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Genetic analysis of the longevity of French sport horses in jumping competition¹

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ABSTRACT: The longevity of sport horses is an economic and ethical issue. The aim of this study was to analyze the duration of the competitive life of jumping horses in France to assess the potential for genetic evaluation and to propose rules of management for sport horses. Data included lifetimes spent in jumping competitions for the 209,296 horses born from 1968 onward with performances between 1972 and 2008; the data set contained 22% right-censored records. Longevity was measured in years. Discrete survival analysis included fixed effects of region of birth, month of birth, year of recording, age at first competition, interaction between sex and level of jumping performance as measured by the logarithm of earnings adjusted for sex, age, year, and random sire and maternal grand-sire effects. There were 16,668 sires and maternal grand-sires. All fixed effects were highly significant ($P < 0.001$). Management of the sports career had an important effect on longevity:

against common belief, the younger the horse started competing, the longer it stayed in competition. For horses that started competing at an age of 6 yr, the risk of culling was 1.33-fold that of horses having started at 4 yr of age. The less success in competition, the greater was the chance for leaving competition, especially for horses without earnings. For a gelding without earnings, the risk of culling was 1.40-fold that of an average-performance gelding and 2.57-fold that of a top-rated gelding (performance at least 2 SD above the mean). Mares always had greater relative risk than geldings or stallions because they may be culled from competition to be used for breeding. The risk of culling for females was 1.45-fold that of a gelding with the same performance. The heritability of the length of competitive life was 0.10. Breeding values were predicted for sires, and 3,303 sires showed an accuracy greater than 0.60. Among these sires, 262 were used for breeding in 2008.

Key words: heritability, horse, jumping, longevity, survival analysis

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INTRODUCTION

Successful performance in riding sports, especially jumping, is the main breeding objective of Warmblood sport horse stud books all over the world (Koenen et al., 2004). However, breeders also aspire to limit the early retirement of horses due to disease-related loss of performance or invalidity, and increase the duration of competitive life. A mature sport horse is not only a financial investment to be preserved, but its welfare is also a moral imperative. Longevity in competition has therefore been claimed to be part of an industry-wide breeding objective; however, no breeding values have been formally included in the breeding objective. To date the only selection for longevity has been based

on indirect selection using conformation traits already relevant for selection (Wallin et al., 2001).

The aim of this study was to determine the factors affecting longevity in jumping competition and to estimate the heritability of this trait using survival analysis to include the resulting breeding evaluations into the breeding plans of the French Stud Book.

MATERIALS AND METHODS

Animal Care and Use Committee approval was not obtained for this study because the data were obtained from an existing database (Fédération Française d'Équitation, Lamotte Beuvron, France, and Les Haras Nationaux, Saumur, France).

Data

In France, show jumping competitions take place principally from March to October. The participation of each horse in competitions depends on the wishes of the rider, the availability of the horse, and the targeted

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championship. The sporting season is annual. A horse may begin competing at 4 yr of age or older. When a horse is no longer used for competition, it simply disappears from the jumping data the following years. All results in jumping competition have been recorded since 1972 by the French Equestrian Federation (Lamotte Beuvron, France). The results from official jumping competitions between 1972 to 2008 were used in this study to analyze longevity. The lifetime of the horse was defined as the time spent in competition, measured in years. For example, a horse with a first competition at 4 yr of age and its last competition at 8 yr of age had a lifetime of 5 yr. Culling was defined as the end of the competing life of the horse, whereas a possible longer use for breeding or leisure is not considered. The study included data from 209,296 horses with an overall 987,879 yr of performance. The lifetimes of horses still in competition in 2008 were considered as right-censored records. There were no left-censored records because only horses born in or after 1968, having begun competing in or after 1972, were included in the analysis. There were 47,766 horses with censored lifetimes (21.9%).

Survival Analysis

Because the measure of time was discrete, the model described by Prentice and Gloeckler (1978) was considered. Ducrocq (1999) demonstrated the equivalence of such a model with a fully parametric model in which the baseline is estimated at every discrete time point and the definition of hazard is modified to take into account the discrete time scale. This attribute allowed them to include this model in their survival kit package (Ducrocq and Sölkner, 1998), which was used here. Let A_j be the time interval (1 yr): $A_j = [a_{j-1}, a_j]$, $j = 1 \dots m$, $a_0 = 0$, $a_m = +\infty$, and λ the hazard function:

$$\lambda(t, \mathbf{z}_i) = \lambda_0(t) \exp(\mathbf{z}_i' \boldsymbol{\beta}),$$

where $\lambda_0(t)$ is the baseline hazard function and \mathbf{z}_i is the design vector for explanatory variables $\boldsymbol{\beta}$ for the horse i . Culling or censoring during the time interval A_j is denoted t^j . We have the following:

$$S(t^j, \mathbf{z}_i) = \prod_{k=1}^{j-1} \alpha_k^{\exp[\mathbf{z}_i' \boldsymbol{\beta}]},$$

where S is the survivor function and $\alpha_k = \exp\left(-\int_{a_{k-1}}^{a_k} \lambda_0(x) dx\right)$. The hazard function during a given time interval is similarly written as $\lambda(t^j, \mathbf{z}_i) = 1 - \alpha_j^{\exp(\mathbf{z}_i' \boldsymbol{\beta})}$. The variances of random effects included in $\boldsymbol{\beta}$ were obtained from their marginal posterior density and the parameters $(\alpha_j, \boldsymbol{\beta})$ were estimated by maximizing the joint posterior density, given the variance.

Culling Factors

The following factors affecting the competitive lifetime were included in the model:

- i. Region of birth with 22 levels based on the administrative regions in France.
- ii. Month of birth with 6 levels: January and February were grouped together, as well as July to December; the most frequent month of birth was April (36%).
- iii. Year of recording with 36 levels from 1972 to 2007.
- iv. Age at first competition with 6 levels: 4, 5, 6, 7, 8, 9 yr and more. The most frequent age at first competition was 4 yr (40%), followed by 5 yr (27%) and 6 yr (14%). Only 19% of horses began competing at an older age.
- v. Level of performance. The ability of the horse to perform well in competition is a major effect influencing the longevity of the horse in competition. To measure this, we used the traditional measurement of performance, which has been in use in the French breeding evaluation system for many years. This measurement is the natural logarithm of the sum of earnings in competition during the sport season (i.e., during the year; Langlois, 1980). Earnings are allocated to horses according to the technical level of the competition and their rank among the top 25% of all horses. Horses that did not earn money in the year were considered in a single class of nonearning horses. This measurement was corrected for year, sex, and age effects. The effect of performance varied throughout the years of the competing lifetime of the horse because it depended on time. The level of the performance effect was the level achieved the previous year. This choice was made because the measurement of performance depended on the total number of starts per year. The duration of continued competing for a given year depends directly on culling, which causes the 2 factors to merge. This was avoided by using performances from the previous year. For each year (except when the first year was studied), there were 12 levels of performance: $\ln(\text{earnings})$ of previous year classified into 10 classes ($< \mu - 2\sigma$, from $\mu - 2\sigma$ to $\mu = 2\sigma$ by 0.5σ unit, $> \mu + 2\sigma$), previous year without performance (except when the second year of competition was studied), previous year without earnings (but with some starts). The performance effect was combined with sex (mare, stallion, gelding) and the number of years in competition (1, 2, 3, 4, and more). So that in total, 96 levels were used: 3 for the first year (only sex, no previous performance), 27 for the second year (no previous year without starts and performances above 1 SD pulled together due to the decreased variability of performances for the

first year of competition), 30 for the third year (same levels as for the second year plus 3 levels for each sex having a previous year without starts), and 36 for the fourth and following years (all variations in performance).

- vi. Random sire and maternal grand-sire effect. A total of 16,668 sires and maternal grand-sires were identified, and 23,413 sires including ancestors were used in the analysis to account for all sire-maternal grand-sire relationships. There were 7,244 sires with progeny and grand progeny, 4,497 with only progeny and 4,927 with only grand progeny. There were no sires missing and only 5% of maternal grand-sires, so the completeness of pedigree was good. The mean family size was 17.8 progeny by sire (from 1 to 1,001), 16.3 grand progeny (from 1 to 1,156). Family size decreased exponentially: only 9% of sires had 50 or more progeny, and 69% of sires had less than 10 progeny.

Heritability

Heritability was defined according to Yazdi et al. (2002). Assuming a proportion of uncensored records p , the heritability was the equivalent heritability that can be used to directly compute reliability of sires using the index of selection:

$$h^2 = \frac{4\sigma_s^2}{\sigma_s^2 + \frac{1}{p}}$$

RESULTS

Baseline Functions

Baseline functions were illustrated for a reference horse with the following factors: the region of birth, Basse Normandie; month of birth, April; age at first start, 4 yr old; gelding; with corrected $\ln(\text{earnings})$ at 0.5 SD below the mean ($[\mu - \sigma/2, \mu]$). Figure 1 shows the survival function, the density function, and the hazard function. The hazard function decreased between the first and second year in competition, indicating that the first year in competition is crucial for the horse. Subsequently, the hazard function remained stable between the second and third year and increased with time spent in competition, illustrating the aging effect. The relative risk obtained the first year (13% of horses culled after having begun competition) was reached again only after the fifth year. The half-life spent in competition (50% of horses still present) was 6.0 yr.

Fixed Effects

All fixed effects included in the model were tested using the sequential log-likelihood ratio test and were

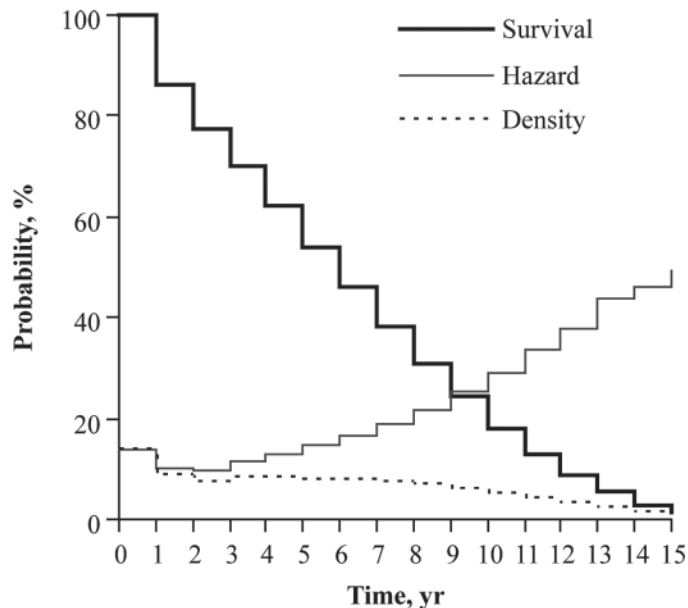


Figure 1. Survival, density, and hazard functions of longevity in jumping competition for a reference horse [region of birth, Basse Normandie; month of birth, April; age at first start, 4 yr old; gelding; and with corrected $\ln(\text{earnings})$ between the mean and one-half SD below the mean.

highly significant ($P < 0.001$). The largest increase of log-likelihood was obtained when adding the year effect, the age at first competition effect, and the level of competition effect.

The region of birth effect was moderate; the relative risk varied from 0.86 to 1.03 (Supplemental Table 1; <http://jas.fass.org/content/vol89/issue10/>). The number of births per region was not correlated with the region effect. In each case it showed the influence of a particular territory. The influence of the month of birth on the relative risk was low: from 1.00 to 1.04 with an advantage for horses born in April (Supplemental Table 2; <http://jas.fass.org/content/vol89/issue10/>). The influence of year was important with a relative risk varying from 0.54 to 1.37 and a large edge effect (Figure 2). The low relative risk observed with the earliest data records was due to samples including only young horses before 1976 because data contained only horses born from 1968 onward. The high relative risks observed in 2006 and even the more so in 2007 are explained as follows: horses in competition in 2007 but not in 2008 were considered culled in 2007 although they may compete again in 2009 after only 1 yr without performances. Up to 2005, 1 or 2 yr of absence was not considered as culling but as years without performance before further participation in competition. These years were included in the time spent in competition. Such temporary pauses in competition were considered as the end of the competing life of the horse for 2006 and 2007 and thus explain the larger estimates observed for the level of culling. When the edge effects are ignored, the tendency was a slight decrease of the relative risk as a function of years (from 1.06 to 0.94), showing an increased environmental resistance of the horses, with

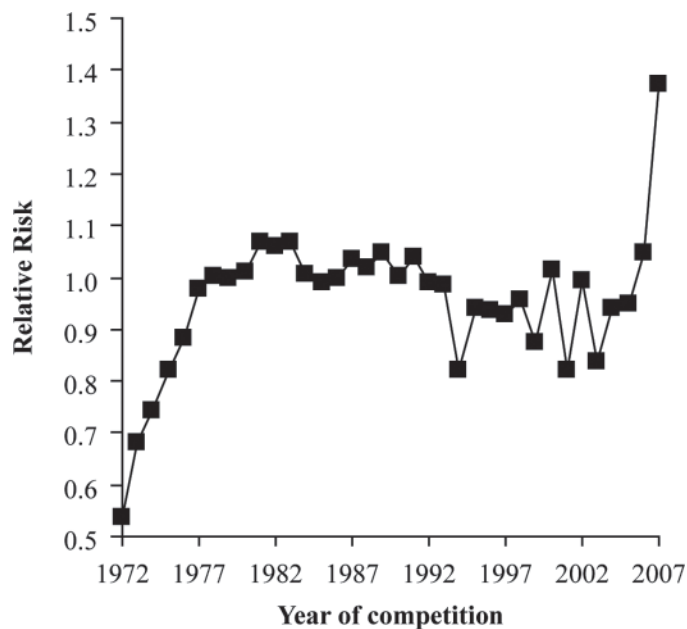


Figure 2. The figure shows the effect of year of performance on the relative risk of culling.

fluctuations in a recent past due to a change in the rules of official competitions (2003) and some sanitary episodes (foot-and-mouth disease in 2001).

Whereas the previously stated effects dealt with environmental conditions, other effects referred to the choices of the rider in the management of his/her horse and the ability of the horse to compete. The age at first competition had a great influence on longevity in favor of horses that began at 4 yr of age (Figure 3). The younger the horse started competing, the longer it stayed in competition. The half-life was 6.0 yr in competition for horses beginning at 4 yr of age vs. 4.8 yr of age for horses that began at age 6 (with the same mean performance). The level of performance had a great impact on longevity with variations depending on sex and the number of years already spent in competition. For the first year of competition, the relative risk was computed only according to sex because no previous performance was available to measure the ability in jumping competition. The relative risk of culling was greater ($P = 10^{-7}$) for mares (1.29) and stallions (1.17) when compared with geldings (Supplemental Table 3; <http://jas.fass.org/content/vol89/issue10/>). Figure 4 shows the relative risk for the second year of performance and Figure 5 for the fourth and later years. The greater relative risk observed for females compared with stallions and geldings occurred throughout the career of the horse (with 1, 2, 3, or more years in competition). From the second year of performance onward, the risk to be culled decreased when performance increased, with a plateau of performances more than 1 SD above the mean. This decrease of relative risk with the increase in performance was more pronounced for horses after their third year in competition than for the second year. The very best horses (>2 SD above the mean)

had a slightly greater relative risk than good horses, especially for stallions the second year of performance. A year of participation in competition but no earnings corresponded to a low performance with greater relative risk of culling. However, a year of absence from jumping competition seemed to have no effect on the decision of culling the year afterward (relative risk between 1.04 and 1.15).

Heritability and Breeding Values

The sire variance component was estimated at 0.0257 (SD = 0.0015); the equivalent heritability (Yazdi et al., 2002) was 0.08 with $P = 0.781$, the proportion of uncensored records. There were 3,303 sires for which the accuracy was greater than 0.60, and among them, 262 were used for breeding in 2008. The mean relative risk for these 3,303 sire effects was 0.98, with a SD of 0.11, and maximum and minimum values of 1.54 and 0.70, respectively. Sires were mostly of advanced age: 77% were born before 1983 and only 2% (51 sires) were born after 1992. Figure 6 shows the survival curve of progeny from the best sire used for breeding in 2008 and from the worst sire for longevity.

DISCUSSION

Choice of Model and Data Adequacy

The aim of this study was to determine the genetic factors of functional longevity. The definition of functional longevity was the robustness of a horse for a given jumping ability. The trait analyzed was the length of the competing life in jumping competition.

The principal flaw of competition data is the lack of information on the causes of culling. The end of competitive life may be death, invalidity for competition for multiple reasons including diseases, beginning of a

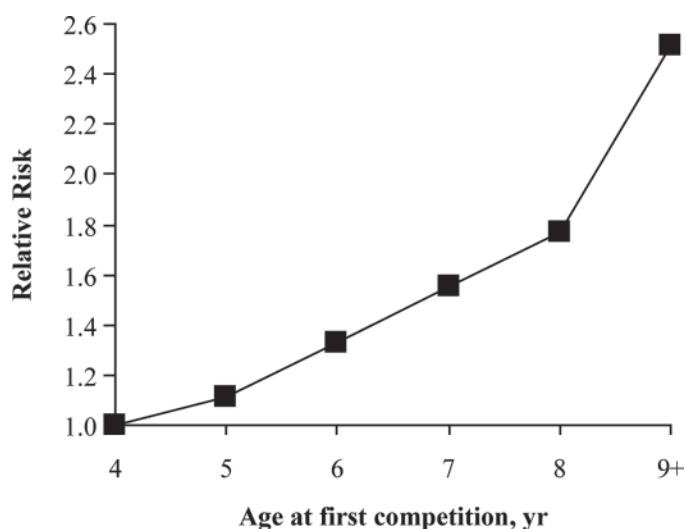


Figure 3. The figure shows the effect of age at first competition on the relative risk of culling (SE < 0.02).

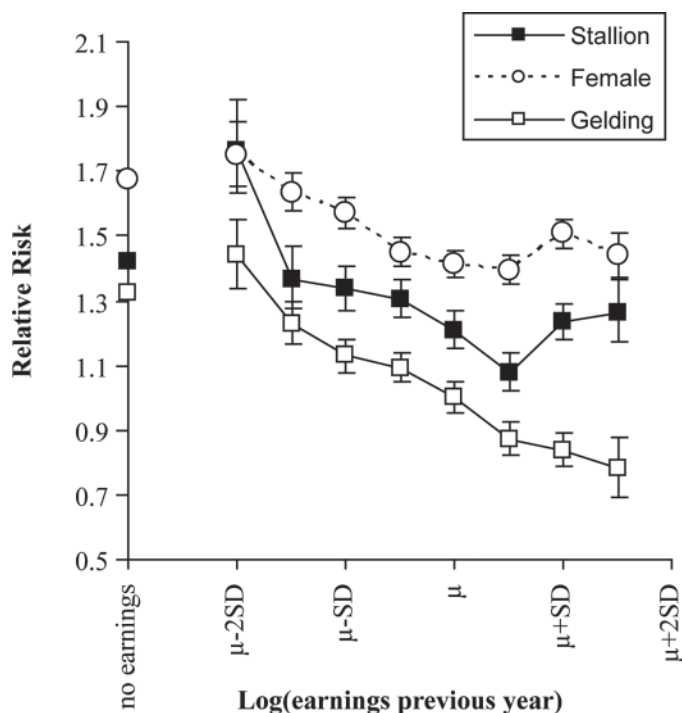


Figure 4. The figure shows the effect of level of performance in jumping competition the previous year on the relative risk of culling during the second year in competition according to sex (μ = mean).

breeding career (particularly for mares), or exportation to continue jumping competition abroad. Competing may also be stopped temporarily or even permanently due to factors that are not related to the individual horse, but to the rider (e.g., lack of time because of

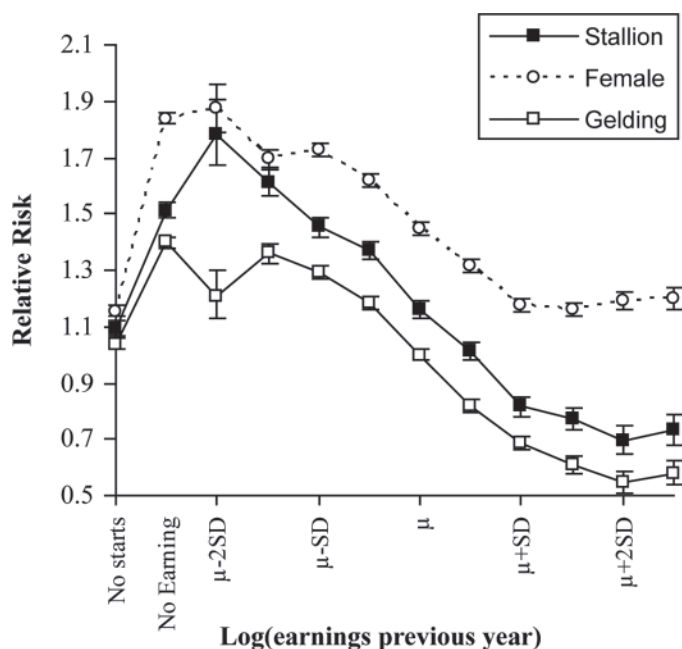


Figure 5. The figure shows the effect of level of performance in jumping competition the previous year on the relative risk of culling during the fourth and following years in competition according to sex (μ = mean).

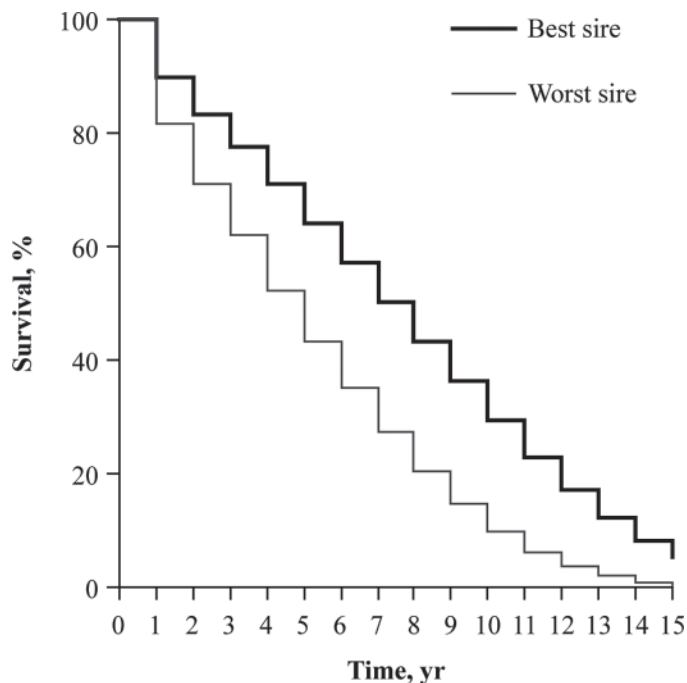


Figure 6. The figure shows the survival function for reference progeny from the best and worst sire for longevity used in breeding in 2008.

professional activities, moving to a place with limited training opportunities). Accordingly, it was not always easy to distinguish between involuntary (e.g., death, invalidity) and voluntary culling (e.g., breeding activities, opportunities of the rider). The knowledge of the reproductive life of mares (date of foaling) would not solve the problem because even mares with musculo-skeletal problems that make them inappropriate for competition could reproduce and are used for reproduction. Concerning the rider effect, there is no way to record the reasons of the rider for leaving competition. Because the majority of riders in jumping are nonprofessional, many of the reasons for culling may be voluntary but not taken into account in the model. The only effect that may account for the collective behavior of riders was the year effect (e.g., when the overall economic situation may influence the sport industry). The reasons for riders stopping competition led to an overestimation of the residual variance and an underestimation of heritability. For this reason, EBV may be biased, but the personal decisions of the rider had no reason to be linked to the sire of the horse they ride. The reliability of the EBV of the sire should be less than expected and associated with greater heritability. Similar cases are expected with farm data in other species. Important bias was expected only if the decision of the rider depended on the quality of the horse as is the case with exportations. However, exportations were not recorded in the database, so only the correlation between the probability of being exported and quality of the horse for jumping were taken into account by the addition of the level of performance effect in the model. If exportations are more frequent for the progeny of

a sire for unknown reasons and not related to ability, then correction is not possible and bias in the EBV may be expected.

In comparison with the first French study on longevity (Ricard and Fournet-Hanocq, 1997), the model has been greatly improved by including both the performance measured the year preceding the event of failure or censoring and the interactions due to the sex of the horse. In the previous study, the model for performance was based on 2 effects: the number of starts and yearly earnings. The competing lifetime was precorrected against the yearly earning effect obtained with the full model and then reanalyzed without including the number of starts to obtain an estimate for heritability. This avoided any confusion between the level of the earnings obtained and possible culling. In the model used here, use of the number of starts is no longer necessary because it measures the performance of the horse for the year preceding the studied time interval. In addition, and contrary to the previous study from which mares had been excluded, the inclusion of interactions due to the sex of the horse meant that the special status of mares due to the impossibility of simultaneously breeding and competing could be assessed.

Management of Horses

Choices relative to the management of horses have a great impact on their longevity in competition. Horses beginning their career at 4 yr of age stayed in competition longer than horses beginning at 5 yr of age, and those horses stayed longer than horses that began at 6 yr of age. This contradicts the common belief of riders that the use of young horses in competition handicaps their health. Early habituation to competition may therefore be advantageous for the career of the horse. This habituation concerned horses beginning at 4 or 5 yr of age because they have a similar relative risk; the increase of relative risk was more important after the age of 6 yr. We assumed that this habituation was carried out with care and was not too intensive. However, at a given age rather than at a given number of years spent in competition, the survival probability for horses having started competition later was still greater than for those having started earlier, although the former spent less time in competition.

The influence of the level of performance was also important. As expected, horses with poor performance had a greater risk of culling than horses with better performance. This may be the result of the voluntary choice of the rider (he/she does not want to continue competing with a horse that is unsuccessful) or indicate that the horse has experienced health problems that make it no longer competitive and result in culling. This effect was moderate the first year in competition (maximum risk ratio according to sex: 1.84) but became important after the third year spent in competition (maximum risk ratio according to sex: 2.57). The

relative risk of mares being culled was always greater than that for stallions or geldings because they can always be used for breeding. Accordingly, their longevity in competition depended less on their own ability: the range of relative risks according to performance was less for mares than for geldings. In addition, the relative risk increased for mares with good performance because good sport mares were more susceptible to be used for breeding (when they reached performances of 0.5 SD above the mean; i.e., among the best 30%). An increase of the relative risk was also observed for very good sport stallions and geldings. The explanation may be that these good young horses were exported and disappeared from French data or, for stallions, that they were used exclusively for breeding (even if stallions can be used simultaneously for breeding and competition). Another explanation may be that very good performances put greater strain on their locomotory system and result in increased involuntary culling for health problems. The relative risk was always less for geldings because they can only be used in competition. Surprisingly, 1 yr without participation or without earnings had a very different effect on the relative risk. A year of absence from competition had no effect on the decision to cull the year afterward. This indicated that either the absence was not due to health problems or that any health problems were solved after a year of rest. On the contrary, a year of participation but no earnings, and therefore no success in competition, always led to a greater relative risk of culling, as with very bad performances.

Selection

The trait longevity in competition showed genetic variability, even though causes for culling were not considered when it was defined. As an illustration, Figure 6 shows that, after 7 yr in competition, 50% of the progeny of the best sire were still in competition for their eighth year (thus aged 12 yr or more) against 27% for the worst sire when all other factors were kept equal. This is not a negligible effect, especially for jumping ability. There were no similar results found in the literature, except for a previous French study (Ricard and Fournet-Hanocq, 1997) which gave similar results for the variance of the sire effect (0.0261). However, calculation of the EBV is not the only factor required to define the selection plan. According to the biological characteristics of the species and testing structures (field test for young horses or competition tests), selection of sires in sport horse breeding is essentially based on their own performance and performance of contemporary relatives (Dubois et al., 2008). The EBV for longevity stemming from results of the progeny of the sire in competition are obtained too late to affect genetic progress and to be used to select stallions having already produced many progeny. That is why most people try to develop indirect criteria to select for lon-

gevity, or in reality against early retirement. Wallin et al. (2001) found that better conformation score (best 10%), good leg note (best 75%), and high orthopedic status (best 36%) measured at 4 yr old in the Swedish Riding Horse Quality Test were associated with a decreased relative risk of culling during the entire life of the horse (in and out of competition). Wallin et al. (2001) suggested that these traits should be used for selecting young horses. Stock and Distl (2005) found that the prevalence of radiographic findings on young horses sold in auctions influenced the number of later participations in competition, even if there was no effect on successful participation. Ducrocq et al. (2009) found a negative effect of uneven feet on the duration of competitive life especially in Elite Jumping (risk ratio 0.52 for even feet). All these reports showed the importance of limb conformation, which may be detected at an early stage, for the longevity of horses. However, the EBV for longevity in competition, as proposed in this paper, shows a greater reliability due to a larger data set (more than 200,000 horses against about 2,000 to 14,000 horses in the other studies), a reduced proportion of censoring (22% against sometimes 73%), and included more voluntary and involuntary reasons for culling. In competition data, large data sets are often available and proportion of censoring is low and may be even less as shown by Árnason (2006), which found only 15% of censoring for 32,504 racing careers of Swedish Standardbred. Causes other than the musculoskeletal system, which may be anticipated by analysis of limb conformation, represented about 40% of causes of death in Wallin et al. (2000). The inclusion of voluntary causes of culling enabled us to assess functional longevity rather than true longevity. Although obtaining highly accurate EBV for longevity is difficult at early ages, the use of even less accuracy EBV is an improvement over individual phenotypic observations of structural characteristics. An optional approach could be to combine the observation of structural traits with the quality of longevity performance data to produce more accurate EBV for longevity. In near future, late EBV calculation may no longer be a problem because it can provide the basis for genomic selection (Meuwissen et al., 2001). With the help of EquineSNP50 BeadChip (Illumina Inc., San Diego, CA), the data for older sires may be used to predict accurate breeding values for young candidates, both stallions and females. However, as many are finding out, databases containing both genomic scan data and individual performance data (such as longevity) of considerable size are needed to establish the relationships between genomic information and longevity.

Conclusion

Competition data provide a good tool to measure the jumping longevity for sport horses and EBV for sires. Although the trait did not detail the causes of involuntary culling, genetic variability was found and resulted in suggestions relating to management. Horses that started competition late and low performance horses had greater relative risk of culling. Heritability was 0.10. Breeding values were computed, and even if high accuracy was obtained only late in the life of the sire, their use will be emphasized in the future with the help of genomic selection.

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Supplementary Material

Supplementary material can be found at:

<http://www.journalofanimalscience.org/content/suppl/2011/09/20/jas.2011-3931.DC1.html>

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