Genet. Sel. Evol. 33 (2001) 175–190

Original article

Genetic parameters of eventing horse competition in France

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(Received 7 June 2000; accepted 26 September 2000)

Abstract – Genetic parameters of eventing horse competitions were estimated. About 13 000 horses, 30 000 annual results during 17 years and 110 000 starts in eventing competitions during 8 years were recorded. The measures of performance were logarithmic transformations of annual earnings, annual earnings per start, and annual earnings per place, and underlying variables responsible for ranks in each competition. Heritabilities were low (0.11 / 0.17 for annual results, 0.07 for ranks). Genetic correlations between criteria were high (greater than 0.90) except between ranks and earnings per place (0.58) or per start (0.67). Genetic correlations between ages (from 5 to 10 years old) were also high (more than 0.85) and allow selection on early performances. The genetic correlation between the results in different levels of competition (high/international and low/amateur) was near 1. Genetic correlations of eventing with other disciplines, which included partial aptitude needed for eventing, were very low for steeplechase races (0.18) and moderate with sport: jumping (0.45), dressage (0.58). The results suggest that selection on jumping performance will lead to some positive correlated response for eventing performance, but much more response could be obtained if a specific breeding objective and selection criteria were developed for eventing.

horse / eventing / heritability / rank

1. INTRODUCTION

In France, the most popular sport for riding horses is the jumping competition. But eventing is also a sport with a good participation: more than 4 000 horses compete each year. This sport combines dressage, jumping and cross, which is a natural circuit of some kilometres with natural obstacles. The aptitudes required for this sport are complex since the different tests depend on different physical and mental traits and are combined with different weightings. So it will be interesting to evaluate specific genetic parameters for this competition and to estimate genetic correlations with the other sport competitions (dressage and jumping) and with results of steeple chases (races)

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which separately require the different aptitudes needed for eventing. These estimations have rarely been made in the recent history of horse competition.

Estimations of genetic parameters on eventing have rarely been made in the recent history of horse competition. The different genetic abilities needed for eventing were studied alone: dressage, jumping, with few interests for cross country which have disappeared from station test in most countries. These abilities were studied in station test or field test and in competition. Heritabilities in station test in Europe for traits related to dressage (0.32 in Germany [2], 0.64 in Dutch land [8], 0.37 and 0.46 in Sweden [4]) and jumping (0.62 in Germany [2], 0.31 (jumping under rider) and 0.30 (free jumping) in Dutch land [8] and 0.32 (jumping under rider) and 0.47 (free jumping) in Sweden [4]) were rather high. In competition, results were based on each ranking in each competition and heritabilities were lower: about 0.10 to 0.15 [13] but higher when using annual summarize of results: 0.26 for jumping [16] and 0.34 for dressage in France [12]. Genetic correlations between these abilities were low: near 0 in Germany [2], 0.18 to 0.05 in Dutch land [8], 0.14 (for trot) to 0.54 (for gallop) in Sweden [4]. The only result on cross country in station test [8] gave an heritability of 0.41 and genetic correlation of 0.30 with riding ability and 0.63 to 0.72 with jumping. These results allows to expect heritability for eventing, even in competition with appropriate trait, but the low correlations between aptitudes may reveal surprises and there is lack of results on the third highly specific test needed, the cross country.

2. MATERIAL AND METHODS

2.1. Material

Two kinds of results in eventing were recorded: the annual results (annual earnings, number of starts, number of places) from 1980 to 1996 and details in each event (rank in each competition) only from 1989 to 1996.

Elementary statistics on size of the annual data are in Table I. In the data of annual results, horses with no earnings in the year were deleted. Pedigree information covered at least two generations of ascendants from horses with performances. All relationships between horses in pedigree were used in variance component estimation but a majority of information came from paternal half sibs. To give an idea of this kind of relationship, the number of sires with direct progeny in competition was given. To calculate the correlation with other disciplines, the data with all horses with at least one year of performance in one of the two disciplines were used. The data from horses with performances in eventing *or* steeple chases were recorded during the same period than single trait analysis: 1980 to 1996. For dressage, performances were taken from 1990 only because the rules of competition in that discipline have completely

Table I. Data used for analysis.

Discipline	Eventing	Eventing / Steeple chases	Eventing / Dressage	Eventing / Jumping
Number of horses	12 998	35 434	11 073	23 503
Number of annual performances	30 109	78 686	26 412	80 037
Number of ancestors	31 803	51 721	27 993	33 881
Number of sires	2 873	2 594	2 704	2 551
% of horses in the 2 disciplines		1%	15%	12%
% of horses in eventing only		84%	42%	2%
% of horses in the other discipline only		15%	43%	86%
Number of sires with offspring in the two disciplines		882	1 399	1 170

changed since then. For jumping, there were too many horses during these 17 years to make calculations. So the data were restricted to horses born from 1982 to 1986 and aged 4 to 10 in jumping and 5 to 10 in eventing.

The data from detailed performances contained 12 946 different horses (horses with no earnings but with starts in some events were kept) with 112 723 different starts in competition (mean = 8.7 starts per horse). The number of horses in pedigree with at least two generations was 32 282, with 2 744 sires having direct progeny in competition, the mean number of progeny being 4.7, and 357 sires having more than 10 competitors (6 000 horses). For estimating variance components, a random sampling was extracted from the sub data of the 357 sires with at least 10 offspring in competition. This sample contained 246 sires with 4 124 offspring. For estimating correlation with annual criteria, annual results before 1989 were added to this sample. Only sires with more than 10 offspring with annual performances before 1989 were added (196 sires). The total data contained 382 different sires, with 181 sires with progeny in the two criteria, 136 sires with only progeny with annual results before 1989 and 65 sires with progeny with only details of results after 1988.

2.2. Method

The performance of one horse was measured with two kinds of traits: annual summary or ranks in each competition. The two alternatives are explained.

The first measure of performance were taken as the logarithm of earnings with different traits:

- ln(annual earnings): this trait evaluates the global success of a complete year of competition.

Table II. Elementary statistics on annual criteria for eventing.

	ln(earnings)	ln(earnings/starts)	ln(earnings/places)
Mean	6.89	5.42	6.12
Standard Deviation	1.26	1.09	0.88
Skewness	0.45	0.30	0.99
Kurtosis	0.12	0.96	2.04

- ln(annual earnings/annual number of starts): this trait evaluates the success regarding the level of exploitation of the horse in the year. It is a measure of the possibility of a horse to succeed in the competition in which it is engaged.
- ln(annual earnings/annual number of places). A place is a start with earnings (so in our competition a context for the first third of starters after ranking). This trait evaluates the level of competition the horse is able to reach whatever the number of times he tried, since the defeats of the horse are not taken into account.

All these criteria were logarithm transformed because the rules of distribution of money in each event depend on an exponential scale relative to the rank of the horse and because the distribution of the total amount of money in one competition also has exponential rules relative to the technical level of the competition. The use of logarithm transformation leads to a nearly normal distribution of these criteria, see elementary statistics in Table II.
The model of analysis for annual criteria was the following:

$$\mathbf{y} = \boldsymbol{X}\mathbf{b} + \boldsymbol{Z}\mathbf{u} + \boldsymbol{Z}\mathbf{p} + \mathbf{e}$$

where **y** is the annual criterion, **b** is the vector of fixed effects, **u** the vector of additive animal genetic effects, **p** the vector of permanent environmental effects and **e** the vector of residuals. Expectation and variance covariance matrices were the following:

$$\mathbf{E}\begin{bmatrix}\mathbf{y}\\\mathbf{u}\\\mathbf{p}\\\mathbf{e}\end{bmatrix} = \begin{bmatrix}\boldsymbol{X}\mathbf{b}\\\mathbf{0}\\\mathbf{0}\\\mathbf{0}\end{bmatrix}, \quad \mathbf{V}\begin{bmatrix}\mathbf{u}\\\mathbf{p}\\\mathbf{e}\end{bmatrix} = \begin{bmatrix}\mathbf{A}\hat{\sigma}^2_{\mathbf{u}} & \mathbf{0} & \mathbf{0}\\\mathbf{0} & \mathbf{I}\hat{\sigma}^2_{\mathbf{p}} & \mathbf{0}\\\mathbf{0} & \mathbf{0} & \mathbf{I}\hat{\sigma}^2_{\mathbf{e}}\end{bmatrix}$$

with **A**, the genetic relationship matrix.

The fixed effects were the following:

- The first effect was age. For horses of 7 years old and more, there was one level by steps of one year until 13 years old and more. For 4 to 6 year old horses, this effect was combined to breed because there are special competitions for young horses with special endowments of the "Selle Français" and "Anglo-Arabe" saddle breeds. These special competitions give an advantage in earnings which needs to be taken into account. So there were two added levels: horses aged from 4 to 6 from the Selle Français and Anglo-Arabe breeds and horses aged from 4 to 6 of other breeds.

- The second effect was the year of performance (from 1980 to 1996 by steps of one) combined with sex effect (males and geldings / females). There were two categories of this effect according to young horses (≤ 6) and older horses (≥ 7), because the policy of the proportion of total endowment allocated to special competitions for young horses compared to other competitions varies with time.
- The third effect was region of birth (24 levels).
- The fourth effect was month of birth (6 levels).

This model was applied to the three annual criteria in eventing, then to one criterion considered as different traits for different ages (three ages in the same analysis: 5/6/7, 6/7/9 and 6/8/10) and then to criteria on eventing and other disciplines. When traits were analysed in a multivariate model, there were correlations between each random effect of the model and correlations between residuals for performances in the same year. When traits were different traits per age there was no permanent environmental effect (one performance by age) and there were residual correlations between ages.

Variance components were estimated using a restricted maximum likelihood (REML) procedure with version 4.2 of the VCE computer package [10].

The second measure of performance was rank which was free of the rules of delivery of earnings and incorporated horses with no earnings. The true difficulty for a horse to be ranked in a competition does not necessarily depend on the level of money to be earned but on the level of the ability of the horses which compete in the same event. So the results of each competition (*i.e.* ranking) were used directly without transformation to earnings. The results were not summarised in an annual measure but are given as a measure for each event. No points or metric measures were allocated to the ranks. We supposed that there was an underlying physical performance and that what we could see was the relative places of each performance of each horse in the event. The mathematical model was that of Tavernier [15]. Horses with no earnings in a competition were considered: their performances were simply behind the performance of the last horse ranked in the event.

The following model was used:

$$\mathbf{y} = X\mathbf{b} + \mathbf{Zs} + \mathbf{Zc} + \mathbf{e}$$

where **y** is the underlying "true" performance responsible for ranks, **b** is the vector of fixed effects, **s** the vector of sire effects, **c** the vector of effects common to the different performances of the same horse and **e** the vector of residuals.

The fixed effects were the following:

- Age effect from 4 to 13 years and more, by steps of one year;
- Sex effect (males and geldings / females);
- Region of birth (24 regions);
- Month of birth (6 levels).

Year effect does not appear because an effect that is always of the same level in a race cannot be estimated.

A sire model was used rather than an animal model for two reasons. The first one was the size of the system. The matrices were inverted, and this was difficult because matrices were less sparse than for a classic animal model (there were coefficients between all horses of the same race). So it would be difficult to use an animal model. The second reason was a statistical one. We used, as for analysis of categorical data [3], the mode of posterior distribution to estimates effects and not their expectation. There is no problem in these estimations but in estimation of variance components the formula uses also sum of squares of expectations of effects which are always approximated with modes [3, 7]. This leads to numerical problem when the mode may be different from their expectation which will probably occur with an animal model where the number of information by random effect is few [3, 6]. So a sire model is always recommended for categorical analysis. Much work must be done in this area.

To estimate the variance component, we used an iterative scheme similar to REML for normal variables which estimates the mode of the marginal posterior distribution of the variances [5]. This is based on the fact that the logarithm of posterior density of the parameters, knowing the data and the variances ($L(\Theta) = \ln[f(\mathbf{b}, \mathbf{s}, \mathbf{c}/\mathbf{y}, \mathbf{G}, \mathbf{H})]$), is proportional to:

$$\sum_{k=1}^{m} \ln(P_k) - 1/2\mathbf{s}'\mathbf{G}^{-1}\mathbf{s} - 1/2\mathbf{c}'\mathbf{H}^{-1}\mathbf{c}$$

where P_k is the probability of the ranking in event k, m is the number of events, $\mathbf{G}$ is the variance matrix of sire effects ($\mathbf{s}$), $\mathbf{H}$ is the variance matrix of the effect common to the performances of the same horse ($\mathbf{c}$). The probability P_k may be written:

$$P_k = \int_{-\infty}^{+\infty} \int_{y_{(n)}}^{+\infty} \dots \int_{y_{(3)}}^{+\infty} \int_{y_{(2)}}^{+\infty} \prod_{t=1}^{n_k} \varphi(\mathbf{y}_{(t)} - \mathbf{b}_{(t)} - \mathbf{s}_{(t)} - \mathbf{c}_{(t)}) \mathrm{d}\mathbf{y}_{(t)}$$

with n_k the number of starters in event k, (t) the order of the horse in the event, and φ the normal density.

The estimation of variances were based on:

$$\left[\hat{\sigma}^2_{\mathbf{s}}\right]^{[i+1]} = \left[\hat{\mathbf{s}}'\mathbf{A}^{-1}\hat{\mathbf{s}} + \mathrm{tr}(\mathbf{A}^{-1}\mathbf{C}_{\mathbf{ss}})/n_{\mathbf{s}}\right]^{[i]}$$

with i the round of iteration, $\mathbf{G} = \mathbf{A}\sigma_s^2$, $\mathbf{C}_{ss}$ the inverse of the opposite of the second derivatives of $L(\Theta)$ corresponding to $\mathbf{s}$, $\hat{\mathbf{s}}$ the estimation of $\mathbf{s}$, for example obtained by the Newton Raphson algorithm. Details of calculations are given in [14] and [15].

The practical problem was the size of the matrix to be inverted (equal to the number of fixed effects added to the number of sires and horses) and the fact that this matrix was less sparse than usual because there was one term between all horses that competed in the same event. So we used a sample from the whole population to estimate the variance components. But this sample cannot only be a truncation from the whole population since horses must be evaluated with all horses in the same competition and there were a lot of relationships of this kind between all horses. So the horse effect ($\mathbf{s} + \mathbf{c}$) was estimated for all horses with the complete file and a given repeatability (correlation between two performances). Then, the estimation of the horses which were not in the sample was used as a fixed parameter in the evaluation of variances. Horses in the sample were variables used to estimate the variance component. The matrices to be inverted were the matrices between horses and sires of the sample. Fixed horses were passed in the right hand side. Fixed horses were then estimated with the new genetic parameters unless repeatability converged. Personal computer programs were used for the calculations.

First, this model was applied to underlying performances responsible for rank alone. Second, it was applied to underlying performance and a sire model similar to the animal model was applied to annual criteria to estimate correlation. The joint posterior density was the product of the two single posterior densities because there was no residual correlation since the files used contained annual and detailed performances for different years. There were correlations between sire effects and effects common to the different performances of the same horse. Third, the model was applied with underlying performances considered as different traits according to the age of the horse. There were correlations between sire effect and effects common to the different underlying performances of the horse. Finally, this was applied to the underlying performances considered as different traits according to the official technical level of the competition.

3. RESULTS

3.1. Heritability and correlation between criteria for eventing

Heritabilities for annual criteria on earnings were low but not negligible (Tab. III). According to high genetic correlation (0.94 to 0.98), all these criteria covered the same aptitude: winning in eventing. The heritability for earnings per place is little higher than those of other criteria. This was not general for

Table III. Heritability (a, **bold**), repeatability (b), genetic correlation (c), correlation between permanent environmental effects (d), correlation between residuals in the same year (e), phenotypic correlation in the same year (f) and between years (g) for annual earnings criteria in eventing.

	ln(annual earnings): ln(E)	ln(annual earnings / number of starts): ln(E/S)	ln(annual earnings / number of places): ln(E/P)
ln(E)	**0.14** (0.01) [a] 0.45 (0.01) [b]	0.95 (0.01) [c]	0.98 (0.01) [c]
ln(E/S)	0.81 (0.01) [d] 0.81 (0.00) [e] 0.83 [f] 0.37 [g]	**0.11** (0.01) [a] 0.42 (0.01) [b]	0.94 (0.01) [c]
ln(E/P)	0.93 (0.00) [d] 0.74 (0.00) [e] 0.83 [f] 0.42 [g]	0.91 (0.01) [d] 0.77 (0.00) [e] 0.83 [f] 0.39 [g]	**0.17** (0.01) [a] 0.44 (0.01) [b]

( ): error standard deviation.

sport horses, but perhaps due to the few number of starts in one year, comparing to jumping or dressage. Phenotypic correlations were deduced from genetic, common environmental and residual correlations (these last ones exist only for performances realised in the same year). In any case the three phenotypic correlations reached 0.83 the same year and were between 0.37 and 0.42 when the years were different. Repeatability of the same criteria between years ranged from 0.42 to 0.45. The residual correlation was smaller between earnings per place and other criteria than between earnings and earnings per start but the correlation between the permanent environmental effect in this case was higher. A phenotypic correlation of 0.83 suggests some re-ranking of horses between the three criteria for measuring eventing performances but genetically the traits are nearly equal.

Heritability for criterion based on ranking in the single trait analysis was lower than for annual criteria: 0.07, with a repeatability of 0.33. This was expected since annual criteria were the summary of a complete year of competition. There was a mean of four events in one year per horse and so accuracy based on the evaluation of annual earnings would be similar to the accuracy based on four repeated records for ranking.

In multiple trait analysis between criterion based on ranking and each annual criterion (Tab. IV), heritability for ranking was higher (0.10 to 0.15) than for single trait analysis and heritability for annual criteria was of the same magnitude than for analysis of annual traits together. Genetic correlations between

Table IV. Heritability, repeatability, genetic correlation and correlation between effects common to the different performances of a horse for annual earnings criteria and the underlying trait responsible for ranks in eventing with multiple trait model.

	ln(annual earnings): ln(E)	ln(earnings / number of starts): ln(E/S)	ln(earnings / number of places): ln(E/P)
Heritability of annual trait	0.13	0.10	0.15
Heritability of underlying performance for ranking	0.13	0.14	0.14
Repeatability of annual trait between years	0.43	0.41	0.41
Repeatability of underlying performance between events	0.33	0.32	0.33
Genetic correlation	0.90	0.67	0.58
Correlation between common effect	0.60	0.58	0.39

underlying performance responsible for ranks and earnings were very different according to the criterion used: from 0.58 for earnings per place to 0.90 for total earnings. The correlations between permanent environmental effect were 0.39 for earnings per place and 0.59 for annual earnings and earnings per start. These correlations produced phenotypic correlations (in different years of competition) from 0.15 to 0.23.

3.2. Correlation between ages

Because of the size of the model, correlations between ages were calculated by groups of three (annual criterion) or two (ranking), according to the possibility of selection at previous ages. There was no permanent environmental effect for annual criteria taken per age. The results for ln(earnings/places) are reported in Table V and the results for criterion based on ranks are given in Table VI.

There was a very good consistency of the results from the various analyses for annual criterion. An early age was always used in analysis to take into account selection on previous performances to estimate correlation. Heritabilities increased with age, with perhaps an optimum at mature age before ageing from 0.07 to 0.26. Variances were lower in an early age as well as heritability. Genetic correlations between ages were very high whatever the age. Phenotypic correlations were lower (from 0.56 between 8 and 10 to 0.23 between 6 and 10), in particular because the residual correlation decreased with the time interval between ages, as might be expected in practical conditions, and because low heritability cannot be expressed in the visible scale of the good genetic correlations.

Table V. Genetic correlation (above diagonal), heritability (diagonal) and residual correlation (below diagonal) for ln(annual earnings / annual number of places) between ages in eventing.

Age of horse	5 years	6 years	7 years	8 years	9 years	10 years
5 years	0.07 (0.02)*	0.99(0.02)*	0.89 (0.11)*			
6 years	0.34 (0.02)*	0.13 (0.02)*	0.93 (0.06)*	1.00 (0.00)***	0.95(0.09)**	1.00 (0.00)***
		0.13 (0.02)**	0.94 (0.07)**			
		0.13 (0.02)***				
7 years	0.19 (0.03)*	0.38 (0.02)*	0.25 (0.03)*		0.85 (0.07)**	
		0.38 (0.02)**	0.24 (0.03)**			
8 years		0.25 (0.02)***		0.26 (0.03)***		1.00 (0.00)***
9 years		0.20 (003)**	0.44 (0.02)**		0.26 (0.03)**	
10 years		0.07 (0.03)***		0.41 (0.02)***		0.23 (0.03)***

Results from analysis of 5/6/7$^{(*)}$, 6/7/9$^{(**)}$ and 6/8/10$^{(***)}$, ( ): error standard deviation.

Table VI. Genetic correlation (above diagonal), heritability (diagonal, **bold**), repeatability in the year(diagonal, standard) and correlation between permanent environmental effect (below diagonal) for criterion based on ranks between ages in eventing.

Age of horse	5 years	6 years	7 years	8 years
5 years	**0.07** / 0.32 * **0.06** / 0.32 **	0.94 *	0.93 **	
6 years	0.82 *	**0.10** / 0.33 *		
7 years	0.75 **		**0.08** / 0.32 ** **0.06** / 0.33 ***	0.98 ***
8 years			0.90 ***	**0.08** / 0.33 ***

Results from analysis of 5 / 6^(*)^, 5 / 7^(**)^ and 7 / 8^(***)^.

For ranking there was also a very good homogeneity and high correlations between ages. The correlations between environmental effects were high but led, however, to lower phenotypic correlations between ages than earnings.

3.3. Correlation between disciplines

Correlations were computed between eventing and sport disciplines (dressage and jumping) and between eventing and one race discipline (steeplechase). The criterion for all disciplines was the ln(annual earnings). The model took into account a residual correlation for performances obtained in the two disciplines the same year, and a correlation between permanent environmental effect for performances obtained in the two disciplines for any year.

The results are given in Table VII. Estimates of heritability of eventing were higher in the analysis of jumping because the file was restricted to a certain period of age and time, which perhaps gave more homogeneity to performances. In the other cases, heritabilities were homogeneous with those of previous studies in each discipline [12]. Genetic correlations were positive but low with races (0.18) and moderate with other sport disciplines (0.45 with jumping and 0.58 with dressage). There were no correlations between environmental effects (permanent environment and residuals). This resulted in very low phenotypic correlations (from 0.20 between eventing and dressage in the same year to 0.05 with steeplechase).

3.4. Correlation between level of competition

One practical problem in evaluating horses is to know whether winning on a low level of competition depends on the same aptitude as winning on a high level. The level of competition is given in France by the level of rider (declared and depending on past earnings) combining to the past earnings of the horse. Technical difficulties are linked to the four classes defined (A to D).

Table VII. Variance components for the three bi-traits analysis between ln(annual earnings) in eventing and ln(annual earnings) in one other discipline (Steeplechase or Jumping or Dressage).

Variance components	The other discipline involved in each of the bi-trait analysis with eventing		
	Steeplechase	Jumping	Dressage
Heritability			
• for eventing	0.14 (0.01)	0.24 (0.03)	0.19 (0.02)
• for the other discipline	0.18 (0.01)	0.29 (0.01)	0.36 (0.03)
Repeatability			
• for eventing	0.40 (0.01)	0.47 (0.03)	0.52 (0.02)
• for the other discipline	0.45 (0.01)	0.49 (0.01)	0.59 (0.02)
Correlations			
Genetic	0.18 (0.07)	0.45 (0.05)	0.58 (0.07)
Permanent environmental	0.07 (0.10)	0.02 (0.07)	−0.01 (0.08)
Residual	0.00 (0.00)	−0.00 (0.01)	0.12 (0.02)
Phenotypic in the same year	0.05	0.12	0.20
Phenotypic in different years	0.05	0.12	0.15

Table VIII. Heritability (on diagonal, **bold**), repeatability (on diagonal standard), genetic correlation (above diagonal), correlation between permanent environmental effect (below diagonal standard), phenotypic correlation (below diagonal, *italic*) between levels in eventing with criterion based on ranks.

	Low level	High level
Low level	**0.06**	0.99
	0.33	
High level	0.86	**0.17**
	0.27	0.31

With annual criteria, it is not possible to verify easily this hypothesis, because in the same year horses may participate to different levels of competition and annual results are based on sum of earnings. With ranking, performances in low level (Classes D and C) and high level (level B and A and international competitions) may be considered as two different traits. The results are given in Table VIII. Heritability seemed to be higher for a high level of competition rather than for a low level. Genetic correlation was very high and close to 1. There was also a good correlation between environmental effects (0.86), even if the phenotypic correlation remained low (0.27).

4. DISCUSSION

The reliability of these analyses must be discussed for these three points: Is the amount of information sufficient for good accuracy? Is the use of the sire model for analysis of ranking source of bias? Is the use of selected populations for analysis of earnings also a source of bias? The number of horses (minimum 4 124 horses) in each analysis and the number of sires (minimum 246) used to estimate genetic parameters and correlation were sufficient to assure a good accuracy of results. There are always progeny and sires with progeny in the different traits when multiple trait analysis is performed. The second problem is the use of a sire model when analysing underlying performance responsible for ranks. But, as we saw, there are statistical reasons as for the analysis of categorical traits. In our case, the use of a sire model may also be authorised by the absence of selection on performance in eventing. There is no true selection of the breed on this trait and so variability and effects due to the maternal part are random and do not affect the estimation of the genetic parameters. Our results confirmed this hypothesis because heritabilities for annual traits estimated by a sire model in the multiple trait analysis earning / ranking were the same as those with the animal model. The use of a culled population when earnings are the trait measured is the third problem. Only 53% of horses earn money in a year compared to the horses which had started. This low percentage was due to the low number of events by a horse in the year. Another solution is to affect a "zero" performance to all these horses, but this leads to the problem of a really non normal distribution of performance and we prefer to consider that these horses have not really been tested in competition and so are unknown rather than known badly. The mean of starts of nonearning horses was 2.1 per year and 5.4 for earning horses. It is better to consider all starters with the methodology of ranks with no particular problem of estimation in spite of low accuracy of evaluation of nonearning horses since they have a few number of starts and they are tied with all the same place beside the last ranked horse.

The results of heritabilities and genetic correlations according to the various single trait or multiple traits analysis were consistent except for the heritability of the underlying performance which was higher in the analysis in the multiple trait model with earnings (0.10 to 0.15) compared to the simple trait analysis (0.07). In the data of multiple trait analysis compared to those of single trait analysis, we added an additional sample of sires (with more than 10 offspring) to the sample already used in single trait analysis. Earnings of all horses (added sample and old sample) were used from a period before obtaining ranks to avoid residual correlations. So there were horses with ranks and no earnings, horses with earnings and no ranks and horses with the two traits. Information coming from ranks was the same in the single and multiple trait analysis. But differences in the estimation of heritability were perhaps an effect of selection on earnings as they were obtained before the ranks (from 1980 to 1988). In any case, this was in favour of multiple criteria to measure success in eventing rather than unique criteria.

These analyses must help to determine a strategy for the selection of a horse for eventing.

The first answer is that this combination of aptitude had a moderate heritability, compared to dressage or jumping. This was in agreement with other rare previous analyses made in France and Germany [1,9,11]. The natural explanation is that eventing requires multiple aptitudes which may not be very well correlated. Details of the results in the three tests were not available so this hypothesis cannot be tested. Whatever the criteria, very high correlations were found for annual measure and moderate correlation (as long as this was the same aptitude which was measured) with criteria per event. There are several factors in the success of the horse: the possibility to reach a maximum, which is better measured by a trait as earnings per place, the regularity which is better measured by the detailed criteria and longevity which is better measured by sum of earnings. So the choice of the strategy of breeding evaluation will be a multiple trait evaluation combining the less correlated annual trait: log(earnings per places) and the underlying performance responsible for ranks. With this solution we considered the multiple features of the success and we incorporated nonearning horses, with less influence from irregularity of earnings.

The good correlation between the level of performances suppressed the risk of having different aptitudes according to the level of competition and the riders. This was also due to a correct definition of the trait through regimentation of the sport and the indication that the corresponding aptitude is needed even in low levels of competition. The difference in observed performance was mainly due to the environment rather than the aptitude.

The third question was the possibility to select on early performances. According to the age effect, the age when a horse performs best ranges from 8 to 12 years of age. It would be very interesting to select good horses on performances, earlier. In order to have good estimations of correlations between ages, we took into account the effect of selection on performances at every age kept in the analysis. The importance of such selection was measured by the mean of performances realised at the first age for horses present later in competition. The deviation of this mean from the general mean of performances at early ages was translated into the equivalent selection intensity by truncated selection on normal distribution. The results were different according to the age and the criterion used. Each year, for adult horses (from 6 to 11 years of age) selection differential is about 80% on ln(earnings). That is, the deviation of the mean of performances of horses kept for the following year from the general mean corresponds to a truncation selection of the best 80%. Selection differential on ln(earnings/starts) and ln(earnings/places) was near 90%. At 5 years, selection was lower for ln(earnings) (91%) and there was a counter selection for ln(earnings/start) and ln(earnings/places) (mean of performance at 5 years of age of -0.07 to -0.18 phenotypic standard deviation for horses present at 8 to 10 years of age). But older performances for horses present at this early age (5 years old), in spite of low selection, were better than the mean of the population, they correspond to the 78% best performances for the criterion ln(earnings). So it seems that the population at 5 and 6 years of age was a selected population, selected before entry in competition on other criteria than their own performances. There was a very good homogeneity of the high correlation between performances at each age whatever the criteria used. So selection on early performances (5 / 6 years of age) is possible and use of these performances in evaluation can be done as the same trait for all ages.

The knowledge of correlation with other disciplines gives information about present and future selection. At present, selection of sport horses in France is made on jumping. The positive genetic correlation (0.45) suggests a positive correlated response for eventing traits. However direct selection for eventing performance would lead to considerably more response. The second solution to select for eventing could have been using existing selection of horses on races with obstacles, since this is the only other discipline with cross country. But the genetic correlation is really too low (0.18) to expect any progress from this area, and in any case, there was a very different level of economic valorisation in the two aptitudes. The correlation with dressage was rather high (0.58) and would be a good thing for mutual selection of horses for dressage and eventing. But for a practical horse professional this is difficult to understand. Theoretically, the animal model and the use of all performances in the two disciplines correct for selection on one of the two traits. A lack of aptitude due to parental evaluation before entering the competition has been taken into account. But we are not sure that there is not a larger pre-selection on aptitude before entering competition, since it is difficult to know in which proportion this pre-selection is taken into account by only the knowledge of parental information. This good correlation may only reflect the fact that a horse must be good in jumping and dressage to be a good eventing horse but does not take into account the third dimension of cross aptitude.

ACKNOWLEDGEMENTS

The authors are grateful to one anonymous reviewer for its detailed comments and criticisms which helped to improve the manuscript.

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