toe in – toe out), hind leg (sickle – straight), hind pastern (upright – weak), foreleg activity in trot (shoulder free – short), and stride length in canter (long – short). These optimal scores were all intermediate (e.g., stride length in canter, Figure 4a), except for foreleg activity in trot where the trend flattened out towards lower sores (Figure 4b).

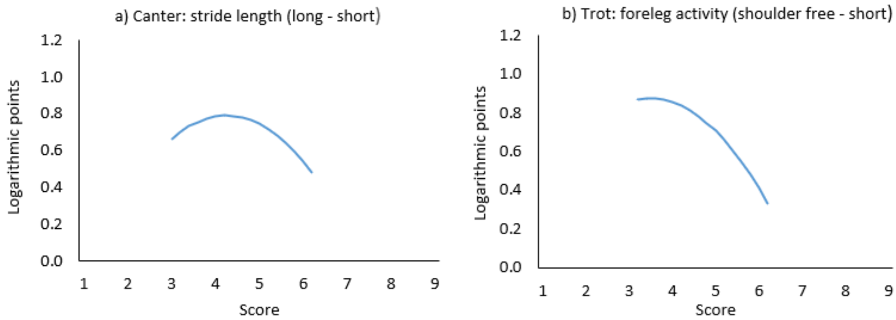

Figure 4. The associations between competition performance in dressage and the linearly scored traits stride length in canter (a) and foreleg activity in trot (b) based on the regression coefficients. The assessment scale A to I is transformed to numerical values 1 to 9.

4.3.4 Prevalence of orthopedic diagnoses

In study III, the prevalence of orthopedic diagnoses was investigated for different groups of insured SWB horses, i.e., according to discipline category, sex, test status, and competition status. The population of insured J and D horses was in general representative of the total SWB population of J and D horses with respect to sex, discipline category, and the proportions of tested and competed horses (Table 3). The 915 orthopedic diagnose codes in the data were categorized into eight subgroups, where the orthopedic disease of extremities or the axial skeleton had the highest number of insurance claims (Table 4).

D horses had a higher proportion of individuals with orthopedic diagnoses than J horses (50.9% vs 43.9%, $p<0.0001$), and male horses had a higher proportion than female horses (49.7% vs 45.0%, $p<0.0001$) (Table 5). Tested horses (i.e., horses that had participated in a young horse test) had a higher proportion than non-tested horses (49.9% vs 44.9%, $p<0.0001$), whereas no significant differences were seen between competed and non-competed horses. However, significant differences were found for most of the subgroups of orthopedic disease regarding the competed versus non-competed horses.

Tabell 3. Comparison between the population of insured jumping (J) and dressage (D) horses (study III) and the total SWB population of J and D horses born 2010-2020

	No of horses	Sex (%)		Discipline category (%)[1]		Tested (%)	Competed (%)[1]
		Female	Male	J	D		
Insured pop.	14,274	51.2	48.8	63.3	36.7	41.7	52.6
Total pop.	23,947	50.0	50.0	62.4	37.7	34.3	49.9

[1]J and D horses born 2010-2019. N=13,085 (insured pop.), N=22,994 (total pop.)

Table 4. Subgroups of orthopedic diagnoses, number of orthopedic diagnoses, and number of claims connected to orthopedic diagnoses for all horses (N=15,619)

Group of orthopedic diagnoses	No of diagnoses	No of claims
Orthopedic disease of extremities (not acute trauma)	413	19,363
Orthopedic disease of the axial skeleton (not acute trauma)	76	4,448
Osteochondrosis/osteochondrosis dissecans	46	933
Developmental disease in limbs or hooves (other than OCD)	88	781
Traumatic orthopedic disease	213	2,517
Neurologic disease	6	338
Laminitis	12	289
Infectious disease in joints or skeleton	61	393
Total	915	29,062

4.3.5 Risk of having an orthopedic diagnosis

Survival analysis was used to investigate the risk of having an insurance claim for an orthopedic diagnosis for each group of horses (i.e., according to discipline category, sex, test status, and competition status) and for three birth cohorts (2010, 2015, and 2020). The analysis revealed that all factors had a strong significant effect ($p<0.0001$) on the risk of having a diagnosis during the studied time period. D horses were at a higher risk than J horses (Figure 5a), and male horses were at a higher risk than female horses during the whole time period (Figure 5b). Tested and non-tested horses were at almost the same risk during the first 3 years of age (Figure 5c). Then, a more rapid increase in risk was seen for tested horses compared with non-tested horses. Non-competed horses were at a higher risk during the first 9 years of age (Figure 5d). From approximately 9 years of age, the risk flattened out for non-competed horses, whereas the risk was still increasing for competed horses, leading to a shift where competed horses were at a higher risk instead. When comparing the three birth cohorts, later cohorts were found to be at a higher risk than earlier cohorts (Figure 5e).

Table 5. Least squares means of proportion (in %) of horses[a] with insurance claim records (ICR), locomotor (orthopedic) diagnosis (LOC), and different subgroups of LOC diagnosis for groups of horses according to sex, discipline category (jumping (J) and dressage (D) horses), test status, and competition status together with level of significance for differences between categories within each group

	Sex			**Discipline category**			**Test status**			**Competition status**		
Item	**Female**	**Male**	**Sign[b]**	**J**	**D**	**Sign[b]**	**Tested**	**Non-tested**	**Sign[b]**	**Comp**	**Non-comp**	**Sign[b]**
ICR	63.3	66.9	****	61.1	68.9	****	67.8	62.3	****	65.0	65.2	n.s
LOC	45.0	49.7	****	43.9	50.9	****	49.9	44.9	****	48.2	46.5	n.s
EXT	34.2	37.9	****	33.6	38.5	****	38.2	33.9	****	38.9	33.3	****
AXI	13.0	14.3	*	12.1	15.3	****	15.1	12.2	****	14.6	12.7	**
OCD	3.8	5.1	***	4.2	4.5	n.s	5.1	3.7	***	4.3	4.4	n.s
DEV	3.0	3.0	n.s	2.6	3.5	**	3.4	2.6	*	2.3	3.9	****
TRA	9.2	9.2	n.s	8.4	10.1	**	9.6	8.8	n.s	8.6	9.8	*
NEU	0.7	1.8	****	0.9	1.4	**	1.1	1.2	n.s	0.6	2.0	****
LAM	0.8	0.6	n.s	0.6	0.9	**	0.6	0.8	n.s	0.5	1.1	****
INF	1.6	1.7	n.s	1.6	1.7	n.s	1.9	1.4	*	1.4	1.8	n.s

[a]J and D horses born in 2010-2019 (N=13,085)

[b]*P<0.05, **P<0.01, **P<0.001, ****P<0.0001, n.s = not significant.

Abbreviations: EXT: Orthopedic disease of extremities, AXI: Orthopedic disease of the axial skeleton, OCD: Osteochondrosis, DEV: Developmental disease in limbs or hooves, TRA: Traumatic orthopedic disease, NEU: Neurologic disease, LAM: Laminitis, INF: Infectious disease in joint or skeleton.

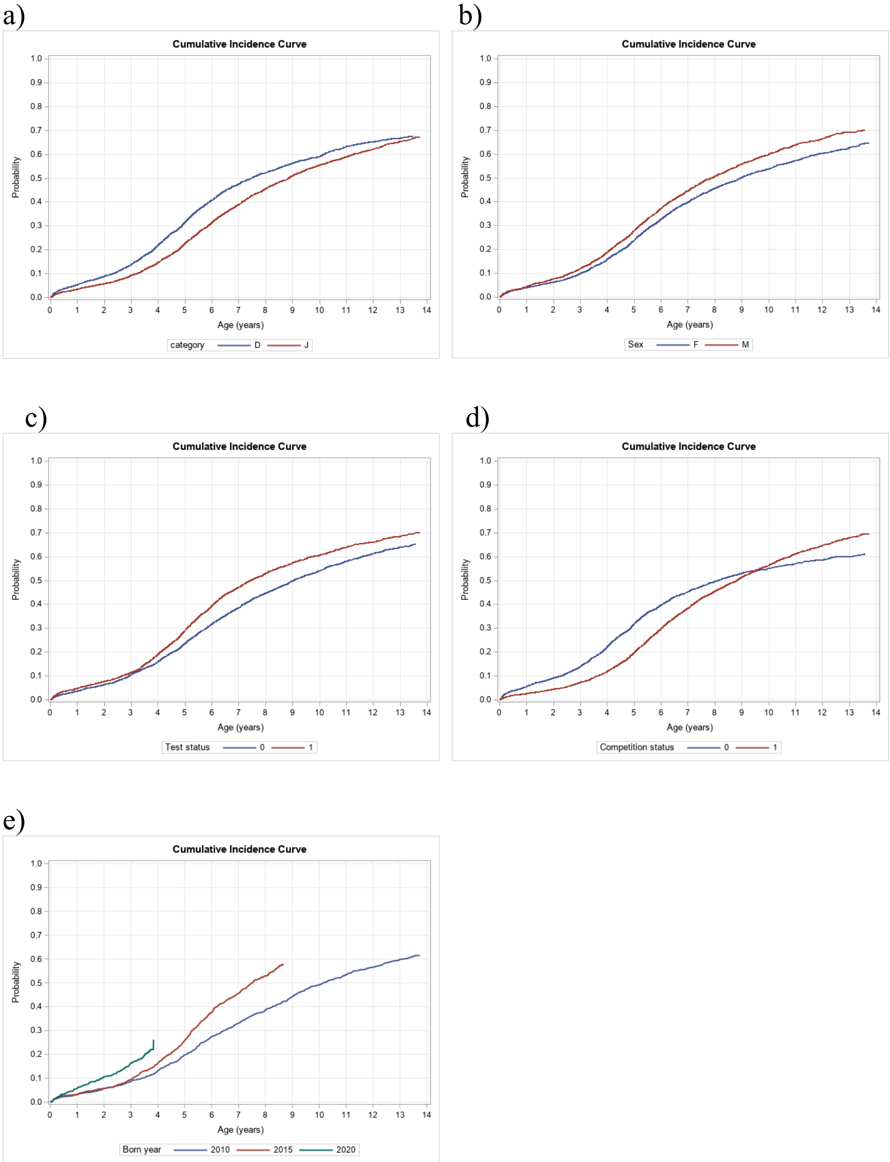

Figure 5. The probability of having an orthopedic diagnosis as a function of time (cumulative incidence function) according to a) discipline category (dressage (D) or jumping (J) horses), sex (female (F) or male (M) horses, c) test status (tested (1) or non-tested (0) horses), d) competition status (competed (1) or non-competed (0) horses), and e) birth cohorts (2010, 2015, 2020).

4.3.6 Phenotypic associations with orthopedic disease

In the fourth study (IV), phenotypic associations between assessed traits and the probability of having an orthopedic diagnosis were investigated for J and D horses with survival analysis. In general, the regression coefficients were significant only for a few traits, and some of the associations were hard to interpret.

For J horses, five linearly scored traits, one evaluated trait, and height at withers showed significant associations with orthopedic diagnosis (Table 6). Out of the linearly scored traits that had a significant association with orthopedic diagnosis, two were connected to trot and three were connected to jumping. Hindlegs in trot scored towards 'active' and 'under the body' were associated with less risk of having an orthopedic diagnosis. For the jumping traits 'power in take-off', 'scope', and 'balance', scores towards the extreme values 'A' or 'I' were both associated with higher risk of having an orthopedic diagnosis.

For D horses, six linearly scored traits, one evaluated trait, and height at withers were significant (Table 7). Out of the linearly scored traits that had a significant association with orthopedic diagnosis, two were connected to the extremities, where upright front pasterns and straight hindlegs were associated with higher risk of having an orthopedic diagnosis. Also, horses scored towards 'short' foreleg activity in trot and 'not careful' regarding carefulness in jumping, were at a higher risk of having an orthopedic diagnosis. Furthermore, the trait 'stride length in trot' was significant, presenting an association where horses scored towards either long or short had less risk of having an orthopedic diagnosis. For the trait 'rhythm in canter, horses scored towards either extreme (even or uneven) had a higher risk for orthopedic diagnosis.

For both J and D horses, 'trot at hand' was the only evaluated trait that was significant for the risk of having an orthopedic disease, where a high-scored trot was associated with less risk of having an orthopedic diagnosis (Figure 6). Also, height at withers were significant for both J and D horses, where a high withers height was associated with increased risk of having an orthopedic diagnosis (Figure 7).

Table 6. Linear and quadratic regression coefficients with p-value of linearly scored traits, evaluated traits, and height at withers on hazard for orthopedic diagnoses in insured Swedish Warmblood jumping horses (N=3,445). Only traits that had a significant association with orthopedic diagnosis are included (significant coefficients in bold)

		Jumping horses			
Trait	**Extreme values**	**Linear**	**p-value**	**Quadratic**	**p-value**
Trot - Hind leg position	*under the body – behind the body*	**0.104**	0.025	**-0.108**	0.037
Trot - Hind leg activity	*active – inactive*	**0.086**	0.031	-	-
Jumping - Power	*powerful – weak*	-0.007	0.838	**0.070**	0.006
Jumping - Scope	*much – little*	0.009	0.779	**0.049**	0.030
Jumping - Balance	*balanced – unbalanced*	0.055	0.214	**0.096**	0.012
Trot at hand[1]		**-0.118**	0.014	-	-
Height at withers[1]		**0.017**	0.010	-	-

[1] N=3,133

Table 7. Linear and quadratic regression coefficients with p-value of linearly scored traits, evaluated traits, and height at withers on hazard for orthopedic diagnoses in insured Swedish Warmblood dressage horses (N=2,546). Only traits that had a significant association with orthopedic diagnosis are included (significant coefficients in bold)

		Dressage horses			
Trait	**Extreme values**	**Linear**	**p-value**	**Quadratic**	**p-value**
Pastern, front	*upright – weak*	**-0.176**	0.036	-	-
Hind leg	*sickle – straight*	**0.103**	0.048	-	-
Trot - Stride length	*long – short*	0.055	0.268	**-0.155**	0.002
Trot - Foreleg activity	*shoulder free – short*	**0.127**	0.007	-	-
Canter - Rhythm	*even – uneven*	-0.010	0.840	**0.168**	<0.001
Jumping - Care	*too careful – not careful*	**0.122**	<0.001	-	-
Trot at hand[1]		**-0.153**	<0.001	**-0.112**	0.019
Height at withers[1]		**0.032**	<0.0001	-	-

[1] N=2,373

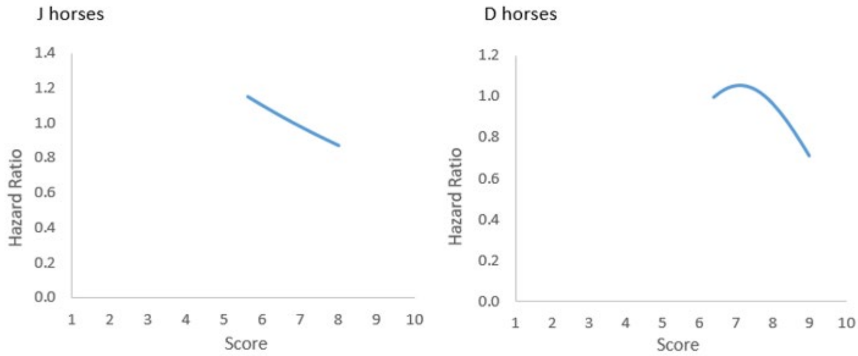

Figure 6. Illustration of the associations between the hazard ratio for orthopedic diagnosis and the evaluated trait ‘trot at hand’ in jumping (J) (N=3,133) and dressage (D) horses (N=2,373) The graph is based on the significant linear regression coefficient for J horses, and the significant linear and quadratic regression coefficient for D horses.

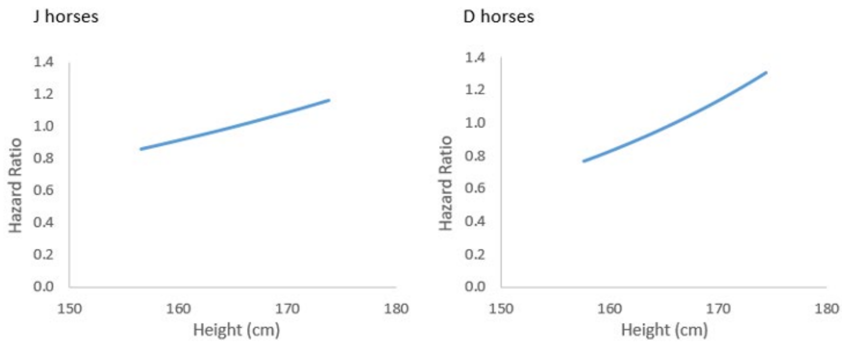

Figure 7. Illustration of the associations between the hazard ratio for orthopedic diagnosis and height at withers in jumping (J) (N=3,133) and dressage (D) horses (N=2,373) based on the significant linear regression coefficient.

5. General discussion

5.1 Specialization

5.1.1 Signatures of specialization

International equestrian sport has undergone substantial development over the last century, and horses aimed for either show jumping or dressage have become highly specialized. The conformation, gaits, and jumping ability are in many ways differentiated between show jumping and dressage horses, and this specialization will most likely continue as long as the interest and development of the equestrian sports remains. However, this kind of specialization is not unique for the warmblood sport horse. In a study by Petersen et al. (2013), genetic diversity was investigated in 36 horse breeds using genome-wide SNP markers. The authors found that the genetic divergence among horse populations is high, whereas the level of genetic variation differed markedly within breeds. One example of a breed with a high within-breed diversity was the Finnhorse, and the authors suggested this was likely due to the large phenotypic diversity of the breed as a result of the substructure of the studbook, with four sections consisting of draft horses, trotters, riding horses, and ponies.

The genetic divergence of the SWB breed has been investigated as well. In a study based on high-density genotype data from 380 SWB horses born between 2010 and 2011, the authors found genetic divergence between horses with high versus low EBVs for jumping (Ablondi et al., 2019). These findings indicated a specialization into disciplines within the SWB breed. The results from study I and II in this thesis provide additional support for this, because of a clear decrease in AR horses, pronounced differences in discipline-specific traits, and a noticeably decrease in relationship between J and D horses. The differences between J and D horses for evaluated traits were larger in the late period (2010-2020) compared with the early period (1999-2009), which suggest an ongoing specialization process.

Also in the KWPN population, a specialization process into disciplines is apparent. Rovere et al. (2014) investigated KWPN horses born between 1995 and 2009 and found that the genetic similarity had decreased considerably between groups of jumping and dressage horses, whereas the relatedness within these groups had increased. These horses originated from the same genetic pool, but with a continuing specialization, it will result in two genetically unrelated groups, the authors concluded. With an ongoing specialization, the SWB breed will probably also give rise to unrelated subpopulations of J and D horses. Noteworthy, the SWB population is considerably smaller than the KWPN population (WBFSH, 2025). If the SWB population was separated into different breeding programs, it could possibly have negative consequences for the effectiveness of breeding and may also increase the risk for higher levels of inbreeding in this small population. On the other hand, warmblood breeding is highly international today, with exchanges of stallions between countries and possibilities to purchase semen from stallions worldwide, which diminishes that risk. A separation into disciplines could be performed either by the breeding organization, meaning that foals are registered as either jumping or dressage horses depending on the pedigree. It could also be performed similar to the KWPN studbook, where the owner chose whether to register the foal as a jumping or dressage horse (Rovere et al., 2014). However, it is important that connections between subpopulations are allowed, meaning that crossing of show jumping and dressage horses are accepted by the studbook.

5.1.2 Discipline-specific testing of young horses

Discipline-specific testing of young horses was implemented in the DWB studbook in 2003 (Dansk Varmblod, 2025), and in the KWPN studbook, an optional assessment of jumping traits has been available since 1998 at the studbook entry for young horses. This has led to consideration of whether a discipline-specific YHT may be feasible also in SWB. In the first study (I), two different future scenarios were investigated with the aim to examinate how a discipline-specific YHT would affect the genetic evaluation in SWB. These scenarios were supposed to reflect a situation in which the horse owner is aware that their horse would probably receive a modest score for either jumping or for walk and trot; and therefore chooses to have the horse assessed as either a dressage or jumping horse. In both cases, the heritability estimates and genetic variances for discipline-specific traits decreased compared with the original situation. This could potentially slow down genetic progress in the population and thus be an argument for retaining assessments for all traits. However, when examining the sire ranking based on EBVs for approved J and D stallions, it was found that the ranking of sires was only slightly altered for the stallions' main discipline in the simulated scenarios. Based on this, implementing a discipline-specific YHT appears feasible from a genetic evaluation perspective, because the main objective is to obtain 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) and the accuracy of EBVs for these traits declined markedly in both scenarios. This indicates that sire EBVs for these traits would be less reliable, potentially making it more difficult for breeders to produce horses that have talent for both disciplines, such as AR horses or eventing horses.

5.2 Associations between linearly scored traits and performance

Linearly scored traits were implemented in the KWPN studbook already in 1989 (Koenen et al., 1995), and linear profiling data have been used in several studies to investigate how such traits relate to performance. For example, Koenen et al. (1995) investigated genetic and phenotypic correlations between linearly scored conformation traits and competition performance in show jumping and dressage in KWPN horses. Later, Ducro et al. (2007) and Rovere et al. (2017) investigated the genetic correlations between linearly scored gait and jumping traits and competition performance in the KWPN population. Genetic correlations between linear scored traits and competition performance have also been investigated in the Oldenburg warmblood populations (Stock et al., 2024). In the second study (II) in this thesis, phenotypic associations between linearly scored traits and competition performance in SWB horses were studied.

5.2.1 Associations with performance in show jumping

For J horses, all linearly scored jumping traits were significant for show jumping performance, as were elasticity in canter. The importance of these traits was also shown in the 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. Similar findings were also seen 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, eight conformation traits were significant for show jumping performance, which suggests that some conformation traits of a warmblood show jumping horse are associated with competition performance. However, these associations were in general less significant than those observed for the jumping traits, indicating that conformation traits may be of less importance compared with the jumping traits. In the study by Koenen et al. (1995), the phenotypic correlations between linearly scored conformation traits and show jumping performance were low, and the authors concluded that indirect selection for performance based on conformation traits has limited value. In our study, the associations between walk and trot traits and performance were not significant, except for hindleg activity in trot, suggesting that these gaits have little or no importance for a show jumping horse. These results are in accordance with Viklund et al. (2010), who found low genetic and phenotypic correlations between walk and trot assessed at RHT and competition performance in show jumping.

5.2.2 Associations with performance in dressage

For D horses, all linearly scored traits associated with trot and canter had a significant association with performance in dressage, whereas traits associated with walk were not significant. The importance of trot and canter for a dressage horse was also shown in the 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 seem to be of high importance at the phenotypic level. High importance of such traits was previously reported 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 conformation traits were also significantly associated with dressage performance. The results suggest that a long-legged, uphill body conformation, together with a long, arched neck and a sloping shoulder, is highly desirable in dressage horses. Similarly, Stock et al. (2022) reported genetic trends in conformation traits representing clear development towards a larger frame, longer legs, and a shorter back.

5.2.3 Optimal scores

When breeding warmblood horses that can be competitive at the highest level in show jumping or dressage, there might be a risk that the breeding becomes too extreme, causing negatives effect on the welfare of the horses. Identifying linearly scored traits that exhibit an intermediate optimal score may thus be valuable, as it underscores traits that should receive increased attention in breeding programs. The idea of using optimal scores to identify the most suitable expression of a specific trait is not new. Already in the 1980s, optimal scores for linearly scored conformation traits were estimated for dairy cattle in relation to milk production and herd life (Foster et al., 1989). Optimal scores have previously also been investigated in other horse breeds, e.g., Kristjansson et al. (2016) found optimal conformation measurements for riding ability in Icelandic horses.

In the second study (II) of this thesis, linearly scored traits were investigated to examine if they had a linear association with competition performance, or an association with an intermediate optimal score. The results showed that most linearly scored traits that were significant for performance in either show jumping or dressage presented a linear association, indicating that expressions towards one of the two extremes are favorable. In all those cases, a score towards 'A' on the linear assessment scale was associated with better performance on average. For J horses, four traits showed a non-linear association with show jumping performance, but none of them presented an association with an optimal score. For D horses, six of the linearly scored traits had a negative quadratic regression coefficient, indicating an association with an optimal score. Three of these traits were describing different aspects of correctness of legs: toed in to toed out foreleg, sickle to straight hind leg, and upright to weak hind pastern. These findings seem reasonable because of the non-linear nature of traits connected to the legs, where scores towards both extremes are undesirable, as concluded by Koenen et al. (1995). Also, the traits 'line of back' (straight – swayback) and 'stride length in canter' (long – short) showed an optimum, where scores towards both extremes appear to be unfavorable for performance in dressage. Furthermore, the trait 'foreleg activity in trot' (shoulder free – short) presented an association with an optimum. However, the plotted graph showed a flattening curve towards 'A', suggesting that breeding for more extreme expression neither improves nor negatively affects performance.

5.3 Orthopedic diagnoses in the SWB population

Lameness is a considerable health problem in riding horses and has been so for decades. In a study on SWB horses born between 1965 and 1982, the most common cause of culling was diseases of the musculoskeletal system (Wallin et al., 2000). Lameness has also been found to be the main cause for interruption or termination of the competition career, in a study based on data from Dutch sport horses (Sloet van Oldruitenborgh-Oosterbaan et al., 2010). 'Lameness' is a broad term, comprising many diagnoses in a range from very specific to very vague. Lameness can be caused by several factors, including environmental factors such as management and training. However, the risk of having a lameness problem may also be associated with other factors, including sex, age, and competition participation.

Survival analysis is a useful statistical method when investigating the time until a specific event occurs, e.g., death or disease (Klein & Moeschberger, 2003). The main benefit of the method is that non-affected individuals are included in the analysis; these individuals are censored in the data but still contribute valuable information, even though they did not experience the event. Survival analysis has been used in previous studies when investigating disease and death in horse populations. For example, Árnason and Björnsdóttir (2003) investigated age at onset of bone spavin in Icelandic horses, and Wallin et al. (2000) investigated longevity in Swedish Warmblood and Coldblooded horses, using survival analysis.

In the third study (III), both the prevalence and risk of having an orthopedic diagnosis were investigated in different groups of SWB horses. Significant differences were found between J and D horses, but also among other factors including sex, birth cohorts, and participation in young horse tests and competition. Orthopedic diseases of the extremities or the axial skeleton were by far the most common orthopedic diagnoses, but also other types of orthopedic diagnoses were included in this study, such as osteochondrosis, laminitis, and neurological disease.

5.3.1 Differences between groups of SWB horses

Differences between jumping and dressage horses

D horses had a significantly higher prevalence of orthopedic diagnoses than J horses. This difference was also seen for all subgroups of orthopedic diagnoses, except for osteochondrosis and infectious disease in joint or skeleton. Also, the survival analysis revealed a higher risk for D horses having an orthopedic diagnosis compared with J horses (Figure 5a). This is the first study investigating differences in prevalence of orthopedic disease on a population-level between horses classified as jumping or dressage. Several factors may have an influence on the difference in prevalence between J and D horses, such as differences in conformation, gaits, and temperament, and external factors like management, housing, and training. In a study by Murray et al. (2006), data from 1,069 horses that underwent orthopedic evaluations between 1998 and 2003 were analyzed in relation to sport discipline and performance level. Both factors significantly influenced the type of diagnosis, and the results showed that horses competing in show jumping and dressage were predisposed to different types of injuries.

Differences between males and females

Penell et al. (2005), found that geldings had a higher risk for injuries connected to the joints than mares, and Ross and Kaneene (1996), found that geldings and stallions had a higher risk of experiencing lameness than mares in the Michigan horse population. Also in our study, male horses had a significantly higher prevalence and risk of orthopedic diagnoses than females (Figure 5b). One explanation for male horses having more orthopedic diagnoses than mares could be that geldings have no value for breeding, as concluded by Penell et al. (2005) and Ross and Kaneene (1996). Some mares will become broad mares at an early age, whereas the owner of a gelding probably will put more effort into having the horse back as a riding horse in case of an injury. In a study by Ricard and Blouin (2011), the authors concluded that females always had a higher relative risk than geldings or stallions to be removed from competition because they could be used for breeding instead.

In addition to orthopedic diseases in the extremities and in the axial skeleton, male horses also had a significantly higher prevalence of osteochondrosis (Table 5). Similar findings have been reported in other species, e.g., Engdahl et al. (2024) found that male dogs had a significantly higher risk of having osteochondrosis compared with females, in a study based on insurance data from approximately 600,000 dogs. Osteochondrosis is a multifactorial disease, where nutrition, genetics, and fast growth rates may have an influence (Foerner, 2003). In our study, male horses were also significantly more affected of neurological disease than mares. Similar results were found in a study by Levine et al. (2008), where male horses had significantly higher likelihood of having cervical vertebral compressive myelopathy (CVCM). The reason for this sex difference is unclear, but the authors suggested that males have different behavioral patterns than mares which may predispose the vertebral to chronic microtrauma or acute traumatic events.

Differences between tested and non-tested horses

Horses tested at a young horse test (YHT or RHT) had significantly higher prevalence of orthopedic diagnoses than non-tested horses (Table 5). However, the survival curve (Figure 5c) shows almost no difference in risk between tested and non-tested horses during the first three years of age. From then on, the risk of having an orthopedic diagnosis increases more rapidly for tested horses than non-tested horses. This difference may reflect a pre-selection effect, where owners who participate with their horses at a young horse test are more likely to also aim for a competition career. This interpretation is supported by the finding that tested horses competed more frequently than non-tested horses in our study (60% vs. 47%, Table 4 in study III). Competing is most likely increasing the risk of having an orthopedic disease in the extremities or the axial skeleton, which is supported by the findings in study III.

Differences between competed and non-competed horses

It is reasonable to assume that competing horses may have a higher risk of orthopedic injuries than non-competing horses, due to the greater physical strain and workload they are exposed to. In the third study (III), there was no significant overall difference in the prevalence of orthopedic diagnoses between competed and non-competed horses. However, there were significant differences for most of the subgroups of diagnoses. Competed horses were predisposed to orthopedic diseases in the extremities and axial skeleton, whereas non-competed horses were predisposed to developmental disease in limbs and hooves, traumatic orthopedic disease, neurological disease, and laminitis. This suggests that some of the non-competed horses have never been able to compete, possibly as a consequence of having a diagnosis early in life. For example, developmental diseases in limbs and hooves commonly appear in young, growing horses, and individuals with such diagnoses may be prevented from entering competition later in life. The same may apply to horses that have an orthopedic trauma early in life. Neurological diseases usually have a severe impact on the health of the horse and often lead to euthanasia (Rech and Barros, 2015), which may explain the higher proportion of these diagnoses for non-competed horses. Laminitis commonly affects older horses, with a high body condition score (Alford et al., 2001). Owners of horses that compete may be more attentive to keeping their horse in an appropriate body condition score than owners of non-competed horses, which may explain the higher proportion of laminitis observed in non-competed horses.

The suggestion about how different types of orthopedic diagnoses influence competition status is supported by the survival analysis (Figure 5d). Horses that never competed were at a higher risk of having an orthopedic diagnosis during the first 9 years of age, compared with competed horses. Slightly before 10 years of age, the survival curves crossed, meaning that the risk for orthopedic diagnoses from then on was higher for competed horses. This suggests that horses that later in life were able to compete were healthy at a young age, thus enabling training and preparation for future competitions. As a conclusion, orthopedic health seems to be a factor for pre-selection for participation in competition.

Differences between three birth cohorts

The cohort of horses born in 2020 had a higher risk for orthopedic diagnoses at a young age compared with the cohorts of 2015 and 2010 (Figure 5e). Also, the cohort of 2015 had a higher risk for orthopedic diagnoses than the cohort of 2010 from around three years of age. This indicates that the risk of having these diagnoses at a young age has increased with time. The reason for this is unclear, but some plausible factors could be more intense training and competing with young horses, more discipline-specific training (meaning less variation in training), horses that are more sensitive to physical strain, and/or owners that are more eager to contact a veterinarian. Further investigation and continued monitoring of this trend are needed, to ensure the horse welfare and maintain the social acceptance of equestrian sports.

5.4 Phenotypic associations between assessed traits and orthopedic diagnoses

The assessment of linearly scored traits has previously been found to be related to performance in show jumping and dressage in (Ducro et al., 2007; Rovere et al., 2017). This was also seen in study II of this thesis, indicating that such traits are useful as indicator traits of later sport success. However, because of the high importance of achieving orthopedic health in sport horse populations, there is a need to identify reliable indicator traits of orthopedic status. In the fourth study (IV) of this thesis, linearly scored traits and evaluated traits from young horse tests were investigated to examine if these traits had an association with orthopedic diagnoses.

5.4.1 Evaluated traits and height at withers

In a study by Jönsson et al. (2014), the authors found that correct movement in trot and intermediate height at withers (between 163 and 169 cm) were beneficial for the orthopedic health, based on data from SWB horses assessed at RHT between 1982-2005. The importance of the assessment score for trot was also seen in our study (IV). 'Trot at hand' was the only evaluated trait that had a significant association with orthopedic diagnosis, indicating that high scores were associated with less risk of having an orthopedic diagnosis (Figure 6). In contrast to the findings by Jönsson et al. (2014), the results from our study showed that the risk of having orthopedic diagnoses increased with greater height at withers (Figure 7). This association was stronger for D horses than J horses. Comparable results were seen in a study by Ducro et al. (2009), who found that horses with greater height at withers had an increased risk of early retirement in sport, and the influence was higher for dressage horses than jumping horses.

5.4.2 Linearly scored traits

According to the result from the fourth study (IV), few linearly scored traits had a significant association with orthopedic diagnoses, and the associations were in some cases hard to interpret. One possible explanation for these weak associations could be that most horses received scores within the normal range, between D and F. With small variations within a trait, it is less probable to find significant associations. However, some of the associations may be explainable. For J horses, the jumping traits 'power in take-off', ‘scope’, and ‘balance in jumping’ had a significant positive quadratic association with orthopedic diagnosis. These traits are strongly positively correlated (Nazari-Ghadikolaei et al., 2023) and showed a similar association with orthopedic diagnoses: horses were at higher risk with a score towards either one of the two extremes, compared with horses with intermediate scores. One possible explanation could be that talented horses will be trained and competed to a higher extent, thus having an increased risk of having injuries. Less talented horses, scored towards unbalanced and weak take-off in jumping, may also be at a higher risk of having injuries. Comparable findings were seen in a study Wallin et al. (2001), where horses had a higher risk of being culled when achieving either high or low scores for jumping at RHT.

For J horses, horses with hindlegs in trot scored towards ‘behind the body’ and ‘inactive’ showed an increased risk for having an orthopedic diagnosis, compared with horses with hindlegs in trot scored towards ’under the body’ and ‘active’. Similarly, for D horses, the trait ‘foreleg activity in trot’ showed a significant association with orthopedic diagnoses, where horses scored towards ‘short’ were at a higher risk than horses scored towards ‘shoulder free’. These findings are in accordance with the study by Jönsson et al. (2014), who found that good hind limb energy and free shoulder movement in trot had an association with orthopedic health.

5.4.3 Future health measurement

Because of the few significant associations between assessed traits and orthopedic diagnoses, alternative health measurements of young SWB horses are needed to facilitate improved health through breeding. Until 2005, a health examination was performed at the RHT, and these records were found to be useful as indicators of future health and longevity in sport (Jönsson et al., 2013). However, reintroducing the health examination at the RHT is likely not a feasible option, primarily due to the marked decline in the proportion of horses participating in the RHT (Gelinder Viklund et al., 2025).

From the 1st of January 2026, it will be mandatory for veterinarians to report all pharmaceutical treatments prescribed for horses to the Swedish Board of Agriculture (Jordbruksverket, 2025). These data have potential to provide insights into the extent of pharmaceutical use and the diagnoses for which these treatments are prescribed. In the future, it will thus be possible to get an overview of the health status of the Swedish horse population. This system has already been used for cattle in Sweden since 1999 and has become a valuable tool for improving breeding and animal health. For example, the Nordic cattle genetic evaluation (NAV) publishes index for general health and udder health for dairy cattle based on such veterinarian records (NAV, 2025).

Another possible option for collecting health data could be a mandatory health examination before a horse participates in an official competition for the first time. This examination could be performed by a veterinarian in a manner similar to the previous health assessments at the RHT, with the results reported to the breeding association. This would provide valuable information on the health status of the competing population and could potentially be incorporated as a health measurement in the routine genetic evaluation. However, this would entail additional costs for owners and would require resolving some practical challenges.

Data from radiographic examinations of young horses may also have potential to be used as a health measurement. Radiographic findings in the limbs may indicate a predisposition to orthopedic disease, and many young horses are thus screened prior to breaking, purchase, or breeding. Jönsson et al. (2011) used equine hospital data to study the prevalence of osteochondrosis in the SWB horse population. They concluded that routine recording for such diagnoses has potential to be useful for the genetic evaluation, to select against genetically diseases or abnormalities, such as osteochondrosis. Thus, implementing a standardized radiographic screening of young horses and registering the results could ultimately provide useful indicator measurements for future orthopedic health.

Furthermore, artificial intelligence (AI) could possibly be a useful tool for future health recording. A markerless AI system for the detection of lameness and asymmetries in horses was initiated in 2020 and is now used by veterinarians in several countries (Sleip, 2025). The system has potential to complement the traditional evaluation by providing objective locomotion data from young horses. Such data could be valuable both for research purposes and possibly as a health measurement. However, a single measurement taken on one occasion may not be adequate as a standalone health measurement.

5.5 Practical implications

The results from study I showed a clear specialization into show jumping and dressage in the SWB population, and that introducing a discipline-specific YHT would be feasible. Further in the future, also separate breeding program may be considered. This would be a logical course of action, as the population is likely to continue the specialization process, ultimately resulting in two differentiated subpopulations of J and D horses. However, there may also be a need for versatile and/or amateur-friendly horses, suitable for the eventing sport, leisure riding, or riding schools. A breeding program for such horses may also be considered. Since 2025, horses are awarded as "riding horse talent" at YHT if they received score 7 or higher for all assessed traits, and at least 22 points in total for the three conformation traits. This award was implemented to promote suitable horses for versatile riding and sport (Swedish Warmblood Association, 2025). However, implementing several specialized breeding programs in a small breed like SWB may slow down the genetic progress in the population, due to a decrease in selection intensity.

In the second study (II), several linearly scored traits were found to be significant for performance in show jumping and dressage. Most of these traits had a linear association with performance, whereas a few traits had an association with an optimal score. In both cases it is important to monitor these traits in the population. Selection beyond an optimal score is unlikely to improve sport performance, making it necessary to pay particular attention to these traits. It is also important to consider traits that have a linear association with performance, as selecting for extreme expressions of certain traits may have negative consequences on health and 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).

Study III showed that D horses had higher prevalence and risk of having an orthopedic diagnosis than J horses. Factors that may have an influence are differences in housing, management, and training in D horses in comparison with J horses. Also, breeding may have an influence. Focus on producing dressage horses with extraordinary gaits that are highly elastic and flexible, may have led to an increased risk of having orthopedic diseases. The same study also showed that later cohorts (born 2020) were at a higher risk of having orthopedic diagnoses at a young age compared with earlier cohorts (born 2015 and 2010). The reasons for this are unclear but underscores the importance of monitoring the orthopedic health status of the population. As concluded in study IV, there is a lack of health measurements that can be useful as indicator traits of orthopedic health. Thus, to find and implement such methods is recommended, which may require cooperation between stakeholders in the sport horse sector, including the breeding organization, veterinarians, insurance companies, and horse owners.

6. Conclusions

- The Swedish warmblood horse population has become clearly specialized towards show jumping and dressage, indicated by the decreased proportion of horses classified as ‘allround’ and the decrease in relationship between jumping and dressage horses since 1980.

- Discipline-specific testing of young horses is possible, because the breeding values of sires’ main discipline would still be reliable.

- Several linearly scored traits had a significant association with competition performance in show jumping and dressage.

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

- The prevalence and risk of orthopedic diagnoses was higher for dressage horses than for jumping horses. Also, later cohorts were at higher risk compared with earlier cohorts.

- Few linearly scored traits had a significant association with orthopedic diagnoses. Thus, alternative health measurements for young horses need to be considered.

7. Future research

In this thesis, phenotypic associations between linearly scored traits and performance in show jumping and dressage were investigated. To get a deeper understanding of how linearly scored traits influence performance, it would be of high interest to also investigate the genetic associations between these traits and competition performance. This could provide more information on what characteristics are the most important to take into consideration when breeding horses for international sport. Furthermore, it would be of value to investigate the genetic associations between assessed traits and orthopedic diagnoses. Even though relatively few traits presented significant phenotypic associations with orthopedic diagnosis, the genetic associations may provide further information about the biological relationship between assessed traits and orthopedic disease.

In 2026, it becomes mandatory to report of all pharmaceutical treatments prescribed to horses to the Swedish Board of Agriculture begins. This will within a few years provide a valuable resource for research. These data will cover the entire Swedish horse population and will also include information on minor veterinary treatments that may not be captured in insurance records. The data can in the future be used to investigate the incidence and frequency of veterinary treatments in the SWB horse population, as well as to provide an overview of the most common health problems in the breed. Such research may provide insights into the overall health of the population and highlight areas where efforts are needed to improve health in the SWB population.

In 2025, four new linearly scored traits were added to the YHT protocol. These traits relate to behavior, reflecting that personality traits are considered as important as performance traits among both competition and leisure riders (Graf et al., 2013). The new traits should be evaluated in future studies to estimate their heritability, investigate associations with performance, and how these traits may differ between jumping and dressage horses. In addition, breeding values for these traits may be developed, providing breeders with a tool for selecting horses with a desirable temperament.

The European sport horse breeding consists of many studbooks, where the cooperation between studbooks in many cases is limited (Doyle et al., 2022). Most studbooks have their own organization, including assessment of horses and genetic evaluation. However, because of the exchange of stallions and semen across studbooks, common bloodlines are represented in most populations (Thoren Hellsten et al., 2008; Ruhlmann et al., 2009). Such exchange of genetic material in combination with similar breeding goals will reduce the differences between studbooks over time, resulting in a more uniform warmblood sport horse within each discipline. Extended cooperation and openness between studbooks, and a harmonization of the assessment of horses and methods used for genetic evaluation, would benefit the development of international horse breeding. A decision to work towards international breeding values (IBVs) was taken at the WBFSH annual meeting in 2019 (WBFSH, 2019). IBVs would enable comparisons of horses across studbooks and promote genetic progress in each participating studbook. However, efforts are still needed to determine how financial and practical challenges should be addressed before IBVs can be implemented.

Another field of research that is of high relevance for national and international horse breeding is genomic breeding values. Although genomic selection has many advantages and has been successfully implemented in other species, the development has been slow in the sport horse breeding (Stock et al., 2016). In dairy cattle breeding, genomic selection has been beneficial especially to shorten the generation interval. However, to make use of genomic selection, a rather large reference population is needed, with both genomic and phenotypic data. Currently, genomic information is available for only a limited number of SWB horses. The routine parentage verification, conducted for all SWB foals upon registration in the studbook, is currently based on microsatellite marker analysis (SLU, 2025). A transition to SNP-based analysis would provide genomic data for all newly registered foals, gradually enabling genomic information for a large number of horses. Genomic breeding values tend to be most useful for traits with low heritability or traits that are difficult to measure (Muir, 2007), e.g., health and temperament traits. In KWPN, genomic breeding values for osteochondrosis were introduced in 2016 (KWPN, 2025). These breeding values indicate the genetic predisposition for osteochondrosis, in relation to the current population. This genomic testing has replaced the radiographic examination for osteochondrosis at stallion performance tests in KWPN. However, such breeding values may not be directly transferable and need to be validated in the SWB population. Thus, research efforts are needed before such breeding values can be implemented in the genetic evaluation of the SWB breed.

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Popular science summary

Equestrian sport has developed remarkably in recent decades, which has led to an increasing demand for athletic horses with talent for either show jumping or dressage. As a result, sport horse breeding has become highly specialized, and most horses today are bred specifically for one of these disciplines. Some international breeding organizations have thus introduced discipline-specific testing of young horses, which has brought the question to the forefront also in the organization for the Swedish Warmblood (SWB).

Assessment of young horses is an important part in most breeding organizations. These tests aim to select suitable individuals for breeding and sport and to provide data for the genetic evaluation. As a complement to the traditional evaluation, where traits are valued in relation to the breeding goal, a linear assessment of traits was introduced at the young horse test in SWB in 2013. These traits are described on an assessment scale between two biological extremes, and the aim is to give a more objective and detailed assessment of the horse. To date, a considerable amount of data is now available, making it possible to investigate the associations between linearly scored traits and competition performance.

A central prerequisite for performance is health. Orthopedic diseases are the most common health problem for warmblood horses, and one major cause for interruption or termination of the competition career. To identify measurements in young horses that can be useful as indicators of future orthopedic health are thus of high interest. Whether linearly scored traits have potential to be a valuable tool for this purpose has not previously been investigated.

The overall aim of this thesis was to investigate the specialization into show jumping or dressage within the SWB breed, and to examine assessed traits in young horses and their associations with competition performance and orthopedic disease.

Specialization into disciplines

SWB horses born between 1980 and 2020 were classified into categories according to pedigree; jumping, dressage, allround, or Thoroughbred. The proportion of allround horses decrease considerably since 1980, whereas the proportion of jumping and dressage horses increased. Also, the relationship between jumping and dressage horses decreased, while the relationship within these groups increased over the past decade. Furthermore, clear differences between discipline-specific traits assessed in young jumping and dressage horses were found, where dressage horses had better scores for walk and trot while jumping horses had considerably better scores for jumping traits. These differences have also become larger over time.

Future scenarios with a discipline-specific young horse test were investigated as well. It was assumed that some owners of dressage horses would omit the assessment of jumping traits, whereas some owners of jumping horses would opt out of the assessment of walk and trot. The results showed that heritability estimates would decrease for traits that were not assessed for all horses, which may slow down the genetic progress in the population. However, the sire ranking for traits connected to stallions' main discipline was only slightly altered in the scenarios. This suggests that the breeding values for these traits would still be reliable, indicating that introducing a discipline-specific young horse test would be feasible. On the other hand, considerable re-ranking was observed for the opposite traits (i.e., jumping traits in dressage sires and walk and trot in jumping sires), which could make it more difficult to breed horses with talent for both disciplines.

Association between linearly scored traits and competition performance

For jumping horses, 25 out of 48 linearly scored traits had a significant association with competition performance in show jumping. For dressage horses, 21 of these linearly scored traits a significant association with performance in dressage. Most of these associations were linear, meaning that scores towards one of the biological extremes were in general associated with better performance. For example, this was the case for the trait 'power in take-off' in jumping horses, where horses with a powerful take-off had performed better in competition compared with horses with a weak take-off. However, six traits for dressage horses had an association with an intermediate optimum score, meaning that selection beyond this optimum would not result in better performance. For example, this was observed for the trait 'stride length in canter', where both a long and a short stride were associated with poorer performance compared with horses with a more normal stride length. For both linear associations and associations with optimum scores, it is important to follow the progression of these traits. The linearly scored traits can serve as a valuable tool for warmblood breeding to in detail monitor a population over time.

Prevalence and risk of orthopedic disease

By analyzing insurance data from the company Agria, it was found that dressage horses were at a higher risk of having orthopedic diagnoses than jumping horses, and that geldings and stallions were at a higher risk than mares. Furthermore, horses that had participated in a young horse test were at a higher risk of having an orthopedic diagnosis from three years of age compared with non-tested horses. When comparing competed and non-competed horses, no overall significant differences were seen. However, clear differences were found when studying different subgroups of orthopedic diagnoses. Competed horses were more prone to orthopedic diseases in the limbs or in the axial skeleton, whereas non-competed horses were more affected by developmental diseases in limbs and hooves, orthopedic traumatic diseases, neurological diseases, and laminitis. It may be reasonable to assume that some of the non-competed horses were not able to compete as a consequence of having a disease or injury in young age.

Associations between assessed traits and orthopedic disease

Linearly scored traits, evaluated traits, and height at withers were examined to investigate if these traits had an association with the risk of having an orthopedic diagnosis, based on insurance data. High scores for the evaluated trait 'trot at hand' were found to be associated with less risk of having an orthopedic diagnosis, whereas greater height at withers was associated with increased risk of having an orthopedic diagnosis. Relatively few linearly scored traits had a significant association with orthopedic diagnoses. Thus, other measurements of young warmblood horses that can be useful as indicators of orthopedic health need to be considered.

Conclusions

The results from this thesis confirm a clear specialization towards show jumping and dressage in the SWB population, and that introduction of a discipline-specific young horse test is feasible. Linearly scored traits assessed in young horses are useful as indicator traits of sport performance but have limited value as indicator traits of future orthopedic disease.

Populärvetenskaplig sammanfattning

Ridsporten har gjort en betydande utveckling under de senaste årtiondena, vilket har lett till en ökad efterfrågan på sporthästar med talang för antingen hoppning eller dressyr. Som en följd har varmblodsaveln blivit tydligt specialiserad, och de flesta hästar är avlade specifikt för den ena eller den andra disciplinen. En del internationella avelsförbund har därför infört disciplinspecifika unghästtester, vilket har aktualiserat frågan även inom avelsorganisationen för det svenska varmblodet (SWB).

Bedömning av unga hästar vid unghästtester är en viktig del av avelsarbetet. Testerna syftar till att välja ut lämpliga individer för avel och sport samt att tillhandahålla data till avelsvärdering. Som ett komplement till den traditionella bedömningen, där egenskaper bedöms utifrån avelsmålet, infördes en linjär beskrivning av egenskaper på SWBs unghästtestet år 2013. Detta innebär att egenskaper beskrivs på en skala mellan två biologiska ytterligheter, i syfte att ge en mer detaljerad och objektiv bild av hästen. Fram till idag finns en stor mängd data nu tillgängligt, vilket gör det möjligt att undersöka sambanden mellan linjära egenskaper och senare tävlingsprestation.

En grundförutsättning för prestation är hälsa. Ortopediska skador är det vanligaste hälsoproblemet hos varmblodiga ridhästar och en av de främsta orsakerna till att tävlingskarriären avbryts eller avslutas. Att identifiera mätvärden hos unga hästar som kan vara användbara som indikatorer för framtida ortopedisk hälsa är därför av stort intresse. I vilken utsträckning linjärt bedömda egenskaper har potential för att bli ett lämpligt verktyg för detta ändamål har inte undersökts tidigare.

Det övergripande syftet med denna avhandling var att undersöka specialiseringen mot hoppning respektive dressyr inom SWB-rasen, samt att analysera bedömda egenskaper hos unga hästar och deras samband med prestation och ortopedisk sjukdom.

Specialisering mot olika discipliner

SWB-hästar födda mellan 1980 och 2020 delades in i grupper baserat på härstamning; hoppning, dressyr, allround eller fullblod. Andelen allroundhästar minskade tydligt från 1980, medan andelen hopp- och dressyrhästar har ökade. Även släktskapet mellan hopp- och dressyrhästar minskade, medan släktskapet inom dessa grupper ökade under det senaste decenniet. Vidare fanns tydliga skillnader mellan grenspecifika egenskaper bedömda hos unga hopp- och dressyrhästar, där dressyrhästar hade bättre poäng för skritt och trav medan hopphästarna hade betydligt bättre poäng för hoppegenskaperna. Dessa skillnader har också blivit större med tiden.

Framtidsscenarion med ett disciplinspecifikt unghästtest undersöktes också. Det antogs att några ägare till dressyrhästar skulle avstå bedömningen av hoppegenskaper, medan några ägare av hopphästar skulle avstå bedömningen av skritt och trav. Resultaten visade att arvbarheten minskade för egenskaper som inte bedömdes hos alla hästar, vilket skulle kunna sakta ner avelsframsteget i populationen. Hingstrankingen för egenskaper kopplade till hingstarnas huvudsakliga disciplin förändrades dock endast marginellt i scenarierna. Detta innebär att avelsvärdena för dessa egenskaper fortfarande skulle vara tillförlitliga, vilket talar för att det skulle vara möjligt att införa ett disciplinspecifikt unghästtest. Däremot skedde en stor omrangering för de motsatta egenskaperna (dvs. för hoppegenskaperna hos dressyrhingstarna och för skritt och trav hos hopphingstarna), vilket på sikt skulle kunna göra det svårare att avla hästar med talang för båda disciplinerna.

Samband mellan linjärt bedömda egenskaper och tävlingsprestation

För hopphästar hade 25 av totalt 48 linjärt bedömda egenskaper ett signifikant samband med tävlingsprestation i hoppning. För dressyrhästar hade 21 av dessa linjärt bedömda egenskaper ett signifikant samband med tävlingsprestation i dressyr. De flesta av dessa samband var linjära, vilket innebär att den ena av de biologiska ytterligheterna var förknippat med bättre prestation. Detta gällde till exempel för egenskapen ’avstamp’ hos hopphästar, där hästar med ett kraftfullt avstamp lyckats bättre på tävlingsbanan jämfört med de som hade ett svagt avstamp. För dressyrhästar hade dock sex egenskaper ett samband med ett intermediärt optimum, vilket innebär att selektion förbi denna punkt sannolikt inte skulle leda till bättre prestation. Detta gällde till exempel för egenskapen ’steglängd i galopp’, där både ett långt och ett kort steg var förknippat med sämre prestation, jämfört med en mer normal steglängd. Både vid linjära samband och samband med optimum är det viktigt att följa utvecklingen av dessa egenskaper. De linjärt bedömda egenskaperna kan fungera som ett värdefullt verktyg inom varmblodsaveln för att i detalj kunna studera en population över tid.

Förekomst och risk för ortopedisk sjukdom

Genom att analyser försäkringsdata från Agria kunde vi se att dressyrhästar hade en högre risk att drabbas av ortopediska diagnoser jämfört med hopphästar, och att valacker och hingstar hade en högre risk att drabbas jämfört med ston. Vidare hade hästar som deltagit i ett unghästtest en högre risk att drabbas av en ortopedisk diagnos från tre års ålder, jämfört med hästar som inte testats. Vid jämförelse mellan hästar som tävlat och inte tävlat sågs ingen övergripande signifikant skillnad. Däremot fanns det tydliga skillnader när olika undergrupper av ortopediska diagnoser studerades. Tävlade hästar var mer utsatta för ortopediska skador i ben eller i rygg och halskotpelare, medan hästar som inte tävlat var mer drabbade av utvecklingsrelaterade sjukdomar i ben och hovar, ortopediska trauman, neurologiska sjukdomar samt fång. Man kan anta att en del av hästarna som inte tävlat inte har haft möjlighet till det som en följd av att ha drabbats av sjukdom eller skada i ung ålder.

Samband mellan bedömda egenskaper och ortopedisk sjukdom

Linjärt och traditionellt bedömda egenskaper samt mankhöjd undersöktes för att utreda om dessa egenskaper hade ett samband med risken för att drabbas en ortopedisk diagnos, baserat på försäkringsdata. Höga poäng för egenskapen 'trav vid hand' visade sig vara förknippade med lägre risk för ortopedisk diagnos, medan en hög mankhöjd var förknippad med ökad risk för ortopedisk diagnos. Relativt få linjärt bedömda egenskaper hade ett signifikant samband med ortopediska diagnoser. Andra mätvärden hos unga varmblodshästar som kan fungera som indikatorer för ortopedisk hälsa bör därför undersökas.

Slutsatser

Resultaten från denna avhandling bekräftar en tydlig specialisering mot hoppning och dressyr inom det svenska varmblodet, samt att det är möjligt att införa ett disciplinspecifikt unghästtest. Linjärt bedömda egenskaper hos unga hästar är användbara som indikatorer för tävlingsprestation, men har ett begränsat värde som indikatorer för framtida ortopediska skador.

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ORIGINAL ARTICLE

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Consequences of specialized breeding in the Swedish Warmblood horse population

Sandra Bonow[1] | **Susanne Eriksson**[1] | **Emma Thorén Hellsten**[2] | **Åsa Gelinder Viklund**[1]

[1]Department of Animal Breeding and Genetics, Swedish University of Agricultural Science, Uppsala, Sweden

[2]Swedish Warmblood Association, Flyinge, Sweden

Correspondence
Sandra Bonow, Department of Animal Breeding and Genetics, Swedish University of Agricultural Science, PO Box 7023, SE-750 07, Uppsala, Sweden.
Email: sandra.bonow@slu.se

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 $k \sim$ ND (0, $A\sigma_a^2$) (where A is the relationship matrix; σ_a^2 is the additive genetic variance), and e_{ijk} is the random ~IND (0, σ_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

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

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

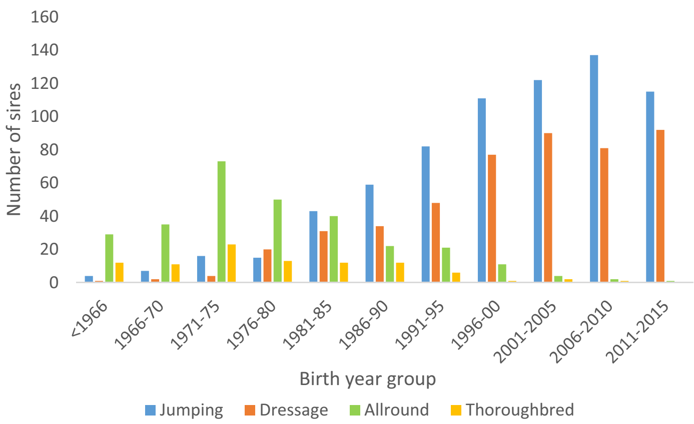

FIGURE 1 Number of sires in Swedish Warmblood breeding by category and birth year group [Colour figure can be viewed at wileyonlinelibrary.com]

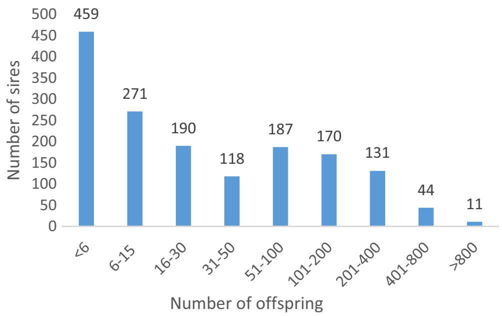

FIGURE 2 Distribution of sires approved for SWB breeding according to number of offspring [Colour figure can be viewed at wileyonlinelibrary.com]

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

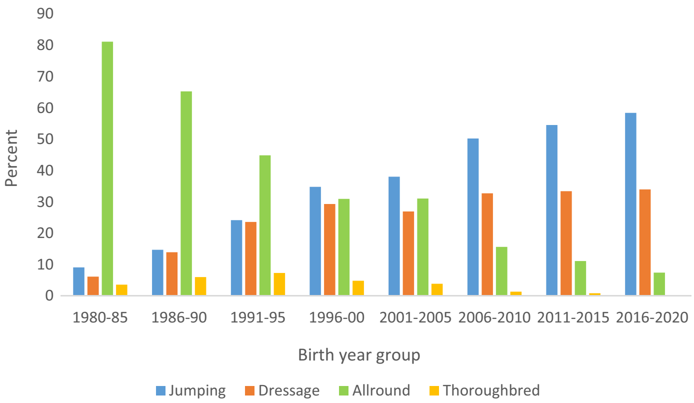

FIGURE 3 Distribution (%) of horses in the Swedish Warmblood population into different categories according to birth year group between 1980 and 2020 [Colour figure can be viewed at wileyonlinelibrary.com]

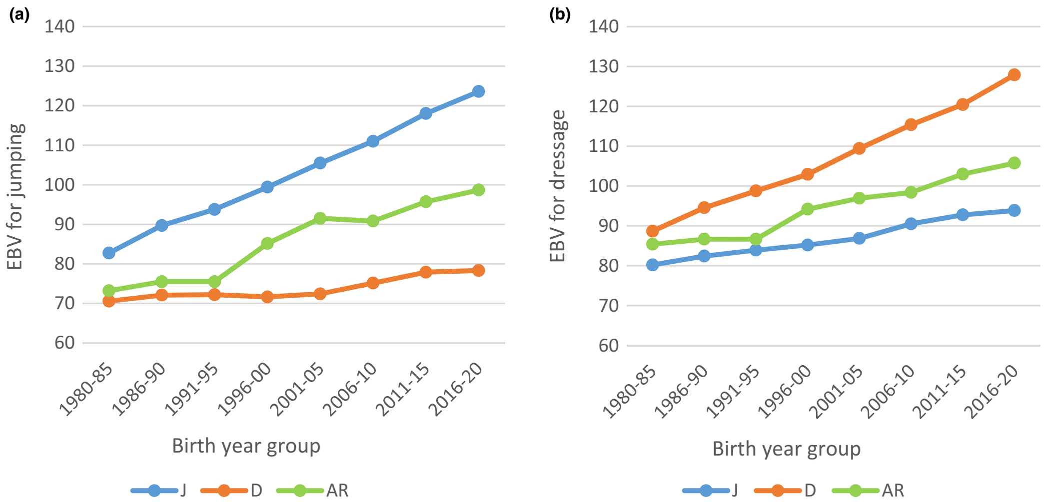

FIGURE 4 Estimated breeding values (EBV) for (a) show jumping and (b) dressage according to birth year group for Swedish Warmblood horses classified as jumping (J), dressage (D), or allround (AR) horses [Colour figure can be viewed at wileyonlinelibrary.com]

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

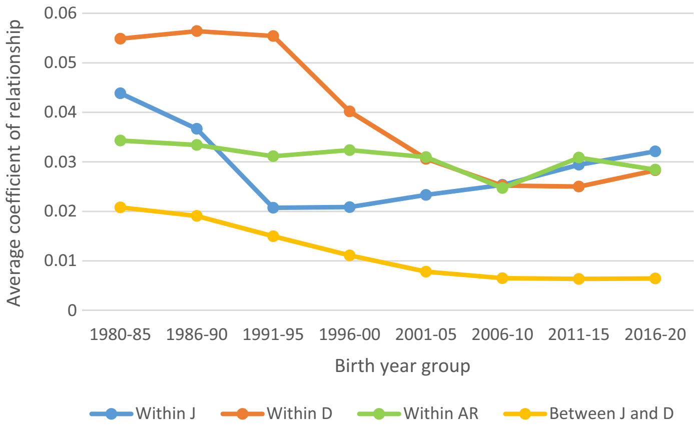

FIGURE 5 Average coefficient of relationship as a function of birth year group within and between categories of Swedish Warmblood horses classified as jumping (J), dressage (D), or allround (AR) [Colour figure can be viewed at wileyonlinelibrary.com]

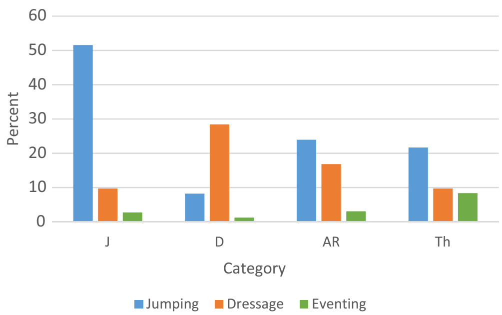

FIGURE 6 Percentage of horses born 1980–2016 competing in show jumping, dressage, or eventing, stratified by their category: Jumping (J), dressage (D), allround (AR), or thoroughbred (Th) [Colour figure can be viewed at wileyonlinelibrary.com]

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.

ORCID

Sandra Bonow https://orcid.org/0000-0002-2685-4325
Susanne Eriksson https://orcid.org/0000-0003-3357-5065
Åsa Gelinder Viklund https://orcid.org/0000-0002-7752-5687

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Phenotypic associations between linearly scored traits and sport performance in the Swedish Warmblood horse population

S. Bonow [a,*], S. Eriksson [a], E. Strandberg [a], E. Thorén Hellsten [b], Å. Gelinder Viklund [a]

[a] Department of Animal Biosciences, Swedish University of Agricultural Science, PO Box 7023, SE-750 07, Uppsala, Sweden
[b] Swedish Warmblood Association, PO Box 2, SE-247 93 Flyinge, Sweden

HIGHLIGHTS

- There are differences in linearly scored traits between jumping and dressage horses.
- Linearly scored traits are associated with success in show jumping and dressage competition.
- Most associations are linear, but associations with optimal scores also exist.
- Breeding for extremes is not optimal for all traits.
- Linearly scored traits can be a valuable tool to select horses for sport.

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ABSTRACT

The goal for most warmblood studbooks is to produce horses that are internationally competitive in sports like show jumping or dressage. The linear scoring system, describing the horse between two biological extremes, is commonly used for a more objective assessment of young horses in many studbooks. However, few studies have examined the phenotypic association between traits linearly scored at a young age and sport performance, and whether there might be an intermediate optimum on the linear scale. This study investigated the phenotypic association between linearly scored traits and competition performance in show jumping or dressage, using the results of linear scoring from young horse performance tests between 2013 and 2021 and competition data between 2014 and 2021 for Swedish Warmblood horses. Sport performance was defined as lifetime accumulated points achieved in show jumping or dressage competitions. Horses were classified as jumping (J) or dressage (D) horses according to their sires' and grandsires' classification. In total, 48 linearly scored traits, assessed on a biological scale from A to I, were analyzed. The phenotypic association between the linear score for each trait and sport performance was studied using linear models for sport performance including fixed effects of sex, birth year and linear and quadratic regression on adjusted linearly scored trait values. Significant differences in LS means between J and D horses were found for all linearly scored traits except for length of body and five traits referring to leg conformation. For J horses, 25 linearly scored traits (eight conformation traits, three gait traits, 13 jumping traits and one behavior trait) were found to be significantly associated ($p < 0.05$) with show jumping performance. A majority of these traits (21 out of 25 traits) showed a linear association with performance, indicating that stronger expression (towards A on the assessment scale) was favorable for performance in show jumping in J horses. For D horses, 21 linearly scored traits (eleven conformation traits and ten gait traits) were significantly associated with dressage performance. Most of these traits (15 out of 21 traits) showed a linear association with performance, while six traits showed an association with optimal scores, indicating that breeding for more extreme expression of the specific trait is not associated with better sport performance. These results underline the importance of linearly scored traits as indicator traits of later sport success.

* Corresponding author.
E-mail address: sandra.bonow@slu.se (S. Bonow).

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1. Introduction

The goal for most warmblood studbooks, including the Swedish Warmblood (SWB), is to produce competitive horses at international level in sports like show jumping or dressage (Koenen et al., 2004). However, competition results at a high level can only be achieved later in life. Most breeding organizations therefore use specially designed young horse tests to collect information relevant for future performance in show jumping or dressage (Ricard et al., 2000). The results from these tests are moderately to highly correlated with performance later in life and can therefore be used as early indicators of competition performance traits (Thorén Hellsten et al., 2006).

In addition to the traditional scoring relative to the breeding goal, a linear scoring system for young horses has been introduced in many studbooks (Duensing et al., 2014). Scoring of traits on a linear scale from one biological extreme to another provides a more detailed description of the horse. The linearly scored traits describe different aspects of conformation, gaits and jumping characteristics, for example long to short neck, long to short stride length, powerful to weak take-off. Regarding the biological interpretation, the linear scoring system has no general optimum. Depending on the trait, the most favorable expression could be at one of the two extremes or somewhere in-between.

To enhance the performance and durability of sport horses, it is important to identify the optimal scores for relevant traits when selecting horses for competition and breeding. For example, Jönsson et al. (2014) derived optimal intervals for withers height and cannon bone circumference using health records from young SWB horses assessed at riding horse test (RHT) during 1983–2005. Also, Kristjansson et al. (2016) found optimal conformational measurements on total score for riding ability in Icelandic horses.

Although the linear scoring system has been used in several studbooks for many years, only a few studies have investigated the phenotypic association between linearly scored traits and competition results in show jumping and dressage. In studies on Dutch Warmblood horses (KWPN), significant phenotypic and genetic correlations between several linearly scored conformation, gait and jumping traits and performance in show jumping and dressage competition were found (Koenen et al., 1995; Ducro et al., 2007; Rovere et al., 2017). Their results were consistent with a study on Oldenburg horses by Stock et al. (2021). The mentioned studies were focused on genetic, and sometimes phenotypic, correlations and did not study possible phenotypic intermediate optima.

For SWB, a linear scoring system was introduced in 2013 at the young horse test (YHT) for three-year-old horses and in 2014 at the RHT for four-year-old horses and five-year-old mares that have had a foal (Viklund and Eriksson, 2018). Since 2017, estimated breeding values (EBVs) for linearly scored traits are officially published by the Swedish Warmblood Association. In 2021, the first age cohort with linearly assessed horses in SWB reached the age of 11 years, and these horses have thus had time to achieve competition results at advanced level in show jumping or dressage. The availability of such data makes it possible to investigate the association between linearly scored traits and show jumping and dressage performance in SWB horses, and to identify optimal scores for these traits in relation to competition performance.

The objective of this study was to investigate the phenotypic associations between linearly scored traits, assessed at YHT and RHT, and performance in show jumping and dressage competitions. More specifically, the aims were to:

1. describe differences in linearly scored traits (least squares means) between jumping and dressage horses in the SWB population,
2. investigate the phenotypic effects of linearly scored trait scores on lifetime accumulated competition points, and
3. identify possible intermediate linearly scored trait optima for show jumping and dressage competition performance, using linear models including both linear and quadratic regressions.

2. Materials and methods

2.1. Population

Pedigree information, results from YHT and RHT, and competition records for all horses in official competitions were obtained from the Swedish Warmblood Association. The study population was restricted to horses with a linear assessment from YHT or RHT between 2013 and 2021. For horses with an assessment from both YHT and RHT (12 %), only the first assessment (YHT) was kept to avoid repeated observations as this was only the case for a small proportion of the horses. The horses were divided into categories according to the classification of their sire and grandsire, as described by Bonow et al. (2023). Sires and grandsires were assigned to one of four categories (jumping, dressage, allround or Thoroughbred) according to breeding values, own performance and offspring performance. In the present study we only considered two categories of horses: jumping (J) and dressage (D). J horses were defined as horses with jumping sire and jumping grandsire, and D horses were defined as horses with dressage sire and dressage grandsire. In total 4216 horses were classified as J, and 3152 horses as D. Horses can compete from four years of age. In total 2414 of the J horses in the dataset had competed in show jumping and 1178 of the D horses had competed in dressage by October 2021. The competing horses in this study were born between 2009 and 2017. A description of the studied population is presented in Table 1.

2.2. Traits

A total of 48 linearly scored traits were investigated, comprising 21 conformation traits, 13 gait traits, 13 jumping traits, and one temperament trait. Only traits that were assessed at both YHT and RHT were considered. The linear scoring system for SWB has a nine-point-scale of A-I, where E is the center score and A and I correspond to the two biological extremes. Scores A-I were converted to numerical values 1–9 to enable statistical analyses. At RHT, horse owners can choose to have their horses assessed either in free jumping or jumping under rider. Two traits, distance estimation and behavior, are only assessed during free jumping, so horses that participated in jumping under rider at RHT did not have any scores for these two traits. During the first year with linear scoring (YHT, 2013), the protocol was slightly different to that used from 2014 onwards, e.g., foreleg activity in trot and balance, reaction, and behavior in jumping were added in 2014, and the trait pastern

Table 1
Number of Swedish Warmblood jumping (J) and dressage (D) horses with a linear assessment and number of J horses and D horses with competition results in show jumping and dressage, respectively, by birth years 2009–2018.

Birth year	Number of assessed J horses	Number of assessed D horses	Number of J horses competing in show jumping	Number of D horses competing in dressage
2009[†]	21	13	20	7
2010	603	413	444	221
2011	522	370	402	192
2012	423	339	308	175
2013	395	297	302	165
2014	358	264	240	115
2015	391	297	253	116
2016	463	394	254	106
2017	558	371	191	81
2018	482	394	–	–
Total	4216	3152	2414	1178

[†] Only mares that were five years old in the first year with linear assessment at the Riding Horse Test (2014).

(upright – straight) was divided into separate traits for front and hind limbs 2014. Additionally, the traits action in canter and approach to assignment in jumping had different definitions of the extreme values from 2014 onwards. Hence, fewer records were available for traits that were not included or had another definition in 2013. The studied traits and their definitions are listed in Table 2 and 3.

Achieved lifetime accumulated points in show jumping or dressage competitions are defined as the breeding goal traits in SWB (Swedish Warmblood Association, 2021). Horses that are placed in an official competition, defined as the 25 % best in each competition, receive points. A horse receives more points for a better placing, a placing at a more advanced level, or both. Horses that are not placed receive no points, but their starts are recorded. Qualification to compete on advanced level is achieved by reaching predefined results on lower levels. For the present 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. Out of 2414 competing J horses, 1654 horses (68.5 %) had achieved points in show jumping, and of 1178 competing D horses, 582 horses (49.4 %) had achieved points in dressage. The distribution of points was right-skewed and was therefore $\log_{10}$-transformed before the analyses. Because some horses had zero points, the number 1 was added before logarithmic transformation in order to enable transformation. The distribution of competition points was similar between linearly scored horses and all horses classified in the same discipline and the same birth year period.

2.3. Statistical analyses

2.3.1. Differences between J and D horses for linearly scored traits

Analysis of variance was performed using the General Linear Models (GLM) procedure in SAS (SAS Institute Inc., 2016). Each linearly scored trait, in total 48 traits, was analyzed separately with the linear model:

$$Y_{ijkl} = \mu + sex_i + event_j + category_k + e_{ijkl} \quad (1)$$

where Y_{ijkl} is the observed linear score (1, 2,…, 9), μ is the population mean, sex_i is the fixed effect of the i_{th} sex (male or female), $event_j$ is the fixed effect of the j_{th} combination of year and location (1, …, 341), $category_k$ is the k_{th} fixed effect of category (J or D) and e_{ijkl} is the random residual $\sim IND(0, \sigma_e^2)$. Least squares (LS) means were estimated and compared between category J and D. The residuals were continuous and for most traits approximately normally distributed. Traits for which the residuals were clearly deviating from normal distribution are marked in Tables 2 and 3.

2.3.2. Effect of linearly scored traits on performance and detection of trait optima

Each category of horses (J and D) was analyzed separately, and each linearly scored trait was analyzed with procedure GLM in SAS, in total 96 analyses. The following linear model was used:

$$Y_{ijk} = \mu + sex_i + event_j + e_{ijk} \quad (2)$$

where Y_{ijk}, μ, sex_i, and $event_j$ were as described for (1) and e_{ijk} is the

Table 2
Mean score, standard deviation (SD) and range for linearly scored conformation and gait traits in Swedish Warmblood jumping (J) horses and dressage (D) horses (*N* = 7368) assessed at young horse test or riding horse test 2013–2021. LS means (LSM) for J horses (*N* = 4216) and D horses (*N* = 3152) and significance level (Sign) between LS means for J and D horses.

			All horses			J horses	D horses	
	Trait	Extreme values	Mean	SD	Range	LSM	LSM	Sign
Type	Type	*refined – heavy*	4.77	0.72	2–8	4.81	4.72	****
	Body: shape a	*long – short*	4.72	0.71	2–7	4.73	4.70	n.s.
	Body: shape b	*long legged - short legged*	4.77	0.72	1–8	4.81	4.72	****
	Body direction	*uphill – downhill*	5.05	0.58	3–8	5.13	4.87	****
Head-neck-body	Length of neck	*long – short*	4.81	0.66	2–8	4.84	4.69	****
	Position of neck	*vertical – horizontal*	4.74	0.74	2–7	4.97	4.58	****
	Shape of neck	*arched – straight*	4.90	0.85	2–8	5.14	4.71	****
	Withers	*high – low*	4.88	0.65	2–7	4.81	4.88	****
	Position of shoulder	*sloping – straight*	5.21	0.70	3–8	5.32	5.06	****
	Line of back	*straight – swayback*	5.13	0.58	2–9	5.14	5.09	****
	Loins	*long – short*	4.79	0.63	2–8	4.77	4.83	****
	Shape of croup	*sloping – straight*	4.65	0.64	2–8	4.62	4.68	***
	Length of croup	*long – short*	4.93	0.60	3–7	5.00	4.92	****
Correctness of legs	Foreleg a	*over at knee – back at knee*	5.08	0.33	3–7	5.08	5.07	n.s.[b]
	Foreleg b	*toed in – toed out*	5.03	0.74	2–9	5.07	4.90	****
	Pastern, front[a]	*upright – weak*	5.10	0.42	2–8	5.10	5.11	n.s.[b]
	Hind leg a	*sickle – straight*	4.94	0.62	1–7	4.93	4.94	n.s.
	Hind leg b	*cow hocked – bowlegged*	5.00	0.48	3–8	5.06	5.04	n.s.[b]
	Pastern, hind[a]	*upright – weak*	5.13	0.46	3–9	5.13	5.14	n.s.[b]
	Correctness in movement	*winging – paddling*	5.09	0.52	3–8	5.06	5.14	****
	Hoofs	*large – small*	4.98	0.38	3–7	4.92	5.00	****
Walk	Cadence	*even – uneven*	4.92	0.51	2–9	5.03	4.83	****
	Stride length	*long – short*	4.96	0.85	1–8	5.14	4.69	****
	Suppleness	*supple – stiff*	4.86	0.83	2–8	5.09	4.64	****
Trot	Stride length	*long – short*	5.07	0.76	1–8	5.30	4.74	****
	Elasticity	*elastic – inelastic*	5.09	0.87	1–8	5.46	4.76	****
	Foreleg activity[a]	*shoulder free – short*	4.94	0.77	1–8	5.22	4.68	****
	Hind leg position	*under the body – behind the body*	4.99	0.75	1–8	5.27	4.75	****
	Hind leg activity	*active – inactive*	4.90	0.83	1–8	5.16	4.66	****
Canter	Rhythm	*even – uneven*	4.76	0.62	1–7	4.83	4.68	****
	Stride length	*long – short*	4.73	0.77	1–8	4.80	4.62	****
	Action[a]	*round – flat*	4.88	0.76	1–7	5.00	4.71	****
	Elasticity	*elastic – stiff*	4.95	0.79	1–9	5.04	4.88	****
	Movement: direction	*uphill – downhill*	4.96	0.70	1–9	5.13	4.79	****

*P < 0.05, **P < 0.01, *** P < 0.001, **** P < 0.0001, n.s. = not significant.
[a] *N*=3698 for J horses; *N* = 2788 for D horses.
[b] residuals were not approximately normally distributed and significance test may be affected.

Table 3
Mean score, standard deviation (SD) and range for linearly scored jumping and temperament traits in Swedish Warmblood jumping (J) horses and dressage (D) horses ($N = 7368$) assessed at young horse test or riding horse test 2013–2021. LS means (LSM) for J horses ($N = 4216$) and D horses ($N = 3152$) and significance level (Sign) between LS means for J and D horses.

			All horses			J horses	D horses	
	Trait	Extreme values	Mean	SD	Range	LSM	LSM	Sign
Take-off	Power	*powerful – weak*	4.99	0.87	1–9	4.71	5.41	****
	Quickness	*quick – slow*	4.74	0.84	1–9	4.63	5.03	****
	Direction	*upwards – forwards*	4.90	0.95	1–8	4.61	5.35	****[d]
Technique	Foreleg	*bent – hanging*	4.72	0.89	1–8	4.58	5.00	****
	Back	*rounded – hollow*	5.06	0.88	2–9	4.78	5.39	****
	Haunches	*open – tight*	4.75	0.88	1–9	4.54	5.10	****
Jumping overall	Scope	*much – little*	5.08	0.94	2–9	4.63	5.66	****
	Elasticity	*elastic – stiff*	4.91	0.83	1–8	4.81	5.07	****
	Carefulness	*too careful – not careful*	4.64	0.93	1–9	4.54	4.87	****
	Balance[a]	*balanced – unbalanced*	4.88	0.61	1–7	4.85	4.93	****[d]
	Reaction[a]	*quick – slow*	4.88	0.73	2–9	4.76	5.15	****
	Approach to assignment[a]	*focused – unfocused*	4.76	0.97	2–9	4.65	4.91	****
	Distance estimation[b]	*secure – insecure*	4.98	0.82	2–9	4.86	5.12	****
	Behavior[c]	relaxed – tense	5.11	0.98	2–9	4.96	5.23	****

*$P < 0.05$, **$P < 0.01$, ***$P < 0.001$, ****$P < 0.0001$, n.s. = not significant.
[a] N=3698 for J horses; $N = 2788$ for D horses.
[b] N=3857 for J horses; $N = 3116$ for D horses.
[c] Temperament trait; $N = 3339$ for J horses; $N = 2751$ for D horses.
[d] residuals were not approximately normally distributed and significance test may be affected.

random residual $\sim IND(0, \sigma_e^2)$. The resulting residuals, i.e. adjusted trait values, were used as explanatory variables in the model for competition performance. The competition performance traits lifetime accumulated points in show jumping for J horses and in dressage competitions for D horses, both $\log_{10}$-transformed, were analyzed using the linear model:

$$Y_{ijkl} = \mu + sex_i + by_j + b_1 \times \text{ residual linear score}_k + b_2 \times \text{ residual linear score}_k^2 + e_{ijkl} \quad (3)$$

where Y_{ijkl} is the is the lifetime accumulated point in show jumping or dressage transformed with 10-logarithm, μ is the population mean, sex_i is the fixed effect of the i_{th} sex (male or female), by_j is the fixed effect of the j_{th} birth year (2009, …, 2017), $b_1 \times$ residual linear $score_k$ and $b_2 \times$ residual linear $score_k^2$ are the linear and quadratic regressions of the residual of one linearly scored trait at the time, and e_{ijkl} is the random residual $\sim IND(0, \sigma_e^2)$. For traits for which there was a significant quadratic regression effect, the regression coefficients from the analyses were used to plot graphs to illustrate the association between the linearly scored trait and lifetime accumulated points. The graphs were plotted using a scale with a mean equal to that of the linearly scored trait within group (J or D) and extended to +/- 2 standard deviations from the mean. This choice of scale was made to avoid biasing toward rare extreme values when using quadratic regressions, and to better represent the actual use of the assessment scale.

3. Results

3.1. Differences between J and D horses for linearly scored traits

Mean scores, standard deviations, and range for linearly scored traits for J and D horses, and LS means for linearly scored traits for J and D horses, respectively, are presented in Table 2 (linearly scored conformation and gait traits) and Table 3 (linearly scored jumping and temperament traits). The significance level for the difference between LS means for J and D horses is also given in Tables 2 and 3. For most traits, mean scores were close to 5, corresponding to the center letter E. Examples of distributions of scores for one conformation trait (shape of neck), one gait trait (trot elasticity) and one jumping trait (scope) for J and D horses are presented in Fig. 1. For J horses, the LS means ranged from 4.54 (carefulness in jumping and jumping technique of haunches) to 5.46 (elasticity in trot) (Tables 2 and 3). For D horses, the LS means ranged from 4.58 (position of neck) to 5.66 (scope in jumping). The differences between LS means for J and D horses were significant ($P < 0.0001$ and $P < 0.001$) for all conformation traits except for body length and five traits referring to correctness of legs. For gait, jumping, and temperament traits, all differences in LS means between J and D horses were highly significant ($P < 0.0001$). The largest differences were seen for traits describing aspects of trot and for the jumping traits scope, power and direction of take-off, and technique of back and haunches.

3.2. Effect of linearly scored traits on performance and detection of trait optima

The estimated linear and quadratic regression coefficients of show jumping and dressage performance in J and D horses, respectively, on the residuals of linearly scored traits adjusted for sex and event and significance levels, are presented in Table 4 (linearly scored conformation and gait traits) and Table 5 (linearly scored jumping and temperament traits). Twenty-five linearly scored traits (eight conformation traits, three gait traits, 13 jumping traits and one behavior trait) were significant ($p < 0.05$) for show jumping performance for J horses, while 21 linearly scored traits (eleven conformation traits, ten gait traits) were significant for dressage performance for D horses. Nine traits were significant for both show jumping and dressage performance: type (refined – heavy), body shape (long legged – short legged), body direction (uphill – downhill), position of neck (vertical – horizontal), shape of neck (arched – straight), position of shoulder (sloping – straight), hind leg activity in trot (active – inactive), elasticity in canter (elastic – stiff) and direction of movement (uphill – downhill). All traits describing aspects of trot were highly significant for dressage performance, whereas only one of these traits was significant for show jumping performance (hind leg activity). For J horses, all 13 traits describing aspects of jumping were significant for show jumping performance, whereas none of these traits was significant for dressage performance. Traits describing aspects of walk were not significant for either show jumping or dressage performance. Except for foreleg (over at knee – back at knee) and hind leg (sickle – straight) for dressage performance, traits describing aspects of correctness of legs were not significant for either show jumping or dressage performance.

In total, the linear regression coefficients were found to be significant in 41 cases and the quadratic regression coefficients in ten cases (Tables 2 and 3). Among the ten traits, four were associated to show

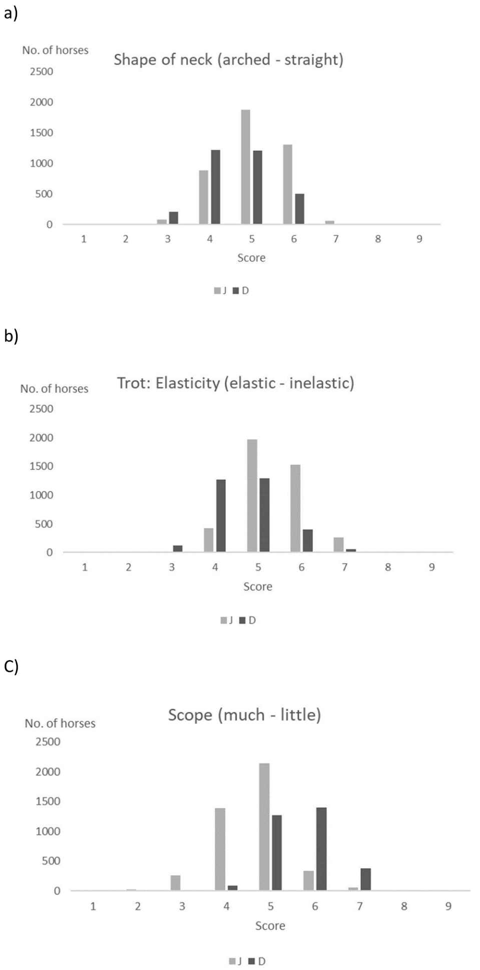

Fig. 1. Examples of distribution of linearly scored traits assessed at in jumping (J) and dressage (D) horses at Young Horse Test and Riding Horse Test for shape of neck (a), elasticity in trot (b) and scope (c). The assessment scale A to I is transformed to numerical values 1 to 9.

jumping performance and six to dressage performance. For show jumping the quadratic coefficients were positive. Body direction and jumping technique regarding both back and haunches showed a trend with the highest logarithmic lifetime accumulated competition points towards score 1 (A) (Fig. 2). Even though the quadratic coefficients were significant there were no upward trends towards the other end of the scale. For length of loins, on the other hand, there was an increasing trend towards both 1 (A) and 9 (I) (Fig. 2). For dressage, the quadratic coefficients were all negative resulting in optima. These optima were intermediate except for foreleg activity in trot where the trend flattened out towards 1 (A) (Fig. 3).

4. Discussion

4.1. Studied traits

This is one of the first studies based on a large number of horses to investigate the phenotypic association between linearly scored traits and competition performance in show jumping and dressage, and the potential optima for these traits. Because of the descriptive nature of the linear scoring, the system is independent of breeding goals and has the advantage of being applicable when assessing traits with the same definition in different studbooks. Thus, it is possible to compare trait differences between horse populations (Sperrle et al., 2016). The linear scoring system can therefore be a useful tool for future international genetic evaluation across studbooks. Also, the linear scoring gives a more detailed description of the horse compared to traditional subjective scoring of the horse relative to the breeding goal (Duensing et al., 2014). This may be of importance when assessing traits with intermediate optimum, such as traits associated to correctness of legs (Duensing et al., 2014; Viklund and Eriksson, 2018).

The Swedish Warmblood (SWB) has strong genetic connectedness to most well-known warmblood studbooks (Thorén Hellsten et al., 2008; Ruhlmann et al., 2009; Pettersson et al., 2016). The results from this study can thus be relevant also in a wider perspective of international sport horse breeding, especially as linear traits are scored and defined in similar ways in several countries (Duensing et al., 2014). In this study the breeding goal traits were measured as lifetime accumulated points in show jumping and dressage, respectively, which also are the defined breeding goal traits in SWB and the measurement used for the routine genetic evaluation (Viklund et al., 2011). Other measurements of competition performance are practiced in genetic evaluation of sport horses in other studbooks, for example "highest level achieved in competition" in German studbooks (Welker et al., 2018) and in KWPN (Rovere et al., 2016).

The effect of rider may have a strong influence on both the assessment under rider at RHT and in future competitions. Some studies have corrected for the effect of rider in the model used, e.g., Rovere et al. (2017) classified the rider effect into six groups based on the highest level achieved by the rider before riding the horse that produced the record. However, it was not possible to include the rider effect in the model in our study because information about rider at RHT was not available in the data, and because competition performance was measured as lifetime accumulated points and a horse may have several different riders during its competition career.

4.2. Differences between J and D horses for linearly scored traits

In the linear scoring system in SWB, all horses are assessed according to the same standardized procedure using the same scale regardless of the discipline they were bred for (SWB, 2021). In this study, all mean scores for horses assessed at YHT or RHT were close to 5 (4.64–5.21), which corresponds to the letter E on the linear assessment scale. This was also seen in a study by Ducro et al. (2007), where mean scores for linearly scored gait and jumping traits in Dutch Warmblood were close to the center of the assessment scale (between 19.6 to 22.1 on a scale ranging from 1 to 40). However, in our study there were significant differences in LS means between J and D horses for all traits except some describing aspects of correctness of legs (for which extreme values are undesirable; Koenen et al., 1995). Borowska & Lewczuk (2023) found significant differences in LS means for six linear conformation traits between warmblood dressage and jumping horses in Poland, of which two referred to correctness of legs. One of the traits was stance of forelegs (over at knee – back at knee) that was one of few traits where there was no significant difference found in the present study.

The LS means showed clear differences between discipline-specific traits for J and D horses, providing further indication of the specialization process in the SWB population reported by Bonow et al. (2023). For

Table 4
Linear and quadratic regression coefficients with significance level, of linearly scored conformation and gait traits on competition results in show jumping and dressage in Swedish Warmblood of jumping (J; $N = 2414$) and dressage (D; $N = 1178$) horses, respectively.

		J horses, show jumping				D horses, dressage			
	Trait	Linear		Quadratic		Linear		Quadratic	
Type	Type	−0.052	*	−0.025	n.s.	−0.081	*	0.042	n.s.
	Body: shape a	0.027	n.s.	0.004	n.s.	−0.039	n.s.	−0.001	n.s.
	Body: shape b	−0.059	*	0.016	n.s.	−0.149	***	−0.061	n.s
	Body direction	−0.102	**	0.083	*	−0.154	**	−0.052	n.s.
Head-neck-body	Length of neck	0.015	n.s.	0.031	n.s.	−0.100	*	−0.005	n.s.
	Position of neck	−0.076	**	−0.026	n.s.	−0.098	*	−0.029	n.s.
	Shape of neck	−0.058	**	−0.008	n.s.	−0.089	**	−0.039	n.s.
	Withers	−0.005	n.s.	−0.004	n.s.	−0.028	n.s.	−0.066	n.s.
	Position of shoulder	−0.054	*	0.012	n.s.	−0.111	**	−0.001	n.s.
	Line of back	0.011	n.s.	0.049	n.s.	0.050	n.s.	−0.147	**
	Loins	0.043	n.s.	0.064	*	−0.017	n.s.	0.000	n.s.
	Shape of croup	−0.031	n.s.	−0.004	n.s.	−0.057	n.s.	−0.023	n.s.
	Length of croup	0.004	n.s.	0.049	n.s.	−0.041	n.s.	0.001	n.s.
Correctness of legs	Foreleg a	−0.035	n.s.	0.020	n.s.	−0.111	n.s.	−0.040	n.s.
	Foreleg b	0.017	n.s	0.014	n.s.	0.047	n.s.	−0.087	*
	Pastern, front[a]	−0.091	*	−0.021	n.s.	0.010	n.s.	−0.060	n.s.
	Hind leg a	0.024	n.s.	0.043	n.s.	−0.125	**	−0.118	*
	Hind leg b	−0.049	n.s.	0.012	n.s.	−0.021	n.s.	−0.010	n.s.
	Pastern, hind[a]	−0.079	n.s.	0.038	n.s.	0.007	n.s.	−0.132	*
	Correctness in movement	0.011	n.s.	0.031	n.s.	0.010	n.s.	−0.045	n.s.
	Hoofs	0.011	n.s.	0.016	n.s.	−0.009	n.s.	−0.025	n.s.
Walk	Cadence	−0.035	n.s.	0.004	n.s.	−0.078	n.s.	0.008	n.s.
	Stride length	0.011	n.s.	−0.010	n.s.	−0.030	n.s.	−0.048	n.s.
	Suppleness	0.011	n.s.	0.031	n.s.	−0.056	n.s.	−0.045	n.s.
Trot	Stride length	−0.015	n.s.	0.009	n.s.	−0.169	****	−0.038	n.s.
	Elasticity	−0.023	n.s.	0.014	n.s.	−0.199	****	−0.029	n.s.
	Foreleg activity[a]	−0.052	n.s.	0.010	n.s.	−0.166	****	−0.074	*
	Hind leg position	−0.043	n.s.	−0.016	n.s.	−0.147	***	−0.041	n.s.
	Hind leg activity	−0.082	***	0.015	n.s.	−0.149	****	−0.030	n.s.
Canter	Rhythm	−0.048	n.s.	0.041	n.s.	−0.128	**	−0.066	n.s.
	Stride length	−0.037	n.s.	0.020	n.s.	−0.061	n.s.	−0.082	*
	Action[a]	−0.046	n.s.	0.043	n.s.	−0.148	***	−0.017	n.s.
	Elasticity	−0.080	***	0.013	n.s.	−0.134	***	−0.008	n.s.
	Movement: direction	−0.068	*	0.003	n.s.	−0.189	****	−0.053	n.s.

*$P < 0.05$, **$P < 0.01$, ***$P < 0.001$, ****$P < 0.0001$, n.s. = not significant.
[a] N=2040 for J horses; $N = 981$ for D horses.

Table 5
Linear and quadratic regression coefficients with significance level, of linearly scored jumping and temperament traits on competition results in show jumping and dressage in Swedish Warmblood of jumping (J; $N = 2414$) and dressage (D; $N = 1178$) horses, respectively.

		J horses, show jumping				D horses, dressage			
	Trait	Linear		Quadratic		Linear		Quadratic	
Take-off	Power	−0.192	****	0.028	n.s.	−0.031	n.s.	0.052	n.s.
	Quickness	−0.099	****	−0.000	n.s.	0.001	n.s.	−0.041	n.s.
	Direction	−0.133	****	0.020	n.s.	0.050	n.s.	0.021	n.s.
Technique	Foreleg	−0.102	****	0.021	n.s.	−0.031	n.s.	0.0126	n.s.
	Back	−0.118	****	0.041	*	−0.021	n.s.	0.014	n.s.
	Haunches	−0.046	*	0.030	*	−0.069	n.s.	0.028	n.s.
Jumping overall	Scope	−0.173	****	0.006	n.s.	−0.016	n.s.	0.037	n.s.
	Elasticity	−0.078	****	0.028	n.s.	−0.055	n.s.	0.033	n.s.
	Carefulness	−0.060	**	−0.017	n.s.	0.014	n.s.	0.015	n.s.
	Balance[a]	−0.131	****	0.005	n.s.	−0.001	n.s.	0.029	n.s.
	Reaction[a]	−0.137	****	−0.022	n.s.	0.003	n.s.	−0.010	n.s.
	Approach to assignment[a]	−0.109	****	0.010	n.s.	−0.012	n.s.	0.008	n.s.
	Distance estimation[b]	−0.084	****	−0.014	n.s.	−0.006	n.s.	0.001	n.s.
	Behaviour[c]	−0.038	*	−0.003	n.s.	0.007	n.s.	0.014	n.s.

*$P < 0.05$, **$P < 0.01$, ***$P < 0.001$, ****$P < 0.0001$, n.s.=not significant.
[a] N=2040 for J horses; $N = 981$ for D horses.
[b] N=2118 for J horses; $N = 1157$ for D horses.
[c] Temperament trait; $N = 1744$ for J horses; $N = 959$ for D horses.

gait and jumping traits, the differences were highly significant ($p < 0.0001$) and the largest differences were seen for traits describing aspects of trot, and for the jumping traits scope, power and direction of take-off, and technique of back and haunches. This highlights the importance of trot for dressage horses and of scope (height and width of the jump) and jumping technique for show jumping horses. For all gait traits, D horses had mean scores closer to 1 (A) than did J horses, which means they had longer strides, showed more elasticity, etc. For all

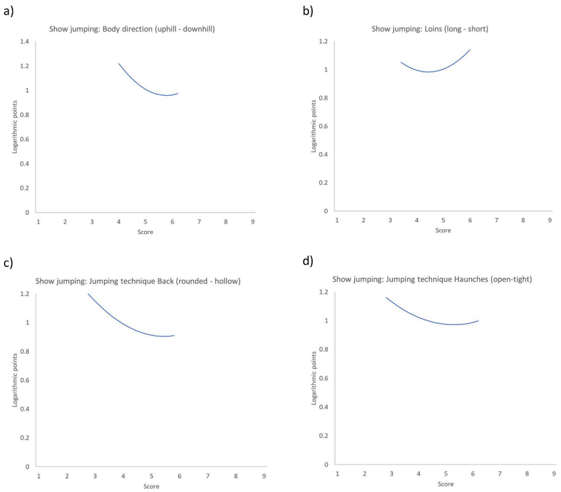

Fig. 2. Illustration of the associations between competition performance in **show jumping** (lifetime accumulated logarithmic points) and linearly scored traits based on the significant quadratic regression coefficient. The assessment scale A to I is transformed to numerical values 1 to 9. The graphs were plotted using a scale with a mean equal to that of the linearly scored trait within jumping horses and extended to +/- two standard deviations from the mean.

jumping traits, J horses had mean scores closer to 1 (A) than did D horses, meaning stronger and quicker take-off when jumping, more scope, etc. in J horses. Rovere et al. (2015) also concluded that the specialization process in Dutch Warmblood had resulted in differences in phenotypic mean trait values regarding linear movement traits between dressage and jumping horses. In the Polish study by Borowska & Lewczuk (2023) only one linear movement trait (balance in canter) and no linear jumping traits showed significant differences in LS means between dressage and jumping horses. The lack of significance regarding jumping traits may be due to their smaller data set, in which only 139 horses were assessed in jumping.

4.3. Association between linearly scored traits and show jumping performance

For J horses, all of the linearly scored jumping traits had a significant phenotypic association with show jumping, as did elasticity in canter. The importance of these traits was also shown by Ducro et al. (2007) who estimated significant positive phenotypic correlations (0.10–0.16) between linearly scored jumping traits and show jumping in KWPN horses. Both Ducro et al. (2007) and Rovere et al. (2017) also 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 Oldenburg horses, Stock et al. (2021) found significant correlations between EBVs for linearly scored jumping traits and EBVs for show jumping performance.

In our study, eight conformation traits (type, body shape (long legged – short legged), body direction, position of neck, shape of neck, position of shoulder, length of loins and front pastern) were significant on a phenotypic level for show jumping, which suggests that some conformation traits of a warmblood show jumping horse are associated with competition performance. In contrast, Koenen et al. (1995) found low phenotypic correlations, close to zero, between linearly scored conformation traits and show jumping.

In our study, the linear scores for walk and trot traits were not significant at a phenotypic level for show jumping (except for hind leg activity in trot) indicating that these gaits are generally not associated with show jumping performance. This was also seen in a study by Ricard et al. (2020), who concluded that assessing gait traits using accelerometers and judge scores in order to improve jumping performance is unhelpful, because the genetic correlations are low. Ducro et al. (2007) and Rovere et al. (2017) also found low genetic correlations between linearly scored walk and trot traits and show jumping performance. However, because our study was based on phenotypic associations, comparisons with results from genetic analyses should be made with caution.

Direction and power of take-off, balance, scope, and technique of the back were jumping traits that had a highly significant ($p < 0.0001$) association with 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.

The majority of the linearly scored traits that were significant for show jumping showed a linear association, which indicates that expressions towards one of the two extremes are more favorable. Thus, the more towards 1 (letter A) a horse is scored on the linear assessment scale, the higher the probability of that horse competing on a high level in show jumping. The selection of horses for breeding and sport will thereby take place at this part of the assessment scale, and horses classified in the other direction, towards 9 (letter I), are of less interest. Significant quadratic regression coefficients were found for four traits. When plotted in relation to the phenotypic mean and standard deviation it was demonstrated that for three of the traits, there continued to be a general trend indicating improved competition results associated with lower values of the linearly scored traits. For the fourth trait, length of loins, the plotted graph indicated that a length deviating from the average population would be beneficial for competition performance. However, the graph shows that the differences are small and therefore length of loins will probably have no major importance when selecting show jumping horses.

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. For example, since 2022, time faults have become more costly at international competitions and more restricted rules regarding hind boots and spurs has been introduced, and in 2023 the maximum depth of pole cups was reduced (FEI, 2022). Such changes

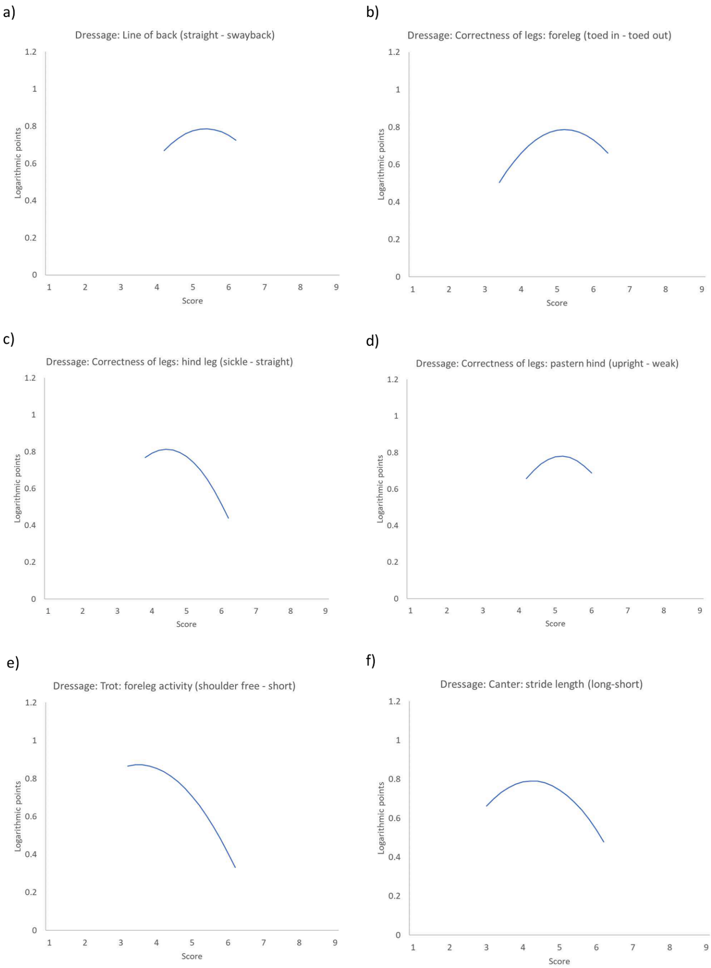

Fig. 3. Illustration of the associations between competition performance in **dressage** (lifetime accumulated logarithmic points) and linearly scored traits based on the significant quadratic regression coefficient. The assessment scale A to I is transformed to numerical values 1 to 9. The graphs were plotted using a scale with a mean equal to that of the linearly scored trait within dressage horses and extended to +/- two standard deviations from the mean.

indicate that horses will probably need to be quicker, more sensitive, and more careful to be successful at international level in the near future.

4.4. Association between linearly scored traits and dressage performance

For D horses, several conformation traits had a significant phenotypic association with performance in dressage. Based on the results, a refined, 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 in dressage horses indicated significant development towards a larger frame, longer legs, and a shorter back. Positive genetic associations between dressage performance and a sloping shoulder as well as a long neck has previously been shown in the study on Dutch Warmblood by Koenen et al. (1995). An uphill body direction seemed to be favorable for both J and D horses. Also in Icelandic horses, an uphill conformation, measured as the difference in cm between height at front and height at hind and with an optimum of 6 cm, was shown to be one of the most important characteristics for riding ability (Kristjansson et al., 2016). In the Pura Raza Español horse, EBVs for the upper neck-line and angle of shoulder, among 13 morphological linear traits, were found to be useful to predict EBVs for both gait score and total score in dressage test for 4 to 6-year-old horses (Sánchez-Guerrero et al., 2017).

At the phenotypic level, all traits in our study describing aspects of trot and most traits describing aspects of canter were significant for performance in dressage, whereas no trait describing aspects of walk was significant. The importance of trot and canter traits for a dressage horse was also identified in the study by Ducro et al. (2007) where linearly scored traits associated with trot and canter had significant positive phenotypic correlations with dressage performance. Ducro et al. (2007) and Rovere et al. (2017) also estimated moderate to strong genetic correlation between trot and canter and dressage performance. Both studies found that correctness of walk had a low genetic correlation to dressage performance, but that stride length and elasticity in walk had a high genetic correlation. 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 previously reported by Stock et al. (2021), who found strong correlations between EBVs for linearly scored traits and EBVs for dressage performance for carrying power and freedom of shoulders in trot and direction of movement in canter in Oldenburg dressage horses.

Six linearly scored traits that were significant for dressage performance had a significant and negative quadratic regression coefficient, indicating an optimum. Three of the traits were describing different aspects of correctness of legs; toed in to toed out foreleg, sickle to straight hind leg, and upright to weak hind pastern. As pointed out by Koenen et al. (1995), extremes for this category of traits are not desirable and both extremes have an adverse effect on performance in competition. Another conformation trait, line of back, also exhibited an optimum in our study. The graph indicated that the population mean is closely aligned with the optimum with respect to dressage performance. Among the linearly scored gait traits, two showed an association to dressage performance with an optimum; foreleg activity in trot and stride length in canter. The graph of foreleg activity showed a flattening curve towards 1 (A), indicating that breeding for a more extreme expression will not be favorable, although the negative impact on the sport performance would be limited. In terms of canter stride length, neither too short nor too long strides appeared to be advantageous for dressage competition. According to the graph, the studied population could still move slightly towards a longer stride length 1 (A) before the optimum is reached. However, because dressage is a subjectively judged sport known to develop over time (Hess, 2010), the most favorable expressions can change and the most advantageous traits today may not be the same in 10 years.

4.5. Potential use of linear scoring in the future

In order to produce competitive horses at an international level, it is necessary to breed for extraordinary abilities in jumping or dressage. In our study, many linearly scored traits showed a linear association with performance, meaning that scores towards 1 (letter A) on the assessment scale would be more advantageous for sport performance. This may suggest that, in the future, a higher prevalence of horses with more pronounced or distinct expressions of these traits will become more common, as breeders aim to produce horses for elite-level sports. However, breeding for extreme expressions of some specific traits may have negative consequences on health and durability of the horse. For example, it has been shown that heterozygosity of the mutation causing fragile foal syndrome is connected to elasticity in trot, indicating that breeding for that trait could increase the prevalence of the deleterious mutation in the population (Ablondi et al., 2022). Monitoring of health and durability, as well as inbreeding, in the population is highly recommended to avoid extreme breeding that could have negative effects on the welfare of the horse. Such monitoring would require cooperation between the breeding organization, veterinarians, insurance companies, and horse owners. Attention should also be paid to continuous training of judges, to maintain uniformity between judges when scoring linear traits (Gmel et al., 2020). It is important to monitor the population average in relation to the optimum in the breeding program and pay special attention to combining mare and stallion for traits with intermediate optimum scores. A proper knowledge of the genetic correlations among performance and functional traits is of importance for future selection within the breed and this should be investigated in further studies.

4.6. Limitations of the study

One potential limitation of the statistical analysis was that for some of the studied traits the residuals were not normally distributed. However, in our experience contrasts and significance tests from linear models with large number of observations are robust to any deviation from normality. Some authors even go as far as recommending the use of linear models for the analysis of 0/1 traits, where the residuals almost never are normally distributed, mostly owing to the direct interpretability of the estimates (Hellevik, 2009; Gomila, 2021). In our situation, we had a truly continuous dependent variable (lifetime accumulated points).

We used a linear and quadratic regression on the linearly scored traits to objectively decide whether an optimum existed or not. We also tried to use the unadjusted classes as categorical explanatory variables in the model but abandoned that approach because the definition of a non-linear relation became more subjective. Further, we wanted to adjust the linear scores for sex and event, which made the adjusted values (the residuals) continuous variables.

5. Conclusions

This study clearly highlighted linearly scored traits of importance to identify potentially successful show jumping or dressage horses. Differences in linearly scored traits between jumping and dressage horses confirm the specialization within the SWB population. For show jumping horses, all linearly scored jumping traits were found to be of high importance for sport performance, as were some traits associated with conformation and gaits. For dressage horses, all traits associated with trot were highly important, as were several traits associated with conformation and canter. A majority of the traits that were significant for show jumping showed a linear association (21 of 25), meaning that stronger expression of these traits was associated with on average higher competition performance. Among traits that were significant for dressage performance several (6 of 21) showed intermediate optimal scores, indicating that more extreme expression of these specific traits was not associated with better competition performance. The results in this study confirm that linearly scored traits serve as valuable tool for identifying and monitoring the development of traits essential for sport performance in show jumping and dressage horses.

CRediT authorship contribution statement

S. Bonow: Formal analysis, Writing – original draft, Writing – review & editing. **S. Eriksson:** Methodology, Writing – review & editing, Supervision. **E. Strandberg:** Methodology, Writing – review & editing, Supervision. **E. Thorén Hellsten:** Conceptualization, Writing – review & editing, Supervision. **Å. Gelinder Viklund:** Conceptualization, Data curation, Methodology, Writing – review & editing, Supervision.

Declaration of competing interest

Swedish Warmblood Association has provided the data for this study and has also supported the supervision by Emma Thorén Hellsten, who is a former employee at the organization.

Åsa Gelinder Viklund has regular commitments for Swedish Warmblood Association, regarding the routine genetic evaluation.

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Prevalence and risk of orthopedic diagnoses in insured Swedish Warmblood horses

S. Bonow *, E. Hernlund, S. Eriksson, E. Strandberg, Å. Gelinder Viklund

Swedish University of Agricultural Sciences, Department of Animal Biosciences, P.O. Box 7023, Uppsala SE-750 07, Sweden

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Young horse test

ABSTRACT

Sweden has a strong tradition of insuring horses for veterinary costs, and orthopedic diagnoses are the most common for insurance claims. The aim of this study was to investigate differences in prevalence and risk of orthopedic diagnoses for Swedish warmblood (SWB) horses classified as jumping (J) or dressage (D) horses. Also, other factors that may influence orthopedic health were investigated, i.e., sex, birth cohort, and participation in young horse tests and competition. The data consisted of 15,619 insured SWB horses born between 2010 and 2020. Horses were classified as J or D horses according to pedigree. The prevalence of orthopedic diagnoses was investigated using logistic regression analysis and presented as Least Squares means. The time from birth to first orthopedic diagnosis was investigated using survival analysis. D horses were at a higher risk of having orthopedic diagnoses compared with J horses (50.9 % vs 43.9 %, $P < 0.0001$). Male horses were at a higher risk than females (49.7 % vs 45.0 %, $P < 0.0001$), and tested horses were at a higher risk than non-tested horses (49.9 % vs 44.9 %, $P < 0.0001$). No significant difference was seen between competed and non-competed horses regarding the risk of having orthopedic diagnoses, but the groups were predisposed to different subgroups of orthopedic diagnoses. Survival analysis showed that later cohorts were more likely to have insurance claims for orthopedic diagnoses at a younger age than earlier cohorts. In conclusion, insurance data can be a useful tool to study which factors influence the orthopedic health status of the SWB horse population.

1. Introduction

Sweden has a strong tradition of insuring animals, more than 70 % of horses and companion animals are insured (Dagens Industri, 2024). The very high proportion of insured animals is unique compared with other European countries (Swedish Competition Authority, 2021). Insurance databases are considered secondary databases when it comes to investigating health and longevity, meaning that data are primarily registered for reasons other than research (Sørensen et al., 1996). The leading insurance company for horses in Sweden is Agria (Agria Insurance, P.O. 70306, SE-107 23 Stockholm, Sweden). Their database contains a considerable amount of information on diagnoses, dates of treatment, and reasons for euthanasia. The database of Agria has previously been used for research when investigating the prevalence of disease and death in the Swedish horse population. Egenvall et al. (2006) investigated the mortality of Swedish horses with complete life insurance by Agria between 1997 and 2000. Similar studies, investigating the morbidity of Swedish horses insured for veterinary care by Agria between 1997 and 2000, have been performed by Egenvall et al. (2005) and Penell et al. (2005). In these studies, variations according to sex, age, breed, location and diagnosis were considered. However, these studies were performed more than 20 years ago, and the SWB horse population has undergone major changes since then.

The SWB horse population has become more specialized towards show jumping and dressage in the last decades (Bonow et al., 2023). More than 80 % of the SWB horses born from 1980 to 1985 were all-round horses, whereas horses born from 2016 to 2020 were mainly jumping (J) horses (58 %) or dressage (D) horses (34 %). Due to differences in usage, conformation, movement and/or temperament between J and D horses, a difference in prevalence and type of injuries between these groups may be expected. Orthopedic diagnoses are by far the most common health problem for riding horses (Egenvall et al., 2013; Murray et al., 2010; Wallin et al., 2000), but whether there is a difference between J and D SWB horses regarding the risk of orthopedic diagnoses has not been investigated before.

Other factors may also influence orthopedic health, e.g., if the horse has been tested at a young horse test or competed. In Sweden, two young horse performance tests are held annually throughout the country,

* Corresponding author.
E-mail address: sandra.bonow@slu.se (S. Bonow).

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where approximately 30 % of the SWB horses are assessed by judges: the Young Horse Test (YHT) and the Riding Horse Test (RHT) (Bonow et al., 2023). These tests are open for participation for all registered SWB horses. However, some pre-selection may occur because owners are probably more likely to have their horse assessed if it has a talent for jumping or dressage and has no severe abnormalities of conformation. There is also most likely a pre-selection based on talent before the horse enters a competition. About 40 % of SWB horses participate in competitions, with a higher proportion of J horses (50 %) than D horses (28 %) (Bonow et al., 2023). Of course, for participation in both young horse tests and competition, the horse also needs to be healthy without any lameness. There are no previous studies of the association between orthopedic diagnoses and the all-or-none traits 'test status' and 'competition status', which are defined as whether or not a horse participated in young horse tests or competitions, respectively.

In this study, we aimed to describe the prevalence, risk, and type of orthopedic disease in the population of SWB horses insured by Agria, and to investigate the effects of sex, discipline category (J or D horses), test status, competition status, and birth cohort. The time from birth to the first orthopedic diagnosis for these groups of horses was analyzed by survival analysis.

2. Materials and methods

2.1. Data

Pedigree information was provided by the Swedish Warmblood Association. Results from young horse tests (YHT and RHT) conducted between 2013 and 2023, as well as competition records for all horses in official competitions from 2014 to October 2023, were also obtained from the Swedish Warmblood Association. SWB horses can compete from four years of age, thus horses born in 2020 and later had no competition records registered at the time of this study. Insurance data was provided by the insurance company Agria and included all insurance claims from April 2010 to January 2024 for insured horses classified as SWB and born from 2010 to 2021. The initial data included 52,446 insurance numbers with the name of the horse, birth year, and identification (ID) numbers connected to the horse, i.e., SWB ID number, chip number, foreign ID number, or international Universal Equine Life Number (UELN) (Universal Equine Life Number., 2025). Horses could have several insurance numbers. For example, a horse receives a new number when changing owner or when the owner changes the type of insurance. The insurance data also included 78,825 unique insurance claim records (ICR) and 2840 different diagnosis codes.

The insurance numbers, with corresponding ICR, were matched to horses in the SWB database by the information connected to the horse (i.e., SWB ID number, chip number, foreign ID number, or international UELN number). In addition, 3453 horses without such information in the insurance data could be manually matched by name and birth year (e.g., if they had a unique name within their birth year). Horses born in 2021 were excluded because they had not had the opportunity to participate in a young horse test yet. Horses sired by an unlicensed stallion were also removed because these stallions were difficult to classify into a discipline. A data set consisting of 15,619 unique horses registered in SWB and insured in Agria, with a total of 53,168 insurance claims, remained after the data editing.

All horses were divided into discipline categories according to their sire and grandsire classification, as described by Bonow et al. (2023). Sires and grandsires were assigned to one of four categories (jumping (J), dressage (D), allround (AR), or Thoroughbred (Th)) according to breeding values, own performance, and offspring performance. Around 58 % of the insured horses belonged to the J category, 34 % to the D category and 8.6 % to the AR or Th category (Table 1). This distribution corresponds well with the same age group in the study of the SWB horse population by Bonow et al. (2023), indicating that the insurance data are representative of the population. The present study mainly considers horses in the J and D categories (N = 14,274 horses).

Table 1
Number of Swedish warmblood horses (SWB) insured by Agria, number of horses in the jumping (J), dressage (D), or allround/thoroughbred (AR/Th) category.

SWB insured by Agria				
Birth year	No of horses	No of J horses	No of D horses	No of AR/Th horses
2010	1662	941	551	170
2011	1627	914	515	198
2012	1428	777	485	166
2013	1247	727	395	125
2014	1193	694	384	115
2015	1292	764	412	116
2016	1440	847	495	98
2017	1472	883	489	101
2018	1513	871	532	110
2019	1493	881	529	83
2020	1252	736	453	63
Total	**15,619**	**9034**	**5240**	**1345**

There are two main types of insurance for horses offered by Agria: veterinary care and life insurance (Egenvall et al., 2008). Veterinary care insurance reimburses the owner for most of the costs of veterinary care, whereas life insurance reimburses the owner if the horse is euthanized or accidentally dies. Almost all horses are insured for both types. The diagnostic registry used has, in some cases, several codes for similar injuries. For example, 'serous osteoarthritis in the fetlock joint' (code: LG411) is similar to 'acute inflammatory conditions in fetlock joint' (code: LG41). These similar diagnoses were merged when investigating the most common diagnoses for veterinary care and life reimbursement.

2.2. Orthopedic disease data from insurance claims

From the insurance data, all diagnoses connected to the locomotor system (LOC) were considered. In total, there were 915 such diagnoses. These diagnoses were divided into eight subgroups, according to type and location of the injury (Table 2). The classification was performed by one of the authors, who is a clinical veterinarian and researcher specializing in the locomotor system. All LOC diagnoses were categorized into only one of the subgroups, even though some diagnoses could belong to more than one subgroup. In these cases, the diagnosis was categorized into the most obvious subgroup. Horses with a diagnosis connected to LOC were categorized according to the eight subgroups,

Table 2
Subgroups of locomotor system (LOC) diagnoses, their abbreviation, number of LOC diagnoses, and number of claims connected to LOC diagnoses for all horses (N = 15,619).

Group of LOC diagnoses	Abbreviation	No of diagnoses	No of claims
Orthopedic disease of the extremities (not acute trauma)	EXT	413	19,363
Orthopedic disease of the axial skeleton (not acute trauma)	AXI	76	4448
Osteochondrosis/ osteochondrosis dissecans	OCD	46	933
Developmental disease in limbs or hooves (other than OCD)	DEV	88	781
Traumatic orthopedic disease	TRA	213	2517
Neurologic disease	NEU	6	338
Laminitis	LAM	12	289
Infectious disease in joints or skeleton	INF	61	393
Total		915	29,062

but some horses appeared in more than one group because of different injuries sustained during the period of the study.

2.3. Statistical analysis

The proportion of horses (J and D horses, N = 14,274) tested at a young horse test or competed was calculated for each subgroup of horses (i.e., according to sex, discipline category, and test status or competition status). Comparisons of proportions within subgroups were estimated using Chi-Square tests for homogeneity in SAS (SAS., 2016). Stallions and geldings were combined into one sex category of male horses in the analyses, because many owners do not report when their stallion is gelded. However, a large majority of the SWB male horses are gelded.

The prevalence of ICR and LOC diagnoses were considered as a 1/0-trait, i.e., either the horse had at least one claim/diagnosis, or not. It was not possible to distinguish between the number of injuries for an individual, because insurance claims could refer to one specific injury with one or several return visits. To compare the prevalence of ICR and LOC diagnoses between different groups of horses, a multivariate logistic regression was used, i.e., the PROC LOGISTIC statement in SAS, with sex (male or female), birth year, discipline category (J or D), test status (1/0), and competition status (1/0) as class variables. The estimates were presented as Least Squares (LS) means. In these analyses, only J and D horses born between 2010 and 2019 that were old enough to compete were included (N = 13,085 horses).

The first decile and median of the age in years at the first insurance claim regarding a LOC diagnosis was calculated in SAS using the PROC UNIVARIATE statement. Only horses with a LOC diagnosis were included in these analyses.

Survival analysis was used to investigate the risk of having a LOC diagnosis by using the information from 'time to event' (i.e., the number of days from birth to the first LOC diagnosis). Horses without a LOC diagnosis were censored in the analysis, where the last day with available insurance data (30th of January 2024) was used as the censoring date. Horses were also censored if they were omitted from the data before the end date for other reasons, either because the owner had the insurance terminated or because the horse died for a reason other than a LOC diagnosis (without previously having a LOC diagnosis). In these cases, the date of termination of the insurance or death of the horse was used as the censoring date instead. The date of any termination of insurance performed before 2018 was unknown. In these cases, the date 31st of December 2017 was set as the censoring date. Survival curves were constructed using the Kaplan-Meier method, where the cumulative probability of survival is presented (Kaplan and Meier, 1958). This was performed by using the PROC LIFETEST statement in SAS. In this analysis, J and D horses born between 2010 and 2020 were included, except for the analysis of competition status, where J and D horses born 2010–2019 were considered. Survival curves (S(t)) were estimated for sex (male or female), discipline category (J or D), test status (1/0), competition status (1(0), and for three birth cohorts (2010, 2015, and 2020), using the strata statement. The survival curves were transformed into Cumulative Incidence Function (CIF) curves ($CIF(t) = 1 - S(t)$) to make interpretation easier.

3. Results

3.1. Descriptive statistics of insurance data

Approximately 56 % of the SWB horse population born from 2010 to 2020 was insured by Agria, based on statistics of born foals (Swedish Warmblood Association (SWB (SWB., (2024)). The sex distribution in the data set was even, with 51 % female and 49 % male horses. Out of 14,274 J and D horses in the data set, 5957 (42 %) had been tested at YHT or RHT (Table 3). A total of 6885 horses (53 %) born 2010–2019 had been competing until October 2023, and had at least one record from an official competition in show jumping, dressage, or eventing.

Table 3
Description of Swedish warmblood jumping and dressage horses born 2010–2020 and insured by Agria; number (N) and percent (%) of horses tested at a young horse test, that competed, that had an insurance claim record (ICR), and that had a locomotor (LOC) diagnosis.

Birth year	Tested		Competed		With ICR		With LOC diagnosis	
	N	%	N	%	N	%	N	%
2010	645	43.2	964	64.6	1073	71.9	843	56.5
2011	562	39.3	949	66.4	991	69.4	771	54.0
2012	479	38.0	759	60.1	837	66.3	659	52.2
2013	454	40.5	697	62.1	737	65.7	574	51.2
2014	402	37.3	674	62.5	703	65.2	535	49.6
2015	448	38.1	671	57.1	761	64.7	590	50.2
2016	534	39.8	729	54.3	832	62.0	612	45.6
2017	614	44.8	675	49.2	826	60.3	569	41.5
2018	639	45.6	485	34.6	798	56.9	472	33.6
2019	659	46.7	282	20.0	695	49.3	397	28.2
2020	521	43.8	-	-	473	39.8	232	19.5
Total	**5957**	**41.7**	**6885**	**52.6**	**8726**	**61.1**	**6254**	**43.8**

Approximately 20 % of the four-year-old horses (born in 2019) had been competing, whereas approximately 65 % of the 13-year-old horses (born in 2010) had been competing. Insurance claim records (ICR) had been made for 8726 horses (62 %) until January 2024 and the number of horses with a LOC diagnosis was 6254 (44 %). The proportion of insured horses with ICR increased with age, where approximately 40 % of the horses born in 2020 had an ICR, and approximately 72 % of the horses born in 2010 had an ICR. The same pattern was seen for the proportion of horses with a LOC diagnosis, with a range from 20 % (horses born 2020) to 57 % (horses born 2010) (Table 3).

More female (44.1 %) than male horses (39.3 %) participated in young horse tests ($P < 0.0001$), whereas a higher proportion of male (56.1 %) than female horses (49.3 %) competed ($P < 0.0001$) (Table 4). More D horses (48.3 %) than J horses (38.0 %) had been tested at a young horse test ($P < 0.0001$). On the other hand, a larger proportion of J horses (62.4 %) than D horses (37.5 %) had competed ($P < 0.0001$). Approximately 60 % of the tested horses had also competed, whereas only 47 % of the non-tested horses had competed ($P < 0.0001$).

The ten most common diagnoses for veterinary care in the data were the same for J and D horses, where lameness (unspecified) was the most common, followed by traumatic injuries in the skin (Table 5). Out of 2032 euthanized horses, 1924 had a life insurance (95 %). The most common cause for euthanasia was lameness (unspecified), followed by chronic osteoarthritis in the spinal joints, and ataxia (Table 6). Of the euthanized horses, approximately 50 % belonged to the J category, 40 % to the D category, and 10 % to the AR/Th category.

3.2. Prevalence of ICR and LOC diagnosis

The class variables birth year, sex, discipline category, and test status had a significant effect on the proportion of horses with a LOC diagnosis in the multivariate logistic regression model. The proportion of ICR and diagnoses connected to LOC was higher for male than for female horses ($P < 0.0001$) (Table 7). Diagnoses connected to orthopedic disease of the extremities (EXT), orthopedic disease of the axial skeleton (AXI), osteochondrosis (OCD), and neurologic disease (NEU) were more common for male horses ($P < 0.0001$ to $P < 0.05$), whereas no significant differences were seen for developmental disease in limbs or hooves (DEV), traumatic orthopedic disease (TRA), laminitis (LAM), and infectious disease in joints or skeleton (INF). The proportion of horses with an ICR and those with a LOC diagnosis was significantly higher for D horses than for J horses ($P < 0.0001$). Also, the proportion of horses with a diagnosis connected to EXT, AXI, DEV, TRA, NEU, and LAM was higher for D horses than for J horses ($P < 0.0001$ to $P < 0.01$). Tested horses had a higher proportion of ICR and LOC diagnoses than non-tested horses ($P < 0.0001$). Also, the proportion of horses with a diagnosis connected

Table 4
Distribution of horses across subgroups (sex, discipline category (jumping (J) and dressage (D) horses), test status, and competition status[a]) for all horses insured by Agria, those tested at young horse tests, and those competing, together with level of significance for differences between categories within each subgroup.

		Sex			Discipline category			Test status			Competition status[a]		
Item	All horses	Female	Male	Sign[b]	J	D	Sign[b]	Tested	Non-tested	Sign[b]	Comp	Non-comp	Sign[b]
No of horses	14,274	7309	6965	-	9034	5,24	-	5957	8317	-	6885	6200	-
Percent tested	41.7	44.1	39.3	****	38.0	48.3	****	-	-	-	47.6	34.9	****
Percent competed[a]	52.6	49.3	56.1	****	61.4	37.5	****	60.2	47.2	****	-	-	-

[a] J and D horses born in 2010–2019, N = 13,085. [b] ****P < 0.0001.

Table 5
The 10 most common diagnoses for veterinary care for jumping horses (no of insurance claims=23,481) and dressage horses (no of insurance claims=17,153), respectively [a] [a]metacarpophalangeal and metatarsophalangeal joints.

	Diagnosis in jumping horses	No	Percent	Diagnosis in dressage horses	No	Percent
1	Lameness (unspecified)	2488	10.6	Lameness (unspecified)	1752	10.2
2	Traumatic injuries, skin	1927	8.2	Traumatic injuries, skin	1454	8.5
3	Fetlock[a] joint osteoarthritis	1100	4.7	Colic	753	4.4
4	Stifle joint osteoarthritis	1049	4.5	Stifle joint osteoarthritis	734	4.3
5	Colic	896	3.8	Fetlock[a] joint osteoarthritis	697	4.1
6	Back pain (unspecified)	783	3.3	Back pain (unspecified)	562	3.3
7	Distal interphalangeal joint osteoarthritis	583	2.5	Suspensory desmitis	426	2.5
8	Suspensory desmitis	570	2.4	Distal interphalangeal joint osteoarthritis	410	2.4
9	Hoof abscess	483	2.1	Hoof abscess	360	2.1
10	Osteoarthritis, unspec. joints	337	1.4	Osteoarthritis, unspec. joints	203	1.2

Table 6
The 10 most common diagnoses for euthanasia of 2032 euthanized horses in the insurance data.

	Diagnosis	No of horses	Percent
1	Lameness (unspecified)	190	9.4
2	Chronic osteoarthritis in spinal joints	125	6.2
3	Ataxia	114	5.6
4	Colic	101	5.0
5	Overriding spinous processes (kissing spines)	98	4.8
6	Osteoarthritis, unspecified joints	53	2.6
7	Laminitis	43	2.1
8	Traumatic injuries, skin	42	2.1
9	Suspensory desmitis	32	1.6
10	Chronic osteoarthritis in fetlock[a] joint	30	1.5

[a] metacarpophalangeal and metatarsophalangeal joints

to EXT, AXI, OCD, DEV, and INF was higher for tested horses than for non-tested horses (P < 0.0001 to P < 0.05). When comparing competed and non-competed horses, no significant differences were seen between the groups regarding the proportion of horses with an ICR or LOC diagnosis. However, competed horses had diagnoses connected to the extremities (EXT) or the axial skeleton (AXI) to a higher extent than non-competed horses (P < 0.0001 to P < 0.01). On the other hand, non-competed horses were affected by DEV, TRA, NEU and LAM to a greater extent than competed horses (P < 0.0001 to P < 0.05). Probably some of the non-competed horses were not able to compete as a consequence of these diagnoses.

3.3. Time to first LOC diagnosis

The first decile and median age in years at first LOC diagnosis are presented in Table 8, showing higher values for diagnoses connected to EXT, AXI, and LAM than for diagnoses connected to DEV. It should be noted that the values in Table 8 only refer to horses with a diagnosis.

3.4. Survival analysis of insurance data

The survival analysis, including all born and insured SWB horses,

Table 7
Least squares means of proportion (in %) of horses[a] with insurance claim records (ICR), locomotor (LOC) diagnosis, and different subgroups of LOC diagnosis for groups of horses according to sex, discipline category (jumping (J) and dressage (D) horses), test status, and competition status together with level of significance for differences between categories within each group. Results are from a multivariate logistic regression model with sex, discipline category, test status, competition status, and birth year as categorical variables.

	Sex			Discipline category			Test status			Competition status		
Item	Female	Male	Sign[b]	J	D	Sign[b]	Tested	Non-tested	Sign[b]	Comp	Non-comp	Sign[b]
ICR	63.3	66.9	****	61.1	68.9	****	67.8	62.3	****	65.0	65.2	n.s
LOC	45.0	49.7	****	43.9	50.9	****	49.9	44.9	****	48.2	46.5	n.s
EXT	34.2	37.9	****	33.6	38.5	****	38.2	33.9	****	38.9	33.3	****
AXI	13.0	14.3	*	12.1	15.3	****	15.1	12.2	****	14.6	12.7	**
OCD	3.8	5.1	***	4.2	4.5	n.s	5.1	3.7	***	4.3	4.4	n.s
DEV	3.0	3.0	n.s	2.6	3.5	**	3.4	2.6	*	2.3	3.9	****
TRA	9.2	9.2	n.s	8.4	10.1	**	9.6	8.8	n.s	8.6	9.8	*
NEU	0.7	1.8	****	0.9	1.4	**	1.1	1.2	n.s	0.6	2.0	****
LAM	0.8	0.6	n.s	0.6	0.9	**	0.6	0.8	n.s	0.5	1.1	****
INF	1.6	1.7	n.s	1.6	1.7	n.s	1.9	1.4	*	1.4	1.8	n.s

EXT: Orthopedic disease of the extremities, AXI: Orthopedic disease of the axial skeleton, OCD: Osteochondrosis, DEV: Developmental disease in limbs or hooves. TRA: Traumatic orthopedic disease, NEU: Neurologic disease, LAM: Laminitis, INF: Infectious disease in joint or skeleton

[a] J and D horses born in 2010–2019 (N = 13,085)

[b] *P < 0.05, **P < 0.01, ***P < 0.001, ****P < 0.0001, n.s = not significant.

Table 8
Age in years at first locomotor (LOC) diagnosis for Swedish warmblood horses with an insurance claim for LOC diagnosis (presented as age at first decile and median), number and percent of horses with insurance claim records for LOC diagnosis and subgroups of LOC diagnoses.

Time to event	1st decile (10 %)	Median	No with LOC	Percent with LOC
Age at first LOC	1.1	4.8	6254	43.8
Age at first EXT	2.7	5.3	4806	33.7
Age at first AXI	4.0	6.2	1862	13.0
Age at first OCD	1.3	2.9	625	4.4
Age at first DEV	0.1	0.3	428	3.0
Age at first TRA	1.0	4.6	1237	8.7
Age at first NEU	1.4	4.1	191	1.3
Age at first LAM	3.2	7.2	147	1.0
Age at first INF	0.3	4.1	212	1.5

EXT: Orthopedic disease of the extremities, AXI: Orthopedic disease of the axial skeleton, OCD: Osteochondrosis, DEV: Developmental disease in limbs or hooves. TRA: Traumatic orthopedic disease, NEU: Neurologic disease, LAM: Laminitis, INF: Infectious disease in joint or skeleton

showed that the probability of having a LOC diagnosis, i.e., being diagnosed with an injury or disease in the locomotor system during the time period, was significantly affected by sex ($P < 0.0001$), discipline category ($P < 0.0001$), test status ($P < 0.0001$), competition status ($P < 0.0001$), and birth cohort ($P < 0.0001$). The risk was higher for male than for female horses, and the difference increased somewhat with age. The risk of having a LOC diagnosis was rather low for both sexes during the first 2.5 years. From approximately 3 years of age, there was a rapid increase in risk for both sexes, where male horses were at a higher risk of having a LOC diagnosis, compared with female horses (Fig. 1). The risk of having a LOC diagnosis was higher for D horses than for J horses (Fig. 2). For tested and non-tested horses, the risk of having a LOC diagnosis was almost the same for both groups during the first 3 years of age (Fig. 3). From then onwards, the risk increased for both groups, where tested horses were at a higher risk compared with non-tested horses. Non-competed horses had a higher risk of having a LOC diagnosis during the first 9 years of age, compared with competed horses (Fig. 4). At approximately 8 years of age, the curve for non-competed horses flattened out, whereas the curve for competed horses continued to increase. After 9 years of age, the curves crossed, indicating that the probability for LOC diagnoses became higher for competed horses in comparison with non-competed horses of the same age. For all these figures (Figs. 1–4), the curves were flattening out before 12 years of age, staying at a probability of around 60–70 % to have a LOC diagnosis.

In Fig. 5, the risk of having a LOC diagnosis is presented for horses born in 2010, 2015, and 2020, respectively. Because the horses in the data had different periods of possible observation time, the curves in the graph end at different time points. The figure shows that later cohorts had a steeper increase in the curve, indicating that the risk for LOC diagnoses has increased with time.

4. Discussion

We found significant differences in the prevalence of orthopedic diagnoses in insurance data between J and D horses but also between categories of other factors (sex, birth cohort, and participation in young horse tests and competition) by using multivariate logistic regression. We also illustrated the differences between categories using survival analysis. Survival analysis is a statistical method to investigate the time until a specific event occurs (Klein and Moeschberger, 2003), e.g. time to first orthopedic diagnosis. The main benefit of the method is that non-affected horses are also included in the analysis and will be censored in the data. Survival analysis has been used in previous studies when investigating disease and death in horse populations (e.g. Ross et al., 1998; Wallin et al., 2000; Árnason and Björnsdóttir, 2003).

Orthopedic diseases affecting the extremities (EXT) and the axial

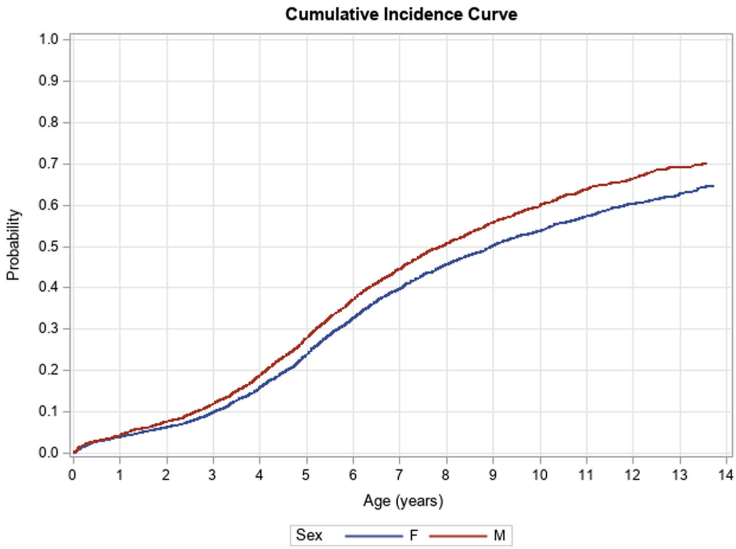

Fig. 1. The probability of having a LOC diagnosis as a function of time (Cumulative Incidence Function) for female (F) and male (M) horses, respectively. N = 7309 and n = 6965 for female and male horses, respectively. The median age of the first LOC diagnosis was 9.0 and 7.9 years for female and male horses, respectively.

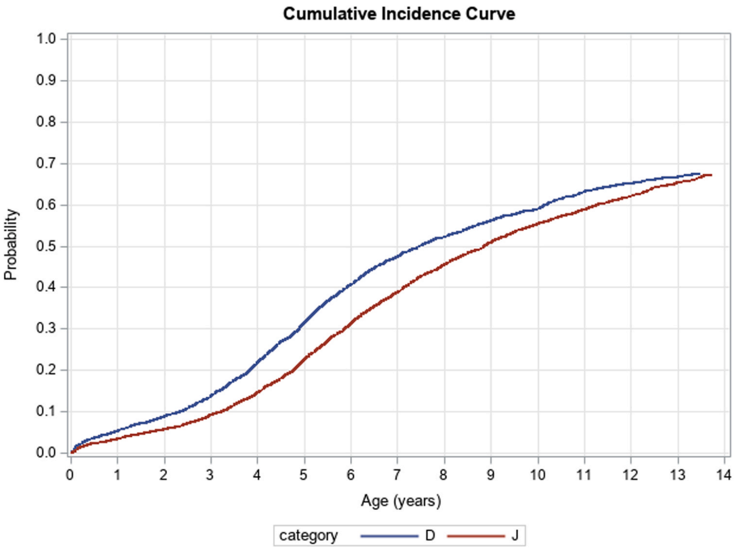

Fig. 2. The probability of having a LOC diagnosis as a function of time (Cumulative Incidence Function) for dressage (D) and jumping (J) horses, respectively. N = 5240 and n = 9034 for d and j horses, respectively. The median age of the first LOC diagnosis was 7.5 and 8.9 years for d and j horses, respectively.

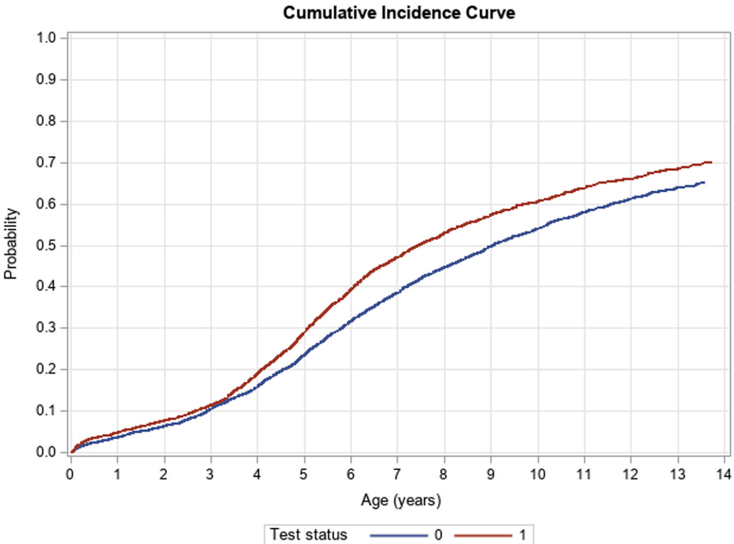

Fig. 3. The probability of having a LOC diagnosis as a function of time (Cumulative Incidence Function) for tested (1) and non-tested (0) horses, respectively. N = 5957 and n = 8317 for tested and non-tested horses, respectively. The median age of the first LOC diagnosis was 7.5 and 9.1 years for tested and non-tested horses, respectively.

skeleton (AXI), often caused by physical workload and/or by abnormalities in the conformation, are commonly associated with lameness. However, in this study, we have also considered other types of diagnoses connected to the locomotor system, i.e., diagnoses connected to OCD, DEV, TRA, NEU, LAM and INF, in order to give a broader description of locomotor diseases in warmblood horses.

4.1. *Usefulness of insurance data*

Insurance data from Agria has been used previously in Swedish

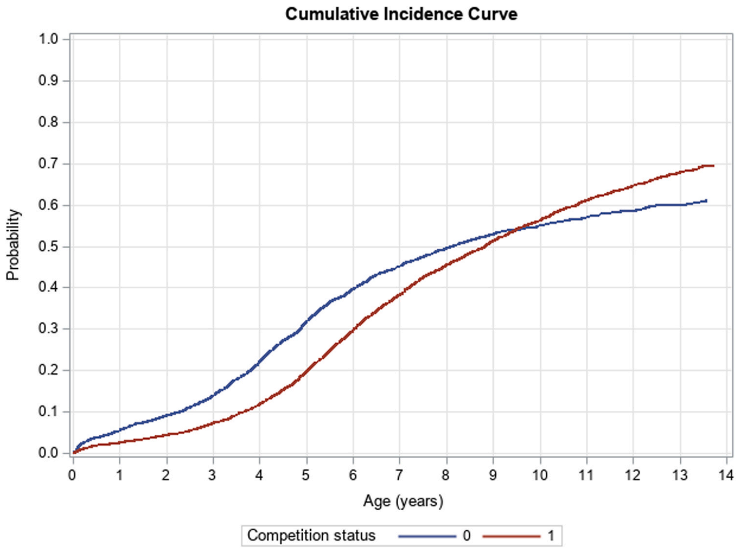

Fig. 4. The probability of having a LOC diagnosis as a function of time (Cumulative Incidence Function) for competed (1) and non-competed (0) horses, respectively. N = 6885 and n = 8317 for competed and non-competed horses, respectively. The median age of the first LOC diagnosis was 8.8 and 8.2 for competed and non-competed horses, respectively.

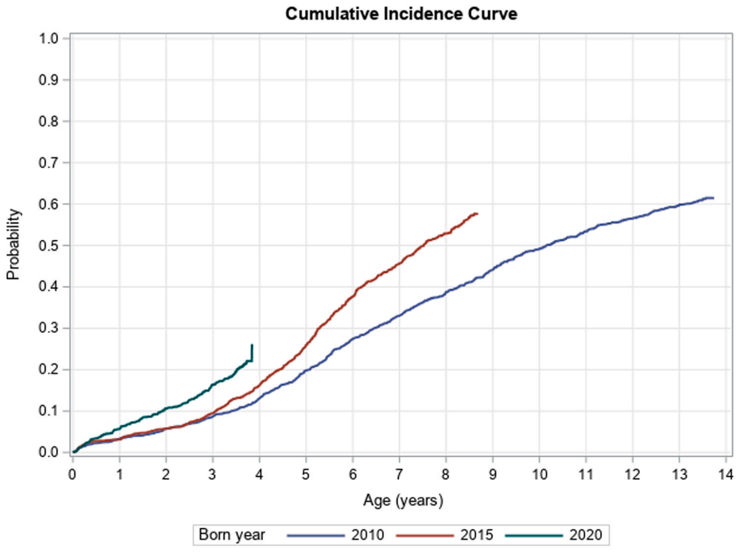

Fig. 5. The probability of having a LOC diagnosis as a function of time (Cumulative Incidence Function) for horses born in 2010, 2015, and 2020, respectively. N = 1492, n = 1176, n = 1189, respectively.

studies (Egenvall et al., 2009). Because few other countries use insurance policies to such a wide extent, the number of studies based on horse insurance date is scarce. Leblond et al. (2000) investigated mortality in 448 insured French horses in 1995, and Higuchi (2006) investigated the prevalence of colic in insured Japanese horses during a three-year period from 2001 to 2003. The insurance data used in this study may have some uncertainties, such as how many horses actually had an injury or how old the horses were when they had their first LOC injury. All horse owners may not use their insurance, even though they have one. There could be several reasons for that, for example that they do not want to have the injury registered, or they may forget or ignore to send in the receipts to the insurance company. Insured horses can have several insurance numbers in the database. Because it was not possible to match all insurance numbers in the database to unique horses, some ICR pertaining to previously matched horses could have been missed. Also, we did not know the termination dates of insurances prior to 2018, which could possibly have an impact on the result of the survival analyses. However, insurance data from Agria was previously validated with clinical records in a study by Penell et al. (2007), and the agreement was high. The same authors concluded that insurance data at least estimates the lower limit of the injury frequency.

The large number of horses in the dataset provides a good basis for drawing conclusions. Also, the proportion of J and D horses in the insurance data was in the same range as in the whole SWB population (Bonow et al., 2023), indicating that the insurance dataset was representative of the population. As much as 56 % of the SWB horse population born from 2010 to2020 was insured by Agria, based on statistics of born foals and number of insured horses.

4.2. Subgroups of LOC diagnoses

Orthopedic diseases are the most common health problem for riding horses, which has been confirmed in several studies (Egenvall et al., 2013; Murray et al., 2010; Penell et al., 2005; Wallin et al., 2000). Also in this study, the diagnosis 'lameness (unspecified)' was the most common diagnosis for both veterinary care (Table 5) and life reimbursement (Table 6), where approximately 10 % of the ICR belonged to this diagnosis. Also, several other more specific orthopedic diagnoses were represented in the statistics of the most common diagnoses for veterinary care for J and D horses (Table 5), e.g., osteoarthritis in the metacarpophalangeal or metatarsophalangeal (fetlock) joint, osteoarthritis in the stifle joint, and suspensory desmitis. Similar results were seen in the study by Penell et al. (2005), where the most common specific diagnosis was osteoarthritis in the fetlock.

In this study, some LOC diagnoses like 'lameness (unspecified)' were broad, whereas others were more specific. Because all LOC diagnoses were classified to solely one subgroup, some diagnoses may have an uncertain classification because they could possibly belong to more than one subgroup. For example, a fractured proximal phalanx could represent both acute trauma and an overuse injury. In this case, we decided to classify fractures as trauma, given that the study population is a riding horse population that would typically experience a lesser risk of stress fractures compared to a race horse population. All 915 diagnoses that were taken into account were connected to the locomotor system, but some have a stronger connection to lameness caused by physical workload or deviations in conformation, for example, most of the diagnoses connected to orthopedic diseases in the extremities (EXT) or in the axial skeleton (AXI). Some other diagnoses could be due to other reasons or unfortunate circumstances. However, we found it reasonable to include all potential LOC diagnoses in this study and separate them into these eight subgroups. It has to be noted that we have not had insight into how a veterinarian had evaluated and registered a particular disease or injury, which could possibly have influenced the results.

Orthopedic disease of the extremities (EXT) and the axial skeleton (AXI) were the most common subgroups of LOC diagnoses, where 34.2–37.9 % and 13.0–14.3 % of the horses (females and males) had a diagnosis connected to these subgroups, respectively (Table 7). These two were by far more common than the other subgroups, thus attention should be paid to reducing these. For example, more research about the etiology behind these diagnoses and targeted information to horse owners about main factors that prevent lameness would be valuable.

The first decile and median age at first diagnosis in Table 8 indicate that developmental disease in limbs or hooves (DEV) are most common in the first year of life, shown by the low decile and median age (0.1–0.3 years). Diagnoses connected to EXT and AXI had a higher first decile age (2.7 and 4.0 years, respectively) and median age (5.3 and 6.2 years, respectively), indicating that the onset of these diagnoses tends to come later in life. The median age corresponds to when most horses have been ridden and competed for a year or two, indicating that the physical strain increases the risk for these types of injuries. In the study by Egenvall et al. (2005), the highest risk for injuries was seen for horses aged 5–15 years. The authors concluded this was probably because most horses had their heaviest workload during that age, which supports our results. Also laminitis (LAM) diagnoses appear later in life, as indicated by the high decile and median age (3.2 and 7.2 years, respectively). This was also seen in studies by Polzer and Slater (1997) and Alford et al. (2001), who found that higher age was a risk factor for laminitis. The median age for first osteochondrosis (OCD) diagnosis was 2.9 years of age, which corresponds to the time when many owners x-ray their horses on a routine basis for future sales or sport career, which may explain a spike in detection at that age.

4.3. Differences between sexes

Male horses had significantly more ICR than female horses (Table 7). This was also seen in the study by Egenvall et al. (2005), where geldings had a higher incident rate for veterinary care than females. The proportion of LOC diagnosis was also significantly higher for male horses than for females, and especially for orthopedic diseases in the extremities (EXT). When using survival analysis, the median age at first LOC was 7.9 and 9.0 years for males and females, respectively (Fig. 1). Similar results were also found in the study by Penell et al. (2005), where geldings were found to have a higher risk for injuries connected to the joints. Also, in a study by Ross and Kaneene (1996), geldings and stallions were found to have a higher risk of experiencing lameness than females in the Michigan horse population. One explanation for males being more affected by lameness than females could be that geldings have no value for breeding, which was considered as one plausible reason in the mentioned studies (Egenvall et al., 2005; Penell et al., 2005; Ross and Kaneene, 1996). Some females will become brood mares early, especially if they have a high breeding value. An owner of a gelding will probably put in high effort to have the horse back as a riding horse when injured, whereas an owner of a mare with health problems may decide to use her for breeding instead. Ricard and Blouin (2011) concluded that females always had a greater relative risk than geldings or stallions to be removed from competition because they could be used for breeding instead. Also in our study, a higher proportion of male horses had been competing compared with females (43.6 % vs. 39.4 %). This was also seen in a study by Murray et al. (2006), where the proportion of geldings in elite show jumping and dressage were 58.7 % and 92.7 %, respectively. It should be noted that in our study, the estimates of proportions for sex were adjusted for competition status in the logistic regression model.

4.4. Differences between jumping and dressage horses

The proportion of horses with a LOC diagnosis was significantly higher for D horses (51 %) than for J horses (44 %) (Table 7). Similar significant differences were also seen for all subgroups, except for OCD and INF. The median age from the survival analysis for the first LOC diagnosis was 7.5 for D horses and 8.9 for J horses. There is no clear explanation for D horses having more LOC diagnoses than J horses. No previous study has investigated the difference in the prevalence of orthopedic disease in horses classified as jumping or dressage horses on a population level. Still, some studies have investigated orthopedic disease in horses competing in show jumping or dressage. In a study by Murray et al. (2006), data from 1069 horses undergoing an orthopedic evaluation between 1998 and 2003 were investigated in relation to sport discipline and performance level. Both discipline and level of performance had a significant effect on diagnosis and that horses competing in show jumping or dressage were predisposed to different types of injuries. In another study by Murray et al. (2010), risk factors for lameness in dressage horses were investigated using a questionnaire sent to members in British Dressage. The authors suggest that dressage horses have an increased risk for suspensory ligament injuries compared with other horse categories, and a plausible factor could be that a considerable load is put on these ligaments during some movements, e.g., collected trot and piaffe.

4.5. Differences between test status

Horses tested at a young horse test had significantly more LOC diagnoses than non-tested horses (Table 7). However, the survival curve (Fig. 3) shows almost no difference in risk between tested and non-tested horses during the first three years of age. From then on, the risk of having a LOC diagnosis increases more rapidly for tested horses than non-tested horses and the median age for the first LOC diagnosis was 7.5 and 9.1 years, respectively. This may be due to a pre-selection for horses tested at young horse tests, inasmuch as the owners of tested horses find them talented and also aim for a competition career. This reasoning is strengthened by the result that tested horses had competed to a higher extent than non-tested horses (60 % vs 47 %).

4.6. Differences between competition status

There was no overall significant difference in the prevalence of LOC diagnoses between competed and non-competed horses. However, there were significant differences for some of the subgroups of diagnoses. Competed horses were predisposed to orthopedic diseases in the extremities (EXT) and axial skeleton (AXI), whereas non-competed horses were predisposed to DEV, TRA, NEU, and LAM. Although our statistical model does not allow for definitive cause-effect conclusions, the results may indicate that competing horses are at a higher risk of having injuries in the extremities and the axial skeleton due to a higher workload and physical strain in comparison with horses that do not compete. Another plausible explanation could be that the owners of a competition horse may be more eager to take the horse to a veterinarian than the owners of a non-competing horse, in case of lameness. Additionally, some of the non-competed horses may not have been able to compete as a consequence of the diagnoses. For example, developmental disease in limbs or hooves (DEV) commonly affect growing horses at a young age, and some of the horses with a DEV diagnosis may not be able to compete due to the diagnosis. This may also be the circumstance for horses having an orthopedic trauma (TRA) at a young age. Neurologic diseases (NEU) usually have a severe impact on the health of the horse and often lead to euthanasia (Rech and Barros, 2015), which may explain the higher proportion NEU diagnoses for non-competed horses. Laminitis (LAM) diagnoses generally affect older horses, and commonly horses with high body condition scores (Alfred et al., 2001). An owner of a competing horse may be more focused on having their horse in a normal body condition than an owner of a non-competing horse, which may explain the higher proportion of LAM diagnoses in non-competing horses. Also, the competing horse is likely to get more exercise which would be beneficial to avoid a high body condition score.

Non-competed horses had a higher risk of having a LOC diagnosis during the first 9 years of age than competed horses (Fig. 4). Slightly before 10 years of age, the curves crossed, meaning that the risk for LOC diagnoses then was higher for competed horses, compared with non-competed horses. The lower risk for LOC diagnoses during the first years for horses that later in life were able to compete probably enabled training and preparing the horses to a higher degree, indicating a pre-selection for competition on health status in addition to talent. Horses are allowed to compete from 4 years of age, and the risk of having an LOC diagnosis started to increase at that age.

4.7. Differences between birth cohorts

The cohort of horses born in 2020 had a higher risk for LOC diagnoses at a young age compared with the cohorts of 2015 and 2010 (Fig. 5). Also, the cohort of 2015 had a higher risk for LOC diagnoses than the cohort of 2010 from around three years of age. This indicates that the risk for LOC diagnoses at a young age has increased with time. There could be several reasons for this, for example, more intense competing with young horses, more discipline-specific training and competing (meaning less variation in training), horses more sensitive to physical strain, and/or owners more eager to contact a veterinarian. Further investigation and monitoring of this development is needed, as orthopedic health in horses is a high priority due to the welfare of horse, the social license to operate equestrian sports, and economic aspects for the horse owner.

5. Conclusions

The majority of the Swedish Warmblood horse population is insured by Agria, making the insurance data a valuable resource for studying orthopedic health within this population. Almost 44 % of the insured horses had at least one locomotor diagnosis. Dressage horses were found to have a higher risk of orthopedic disease compared to jumping horses, male horses were at higher risk than female horses, and horses that had participated in a young horse test showed a higher risk than non-tested horses. While the overall prevalence of orthopedic diagnoses was similar between competed and non-competed horses, the two groups were predisposed to different subgroups of orthopedic diagnoses at different ages. Survival analysis indicated a trend toward developing orthopedic issues at a younger age. These findings highlight the need for further research and monitoring of the orthopedic health of the SWB horse population.

CRediT authorship contribution statement

Sandra Bonow: Formal analysis, Data curation, Writing – original draft, Writing – review & editing. **Elin Hernlund:** Methodology, Data curation, Writing – review & editing, Supervision. **Susanne Eriksson:** Methodology, Data curation, Writing – review & editing, Supervision. **Erling Strandberg:** Methodology, Writing – review & editing, Supervision. **Åsa Gelinder Viklund:** Conceptualization, Data curation, Methodology, Writing – review & editing, Supervision.

Declaration of Competing Interest

Åsa Gelinder Viklund has regular commitments for Swedish Warmblood Association, regarding the routine genetic evaluation.

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Acta Universitatis Agriculturae Sueciae

Doctoral Thesis No. 2026:2

The aims of this thesis were to investigate the specialization of the Swedish Warmblood (SWB) horse population towards show jumping or dressage, and to examine the prevalence and risk of orthopedic diagnoses. Traits assessed in young horses were analyzed to identify associations with sport performance and orthopedic diagnoses. The findings provide insights into the specialization process, the orthopedic health status of the SWB breed, and the potential of assessed traits to enhance sport horse breeding.

Sandra Bonow received her doctoral education at the Department of Animal Biosciences, Swedish University of Agricultural Science (SLU), Uppsala. She received her MSc in Animal Science at SLU, Uppsala.

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