Genetic analysis of competition performance in Swedish warmblood riding horses

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Swedish University of Agricultural Sciences, SLU
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Genetisk analys av tävlingsprestation hos svenska varmblodiga hästar

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Abstract

Genetic evaluation is an important tool in sport horse breeding, as it supports selection of horses with favourable genetic potential for competition performance. In the Swedish Warmblood horse, competition performance is currently evaluated using Lifetime Accumulated Points (LAP), which has limitations because points are mainly awarded to placed horses at higher competition levels. Therefore, alternative performance traits may be useful for improving the use of competition data in genetic evaluation. The aim of this study was to analyse show jumping and dressage competition data from Swedish Warmblood horses and investigate whether Highest Level Achieved (HL) was suitable for use in SWB genetic evaluation.

The data consisted of competition records from the Swedish Equestrian Federation from April 2009 to January 2026. Highest Level Achieved was defined separately for dressage and show jumping according to the highest competition level reached by each horse. Genetic parameters were estimated using animal models, and breeding values, accuracies, stallion rankings and genetic trends were compared with the current genetic evaluation. Genetic correlations between HL and young horse performance test traits were also estimated.

Heritability estimates were moderate to high for both disciplines though slightly higher for show jumping than for dressage, with estimates of 0.44 and 0.33, respectively. The rank-correlations for the new EBV (EBV_{hl}) and the official EBV (EBV_{lap}) were high, 0.86, but not close to unity. Some re-ranking of stallions did occur for the top 30 breeding stallions. The genetic trends were positive and showed good genetic progress over time. Genetic correlations between HL and young horse test traits varied based on discipline, supporting earlier findings of discipline specialisation within the breed.

Overall, HL appears to be a good and genetically informative trait for evaluating SWB competition performance. However, it is also influenced by opportunity to compete, rider, management and longevity, which should be considered in future evaluations.

Keywords: Performance, Genetics, Breeding, Evaluation.

Acknowledgements

During this thesis project I have received a lot of valuable guidance, motivation, and constructive feedback from my supervisor Åsa, for which I am very thankful.

I would also like to thank Therese for being my opponent, your thoughtful comments and support have really helped me with my writing.

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Abbreviations

AFH	Adjusted Fence Height
BTR	Blom-Transformed Ranking
DMU	Derivative-free Multivariate analysis
EBV	Estimated Breeding Value
HL	Highest Level Achieved
LAP	Lifetime Accumulated Points
SAS	Statistical Analysis System
SWB	Swedish Warmblood Association

1. Introduction

Genetic evaluations are central in modern sport horse breeding. These evaluations enable the identification and selection of individuals with desirable genetic characteristics. The Swedish Warmblood Association (SWB), founded in 1918, has had the objective to promote the Swedish Warmblood Horse as one of the world's foremost riding and sport horse breeds, with the aim of producing a noble, correct and durable horse that, through its temperament, high rideability, quality of movement and/or jumping ability, is competitive at the international level (Swedish Warmblood Association 2021; 2026a). During 2025, SWB had 307 registered breeding stallions (Swedish Warmblood Association 2026b), and 2024 approximately 2,700 mares were covered, resulting in approximately 2,300 live-born foals 2025 (Swedish Warmblood Association 2025a). This makes SWB the largest horse breeding organization in Sweden (The Swedish Horse Industry Foundation 2025).

Equestrian sport is one of the most popular sports in Sweden and are predominantly exercised by women (93%) (Idrottsstatistik 2026). According to the Swedish Equestrian Federation, around half a million Swedes participate in equestrian sport for leisure or competition (Swedish Equestrian Federation 2025a) and there are approximately 22,000 licenced competition riders, and 30,000 licenced horses as of 2024. Show jumping accounted for the largest share of starts (77.5%), followed by dressage (19%), eventing (2%) and other disciplines (1.5%) (Swedish Equestrian Federation 2025a). This extensively recorded competition activity provides an important basis for analyses of competition performance and for the development of improved traits for genetic evaluation.

From a quantitative genetic perspective, the way competition performance is defined can influence estimated genetic parameters and the stability of breeding values (Ricard & Touvais 2007; Welker et al. 2018). Increasing availability of detailed competition data from all performance levels, thanks to digital recording systems and centralised databases (Swedish Equestrian Federation 2025b; Equipe Online 2026), provides new opportunities to reconsider how competition performance can be defined. By using a broader range of results, from all competing horses on all levels, it may be possible to better capture the overall competitive ability of horses. This would also make better use of available data and could improve the reliability of genetic evaluation.

In modern breeding programmes for horses, breeding values are usually estimated using quantitative genetic methods, with Best Linear Unbiased Prediction (BLUP) animal models as the standard approach (Thorén Hellsten 2008; Viklund et al. 2010b; 2011; Swedish Warmblood Association 2025b). These models make it possible to simultaneously account for both environmental influences and genetic differences between individuals, while using pedigree information to model the genetic relationships among animals. This kind of genomic selection for sport horses has been implemented in many European countries (KWPN 2006; Vosgerau et al. 2022; Ziadi et al. 2025).

1.1 Competition Performance in the SWB Breeding Programme

The breeding objective for the Swedish Warmblood (SWB) horse is to produce individuals capable of competing successfully in show jumping, dressage or eventing at high levels (Swedish Warmblood Association 2026a). To achieve this, the genetic evaluation system combines information from young horse tests and competition performance (Swedish Warmblood Association 2025b). Young horse tests provide early indicators of genetic potential by assessing conformation, gaits and jumping ability, whereas competition data reflect realised performance later in life (Viklund et al. 2010a).

Competition performance in Sweden is currently defined as Lifetime Accumulated Points (LAP) obtained from competitions and has been used in genetic evaluations in combination with the results from the young horse tests since 2006 (Viklund et al. 2010b; 2011). The current Swedish definition of LAP has limitations that may affect its suitability for genetic evaluation. Although LAP has shown genetic variation, with a reported heritability between 0.15-0.18 in dressage and 0.27-0.28 in show jumping (Viklund et al. 2010b; 2011), the trait is affected by how competition results are converted into points.

In Sweden, points are only awarded to horses placed among the top 25% in 2*-level or higher competitions (Swedish Equestrian Federation 2025c), meaning that all non-placed horses are assigned zero points and all horses competing at lower levels, where 1* is considered the lowest, and 5* the highest, are left out. Furthermore, competitions with too few participants, where it’s a minimum of 5 participants in classes up to Grand Prix, then a minimum of 3, do not generate any points (Swedish Equestrian Federation 2025c). This has become increasingly common in certain disciplines, especially dressage due to declining number of starting horses (Swedish Equestrian Federation 2025a).

1.2 Alternative Approaches to Defining Competition Performance

Genetic evaluation systems for sport horses differ considerably between countries and studbooks, both in the definition of performance traits and in the statistical methods used for breeding value estimation (Doyle et al. 2022).

Two alternative approaches proposed for show jumping performance are the use of Blom Transformed Ranking (BTR) and Adjusted Fence Height (AFH) (Chapard et al. 2023). These methods aim to measure performance by accounting for the difficulty of competitions through fence height, placement and participants. BTR uses ranking within a class together with number of participants in that class in the analysis and AFH combines BTR with the fence height from the same competition.

The authors also suggested that AFH or BTR could provide a more objective and continuous measurement of jumping performance compared with simple rankings or accumulated points. In their study, BTR showed a heritability of 0.06 and AFH had a heritability of 0.12 (Chapard et al. 2023).

Another alternative to measure performance in German sport horses is the trait highest level achieved (HL) (Welker et al. 2018). HL defines performance as the highest competition class successfully reached by a horse during its sporting career. In the study by Welker et al. (2018), HL was treated as a continuous trait in which horses received scores depending on both competition level and success within that level. Participation, placings, and winnings were assigned different points across competition classes ranging from novice to advanced international levels. Horses with less than three records in one class were downgraded to the next lower level. Welker et al. (2018) estimated moderate heritability for HL in both dressage and show jumping, ranging from 0.21–0.24 for dressage and 0.28–0.36 for show jumping, which are considerably higher than other approaches (Aldridge et al. 2000; Chapard et al. 2023).

The Irish Sport Horse evaluation is also based on a single competition trait representing the ranking from all competitions, also including number of faults and time spent in each class, with a single-trait animal model (Aldridge et al. 2000).

However, HL and similar trait definitions have their limitations, and it is still important to account for career length, age of the horse, and also the rider effect on performance. To reduce this bias, Welker et al. (2018) incorporated maximum competition age as a fixed effect in their models. The rider effect is according to the authors, confounded with the horse, and they did not include it.

In Germany, a combined genetic evaluation across breeds is used, including the Hanoverian, Oldenburg, and Holsteiner. The system uses several different traits simultaneously, including transformed rankings from all starts, young horse competition results, as well as HL (Schöpke et al. 2013; Welker et al. 2018). In Germany, single-trait and multi-trait repeatability animal models are used depending on the trait analysed (Doyle et al. 2022).

The Dutch Warmblood (KWPN) genetic evaluation combines information from both competition performance and performance testing (Huizinga & van der Meij 1989; KWPN 2006; Ducro et al. 2007). The evaluation includes placings throughout the horse's competition career together with results from studbook inspections and performance tests. British competition data have previously been used in genetic evaluation studies, particularly in eventing, where the different competition phases, including show jumping, have been analysed (Kearsley et al. 2008).

The environmental effects included in the models also differ between evaluations and countries. However, sex and age-related effects are among the most commonly included factors across studbooks (Doyle et al. 2022). Rider effects are included in models from Denmark and Germany (Doyle et al. 2022), where rider and competition effects are considered important sources of environmental variation influencing performance records. Having horse-rider interaction as a random effect has been shown to increase heritability in some studies (Bartolomé et al. 2018), but its effect is still hard to distinguish from that of the horse (Welker et al. 2018).

1.3 Knowledge gaps

Despite the long-standing use of competition data in sport horse breeding, uncertainty remains regarding how competition performance should best be defined for genetic evaluation. LAP currently used by SWB does not utilise the full amount of available competition information. Several alternative trait definitions have been proposed internationally, including highest level achieved (HL) (Welker et al. 2018), adjusted fence height (AFH) as well as Blom-transformed ranking (BTR) traits (Chapard et al. 2023). Despite this, limited knowledge exists regarding how these alternative definitions perform within Swedish Warmblood horses and whether they are equally applicable across both show jumping and dressage disciplines.

There is a knowledge gap regarding whether utilisation of more complete competition records, including lower competition levels and non-placing performances, could improve estimation of genetic parameters and provide more informative traits for breeding evaluation. As a result, there is a need to investigate alternative definitions of competition performance and to evaluate whether these approaches may improve the genetic evaluation systems.

1.4 Aim of the study

The overall aim of this study was to analyse show jumping and dressage competition data from SWB horses and investigate if the performance definition Highest Level Achieved (HL) is suitable for use in SWB genetic evaluation. Genetic parameters were estimated with two different models and obtained breeding values were used to compare stallion rankings and breeding value accuracies with those from the current genetic evaluation. In addition, genetic correlations between HL and young horse performance test traits were estimated.

2. Materials and Methods

Competition data were obtained from the Swedish Equestrian Federation's competition database and included results from all recorded competitions from 1* up to international level (Table 1) between April 2009 and January 2026. Pedigree data and horse identity information were provided by the Swedish Warmblood Association (SWB). The competition data contained 11 separate files that were imported into the software Statistical Analysis System (SAS) (SAS Institute Inc. 2016). Prior to analysis, the data files needed to be edited, sorted and merged to include all information needed.

This study focused on dressage and show jumping and two discipline specific datasets for dressage and show jumping, respectively, were created. After editing, 8,806 horses had only started 1* dressage competitions and never competed higher, and the corresponding number for show jumping was 8,511 horses.

Table 1. *Distribution of horses after editing by competition status, where 1* is the lowest difficulty and 5* is the highest difficulty.*

Competition Status	Total no. of horses (n)	Horses in dressage (n)	Horses in show jumping (n)	Horses in both disciplines (n)
1*	49,005	11,698	26,237	11,070
2*	43,958	12,754	26,348	4,856
3*	20,737	3,637	16,980	120
4*	3,389	1,036	2,353	0
5*	464	-	464	-
International	4,072	531	3,539	1

The datasets were screened for missing or unrealistic values in the different variables. Incorrect horse identifications were corrected and breeds that were not relevant for this thesis were excluded, only horses registered in the SWB database were kept. Records with missing or inconsistent information in key variables were removed. The distribution of horses by sex and discipline is presented in Table 2. Horses included in the study were born between 1987 and 2021.

Table 2. *Distribution of horses after editing by sex and discipline.*

Discipline	Total horses (n)	Females (n)	Males (n)
Dressage	26,613	11,438	15,175
Show Jumping	39,988	19,961	20,027
Total	66,601	31,399	35,202

2.1 Classification and Adjustment of Competition Difficulty

Classes were described using the categories L, M and S. These letters refer to increasing levels of difficulty: L represents easy/lower level, M represents medium level, and S represents difficult/highest level. The complete classification system used in the data editing process is presented in Appendix 1. Within each of these main categories L, M and S, stars were used to further separate classes of different difficulty (Table 3, Appendix 1). In the end, there were 8 difficulty classes in dressage and 9 classes in show jumping. For dressage, the changes in difficulty represented how advanced the movements were in each dressage test. For jumping, the classification was based on fence height.

The competition difficulty levels represented in the dataset ranged from LE (Easy E) to international Grand Prix in dressage and from 80 cm to 165 cm fence height in show jumping (Appendix 1). The original competition classification was based as far as possible on the already established Swedish Equestrian Federations difficulty classification system (Swedish Equestrian Federation 2025c).

To allow the difficulty level to be used as a numerical trait in the statistical analyses, each class was assigned a corresponding numerical value. Young-horse dressage classes, Para dressage classes and Special Olympics dressage classes were also assigned difficulty levels by looking at the most advanced movement performed in that class and matching them to the most comparable standard dressage class.

The new performance trait Highest Level Achieved, hereafter referred to as HL, was developed by Welker et al. (2018) to describe the highest competition level achieved by each horse. In the present study, HL was calculated according to the method described by Welker et al. (2018). In addition to the numerical difficulty score assigned to each competition class, the horse's result within the competition class was used to further adjust the trait value. A horse that competed in a class but was not placed kept the original difficulty score and was given an added value of 0.0. A horse that was placed in the class, but did not win, received an additional 0.3, while a horse that won the class received an additional 0.6 (Table 3).

***Table 3**. Classification of difficulty for both disciplines and adjusted scoring of Highest Level Achieved (HL).*

Classification of difficulty	Participation (not placed)	Placed (not winning)	Winning (first rank)
L*	1.0	1.3	1.6
L**	2.0	2.3	2.6
L***	3.0	3.3	3.6
M*	4.0	4.3	4.6
M**	5.0	5.3	5.6

S*	6.0	6.3	6.6
S**	7.0	7.3	7.6
S***	8.0	8.3	8.6
S****	9.0	9.3	9.6

After calculating the adjusted scores for all competition records, only the highest value recorded for each horse was kept. Distribution of HL is presented in figure 1. Because the distribution of HL was found not to be normally distributed, a logarithmic transformation of the trait was also considered. The transformed trait was also analysed initially, but the differences between the untransformed and the transformed trait was negligible, and the logarithmic traits was therefore not tested further.

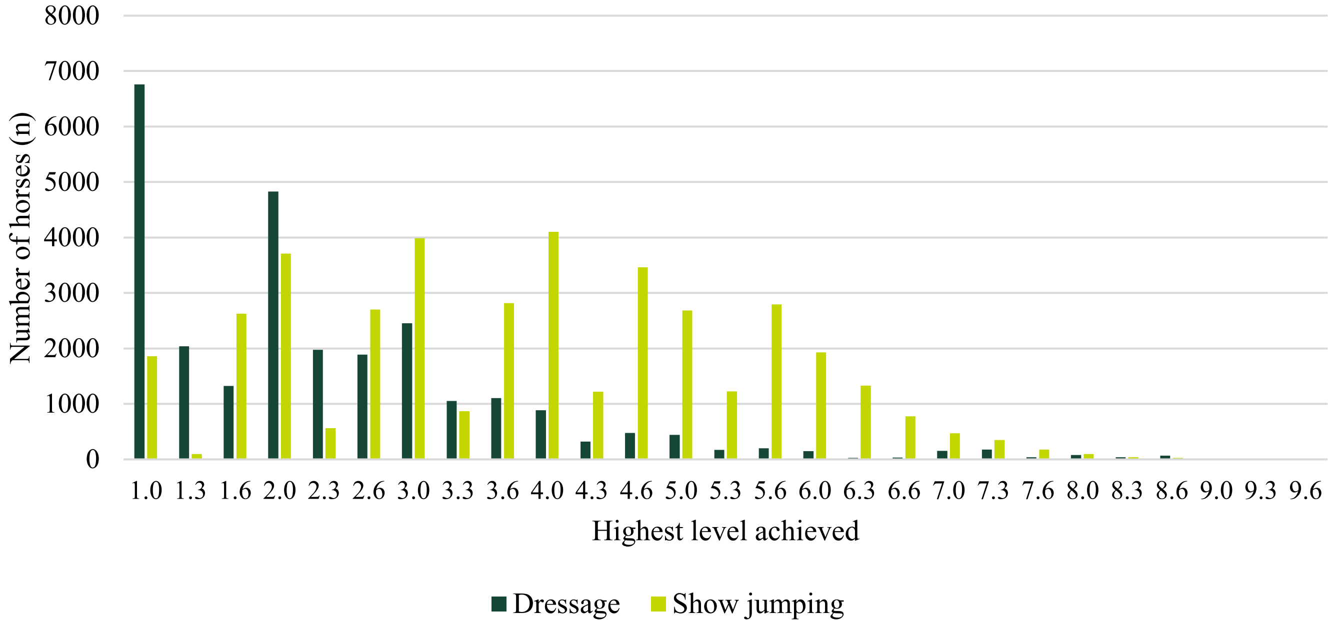

***Figure 1**. Distribution of Highest Level Achieved (HL) by discipline.*

2.2 Preliminary statistical analyses

Initial analyses were carried out in SAS (SAS Institute Inc. 2016) using PROC GLM and PROC MIXED. SAS was used to examine which effects were significantly associated with HL before the genetic analysis were performed. Competition year (comp_year), birth year (birth_year), age at competition (age_at_comp) and sex of the horse, where all significant and included in the models for further genetic analysis.

The fixed effects birth year, competition year, and age at competition were not all included in the same model because age at competition is directly derived from birth year and competition year. This creates linear dependency among the effects, meaning that their individual contributions cannot be estimated independently. To avoid this problem, only two of these effects were fitted at the same time. The different models were further evaluated using coefficient of determination (R^2), and Akaike's Information Criterion (AIC). A lower AIC and a higher R^2 were interpreted as indicating a better model fit (Table 4).

Although one of the models was deemed more suitable for the main analysis, both models were retained and tested. This was done to allow a more complete evaluation of the data and to assess how sensitive the results were to differences in model structure. The best model was therefore used as the primary basis for interpretation, while the second model served as a complementary analysis and contributed to a broader understanding of the data.

Table 4. *Comparison of alternative fixed effects for HL in dressage and jumping, based on coefficient of determination (R^2) and Akaike's Information Criterion (AIC) values.*

Discipline	Fixed Effects	R^2	AIC
Dressage	comp_year + age_at_comp	0.06	89639
	birth_year + comp_year	0.09	88975
Jumping	comp_year + age_at_comp	0.0012	151512
	birth_year + comp_year	0.07	148846

2.3 Genetic analysis

Genetic analyses were performed using univariate and bivariate animal models in DMU (Madsen & Jensen 2013), a software package developed for fitting mixed linear models in quantitative genetic studies. DMU was used to estimate variance components (genetic and residual) for the competition trait HL. Depending on the analysis, Y represented one of two traits: HL in dressage or HL in jumping. Two alternative animal models were evaluated:

$$Y_{ijkl} = \mu + sex_i + comp\_year_j + age\_at\_comp_k + a_l + e_{ijkl} \text{ (model 1)}$$

$$Y_{ijkl} = \mu + sex_i + birth\_year_j + comp\_year_k + a_l + e_{ijkl} \text{ (model 2)}$$

where Y_{ijkl} is HL in dressage or showjumping for the lth horse, μ is the overall mean, sex_i is the fixed effect of sex (male, female), $comp\_year_j$ is the fixed effect of competition year (2009 to 2026), $birth\_year_j$ is the fixed effect of birth year (1987 to 2021), $age\_at\_comp_k$ is the fixed effect of age at competition (4 to 30), a_l is the random additive genetic effect of the lth horse $\sim N(0, A\sigma_a^2)$, and e_{ijkl} is the random $\sim N(0, I\sigma_e^2)$ residual effect. As the resulting variance components from both models were similar to each other, breeding values from model 2 was used for the following analyses.

2.3.1 Standardization and comparison of Breeding Values and re-ranking of stallions

Estimated breeding values and accuracies obtained from the genetic analyses were compared with the existing official breeding values for breeding stallions (Swedish Warmblood Association 2025b). To make the breeding values from this study comparable with official EBVs (EBV_{lap}), they were transformed to the same scale using the following equation (Viklund et al. 2011):

$$EBV_{hl} = \mu + \left(\frac{EBV_u - m_u}{SD_a}\right) \times SD_d$$

where EBV_{hl} is the transformed breeding value for each horse, μ is the mean of EBV equal to 100, EBV_u is the estimated breeding value on the original scale from the analyses, m_u is the mean of estimated breeding values from the reference population, i.e. all horses in this study, SD_a is the additive genetic standard deviation of all competing horses in the data, calculated as the square root of the genetic variance, and SD_d is the desired genetic standard deviation of EBV, fixed to 20 units (Viklund et al. 2011). The EBV_{hl} were used to visualize the genetic trend by birth year for HL dressage and show jumping, respectively. The accuracy was defined as the correlation between true and estimated breeding value (rTI) (Viklund et al. 2011) calculated as:

$$r_{ti} = \sqrt{1 - \frac{\text{PEV}}{\sigma_a^2}}$$

In the equation, PEV represents the predicted error variance from the BLUP equations, and σ_a^2 is the additive genetic variance obtained from the DMU analysis. For the stallions with published EBV_{lap} from the genetic evaluation in 2025, EBV_{lap} was compared to EBV_{hl}. Only stallions that had offspring in the competition data in the present study were included, resulting in 645 stallions with dressage competing offspring, and 629 stallions with show jumping competing offspring. The relationship between the EBVs was evaluated using Spearman correlation. Stallions were also ranked based on EBV_{lap} and EBV_{hl}. Stallions in the top 30 in each discipline were compared.

2.3.2 Genetic Correlations with young horse performance

Genetic correlations between HL and young horse performance test (YHT) traits were estimated using bivariate animal models. The traits from YHT were walk, trot, canter, jumping technique and jumping temperament & general expression. For this, HL model 2 (see above) was used, and for YHT traits the following animal model was applied:

$$Y_{ijk} = \mu + sex_i + event_j + a_k + e_{ijk} \text{ (model 3)}$$

where Y_{ijk} is the individual scores from the young horse test for horse k. μ represents the overall mean, sex_i is the fixed effect of sex (male, female), $event_j$ is the combined effect of test year and location (1 to 712), a_k is the random additive genetic effect of the kth horse $\sim N(0, A\sigma_a^2)$, and e_{ijk} is the random $\sim N(0, I\sigma_e^2)$ residual effect.

In this thesis, AI-based writing tools were used to assist in language-related aspects, such as translation and grammar.

3. Results

The estimated genetic parameters for HL are presented in Table 5. Across both disciplines; the heritability estimates were moderate to high (0.33-0.46), with a little higher estimate for show jumping. The genetic variance estimates for HL were very similar between the two models, and the residual variance was slightly higher in the model including birth year and competition year.

Table 5. *Heritability (h^2), additive genetic variance ($\sigma^2 a$), and residual variance ($\sigma^2 e$), with standard error as subscripts, for highest level achieved (HL) in dressage and show jumping. Model 1 included fixed effects sex, competition year and age at competition. Model 2 included sex, birth year and competition year as fixed effects.*

Trait	h^2	$\sigma^2 a$	$\sigma^2 e$
Dressage (HL)			
Model 1	$0.34_{0.02}$	$0.48_{0.02}$	$0.93_{0.02}$
Model 2	$0.33_{0.02}$	$0.48_{0.02}$	$0.99_{0.02}$
Show Jumping (HL)			
Model 1	$0.46_{0.01}$	$0.92_{0.03}$	$1.09_{0.02}$
Model 2	$0.44_{0.01}$	$0.96_{0.03}$	$1.20_{0.02}$

3.1 Comparison Between EBVs

In total 645 stallions with dressage competing offspring, and 629 stallions with show jumping competing offspring that had at least one offspring with competition results, received EBVs and were included in the comparison. The number of stallions that were in the top 30 for EBVs for both LAP and HL are shown in Figure 2. No stallions were among the top 30 in both disciplines.

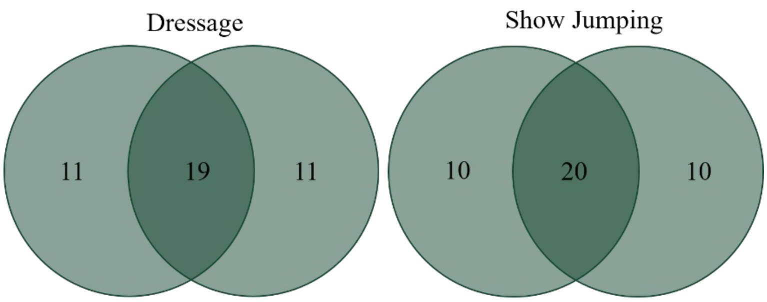

Figure 2*. Venn diagram representing the number of stallions in the top 30 in dressage and show jumping EBV_{lap} and EBV_{hl}, and their corresponding overlap.*

In dressage, one stallion ranked 2nd in both EBVs, and the top stallion in EBV_{hl} was placed on 11th place in EBV_{lap}. The number one stallion in EBV_{lap} had 3rd place in EBV_{hl}. The biggest re-ranking was seen for stallions that were ranked 114th, 80th and 68th in the official EBV_{lap} and in the new EBV_{hl} they received rankings 25th, 9th and 7th. For the top 30 stallions in dressage, the accuracies ranged from 0.62-0.97 for EBV_{hl}, and 0.75-0.97 for EBV_{lap}.

For show jumping one stallion ranked 3rd in both EBVs, and the top stallion in EBV_{hl} was ranked 2nd in EBV_{lap}. By comparison, the number one stallion in EBV_{lap} had rank 7th in EBV_{hl}. The biggest re-ranking between the show jumping EBVs were stallions that were ranked 135th, 92nd and 91st in the EBV_{lap} and in the new EBV_{hl} had received corresponding rankings 19th, 17th and 14th. For the top 30 stallions in show jumping the accuracies ranged from 0.80-0.99 for EBV_{hl}, and 0.85-0.99 for EBV_{lap}.

For dressage the rank correlation was 0.86 between EBV_{lap} and the new EBV_{hl}. For jumping, the corresponding correlation was slightly higher, at 0.88. The relationship between the official breeding values (EBV_{lap}) and the calculated EBV (EBV_{hl}) is shown in Figure 3 & 4.

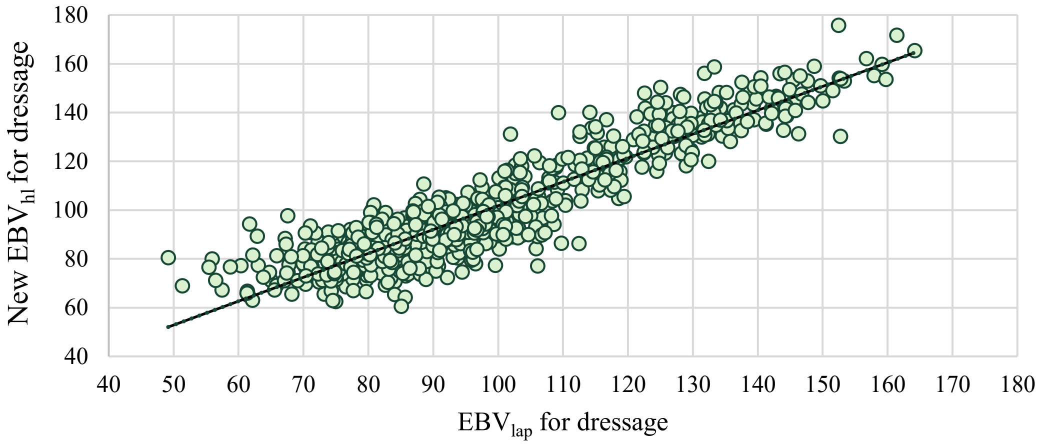

Figure 3. *Relationship between EBV_{lap} and EBV_{hl} in dressage.*

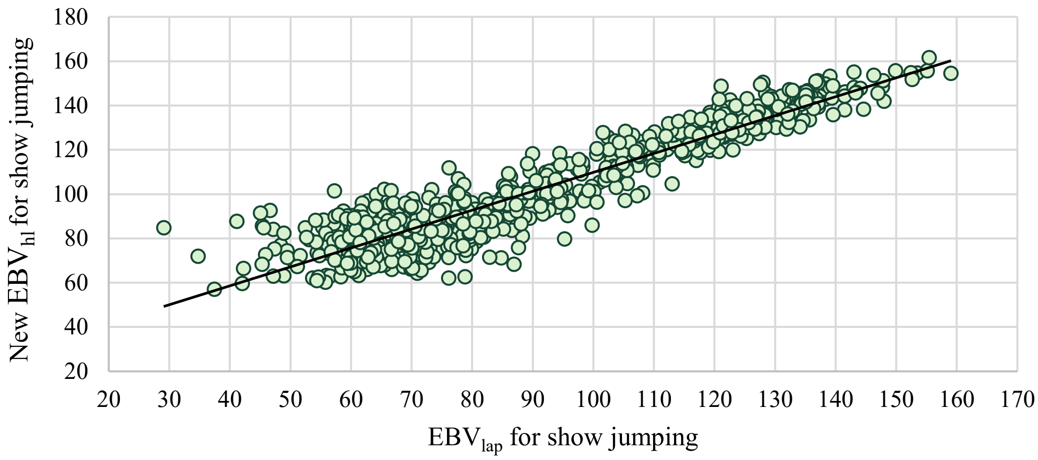

Figure 4. *Relationship between EBV_{lap} and EBV_{hl} in show jumping.*

3.2 Genetic Trends in Competition Performance

Genetic trends for HL in dressage and show jumping, respectively, were assessed using the mean EBV_{hl} for each birth year between year 1990 and 2021. For both dressage and show jumping, the mean EBV_{hl} increased over the years with 1.32 units/year for dressage, and 1.22 units/year for show jumping (Figure 5 & 6). Compared with dressage, the annual means for show jumping showed somewhat greater variation between individual years, but the long-term trend was still positive.

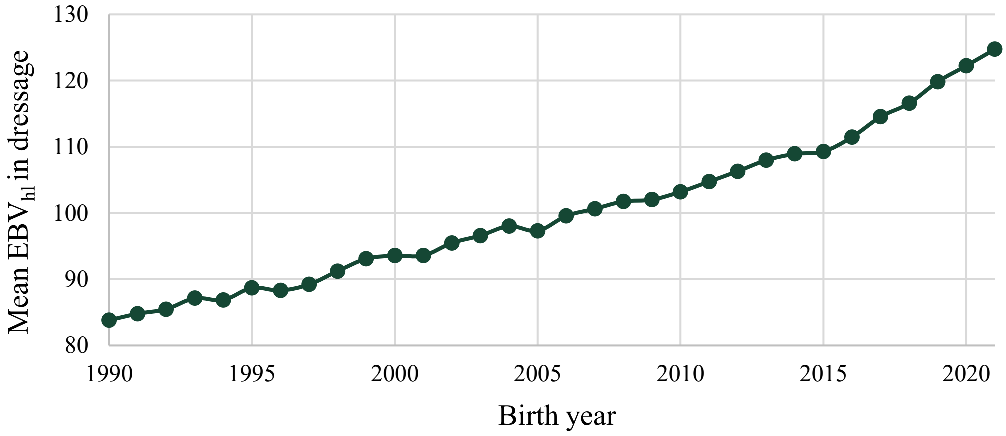

Figure 5. *Genetic trend for dressage based on mean EBV_{hl} by birth year for horses born between 1990 and 2021.*

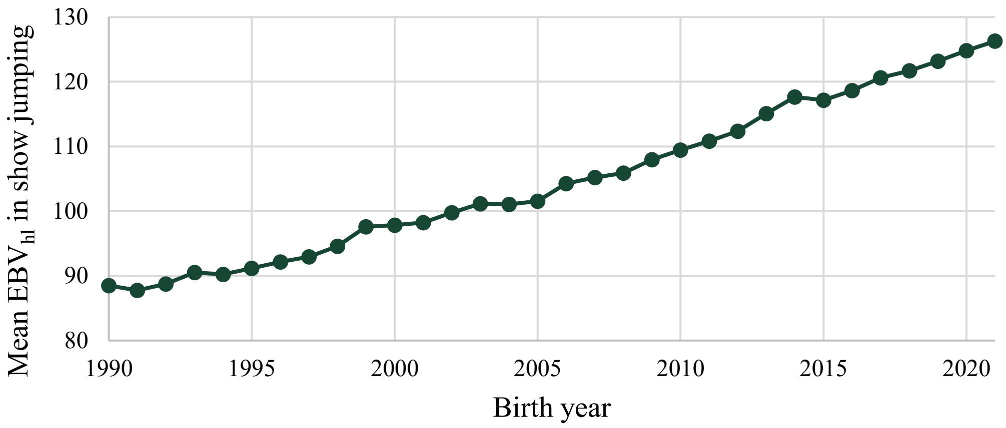

Figure 6. *Genetic trend for show jumping based on mean EBV_{hl} by birth year for horses born between 1990 and 2021.*

3.3 Genetic Correlations between Competition Performance and Young Horse Tests

For dressage, the young horse test (YHT) gait traits showed positive genetic correlations (0.58-0.74) with later dressage performance, with the strongest relationship found between HL and trot (Table 6). The jumping traits showed negative genetic correlations with later dressage performance. For show jumping, the highest genetic correlations (0.77-0.78) were found with the YHT jumping traits, while the correlations with the gait traits were weak (Table 6). Canter was the only gait positively correlated to HL in show jumping. The residual correlations were generally low across the analyses. The heritability estimates for HL from the bivariate analysis (Table 6) were slightly lower than from the estimates from the univariate analysis (Table 5).

Table 6. *Genetic correlations (r_g), phenotypic correlations (r_p), and heritability with standard error as subscript, between young horse test (YHT) traits and later competition performance in show jumping and dressage, respectively.*

	Dressage		Show jumping		
Trait	r_g	r_p	r_g	r_p	h^{2*}
Show Jumping					$0.42_{0.02}$
Dressage					$0.30_{0.04}$
YHT - Walk	$0.58_{0.04}$	0.15	$-0.17_{0.03}$	-0.02	$0.32_{0.02}$
YHT - Trot	$0.74_{0.03}$	0.23	$-0.02_{0.03}$	0.03	$0.51_{0.02}$
YHT - Canter	$0.58_{0.03}$	0.20	$0.20_{0.04}$	0.14	$0.36_{0.02}$
YHT – JT**	$-0.22_{0.04}$	-0.01	$0.78_{0.03}$	0.26	$0.30_{0.02}$
YHT – JTG***	$-0.24_{0.05}$	-0.02	$0.77_{0.03}$	0.22	$0.21_{0.01}$

** = Heritability for young horse traits are average values from both disciplines with the highest standard error as subscript. ** = Young horse test – Jumping Technique. *** = Young horse test – Jumping Temperament & General Expression.*

4. Discussion

The aim of this thesis was to evaluate Highest Level Achieved (HL) as an alternative performance trait for genetic analysis of competition performance in Swedish Warmblood horses.

The dataset contained more geldings and stallions than mares, with approximately 36,000 males compared with 31,000 females (Table 2). This could reflect the differences in management between mares, geldings and stallions. Mares may be removed from sport temporarily or permanently for breeding, whereas geldings are generally used only for sport or leisure. Rider and owner preferences may also contribute to this pattern. Fenner et al. (2019) found that geldings were more often described as calm, reliable, predictable, safe and trainable, while mares were less preferred for both dressage and show jumping. The higher number of males in the present dataset may therefore reflect human selection, breeding use of mares and differences in opportunity to compete.

The distribution of HL differed clearly between dressage and show jumping (Figure 1). Dressage showed a strong concentration of horses at the lowest levels, whereas show jumping had a broader distribution across low and middle levels, and had much more of a bell curve shape. This difference could be because of competition opportunity. There are more competition starts in show jumping than in dressage, because dressage tests take longer than a show jumping round, so you can fit in more horses per hour, as well as more judges needing to be present for dressage, the entry fees are usually a little higher for dressage (Swedish Equestrian Federation 2025b). It could also be because there is a bigger interest for show jumping in Sweden (Bonow et al. 2023; Swedish Equestrian Federation 2025a).

4.1 Heritability for Highest Level Achieved

The heritability results from the genetic analyses suggest that HL contains genetic variation and may therefore be a suitable trait for genetic evaluation of competition performance. The heritability estimates were moderate to high in both disciplines. The higher heritability estimates in show jumping compared with dressage are expected, as they are consistent with previous studies (Viklund et al. 2010b; 2011; Welker et al. 2018) and may indicate that the trait captures genetic differences in performance more clearly in that discipline. The estimates were also relatively consistent between the two model structures, indicating that the results were not strongly dependent on whether age at competition or birth year was included in the model.

The higher heritability estimates in show jumping could be because the data shows significantly more starts and more horses in that discipline compared to dressage (Table 1). More records provide more information about each horse and its relatives, making it easier for the analysis to separate genetic- and environmental effects, resulting in more accurate heritability. This difference could also be because the classification of show jumping levels is based on fence height, which provides a more objective and linear measure of increasing difficulty. In dressage, the difficulty is based on the complexity of the movements in the test, which may involve a more subjective judgement and a higher risk for judgement bias.

4.2 Rank correlations between EBVs

The rank correlations indicate that the EBV_{hl} were largely consistent with the official EBV_{lap} (Figure 3 & 4). The high rank correlations suggest that the models used in this study captured much of the same genetic variation as the current official evaluation, while the remaining differences may reflect differences in data availability, model structure, trait definition, or the fixed effects included in the analysis.

Some re-ranking of stallions in both disciplines did occur, this is expected because EBV_{hl} and the current EBV_{lap} are not based on the same trait definition. LAP is a cumulative trait; it is influenced by how long a horse stays in sport and if it is placed and competes in point-giving classes. HL is more like a threshold, a horse that reaches high level once gets the same score as horses that have competed at the same level many times. Therefore, stallions that have many offspring competing consistently at medium level may then get a higher EBV_{lap} than a EBV_{hl}. In the same way as a stallion that have had few competing offspring, but some of them reached a high level may score higher for EBV_{hl} than EBV_{lap}.

The accuracies for both EBVs were generally high, but the EBV_{hl} did show a slightly wider range. This is likely due to differences in the amount of information available for each stallion and the fact that the official breeding values also include young horse performance test results and that only stallions with at least 10 offspring in young horse tests are receiving official EBVs, whereas all stallions were included in this study of EBV_{hl}.

4.3 Genetic trends for HL across birth years

The genetic trends for HL showed a clear positive development in both dressage and show jumping, indicating that the average genetic merit for reaching higher competition levels has increased in horses born from 1990 to 2021 (Figure 5 & 6). Horses born before 1990 were not included in the genetic trends, as they were very few individuals. These findings are consistent with the long-term development described for the Swedish Warmblood population (Viklund et al. 2011).

In the study from Viklund et al. (2011), genetic progress was limited until the mid-1980s, after which improvement increased in both show jumping and dressage.

The annual genetic gain was 0.056 genetic standard deviation units per year for show jumping and 0.032 for dressage between the years 1985–2002.

4.4 Genetic correlations between HL and YHT

The genetic correlations between HL and young horse test (YHT) traits showed clear discipline-specific relationships. In show jumping, the highest positive correlations were found between HL and Jumping technique and Jumping Temperament & General Expression. This suggests that the jumping traits recorded at YHT are genetically related to later competition performance in show jumping. The same conclusion can be drawn from the correlations in the dressage traits. Walk, trot and canter had all strong positive correlations with future successful dressage careers.

The negative genetic correlations between dressage HL and the jumping traits, and with the gaits walk and trot for jumping HL, are also consistent with the idea that the SWB population are moving towards stronger specialisation for either dressage or show jumping (Bonow et al. 2023). Although SWB is still one breed, breeders often select stallions with a clear discipline profile, and the results from this study support the idea that different genetic components contribute to success in different disciplines.

Earlier research show correlations in the same direction. Viklund et al. (2011) showed positive genetic correlations between YHT and competition performances similar to the findings in this study. For instance, walk, trot and canter had positive correlations between 0.30-0.34 with later dressage performance, and in show jumping the two YHT jumping traits had positive correlations of 0.62 and 0.66 with later show jumping performance (Viklund et al. 2011). The study also estimated correlations between Riding Horse Quality Test (RHQT) and later competition performance and found the same pattern. This agreement with previous studies supports the results of the present study and suggests that HL is a relevant measure of discipline-specific sport performance. It also shows that YHT traits may be useful together with HL in future multi-trait genetic evaluations.

In the future, SWB may need to consider that dressage and show jumping need separate breeding goals, rather than as two expressions of the same general sport-horse ability. At the same time, genetic diversity needs to be maintained, as a too strict selection can negatively affect soundness, temperament and rideability. It is also important to remember that there is still a large part of the equestrian community that wants all-round horses, as seen in the data for the present study were 11,000 horses had starts in both disciplines.

4.5 Choice of trait and alternative trait definitions

The use of HL has several advantages in the context of Swedish Warmblood competition data. In contrast to the current LAP system that include competitions from 2* and higher, HL makes use of information from 1* and higher. This is important because a large proportion of horses compete at low or medium levels (Table 1). HL is also relatively easy to interpret. A horse with a high HL has reached a high level of competition, and the trait therefore reflects realised competition capacity. This makes the trait understandable for breeders, riders and breeding organisations. In addition, HL can be applied to both dressage and show jumping, which was important in this study since both disciplines were included. HL is also used successfully by the Dutch Warmblood breeding organisation but with a different definition (Huizinga & van der Meij 1989; Ducro et al. 2007).

Another advantage of HL is that it reduces a large amount of competition information into a single observation per horse. This simplifies the dataset and makes the trait more straightforward to analyse. To only have one record per horse makes it easier to handle in routine genetic evaluations, which is positive if the trait is to be considered in future genetic evaluation in a multi trait model with young horse test data.

One limitation of HL is that it does not require information on number of competitors, or exact competition conditions, this means that some information is lost. For example, two horses may both have reached the same level, although one was consistently successful at that level while the other only competed there once. To mitigate this, Welker et al. (2018) downgraded horses to the next lower level if the horse had had less than three starts in their highest level. In hindsight, not doing this in this study is a limitation because consistency, career length, longevity and repeated success are important aspects of sport horse performance.

Using number of years in competition as a trait for durability or longevity was investigated by Braam et al. (2011), and was considered a good indicator for health and sport performance because it reflects whether a horse remains sufficiently sound, durable and competitive to continue performing over time. The heritability was estimated between 0.07 and 0.17 depending on model. Combining information on HL with measures of competition longevity may therefore provide a more complete description of functional durability, as it would distinguish horses that reach high levels briefly from those that remain active and competitive over several years.

The approach of using a numerical difficulty score to measure success within a competition was based on the paper from Welker et al. (2018). The adjustment values 0.0, 0.3 and 0.6 were used to distinguish between participation, placing and winning within the same competition level. In extension, this also means that a horse that wins in a lower level still receives a lower HL score than a horse that just participated in a class one difficulty higher. This is reasonable because moving up to a higher competition level generally reflects a higher degree of training, ability and competition capacity.

Other scoring numbers could have been used instead, or a larger step up for wins and placings. However, larger increments could have created problems by making performance within a lower level too similar to participation at a higher level. And since the class was split in three (participation, placing, winning), the easiest solution was to also split the scoring into thirds.

But this scoring system is still a simplification. It assumes that the difference between participation, placing and winning is similar across all levels and both disciplines. The meaning of a placing or a winning may differ depending on the number of competitors, competition level and discipline.

The previously mentioned Adjusted Fence Height (AFH) would have been a good alternative trait to evaluate for show jumping. That trait may offer a more refined measurement of competition performance and may utilise within-level variation better. But because the trait is difficult to translate to dressage, it limits its practical applicability in this thesis. In the future, it may be possible to have different models for different disciplines, and AFH could be an alternative for show jumping.

4.6 Method Choice and Limitations

The use of an animal model was a good choice for this thesis; the animal model is a standard and well-established method in quantitative genetics and is particularly suitable when data from related individuals are available.

One limitation of the dataset is that competition data for 2026 only covered the period January 2026, resulting in fewer competition starts for that year compared with previous years. Although 2026 was still kept as a separate competition year in order to avoid combining records from different calendar years, the limited amount of data for this class may have reduced the stability and comparability of the year effect.

Another limitation in the study was that all horses with competition records were included, regardless of the number of starts. This means that horses with only one start in its career contributed to the analysis in the same way as horses with longer and more complete competition careers. For these horses, the recorded HL may be a less reliable measure of true performance capacity. Horses with very few starts may also increase residual variation in the model. Horses with more starts have more chances to reach a higher level, whereas horses with few starts may be underestimated. This can make the phenotype less comparable between individuals and may reduce the precision of breeding value estimation.

4.6.1 Accounting for Rider Influence in Animal Models

Including rider in an animal model for sport horse competition traits can be biologically and statistically relevant, because competition performance is not only an expression of the horse's genetic ability, but also influenced by the rider's skill, experience, training strategy and ability to present the horse in competition. Rovere et al. (2016) state that ignoring rider effects may cause part of the rider's contribution to be incorrectly attributed to the horse, which can skew estimates of genetic variance and heritability.

Bartolomé et al. (2018) found that including a horse-rider interaction effect increased heritability, and Kearsley et al. (2008) argued that including rider significantly improved the fit of their model. The results further demonstrated that rider variance could be large, especially in dressage, and that the rider effect tended to become more important as competition level increased (Kearsley et al. 2008).

Some difficulties associated with including rider still remained. The authors emphasised that quantifying horse and rider separately required extensive datasets in which both horse and rider were uniquely identified, and such data are not always available. Records without rider information needed to be excluded from the study, and older records had not been recorded consistently. The analysis itself was also computationally demanding and required model adaptations to obtain convergence (Kearsley et al. 2008).

This shows that although rider may improve biological realism, inclusion of rider also increases data requirements and model complexity. Bajková et al. (2025) omitted rider from their analysis of jumping performance because many horses were ridden by only one rider and some riders competed only one or two horses, resulting in higher risk of confounding between horse and rider, as also supported by other sources (Rovere et al. 2016; Welker et al. 2018). This makes it difficult to separate whether a high competition result is due to the horse's genetic merit or the rider's ability. This is especially relevant in dressage, where the study from Rovere et al. (2016) found a higher proportion of riders with only one recorded horse than in show jumping.

In this thesis, the choice was made to not include the rider as a random effect in the animal model due to the confounding between horse and rider, and to limit data complexity.

4.7 Number of starts and data structure

In this thesis, all horses with competition records were included in the study. A discussion was made whether only to include horses that for example, had a minimum of three starts in each difficulty level. That restriction may have given a more reliable measure of competition ability, because horses with very limited information contribute more uncertain phenotypes.

One other important aspect is the number of competition starts available for each horse. In Sweden, the number of registered competition starts has decreased over time (Swedish Equestrian Federation 2025a). This can also be seen in the data from this study. In dressage the number of starts has dropped 48%, and in show jumping 26% between year 2012 and 2025, with a significant drop during the Covid-19 pandemic. A decreasing number of starts can influence the results in many ways. Horses with fewer starts may be more likely to remain at a lower recorded HL, even if they have higher potential. Younger horses may appear genetically inferior or less developed if they have not yet had good opportunity to compete, and decreasing number of available competitions and economic difficulties, may influence the amount of performance information available.

4.8 Social, ethical and sustainability implications

Genetic evaluations and breeding of sport horses must be done responsibly and ethically. Breeding for improved competition performance can contribute to producing horses that are better suited for their intended use, but it may also increase selection pressure. If performance traits are used without considering health, temperament and welfare, there is a risk that breeding decisions favour extreme phenotypes at the expense of long-term soundness, as seen in food production species and certain dog breeds (Ablondi et al. 2022; EFSA AHAW Panel et al. 2023; Bonow et al. 2024; Frehner & Hartnack 2026). HL is not meant to be a welfare trait, so a horse that has reached a high level of competition is not automatically a horse with a high quality of life. Therefore, performance traits should always be used together with information on health, longevity, temperament and conformation, for a sustainable sport.

There is also an aspect related to the fairness in evaluation. Horses differ in their opportunities to compete depending on owner resources, rider skill, geographical location and economic circumstances. If these environmental differences are not fully accounted for, breeding values may partly reflect human-related factors rather than the horse's genetic potential.

The use of competition performance in genetic evaluation should also be considered in relation to the broader Social License to Operate (SLO) of equestrian sport, as well as using horses for competitions in general. SLO refers to the informal acceptance given by society to an industry or activity (Heleski 2023), and it is increasingly relevant for all activities that include using animals for leisure, sport or entertainment. Equestrian sport and its SLO is dependent on public trust, transparency, shared ethical values and the demonstration that horse welfare are prioritized in practice, not only in communication (Douglas et al. 2022).

Considering what we do with our horses in relation to breeding and sport is important because breeding goals influence the type of horses produced for future competition. If selection focuses too narrowly on performance, there is a risk that traits such as health, durability, temperament, rideability and long-term welfare receive less attention. Genetic evaluation can contribute positively to SLO if it supports breeding for horses that are not only performing on a high level, but also sound (both mentally and physically), durable and suitable for their intended discipline.

4.9 Future research

Future research should evaluate alternative definitions of competition performance for comparison with HL, such as Blom Transformed Ranking (BTR) and Adjusted Fence Height (AFH) for show jumping (Chapard et al. 2023). For dressage, further work is needed to develop performance traits that capture quality of performance in a comparable way.

It would also be useful to investigate the effect of applying a minimum number of starts at a certain level, such as three starts, before assigning HL. Another important area for future research is the inclusion of additional fixed effects, such as rider, or career length. These effects could help separate genetic differences between horses from environmental differences in opportunity and management, if done correctly.

Finally, future studies should investigate how HL can be combined with health, longevity and welfare traits in a broader breeding goal. Competition performance is important in sport horse breeding, but sustainable and ethical genetic improvement requires that performance is balanced against durability, soundness and horse welfare.

5. Conclusion

The overall aim of this study was to analyse dressage and show jumping competition data from Swedish Warmblood horses and investigate whether Highest Level Achieved (HL) could be a suitable trait for genetic evaluation. The trait could be applied to both dressage and show jumping and made use of a broader part of the available competition data than the current lifetime accumulated points-based system.

The heritability estimates for HL were moderate to high in both disciplines, with higher estimates in show jumping than in dressage. This indicates that there is additive genetic variation in HL and that selection for improved competition performance based on this trait would be possible. The two model structures gave similar heritability estimates, suggesting that the results were relatively robust to the choice of fixed effects. The comparison between the current EBV_{lap} and the new EBV_{hl} showed relatively high rank correlations in both disciplines, although re-ranking did occur among the top 30 stallions. The genetic trends were positive and showed good genetic progress over time. The genetic correlations with young horse tests showed clear discipline specialization within the breed and the possibility to use HL and young horse test results in a multi trait model in future genetic evaluation is therefore promising.

Based on the results, HL appears to be a promising alternative or complementary trait for describing competition performance in SWB horses. Future research should further evaluate different definitions of HL and how HL could be combined with existing longevity and welfare-related traits in the SWB genetic evaluation.

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Popular science summary

Sport horse breeding aims to produce healthy, rideable and talented horses that can perform well in competition. To support this, breeding organisations use genetic evaluations to estimate which horses are likely to pass on desirable traits to their offspring. In the evaluation for SWB horses, competition performance is already included in the genetic evaluation. It is based on lifetime accumulated points (LAP) given to them after placing in the top 25% in 2* level competitions or higher. This means that horses competing at lower levels, or horses that compete successfully without receiving points, do not get to contribute to the evaluation.

This thesis investigated whether an alternative way of describing competition performance, called Highest Level Achieved (HL), could be more useful in the genetic evaluation. HL describes the highest competition level a horse has reached during its career. The trait includes horses from 1* and higher, and also differentiates if the horse has participated, placed or won that competition.

Competition data from Swedish Warmblood horses in dressage and show jumping were analysed. The data came from Swedish Equestrian Federation competition records and covered the period from April 2009 to January 2026. And pedigree data was obtained from The Swedish Warmblood Association.

HL was defined separately for dressage and show jumping. Genetic analyses were then used to estimate heritability as well as genetic- and residual variances. The study also compared breeding values based on HL with the current breeding values used in SWB genetic evaluation. In addition, the relationship between HL and traits recorded in young horse tests (YHT) were studied.

The results showed that there was genetic variation in HL, and the heritability ranged from 0.33-0.34 for dressage, and 0.44-0.46 for show jumping. The correlations between the new estimated breeding value (EBV) for HL and the official EBV from SWB showed strong correlations (0.86), and there were both similarities and differences in stallion rankings between the two EBVs. The results also showed that young horse test traits and later competition performance were genetically related. This means that performance shown early in life provide some information about later competition ability.

However, HL also has limitations. A horse's highest competition level is not only affected by genetic ability, but also by rider, training, management, health, economy and opportunity to compete. Horses may fail to reach higher levels for reasons that are unrelated to their genetic potential. Therefore, HL should not be seen as a perfect measure of performance on its own.

In conclusion, this study suggests that HL is a suitable trait for future genetic evaluation of Swedish Warmblood competition performance.

Appendix 1

Dressage Competition Level	Shortened	Difficulty Classification	Difficulty Rating
Lätt E	LE	L*	1
Lätt D	LD	L*	1
Lätt C	LC	L*	1
Lätt B	LB	L*	1
Lätt A	LA	L**	2
Medelsvår C	LA	L**	2
Medelsvår B	MB	M*	3
Medelsvår A	MA	M**	4
S:t Georges	MA	M**	4
Intermediaire I	I1	S*	5
Intermediaire II	I2	S**	6
Intermediaire A	I2	S**	6
Intermediaire B	I2	S**	6
Grand Prix	S	S***	7
Grand Prix Special	S	S***	7
Grand Prix Kür	S	S***	7
Grand Prix Intern.	S	S****	8

Fence Height (cm)	Difficulty Classification	Difficulty Rating
80	L*	1
90	L*	1
100	L**	2
105	L**	2
110	L***	3
115	L***	3
120	M*	4
125	M*	4
130	M**	5
135	M**	5
140	S*	6
145	S*	6
150	S**	7
155	S**	7
160	S***	8
165	S****	9

Young-horse competitions	Shortened	Difficulty Level	Difficulty Rating
4-y-old	LB	L*	1
5-y-old	LA	L**	2
6-y-old	MB	M*	3
7-y-old	MA	M**	4

Para-Dressage	Shortened	Difficulty Level	Difficulty Rating
Grade 1	LE	L*	1
Grade 2	LD	L*	1
Grade 3	LD	L*	1
Grade 4	LA	L**	2
Grade 5	MB	M*	3

Special Olympics	Shortened	Difficulty Level	Difficulty Rating
Walk	LE	L*	1
Trott	LD	L*	1
Gallop	LC	L*	1

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