An overview of international genetic evaluations of show jumping in sport horses

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ABSTRACT

The breeding of sport horses to compete in the Olympic disciplines of show jumping, eventing, and dressage is fast becoming a global industry with the increased use of reproductive technologies, including artificial insemination and embryo transfer. Reproductive technologies have facilitated the dissemination of genetics from elite horses across multiple countries and breeds as breeders are no longer limited by location. Due to this increased level of crossbreeding, there is an increased need for estimated breeding values (EBVs) for sport horse performance that can be compared across breeds and countries. However, the implementation of across-breed or across-country genetic evaluations has been limited by the differences in each studbook’s individual breeding programs and genetic evaluations. Consequently, the aim of this review was to compare the genetic evaluations for show jumping of sport horse studbooks worldwide. The top sport horse studbooks in the world according to the World Breeding Federation for Sport Horses Studbook Rankings 2019 were contacted by email to request information on their current breeding programs and genetic evaluations. Twenty-six of the 51 studbooks contacted replied to this request but only 18 of these studbooks conducted their own genetic evaluations or were part of a larger genetic evaluation in their country of origin. The other eight studbooks were not involved in genetic evaluations at present but expressed an interest in the implementation of such in the future. Overall, many differences were identified among the genetic evaluations of each studbook or each country. The definition of show jumping performance differed within each evaluation and the methods and models utilized also differed. Despite some stallions and mares being registered in multiple studbooks or having progeny in multiple studbooks, these differences make comparison of EBVs across studbooks difficult. Further transparency and collaboration of sport horse studbooks with organizations such as Interstallion, will be essential to facilitate any future implementation of international genetic evaluations for show jumping performance.

Key words: best linear unbiased prediction, breeding, genetic evaluations, heritability, show jumping, sport horses

INTRODUCTION

Sport horses are bred worldwide with the aim to compete in the Olympic sports of show jumping, dressage, and eventing. In Ireland alone, the sport horse industry contributes an estimated €816 million to the Irish economy; breeding is the largest sector and accounts for €271 million (33.2%) of this contribution, most of which is generated in the rural economy (Corbally and Fahey, 2017). The success of the sport horse industry is multifactorial; however, implementing successful breeding programs and the genetic improvement of the sport horse are vital to maintaining this success, as unlike environmental effects such as feeding or management, the effect of genetic gain is cumulative and permanent (Falconer and Mackay, 1996). Many sport horse studbooks already have breeding programs in place to enable them to identify and select genetically superior stallions and mares to become parents of the next generation of horses. However, the estimated breeding values (EBVs) published, and the traits included in these evaluations vary among the different studbooks; this could be because of different breeding goals attributable to the different studbooks or, simply due to the availability of data.

Since 1980, there has been a significant increase in the uptake of reproductive technologies in sport horse breeding, including artificial insemination (AI; Aurich, 2012) and embryo transfer (Stout, 2012). For example, in 1985 only 1.4% of German Sport Horses were artificially inseminated, but by 2012 this had increased to nearly 90% (Aurich, 2012). The use of AI has facilitated the dissemination of genetics from breeding stallions across multiple countries and breeds and has led to the globalization of sport horse breeding as breeders are not limited by location. Despite this large exchange of genetic material across breeds, the implementation of across-breed or across-country genetic evaluations has been limited by the differences in each studbook’s individual breeding programs and genetic evaluations. Therefore, the objective of this study was to compare the genetic evaluations for show jumping of multiple sport horse studbooks. The knowledge of differences or similarities in the individual breeding programs may be of importance to studbooks and other researchers to inform them of the steps needed to implement successful across-breed or across-country genetic evaluations for sport horses.

MATERIALS AND METHODS

Animal Care and Use Committee approval was not obtained for the present study as no new data were generated during the present study.
Collation of Information
The 51 studbooks included in the final 2019 World Breeding Federation for Sport Horses (WBFSH) world ranking list for show jumping were contacted by email in July 2020 to request information on their current breeding programs and genetic evaluations. Each studbook was asked did they carry out genetic evaluations and to provide any documentation on these evaluations reporting the traits evaluated, the methods and models used, and the results to enable us to compare the methods used by the different genetic evaluations worldwide. Studbooks were sent a maximum of four follow-up emails and if the studbook did not reply in this timeframe or did not have sufficient information available in the form of scientific papers or studbook publications they were subsequently removed from the study. Of the 51 studbooks contacted, the present study is based on 26 (51%) sport horse studbooks (Table 1).

RESULTS AND DISCUSSION
World Breeding Federation for Sport Horses
The WBFSH publishes both individual and studbook rankings each month for each discipline from April to October each year (www.WBFSH.org; accessed October 8, 2021). The final rankings for that year are then published at the end of this cycle. The individual rankings for show jumping are based on a points system, whereby horses are awarded points for each international competition they compete in; points are awarded based on the results and the difficulty of the competition. The number of points earned by each horse determines its position in the individual ranking (www.WBFSH.org). The studbook rankings are calculated based on the top 6 horses from the individual rankings in each discipline.

The top studbook in the 2021 WBFSH ranking for show jumping studbooks was the Belgian Warmblood studbook (Table 1). Over the last 10 yr, the Belgian Warmblood studbook has been ranked number one studbook twice and the lowest ranking this studbook has received was fifth in 2014 and 2015. Over this same period, the Dutch Warmblood studbook was ranked as the number one studbook five times; the lowest ranking the Dutch Warmblood studbook received in those years was fourth in 2016. Not all studbooks have been as consistent as the Belgian Warmblood and Dutch Warmblood studbooks, with some studbooks falling slowly down the rankings and others rising through the rankings quite rapidly, for example, the Mecklenburg studbook have risen from 35th place in 2015 to 16th in 2021. Eleven of the

Table 1. The studbooks included in the present study, whether they conduct evaluations or not, and their latest, median, lowest, and highest rankings based on the WBFSH world rankings for show jumping studbooks from 2012 to 2021

| Studbook name                        | Abbreviation | 2021 ranking | Median ranking | Highest ranking | Lowest ranking | Genetic evaluations |
|--------------------------------------|--------------|--------------|----------------|-----------------|----------------|-------------------|
| Belgian Warmblood                    | BWP          | 1            | 3              | 1               | 5              | Yes               |
| Selle Francais                       | SF           | 2            | 4              | 2               | 9              | Yes               |
| Holsteiner*                          | HOLST        | 3            | 4              | 1               | 8              | Yes               |
| Dutch Warmblood                      | KWPN         | 4            | 2              | 1               | 4              | Yes               |
| Irish Sport Horse                    | ISH          | 10           | 13             | 8               | 17             | Yes               |
| Belgian Sport Horse                  | SBS          | 11           | 6              | 3               | 13             | Yes               |
| Westphalian*                         | WESTF        | 12           | 8              | 2               | 12             | Yes               |
| Swedish Warmblood                    | SWB          | 13           | 11             | 6               | 15             | Yes               |
| Studbook La Silla                    | SLS          | 17           | 16             | 14              | 20             | No                |
| American Holsteiner*                 | AHHA         | 19           | 24             | 19              | 56             | Yes               |
| Polish Horse Breeders Association    | PZHK         | 20           | 26             | 18              | 32             | Yes               |
| Danish Warmblood                     | DWB          | 22           | 18             | 15              | 26             | Yes               |
| Australian Warmblood                 | AWH          | 23           | 46             | 23              | 57             | No                |
| Breeding Association for German Horses* | ZIDP   | 24           | 24             | 18              | 33             | Yes               |
| Estonian Sport Horse                 | ESHB         | 25           | 31             | 25              | 55             | No                |
| Spanish Sport Horse                  | CDE          | 27           | 26             | 20              | 34             | Yes               |
| Dutch Warmblood North America        | KWPN NA      | 30           | 41             | 30              | 54             | Yes               |
| Anglo-Arab                           | AA           | 38           | 29             | 22              | 38             | Yes               |
| Hungarian Sport horse                | HSH          | 39           | 31             | 25              | 39             | Yes               |
| Slovenian Warmblood                  | SSW          | 40           | 41             | 35              | 50             | No                |
| American Warmblood                   | AWR          | 44           | 51             | 44              | 53             | No                |
| New Zealand Hanoverian               | NZHS         | 48           | 48             | 45              | 51             | No                |
| Canadian Sport Horse                 | CSHA         | 53           | 43             | 30              | 53             | No                |
| Luxembourg Saddle Horse Studbook†    | SCSL         | —            | 29             | 21              | —              | No                |
| Trakehner†                           | TRAK         | —            | 42             | 37              | —              | Yes               |
| International Sporthorse Registry Oldenburg† | ISREG | —       | 45             | 43              | —              | No                |

*Studbook is a member of the German Equestrian Federation (FN).
†Studbook not included in the WBFSH rankings 2021.
studbooks in the 2021 WBFSH Top 20 are included in the present analysis; 10 of these studbooks currently conduct genetic evaluations. Some of the earliest research on the genetic evaluations of sport horses were carried out on Swedish (Ström and Philipsson, 1978) and German (Bruns et al., 1980; Bruns, 1981) horses. The Dutch sport horses first introduced genetic evaluations in the late 1980s (Huizinga and Van der Meij, 1989), followed closely by the French studbooks (Tavernier, 1990, 1991) and then the Irish Sport Horse (Reilly et al., 1998).

Genetic Evaluations

Just eight studbooks, the Swedish Warmblood, Spanish Sport Horse, Danish Warmblood, Hungarian Sport Horse, Holsteiner, Polish Horse Breeders Association, Dutch Warmblood, and the Irish Sport Horse, run their own genetic evaluations. All other studbooks were part of multistudbook multibreed evaluations. All the German studbooks are members of the Fédération Equestre Nationale (FN), the German Equestrian Federation. The FN enlists the central computing center for genetic evaluations of horses and dairy cattle in Germany, Vereinigte Informationssysteme Tierhaltung (VIT) to carry out an integrated breeding value estimation of sport horses on behalf of the FN and its members each year (Jaitner and Reinhardt, 2003). Estimated breeding values for both of Belgium’s studbooks, the Belgian Warmblood and the Belgian Sport Horse are calculated by the University of Leuven. In the case of the French studbooks, Selle Francais and Anglo-Arab, the joint genetic evaluations are undertaken by the Institut Français du Cheval et de l’Équitation. For studbooks that are the daughter studbook of a much larger studbook, such as the Dutch Warmbloods in North America and the American Holsteiner, they follow the breeding programs of their respective parent studbooks and are therefore a part of the genetic evaluations of their parent studbooks.

Breeding Goals and EBVs

The breeding objectives of any organization should be clear and well-defined, reflect the desired characteristics of the animal and the relative importance of each characteristic, and should form the basis of any selection index (Dekkers and Gibson, 1998). Sport horse studbooks usually include the equestrian disciplines (i.e., show jumping, dressage, and/or eventing) and the level of competition that they wish to select for in their breeding objective (Koenen et al., 2004). However, many of the other traits included in equine breeding goals (i.e., the nobility, rideability, and character of the horse) are subjectively defined and hard to quantify, suggesting that current selection responses in sport horse breeding programs may be suboptimal (Koenen et al., 2004).

Each studbook calculates different EBVs based on the traits deemed as important to that organization, as outlined in the breeding objective for that breed (Koenen and Aldridge, 2002; Koenen et al., 2004). The Irish Sport Horse, the Hungarian Sport Horse, and the two Belgian studbooks only publish one single EBV. In comparison, the other studbooks that are conducting genetic evaluations generally publish two or more EBVs with one being for show jumping (Table 2). Other EBVs published most often include dressage, eventing, conformation, or performance test EBVs. For the purpose of this review, the focus is solely on EBVs produced for show jumping performance.

Table 2. The EBVs published by each studbook

| Studbook                                | Show jumping | Dressage | Eventing | Conformation | Performance tests | Other                                      |
|-----------------------------------------|--------------|----------|----------|--------------|-------------------|--------------------------------------------|
| Irish Sport Horse                       | X            |          |          |              |                   |                                            |
| Hungarian Sport Horse                   | X            |          |          |              |                   |                                            |
| Belgian Warmblood and Hungarian Sport Horse | X          |          |          |              |                   |                                            |
| Holsteiner and American Holsteiner      | X            |          |          | X            | X                 | General                                    |
| Polish Horse Breeders Association      | X            | X        |          |              |                   |                                            |
| FN Germany                             | X            | X        |          |              |                   | X                                          |
| Spanish Sport Horse                    | X            | X        | X        | X            |                   | Endurance                                  |
| Swedish Warmblood                      | X            | X        |          |              |                   |                                            |
| Danish Warmblood                       | X            | X        |          | X            |                   |                                            |
| Dutch Warmblood and Dutch Warmblood North America | X          | X        |          |              |                   | Loose movement, free jumping, osteochondrosis |
| Selle Francais and Anglo-Arab           | X            | X        |          | X            | X                 | Gaits, jumping ability                      |
rider scores each animal for rideability, dressage ability, and jumping ability.

Both the Irish Sport Horse and the Hungarian Sport Horse base their genetic evaluations on one single competition trait. In the Irish Sport Horse, this trait is known as the lifetime performance rating of the horse and is the top level of competition the horse has attained with two double clear rounds. The Hungarian Sport Horse base their genetic evaluations on Blom-transformed rankings that consider both the level the horse competes at and its placing within competition (Mezei et al., 2015). The Belgian Warmblood and Belgian Sport Horse evaluations are also based on competition results but split into two levels: the first trait refers to jumping performances at a national and recreational level, while the second trait considers jumping performances at both a national and recreational level.

The genetic evaluations of the Swedish Warmblood, Danish Warmblood, and the Dutch Warmblood horses consider both competition results and studbook inspection/test data. The Swedish Warmblood genetic evaluations consider the least number of traits of these three studbooks: The main jumping index is based on accumulated points from competition, while the two subindexes—technique and ability, temperament and general impression—reflect the results from the Swedish Warmblood young horse tests. The Danish Warmblood produces three EBVs for young horse test, championship test and national sports competitions which are then combined into an overall index value for jumping: 1) the young horse test (mainly 3/4 yr olds) EBV is based on seven traits—capacity, canter, and technique scored while loose, and manners, capacity, canter, and technique under rider, 2) the championship test (4, 5, and 6 yr olds) EBV is based on a horse’s jumping ability, either evaluated directly or as a combination of rideability, capacity, and technique, and 3) the national sports competitions EBV is based on the results of all starts in national show jumping competition and international competitions with Danish riders. The Dutch Warmblood currently base their genetic evaluations on four traits: 1) upper beam scores for free jumping from studbook inspections, 2) ability scores from the 1-d “individual suitability test for horses” test, 3) ability scores from the multiple-day tests for both mares and stallions, and 4) competition data.
consisting of the horse’s placing at specific shows throughout its entire career. The German FN publish three EBVs and an index value for show jumping: 1) the TSP EBV is based on the transformed rank achieved for all starts, 2) the ABP EBV is based on competition results for young horses, 3) the HEK EBV is based on the highest level of jumping achieved derived from the overall starts as a single observation per horse, and 4) the JPF, is an index value based on both competition data and scores from performance tests.

**Genetic evaluation methods** The methods and models used in each studbook’s genetic evaluations are outlined in Table 4. All studbooks, excluding the Belgian Studbooks and the Spanish Sport Horse studbook, that replied to the email request for information on the methods used specified they use an animal model in their evaluations. The type of animal model, i.e., repeatability, single-trait, or multitrait, depends on the studbook and the traits being evaluated (Table 4).

The effects accounted for by each model are also outlined in Table 4. The most common effects accounted for in the genetic evaluation models include sex and age, and it is widely accepted that the sex and age of the horse have a strong impact on performance in sport horses (Koenen and Aldridge, 2002; Welker et al., 2018). On average, stallions and geldings achieve a higher level of performance than mares (Koenen and Aldridge, 2002; Rovere et al., 2016) and the performance of a horse in competition increases with age but will eventually plateau for older horses (Rovere et al., 2016). Different studbooks consider age differently in their genetic evaluation models with some models including the age at highest performance (Ducro et al., 2007), the year of the highest performance (Rovere et al., 2016), or the year of birth of the horse (Viklund et al., 2010). The effect of age in sport horses is dependent on several external factors including the decisions and circumstances as to why and when a horse begins its career and how it develops thereafter (Welker et al., 2018). Therefore, Welker et al. (2018) proposed considering the maximum age of the horse in competition in the model to somewhat compensate for these external factors, to consider the duration of a horse’s performance career and the chances afforded to them to reach the highest levels in competition.

The cooperation of a horse with its rider is of utmost importance in show jumping and previous research has determined that a rider’s personality can affect this cooperation when riding emotionally reactive horses (Visser et al., 2008). Thus, it is unsurprising that rider has been noted in multiple studies as an important effect to include in statistical models evaluating a horse’s performance (Kearsley et al., 2008; Stewart et al., 2012; Rovere et al., 2016; Bartolomé et al., 2018). Including rider as either a class effect or a random effect decreased both the genetic and residual variances

| Studbook                              | Model type                        | Effects accounted for in model                                                                 | Base population                                                                                   | Standardization |
|---------------------------------------|-----------------------------------|-----------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------|-----------------|
| Irish Sport Horse                     | Single-trait animal model         | Sex, year of level achieved, thoroughbred percentage                                         | Rolling base: all Irish Sport Horse mares between 4 and 18 yr old                             | Mean = 100, SD =20 |
| Belgian Warmblood and Belgian Sport Horse | Not specified                     | Sex, age, competition, permanent environment                                                  | Rolling base: all horses between 7 and 18 yr old                                             | Mean = 100, SD =20 |
| Spanish Sport Horse                  | Not specified                      | Not specified                                                                                 | Rolling base: all horses between 3 and 17 yr old                                             | Mean = 100, SD =20 |
| Danish Warmblood                      | Young horse test; multitrait animal model | Young horse test: place × date, age × sex                                                   | Not specified                                                                                 | Mean = 100, SD =20 |
| Dutch Warmblood                      | Animal model                      | Not specified                                                                                 | All Dutch Warmblood horses                                                                   | Mean = 100, SD =20 |
| FN Germany                           | HEK: single-trait animal model    | HEK: sex, year, age of horse at latest start                                                  | Rolling base: stallions between 11 and 15 yr old, having passed a stallions’ performance test or having at least five offspring | Mean = 100, SD =20 |
| Hungarian Sport Horse                | Repeatability animal model        | All others: competition, age × sex, rider                                                     | All horses and sires                                                                          | Mean = 100, SD =20 |
| Polish Horse Breeders Association    | Multitrait animal model           | Training facility × assessment year                                                            | Rolling base: animals born 5 yr before the evaluation with reliability ≥0.22                 | Mean = 0, SD = 20 |
| Selle Francais and Anglo-Arab        | Multitrait animal model           | Trait 1: age, class × year, sex, animal genetic value, permanent environmental effect          | Rolling base: tested horses between the ages of 4 and 18                                       | Mean = 100, SD = 20 |
| Swedish Warmblood                    | Multitrait animal model           | Sex, year of birth, level of scores at different assessment times                             | Rolling base: tested horses between the ages of 4 and 18                                       | Mean = 100, SD = 20 |

Table 4. Methods implemented in the genetic evaluation of show jumping by each studbook
associated with show jumping performance in Dutch warmblood horses (Rovere et al., 2016); however, Rovere et al. (2016) concluded that including rider as a fixed effect that accounts for the level and experience of the rider would be a more effective approach than including a random effect for each rider. Similarly, Bartolome et al. (2018) determined that including the horse–rider interaction (RHI) as a random effect within a model was a better fit than just including the rider; the traits evaluated using these effects had higher heritability estimates when the RHI effect was included in place of the rider alone (Bartolome et al., 2018). In reality, including the effect of rider is often simply not possible due to the structure and/or distribution of the data (Bartolomé et al., 2018; Welker et al., 2018).

In the pursuit of accurate across-breed genetic evaluations in sport horses, where crossbred animals are the norm, one might consider breed classes as an important factor to consider in a genetic evaluation model (Stewart et al., 2010). However, of the studbooks that responded to our request for information, the ISH is the only studbook that currently considers the effect of breed in their model, in the form of the continuous effect of thoroughbred percentage (TB%) where each animal has a TB% value between 0 and 1. The significance of TB%, when fitted as a class effect with four (Schröder et al., 2010) or eight (Koenen et al., 1995) levels has previously been evaluated for conformation traits in Hanoverian warmblood horses (Schröder et al., 2010) and for both conformation and competition traits in the Dutch Warmblood (Koenen et al., 1995). Furthermore, the Hanoverian warmblood horse model also included the proportion of Trakehner and Holsteiner breeds as fixed effects in that model (Schröder et al., 2010). The proportion of Trakehner and Holsteiner breeds, and TB% were significant effects for all conformation traits in the Hanoverian warmblood horses (Schröder et al., 2010). The TB% was also significant in the analysis of most of the conformation traits in the Dutch Warmblood but was not considered a significant effect in the analysis of the show jumping or dressage data (Koenen et al., 1995). Other studbooks have previously included breed in their genetic evaluation models by grouping together the country of origin of the main breeds that are part of that studbook; for example, previous research conducted in the Spanish Sport Horse has included the breed effects as country of origin such as Germany, France, the Netherlands, Spain, and Other, instead of including the individual breed groups (Bartolomé et al., 2018).

**Heritability estimates of jumping in sport horses** Understanding the heritability of a trait is one of the most important factors to consider when devising an effective breeding plan (Lush, 1949). Heritability is defined as the fraction of the observed phenotypic variance of a trait which is attributable to additive genetic variation (Lush, 1949) and while heritability estimates vary by trait, they can also vary within-trait and over-time by population. Therefore, the heritability of show jumping traits can vary due to the phenotypes used in the estimation and the population for which heritability was calculated. In general, heritability estimates for jumping traits measured during station or performance tests generally have a higher heritability than those estimated from competition data (Ricard et al., 2000; Stewart et al., 2011); this may be in part due to the control of environmental factors during station tests (Ricard et al., 2000).

The Belgian Warmblood, Hungarian Sport Horse, and Irish Sport Horse have the lowest heritability estimates, from 0.02 to 0.10, for show jumping performance based on competition results (Janssens et al., 1997; Aldridge et al., 2000; Posta et al., 2009; Mezei et al., 2015). Heritability estimates for show jumping performance based on competition results range from 0.06 to 0.17 in the Spanish Sport Horse (Bartolomé et al., 2013), from 0.08 to 0.28 in the Dutch Warmblood (Rovere et al., 2016), from 0.12 to 0.28 in the Swedish Warmblood (Viklund et al., 2010), and from 0.15 to 0.19 in the French breeds (Langlois, 1980). The highest heritability estimate calculated from competition results was in the German breeds, where the highest level achieved in competition had a heritability between 0.28 and 0.36 (Welker et al., 2018). In comparison, heritability estimates for jumping ability measured during performance tests were estimated between 0.09 and 0.24 in the Swedish Warmblood (Viklund et al., 2008) and as 0.39 in the Dutch Warmblood (van Veldhuizen, 1997).

Sports status is a simple binary trait (0 or 1) that is used to determine whether a horse has competed at a show jumping event previously or not; this trait has a moderate to high heritability ranging from 0.19 to 0.40 in the Dutch Warmblood (Rovere et al., 2016) to 0.71 in the Belgian Warmblood (Janssens et al., 2007). Other estimates of the heritability of jumping ability in the literature come from free jumping phenotypes where the animal jumps several obstacles without a rider. Heritability for this trait is estimated to be between 0.29 and 0.71 depending on the breed of the animal (Huizinga et al., 1991; Gerber Olsson et al., 2000; Gelinder et al., 2001; Jaitner and Reinhardt, 2003; Posta et al., 2009).

**Interstallion**

The vast majority of sport horses are crossbred animals; for example, the ISH is not a breed that has evolved from a single origin but is, traditionally, the product of crossing Thoroughbred horses with Irish Draught horses (Reilly et al., 1998). In recent years, there has been an increase in the use of foreign bred stallions and mares being crossed with traditional Irish Sport Horses in the hopes of creating a successful show jumper. This increase in the use of foreign genetics has been observed across all sport horse breeds and can be attributed firstly, to the trade of horses across countries (Thörn Hellsten et al., 2008), and secondly, to an increase in the success, and therefore, uptake of reproductive technologies including AI and the transport of chilled semen over long distances (Thörn Hellsten et al., 2008; Aurich, 2012). Due to this increased level of crossbreeding, there is an increased need for EBVs for sport horse performance that can be compared across breeds and countries.

Interstallion was established in 1998 with the aim of comparing breeding objectives, testing procedures, and genetic evaluations of sport horses across countries and to determine if there was any international comparability of genetic evaluations (Thörn Hellsten, 2008). These issues are handled in dairy cattle by Interbull, a similar organization to Interstallion, that was founded in 1983 and has successfully implemented international genetic evaluation systems using MACE (Multiple-Trait Across Country Evaluation) in cattle (Schaefler, 1985, 1994; Philipsson, 2005). The MACE system estimates genetic correlations between traits in different countries which are then used to estimate international breeding values for bulls (Philipsson, 2005). The MACE system relies on strong genetic connectedness among different...
breeding populations to accurately estimate the differences in the average genetic merit of populations and to determine the genetic correlations between traits among the populations (Thorén Hellsten et al., 2008). The MACE system been highly successful in dairy cattle populations as these populations are strongly connected genetically as there are similarities in national breeding objectives worldwide (Berry et al., 2016) and families are often represented across multiple populations with bulls having daughters in many countries.

In comparison, sport horse breeding objectives differ substantially between studbooks, there are known discrepancies in breeding objectives as defined by individual studbooks and practiced by breeders, and there are differences in the definitions of the traits used in each studbook’s genetic evaluations (Bruns et al., 2004). Also, AI has not been as widely used in sport horse breeding for as many years as in dairy cattle breeding, but this has been changing in recent years with stallions producing more progeny widely spread among studbooks and countries. Despite this, strong genetic connectedness has been calculated among numerous European sport horse studbooks for show jumping performance traits (Thorén Hellsten et al., 2008, 2009; Ruhlmann et al. 2009a, 2009b). Thus, the implementation of MACE by Interstallion may be possible for at least some of the European studbooks in the near future.

**Genomics**

Since the advent of genomic selection (Meuwissen et al., 2001), genomic evaluations have been implemented successfully in both national and international livestock breeding programs worldwide (VanRaden et al., 2010; Meuwissen et al., 2016). Nevertheless, no sport horse studbook currently utilizes genomics in their show jumping evaluations. The WBFSH recognizes that one of the challenges in breeding sport horses is the generation interval. About 10 yr elapse between breeding decisions being made and the resulting horse reaching their peak performances (WBFSH, 2021). Genomic selection has the potential to increase genetic gain by reducing these long generation intervals; previous research has shown that integrating genomic information into sport horse breeding programs increases the accuracy of EBVs for young horses without their own performance records and horses without progeny (Haberland et al., 2012). Furthermore, previous research using a simulated genomic dataset proved that the inclusion of genomic data into the genetic evaluations of sport horses can increase the accuracy of EBVs for show jumping performance (Schubertová et al., 2014). Despite this increase in accuracy (Schubertová et al., 2014) and the many other perceived benefits of genomics to sport horse breeding (Stock et al., 2016), the integration of genomic selection in sport horses has proved challenging as it requires sufficiently large reference populations (Mark et al., 2014) that have not yet been feasible to attain but may be achieved through international collaboration.

**CONCLUSION**

Many studbooks have successfully implemented genetic evaluations for sport horses however these evaluations vary widely with respect to the traits included and the methods for collection of the data related to these traits. This makes comparison of breeding values across populations challenging to implement. As the interest in across-breed evaluations increases, studbooks should endeavor to be more transparent about their breeding programs. Further collaboration of studbooks, via Interstallion, is essential to facilitate the future implementation of international genetic evaluations and would also enable further research to be conducted on the implementation of genomics to sport horse breeding programs.

**Conflict of Interest Statement**

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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