State of breeding evaluation in trotters

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FOREWORD

The horse commission of the European Association for Animal Production takes the opportunity of the VI. World conference on Animal Production from June 27 to July 1st, 1988 in Helsinky, Finland, to organise a one day symposium on the genetic evaluation of trotters.

Particularly in Europe the need of a more scientific approach for the estimation of the breeding value grows in connection with the increase of the exchange of animals beetween countries. Nearby european geneticists are more and more involved in horse breeding.

We got papers from Belgien, Finland, France, Federal Republic of Germany, German Democratic Republic, Hungary, Italy, The Netherlands, Norway, Sweden and the United States. You will find them in this booklet. They give a good overlook on the topic and I hope that this publication will increase the interest in horse genetics.

Most of these countries developed systems based on classical regression method or BLUP sire models, whereas all of them want to go using BLUP animal models, which seem particularly adapted to the horse situations.

However the criterion used for measuring racing ability varies from country to country according to the data available and the breeding orientation. Some countries like France and The Netherlands are using earnings, others like the USA are using timing, and again others multitraits evaluation like the Scandinavian countries. We are still in an analytical phase in this area. But I think that the situation will evolve very rapidly in a way that in most trotting countries routine methods based on BLUP animal model methodology will be available in a very few years.

We had in Helsinki a good and constructive meeting and we thank our Finnish hosts for the working facilities they provided us and for their kind hospitality.

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ESTIMATION OF BREEDING VALUES OF BELGIAN TROTTERS USING AN ANIMAL MODEL.

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Summary

An animal model was developed to estimate breeding values of Belgian trotters. Best life time (/1000 meters) of 3.333 animals (112 stallions) were taken from the files of "Fedération Belge du Trot".

When sires of animals were unknown they were replaced by a representative parent. Representative parents were assigned to groups according to the country of origin of their progeny (Belgium, Germany, USA, France) considered as separate base populations.

The complete animal model was : $y = X\beta + Wg + Za + e$ where y, β, g, a, e correspond to vectors of production and fixed effects, group, additive genetic, or residual random effects and X, W, Z correspond to incidence matrices. The fixed effects were : sex (male, castrated, female), age (9 classes : 2 - 10 years), hippodrome (5 hippodromes), date of birth (from 1967 to 1983), date of record (from 1975 to 1985), type of start (4 types), distance (1.300 - 1.600 m, 1.700 - 2.200 m, > 2.200 m). The mixed model equations were created using ZQ and QP transformations.

Solutions were obtained by iteration starting with fixed effects and finishing with animal and group effects. Two files corresponding to animals and records and to A-1 elements were created. These two files were continously read during each round of iteration (no coefficients created). One vector corresponding to previous solutions (animals and groups) was used during the iteration process ; an other vector (animals and groups) was used to accumulate correction terms of the fixed effects and A-1 relationships. The convergence criterion was achieved after 50 rounds of iteration.

The results indicate that an animal model with grouping of unknown parents by country of origin should be considered for the estimation of breeding values of trotters in Belgium.

Introduction

Trotter racing is very popular in Belgium where the fisrt society : "Fédération des hippodromes de grands champs" has been created before 1900. In 1976, the name of the Society has been changed to the "Fédération Belge du Trot". More than 3600 owners are members of the Society in 1988.

Up to now only stallions with favourable trotting career were allowed for breeding purposes. A lot of animals, belonging to german, french and to USA populations were continuously imported. The scientific studies of horse performances in Belgium started in the mid 1980's by the analysis of data files of the "Fédération Belge du Trot" (Leroy et al., 1985).

First analysis is concerned with the study of environmental factors on best time in life. The main environmental and non-genetic factors were identified and genetic parameters were estimated.

In the presence of different populations and in order to correct for genetic differences among the populations, grouping has been first introduced (Henderson, 1972).

The animal model (AM) (Henderson, 1972, Quaas and Pollak, 1980, Westell and Van Vleck, 1984), allows simultaneous evaluation of animals for additive genetic values even for animals with no records but which are tied by relationships (Henderson, 1977). As indicated by Quaas (1988) this model with groups is the most complete model to date and will turn out to be the Westell-Robinson model, a model proposed independently by the two authors (Westell, 1984, 1987 and Robinson, 1986).

The objectives of the present study are to develop, in Belgium, the basis of a genetic evaluation program for all the animals with and without performances using an animal model with base population animals, including relationship between individuals and correcting for the environmental and non-genetic factors.

Material and methods

Material

Data included 3,221 records taken from the files of the "Fédération Belge du Trot". The 3,221 records correspond to best time in life (/1,000 meters).

All the animals recorded were born from 1967 to 1983 and had their best time in life from 1975 to 1985; they were progeny of 112 stallions having from over 10 recorded progenies (in average 27 progenies).

The distribution of records by year of birth, sex and age, year, hippodrome, type of start, distance corresponding to best time in life are in given in Table 1.

Table 1. Distribution of the animals by year of birth (from 1967 to 1983), sex (female, geldings, male) and age (9 classes : 2-10 years), year (from 1975 to 1985), hippodrome (5 hippodromes), type of start (4 types), distance (1300-1600 m, 1700-2200 m , > 2200 m) corresponding to best time in life.

	FREQUENCY	PERCENT	CUMULATIVE FREQUENCY	CUMULATIVE PERCENT
YEAR OF BIRTH				
67	10	0.3	10	0.3
68	16	0.5	26	0.8
69	32	1.0	58	1.8
70	73	2.3	131	4.1
71	115	3.6	246	7.6
72	178	5.5	424	13.2
73	217	6.7	641	19.9
74	286	8.9	927	28.8
75	299	9.3	1226	38.1
76	302	9.4	1528	47.4
77	312	9.7	1840	57.1
78	303	9.4	2143	66.5
79	285	8.8	2428	75.4
80	299	9.3	2727	84.7
81	267	8.3	2994	93.0
82	184	5.7	3178	98.7
83	43	1.3	3221	100.0
SEX				
1	1492	46.3	1492	46.3
2	889	27.6	2381	73.9
3	3840	26.1	3221	100.0
AGE				
2	100	3.1	100	3.1
3	490	15.2	590	18.3
4	821	25.5	1411	43.8
5	624	19.4	2035	63.2
6	504	15.6	2539	78.8
7	297	9.2	2836	88.0
8	211	6.6	3047	94.6
9	112	3.5	3159	98.1
10	62	1.9	3221	100.0
YEAR OF BEST TIME IN LIFE				
75	23	0.7	23	0.7
76	113	3.5	136	4.2
77	152	4 7	288	8.9
78	191	5.9	479	14.9
79	295	9.2	774	24.0
80	290	9.0	1064	33.0
81	282	8.8	1346	41.8
82	325	10.1	1671	51.9
83	279	8.7	1950	60.5
84	412	12.8	2362	73.3
85	859	26.7	3221	100.0

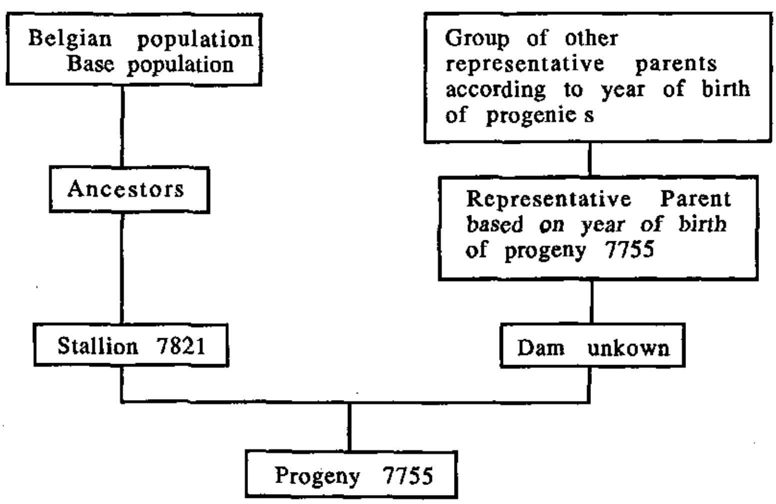
HIPPODROME				
1	844	26.2	844	26.2
2	239	7.4	1083	33.6
4	347	109.8	1430	44.4
5	218	6.8	1648	51.2
6	1573	48.8	3221	100.0
TYPE OF START				
1	855	26.5	855	26.5
2	2125	66.0	2980	92.5
3	26	0.8	3006	93.3
4	215	6.7	3221	100.0
DISTANCE				
1	910	28.3	910	28.3
2	1041	32.3	1951	60.6
3	1270	39.4	3221	100.0

The average of best time was 1 m 22.92 s. and the standard deviation 2.77 s.

When an ancestor was unknown it was assigned to a group considered to be a representative parent (Westell and Van Vleck, 1984, Leroy and Van Vleck, 1987).

Animals were progeny of 112 stallions 20 stallions had ancestors and 92 stallions had no ancestors recorded. For those 92 stallions, representative parents were created (male ancestors) and put in four groups according to their origin : Belgium (n = 33), France (n = 44), USA (n = 13) and Germany (n = 2). The representative parent corresponding to an unknown dam was put in a different group according to the origin of the sire and the birth date of the progeny. The figure 1 illustrates the grouping strategy. Female ancestors were not considered in this preliminary study and were replaced by representative parents.

Figure 1. Example of a progeny of stallion 7821 and an unknown dam



Methods

The complete animal model describing the record is :

$$y = X\beta + Wg + Za + e$$

where y is the vector of records,

ß is the vector of fixed effects associated with the records,(sex (female, castrated, male), age (9 classes : 2-10 years), hippodrome (5 hippodromes : Kuurnes, Waregem, Tongeren, Sterrebeek, Oostende), date of record (from 1975 to 1985), type of start (4 types), distance (1300-1600m, 1700-2200m>2200m),

g is the vector of fixed group effects,

a is the vector of random additive genetic effects associated with the animals,

e is the vector of residuals.

and X, Z and W are incidence matrices for the expression of ß, g, and a, in y with the entire row of Z (and of X) consisting of zeros when the animal has no records.

Also

$$E\begin{bmatrix} y \\ a \\ e \end{bmatrix} = \begin{bmatrix} X\beta + Wg \\ 0 \\ 0 \end{bmatrix}$$

and

$$Var\begin{bmatrix} a \\ \\ e \end{bmatrix} = \begin{bmatrix} Ah^2 & 0 \\ & \\ 0 & I(1-h^2) \end{bmatrix} S^2$$

Where A is the numerator of additive relationships among animals,

h^2 is heritability

S^2 is phenotypic variance

Let the inverse of the full relationship matrix consist of submatrices corresponding to relationships between animals and base animals (A^{10}), between base animals and animals (A^{01}), among base individuals (A^{00}) and among animals (A^{11}) :

$$A^{-1} = \begin{bmatrix} A^{00} & A^{01} \\ & \\ A^{10} & A^{11} \end{bmatrix}$$

The incidence matrix for group effects, W, is equivalent to ZQ_1 where Q_1 assigns group effects to animals (Quaas and Pollak, 1981).

Considering $R\sigma_e^2 = I\sigma_e^2$ the equation system is :

$$\begin{bmatrix} A^{00}t & A^{01}t & 0 & 0 \\ A^{10}t & Z'Z+A^{11}t & Z'ZQ_1 & Z'X \\ 0 & Q_1'Z'Z & Q_1'Z'ZQ_1 & Q_1'Z'X \\ 0 & X'Z & X'ZQ_1 & X'X \end{bmatrix} \begin{bmatrix} \hat{a}_0 \\ \hat{a}_1 \\ \hat{g} \\ \hat{b} \end{bmatrix} = \begin{bmatrix} 0 \\ Z'y \\ Q_1'Z'y \\ X'y \end{bmatrix}$$

Where $t = \sigma_e^2 / \sigma_a^2$

Because $Q_1 = A_{10}Q_0$ where Q_0 assigns base animals to groups and where Q_1 describes the function of group effects of the base animals expressed in the later animals, the equations can be rewritten (Westell and Van Vleck 1984).

Using the QP transformation of the mixed model equations (Quaas and Pollak, 1981) and absorbing unknown parents, Westell (1984) obtained equations which had valuable properties. Her equations were :

$$\begin{bmatrix} Z'Z+(A^{11}-A^{10}(A^{00})^{-1}A^{01})t & A^{01}(A^{00})^{-1}Q_0t & Z'X \\ Q_0'(A^{00})^{-1}A^{01}t & (Q_0'Q_0-Q_0'(A^{00})^{-1}Q_0)t & 0 \\ X'Z & 0 & X'X \end{bmatrix} \begin{bmatrix} \hat{a}_1+Q_0\hat{g} \\ \hat{g} \\ \hat{b} \end{bmatrix} = \begin{bmatrix} Z'y \\ 0 \\ X'y \end{bmatrix}$$

To create the coefficients of these equations that do not involve X or Z, she found simple rules that involves the A-inverse matrix and groups.

Three situations exist : both parents unknown, one parent unknown and two parents known.

Let i be the equation number of the individual and j and k be the equation number of the two parents or if unknown the equation number of the representative group(s) of the parent(s), then the following quantities are accumulated to the associated elements of the mixed model equations and their symetrics : for (i,i), +2t; for (i,j) and (i,k), -1t and for (j,j), (j,k) and (k,k), t/2. When one parent is unknown these three values are 4t/3, -2t/3 and t/3 and when both parents are missing : 1t, -t/2 and t/4 (Westell 1984).

The value of h^2 used in the animal model was 0.11 according to the results of a separate analysis on the 3,221 progenies of the 112 stallions. The value obtained in the analysis was in the range of the results obtained by Minkema (1975), Ronningen (1975) and all other sudies reviewed by Hintz (1980) and Tolley et al. (1985) but lower than values obtained by Katona and Osterkorn (1977), Arnason et al. (1988), Klemetsdal (1988).

Two other mixed models were also used : a BLUP model without groups and without relationships and an Animal Model (AM/1) without groups of unknown parents but with relationships. Data were also analysed by linear fixed models in order to quantify the importance of the fixed effects.

Programming strategy

Before the iteration process the data set was prepared so that identification numbers of animals become indexes of vectors.

Elements of A-inverse generated by relationships with the animals were computed during a first reading of the records. All these elements were sorted and written on a separate file .

Two other data files were created. They correspond to a file of animals with records (used for the estimation of fixed effects) and a file of all animals with and without records for the estimation of the additive genetic effects.

The iteration process involves 4 vectors. These 4 vectors correspond to 2 work areas for fixed effects and 2 vectors for animal effects. In each case, the two vectors correspond to right hand sides (RHS) which separately are adjusted throughout a round of iteration and to previous solutions. Equations are never written and the current solution vector containing RHS at the start are continuously adjusted for solutions obtained earlier in the round. The strategy is related to the approach of Schaeffer and Kennedy (1986).

Convergence criterion is computed as the sum of squares of the difference between previous and current solutions divided by the sum of squares of the current solutions times 100:

$$((\text{sum } x^2) / \text{sum } c^2) * 100$$

with $x = c-p$

c = current solutions

p = previous solutions

Results and discussion

Linear models (fixed effects)

The data set was first analyzed by linear models including the fixed effects and their interactions. The main effects contributed significantly to the variation of best time in life ($R^2 = 0.588$). Some interaction effects were discarded because their low contribution to the variation and only the main effects were included in the animal model.

Age effect contributed more to the variation then other fixed effects included in the model. The contribution of each effect measured in R^2 (by discarding each of them) was in decreasing order :

age 19%, hippodrome 7.2% , year 4%, distance 3.6%, type of start 3% and sex 0,5%.

Effect of the sex

The results of the males were superior to the castrated males and the females (Table 2). Males were 0.498 s faster than the females and 0.385 s faster than the castrated males. Geldings were 0.113 s faster than the females. These results could be compared to values obtained by Ojala and Hellman (1987) for the best racing time of the Standardbred horses in Finland but lower than corresponding values found in the Finnish trotters (Ojala and Hellman,1987) and in the North-Swedish trotters (Ronningen, 1975). Other studies reviewed by Langlois (1982) have all showed the superiority of males. Ojala et al. (1987) obtained different results but on a smaller data set.

Effect of age at best time in life

Estimates of the age effects (Table 2), solutions of the animal model, indicate that the best time decreases with age. It is obvious that younger animals have not yet expressed their potential and that the horses with poor performances don't increase their best time. Figure 2 illustrates the curvilinear decrease of estimates of age (in years) at best performance. The curvilinear relation also indicates that the rate of improvement diminishes with age of best time in life. Similar results were found for best annual racing time in the Finnish trotter populations (Ojala, 1982 and Ojala and Hellman,1987).

Figure 2. Effect of age (in years) on Best Time in Life (BTL-s.)

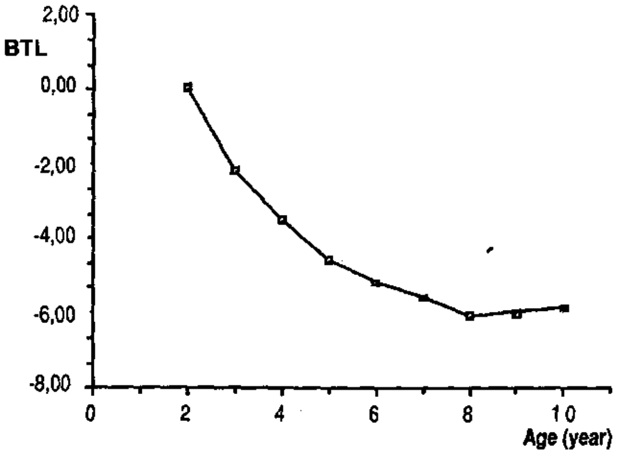


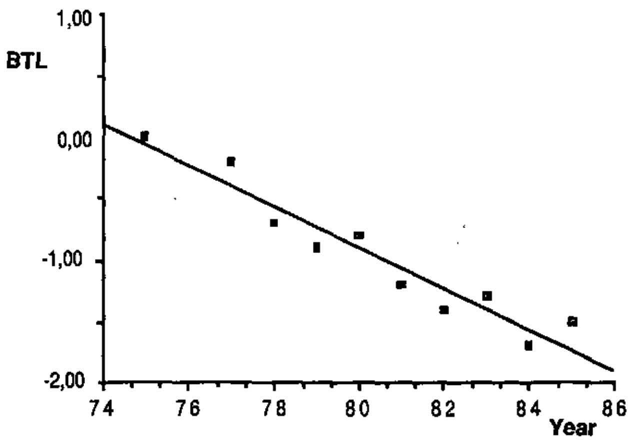
Table 2. Estimates of the fixed effects included in the animal model year of birth (from 1967 to 1983), sex (female, geldings, male) and age (9 classes : 2-10 years), year of best performance (from 1975 to 1985), hippodrome (5 hippodromes), type of start (4 types), distance (1300-1600m, 1700-2200m > 2200m) corresponding to best time in life.

	FREQUENCY	SOLUTION
SEX		
1	1492	0.000
2	889	-0.113
3	840	-0.498
AGE (years)		
2	100	0.000
3	490	-2.416
4	821	-3.540
5	624	-4.578
6	504	-5.137
7	297	-5.493
8	211	-5.877
9	112	-6.106
10	62	-6.327
YEAR OF BEST TIME IN LIFE		
75	23	0.000
76	113	0.619
77	152	-0.150
78	191	-0.680
79	295	-0.927
80	290	-0.774
81	282	-1.184
82	325	-1.426
83	279	-1.328
84	412	-1.701
85	859	-1.505
HIPPODROME		
1	844	0.000
2	239	0.239
4	347	1.064
5	218	0.049
6	1573	-0.814
TYPE OF START		
1	855	0.000
2	2125	1.123
3	26	0.699
4	215	3.476
DISTANCE		
1	910	0.000
2	1041	0.837
3	1270	1.148

Effect of year at best time in life

The rate of improvement with year of the best record in the career is given in Table 2 and illustrated by the Figure 3. Since additive genetic effect is included in the model the decrease of best time in life reflects more the improvement of the enviromental conditions. The linear decrease of the estimates of year effects is close to 0.17 s per year.

Figure 3. Effect of teh year of performance on Best Time in Life (BTL-s.)



Effect of the hippodrome

The effect of the hippodrome where the best time in life was achieved is given in Table 2. An significant hippodrome* date of best performance interaction effect of best time was also found with a different linear model but discarded due to its very low contribution to the variation. The interaction effect indicates that the improvement of the hippodromes was not the same.

Effect of the type of start

Best time in life was the best on autostart (Table 2). That result was also found by Langlois (1984) and Ojala et al. (1987).

Effect of the distance

Three types of distance (1300-1600m, 1700-2200m > 2200m) were considered. The results indicates (Table 2) that the best time in life increase with the distance of the race. The estimates show roughly an increases of 1 second per 1,000 meters of distance which is close to the 1/10 second per 100 meters found by Langlois (1984) and to the conclusion of Ojala et al. (1987).

Animal model - Additive genetic effects

After 50 rounds of iteration the convergence value was $8x10^{-6}$. Averages of the estimates of additive genetic values are given for the two versions of the animal model in Table 3. The value of the variance of the estimates(0.072 (AM/1), 0.079 (AM/2)) is, as expected, lower than the genetic variance estimated by a mixed model including stallion effect (0.338). The values corresponding to the estimates of breeding values and the estimates of the transmitting abilities (BLUP) are given in Table 4.

Table 3. Averages, standard deviation, minimum, maximum, variance of the estimates of breeding values of the 3221 progenies of 112 stallions. AM /1 (animal model without groups), AM/ 2 (animal model with groups of unknown parents).

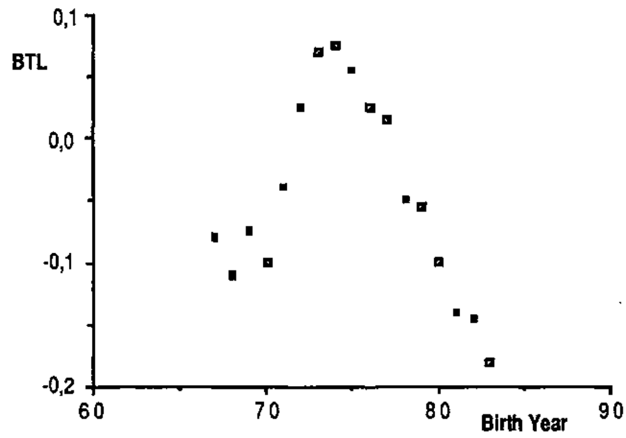
	n	mean	S	minimum	maximum	S^2
AM/1	3221	-0.029	0.268	-1.562	0.941	0.072
AM/2	3221	0.019	0.283	-1.247	0.976	0.079

Table 4. Averages, standard deviation, minimum, maximum, variance of the estimates of breeding values of the 112 stallions.
AM /1 (animal model without groups), AM/ 2 (animal model with groups of unknown parents) , BLUP (BLUP of stallions without groups and without relationships)

	n	mean	S	minimum	maximum	S^2
AM/1	112	0.001	0.366	-1.901	1.011	0.134
AM/2	112	0.057	0.341	-1.653	1.155	0.116
BLUP	112	0.000	0.183	-0.952	0.503	0.033

Birth year averages of the estimates of additive genetic values of the 3221 horses were computed. Figure 4 illustrates the genetic trend of best time from 1967 to 1983. A favourable genetic trend is observed for after 1973. More data are needed to certify the negative trend in the Belgian population.

Figure 4. Effect of the year of birth on the estimates of additive genetic values (BTL-s.)



Spearman correlation coefficients were computed for the 112 stallions. The correlation between BLUP and AM/1 is high (0.999). A lower value is obtained with the animal model including groups indicating that the introduction of groups of stallions and mares has changed the ranking of some animals. The introduction of groups of ancestors and the creation of base populations (by country of origin of the stallions or the mares) tend to correct for the bias due to the genetic level of mares. An other grouping strategy could be implemented within each population according to the performances of the mares. A different approach including genetic relationships between sire and dam effects has been developed by Katona and Distl (1987) who have introduced the genetic correlation between sire and dam effects in a mixed model BLUP model. As pointed out by Tavernier (1987) assortative mating may change the variance-covariance matrix and more work is needed in this area.

We are not able at this stage to measure the amount of the correction brought about by our grouping strategy but we think that the introduction of genetic relationships in an animal model should correct for the preferential choice of mares.

Table 5. Spearman correlation coefficients AM/1 (animal model without groups), AM/ 2 (animal model with groups of unknown parents), BLUP (BLUP of stallions without groups and without relationships)

	BLUP	AM/1	AM/2
BLUP		0.99997	0.93695
AM/1			0.93691

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BREEDING EVALUATION OF TROTTERS IN FINLAND

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Summary

Harness racing is the second most popular sport in Finland when judged by attendance, 1,4 mill. in 1987. The size of trotter population is about 24 000, some 60% of all horses. Slightly more than 50% of the 7 000 horses racing in 1987 were Standardbred trotters and the rest were Finnish trotters.

Registered horses may be eligible for the Stud Book (SB) of Standardbred trotters or Finnish trotters if they meet the conditions set for their own best time record, earnings, individual index and conformation. Only SB-stallions are allowed to be used in breeding. In 1987, some 100 Standardbred trotter stallions were mated to about 2 500 mares of the same breed; in Finnish Horses some 200 stallions were mated to about 2 500 mares. Almost 40% of all mares were artificially inseminated with fresh semen. Individual and sire indexes are being calculated annually in the beginning of a year. Sire indexes are published for stallions having at least five progeny in the youngest age class, 3-yr-olds for Standardbred trotters and 4-yr-olds for Finnish trotters.

Introduction

The Stud Book system has been, and it still is, an integral part of the Finnish horse breeding. The Stud Book of the Finnish Horse was officially approved by a statute in 1905. Since then the division of the Stud Book (SB) and specially the eligibility of a horse for the SB have been modified several times.

About 1 600 foals were born to Standardbred trotter mares and 1 500 foals to mares of Finnish Horses. In addition, some 300 Standarbred trotters were imported in 1987. About 2 500 Standardbred trotter mares were served by 115 stallions in 1987 whereas 198 stallions were used to serve some 2 500 mares in Finnish Horses. Almost 2 000 (40%) of the 5 000 mares were artificially inseminated with fresh semen.

Methods in breeding evaluation and selection

Eligibility for Stud Book

Breeding regulations for Standardbred trotters and Finnish trotters derive from the long traditions in breeding the Finnish Horse as a multipurpose workhorse for agriculture and forestry. Registered horses may be eligible for the Stud Book (SB) of Standardbred trotters (SH, 1986a) or Finnish trotters (SH, 1986b) if they meet the prerequisities set for their own best time record and performance index (individual index). In addition, horses are being judged in SB-shows arranged separately for stallions and mares. Final decision about a horse's acceptance into the SB is made by the board of examiners after judging and scoring a horse's temperament, movements and conformation. Joints of all stallions are being examined using X-ray technique. A stallion may be accepted into the SB for a maximum of five years after which it has to be rejudged.

Some of the minimum conditions to be fulfilled by Standardbred trotter stallions accepted into the SB in 1987 were for 3-yr-olds; best time record per kilometer 1.18 (min. sec) and earnings 50 000 FIM or the individual index 112; and for 4-yr-olds or older stallions : best time record 1.16 and earnings 100 000 FIM or the individual index 112. Finnish trotter stallions had to meet the following minimum conditions : best time record 1.37 (min. sec) for 4-yr-olds, 1.34 for 5-yr-olds, 1.32 for 6-yr-olds, 1.30 for 7-yr-olds and older stallions, and earnings per start about 1 000 FIM or the indivdual index 108. A total of 14 new Standardbred trotter stallions and 32 Finnish trotter stallions were accepted into the SB in 1987.

Indexes for racing performance

Indexes based either on a horse's own race records (individual index) or on progeny's race records (sire index) have been calculated and published annually since 1985. In 1988, both individual and sire indexes were calculated using race records from the years 1980 through 1987 for 3-, 4- and 5-yr-old Standardbred trotters and for 4-5- and 6-year-old Finnish trotters.

A horse's racing performance is a composite trait which can be thought of in terms of contributing component traits. The basic traits available are based either on a horse's time per unit distance, earnings or placings. Several traits are possible if a horse's race records are summarized on an annual basis. It would be useful if the component traits were combined into a multitrait index. This presupposes a definition of the component traits.

Percentage of first placings relative to all starts in a year may reflect a horse's temperament, its spirit and willingness to win. This definition applies, of course, only for horses having a sufficient basic speed. Percentage of first to third placings reflects a horse's level relative to that of the mates in the same race. Annual earnings per start reflects a horse's level relative to that of all horses raced. Best annual racing time, expressed in seconds per kilometer, on either auto- or volt-start reflects the maximum speed a horse may achieve on a distance of at least 1 600m. Best racing time also indicates a horse's level relative to that of all horses raced.

The individual index was a combination of indexes calculated for the following five traits :

		h^2	r
1.	square root of percentage of first placings in a year	.20	.40
2.	percentage of first to third placings in a year	.20	.40
3.	fourth root of annual earnings per start	.25	.50
4	best annual racing time on auto-start	.30	.60
5.	best annual racing time on volt-start	.30	.60

Estimates of h^2 and r for the traits were decided based on Ojala and Van Vleck (1981), Ojala (1987) and the available international literature. Records were deviations from year-sex subclass means within an age class in the two breeds. Predictions of breeding values for horses with regard to each trait were calculated within the three age classes using an approximate procedure for multiple trait selection index (Van Vleck, 1983). Thus, a horse's annual number of starts, and estimates of heritability and repeatability for the traits were taken into account, but correlations among the traits were ignored. Predicted breeding values for the five traits were standardized to indexes (I1 to I5) with lean 100 and standard deviation 10.

All horses do not race under both methods of start, consequently two combined indexes were constructed from the indexes of the single traits using the following weights :

$$IA = .03(I1) + .05(I2) + .12(I3) + .80(I4)$$
$$IV = .03(I1) + .05(I2) + .12(I3) + .80(I5)$$

The importance of the role of the SB-system in the Finnish horse breeding was strenghtened by a rule given in late 1970s. It was required that a foal born in 1978 or later is eligible to participate in harness races only if its sire was accepted in the Stud Book before the time of service. This rule increased the need to ensure that the requirements of eligibility for the SB are as fair as possible.

The objectives of this paper were to state some characteristics of the Finnish trotting industry, to summarize the principles used in evaluation and selection of breeding stock, and to list some recent research topics related to breed improvement

Harness racing and population of trotters

Harness racing is the second most popular sport in Finland when judged by attendance, 1.4 mill. in 1987. Total betting during about 700 race days on some 40 tracks amounted to 741 mill. FIM.

In 1987, the size of trotter population was about 24 000 which is some 60% of all horses. Slightly more than 50% of the 7 000 horses racing were Standardbred trotters and the rest were Finnish trotters. Prize money totalled 84 mill. FIM of which almost 60% was earned by Standardbred trotters (SH, 1987). Number of horses and total earnings were distributed across age classes more uniformly in Finnish trotters than in Standardbred trotters (Table 1).

Table 1. Number of horses raced and distribution of total earnings by age of horse in 1987.

	Standardbred trotters		Finnish trotters	
Age class	N° of horses raced	Total earnings, FIM	N° of horses raced	Total earnings FIM
All age classes	3 629	49 478 700	3 343	34 654 150
2-yr-olds	1%	0%	-	-
3-yr-olds	15%	15%	3%	1%
4-yr-olds	21%	26%	13%	10%
5-yr-olds	21%	24%	16%	15%
6-yr-olds	17%	17%	15%	15%
7-yr-olds	11%	9%	12%	15%
8-yr-old	7%	6%	12%	14%
9-yr-olds	4%	2%	10%	11%
10-yr-olds	2%	1%	8%	10%
Older than 10 yrs	1%	0%	11%	9%

where IA and IV are individual indexes having a major weight either on best annual racing time on auto-start or volt-start, respectively. As implied by the weights, the major emphasis is on improving a horse's capacity for maximum speed which is supplemented by other characteristics of racing performance.

The sire index was based within progeny's age classes for the following five traits :

	h^2
1. percentage of raced progeny of all progeny for a sire in the age class	.05
2. percentage of first placings in a year	.25
3. percentage of first to third placings in a year	.25
4. square root of annual earnings per start	.30
5. best annual racing time on volt-start	.30

Earnings were preadjusted for inflation using multiplicative adjustment factors based on the wholesale price indexes. All traits were adjusted for year-sex subclass effects. Means of preadjusted records for a sire's progeny group were adjusted for the size of progeny group and level of heritability according to principles of the selection index (Van Vleck, 1983). A progeny's annual number of starts and correlations among the traits were ignored.

Sire's predicted breeding values for the five traits were *standardized to indexes (S1 to S5) with mean* 100 *and standard* deviation 10. Indexes for the five traits were combined into the sire index (SI) within progeny's age classes as follows :

$$SI = .05(S1) + .05(S2) + .05(S3) + .15(S4) + .70(S5)$$

For sires having at least five raced progeny in more than one age class, an overall index (OI) was calculated as a weighted average of the within age class sire indexes (SI). Weights were the number of raced progeny in an age class. Sire indexes are published annually for stallions having at least five progeny in the youngest age class, 3-yr-olds for Standardbred trotters (Appendix) and 4-yr-olds for Finnish trotters. In 1988, indexes were published for 145 Standardbred trotter stallions and 135 Finnish trotter stallions.

Research topics related to breed improvement

Files consisting of race records are being maintained and updated by Suomen Hippos, the Finnish Trotting and Horse Breeding Association, for supervising parimutuel races. For breeding purposes, the files continue to lack sufficient information, especiallly on dams. As a result, it has not been possible to account, for example, for the level of mates in computing sire indexes. There are plans at Suomen Hippos to supplement the files with pertinent information in near future. General programs to compute BLUP of breeding values under an animal model are being developed both on main frame and PC computers. These programs are planned to be applied also in breeding evaluation of trotters.

Results from the study by Pylvänäinen (1987) confirmed that the magnitude of heritabilities for the traits in indexes is about right when pooled over age classes in the two breeds. logit transformation produced the best distributional properties for traits based on placings. Heritability for logit of disqualified starts averaged .14 in Standardbred trotters and .10 in Finnish trotters. This trait might add a new component about a horse's temperament into a multitrait index. Phenotypic and genetic correlations among the traits were also made available through this study.

Besides the indexes for racing performance, other information about a sire or its progeny may also prove useful for horsemen. Lists of sires including the number of mares served and progeny born are being published annually by Suomen Hippos. This information would obviously be more reliable if records from several years were combined. A study is in progress to estimate influences of contributing factors and repeatability for the percentage of foals born relative to mares served (Ojala, unpublished). Data for osteochondrosis, chipfragments and birkeland-fractures have been collected from horseclinics and tabulated (Tupamäki, unpublished; Ala-Huikku, unpblished). Influences of joint defects on a horse's own and its progeny's racing performance are being investigated. Provided that sufficient amount of data are available, these data could be used in evaluation of sires.

Use of artificial insemination has increased rapidly in the Finnish horse breeding. Methods allowing a long-distance transfer of fresh semen have been developed (e.g., Heiskanen et al., 1987) and applied to nearly 100 mares in 1987. Research in improving the available deep freezing methods of semen is in progress. A successful freezing method would obviously change the breeding strategies and increase the expected genetic gain in trotters.

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Appendix. Best sire indexes for Standardbred stallions in 1988.

Name of stallion	3-year-old progeny No	S1	S2	S3	S4	S5	SI	4-year-old progeny No	S1	S2	S3	S4	S5	SI	5-year-old progeny No	S1	S2	S3	S4	S5	SI	OI
Speedy Crown	26	103	148	135	146	132	133	33	90	148	134	150	134	135	26	73	129	131	140	125	125	131
Super Bowl	25	97	131	125	123	123	122	37	94	135	131	132	127	127	40	92	141	135	146	133	133	128
Nevele Pride	8	92	124	115	125	118	118	19	101	119	119	132	124	123	10	85	116	121	136	118	119	121
Speedy Somolli	11	102	117	113	117	116	115	13	100	132	133	138	122	124	7	98	114	109	113	115	113	118
Quick Pay	13	96	113	120	124	113	114	16	91	118	123	122	114	115	18	99	116	130	123	117	118	116
Speedy Count	6	97	104	107	114	116	114	16	106	112	111	115	123	120	13	93	103	98	107	113	109	115
Speedy Scot	8	104	99	103	107	116	113	13	120	106	109	113	120	118	16	113	102	100	109	116	113	115
*Choctaw Brave	34	144	110	109	126	112	115	-	-	-	-	-	-	-	-	-	-	-	-	-	-	115
Arnie Almahurst	5	98	106	100	100	109	107	9	99	136	116	115	114	115	6	93	141	127	140	116	120	115
Pay Dirt	16	109	115	120	111	110	111	20	107	111	122	115	118	117	19	98	104	115	111	118	115	114
The Prophet	21	90	107	119	116	110	110	34	84	117	120	118	114	113	42	109	111	122	124	116	117	114
Pershing	15	107	119	114	118	110	112	15	105	117	120	123	114	115	13	108	116	119	119	110	112	113
Carlisle	8	108	101	99	101	113	109	12	111	101	101	108	119	115	10	102	101	111	106	114	112	113
Glasgow	13	108	106	106	112	114	113	14	101	104	102	106	113	110	12	98	114	114	116	117	116	113
*Super Moon	30	112	116	113	118	116	116	38	108	113	116	110	114	113	26	100	98	105	106	107	106	112
Texas	7	102	130	124	118	113	115	7	94	117	115	120	112	113	8	97	107	108	123	103	106	111
*Express Pride	161	118	107	112	113	110	111	208	126	115	114	115	109	111	146	102	111	110	108	109	109	111
Zoo Suit	8	99	114	117	110	107	108	8	93	129	121	124	111	114	8	109	111	114	119	111	113	111
Fine Shot	11	103	101	107	105	110	108	17	99	108	112	111	112	111	16	101	121	112	112	113	112	111
*Gus Lobell	54	126	109	115	113	111	112	40	112	109	108	112	107	108	6	92	96	99	99	96	96	110
Shatter Way	14	100	116	121	109	108	109	21	98	105	111	110	113	112	16	87	106	105	108	112	110	110
Buckeye Count	9	100	106	104	103	106	105	14	105	113	111	112	113	112	14	113	116	109	113	112	112	110
Speedy Spin	5	92	99	98	106	103	103	12	82	110	103	110	112	110	322	86	128	124	114	110	111	110
Songcan	5	99	115	117	109	103	105	10	98	118	126	120	110	112	5	92	101	100	104	107	105	109
Bonefish	5	94	118	110	110	110	110	11	94	100	93	102	114	109	11	94	99	110	109	108	107	109
*Turn For Home	15	106	97	108	113	108	108	7	105	98	95	109	113	110	-	-	-	-	-	-	-	109
Count's Pride	14	120	105	106	111	105	107	13	107	106	108	112	113	112	7	98	107	111	112	110	109	109
Dartmouth	9	97	109	109	105	102	103	20	103	106	109	110	109	109	22	107	110	110	110	112	111	109
*Casual Pride	23	131	100	104	97	104	104	25	113	113	119	114	113	113	16	103	104	99	102	105	104	108
Florida Pro	8	106	98	100	104	114	110	7	98	101	103	106	107	106	5	94	104	110	115	108	108	108
Lullwater Song	9	1096	101	99	103	107	105	12	111	101	106	107	107	107	12	123	115	117	116	109	111	108

Hickory Smoke	5	118	101	97	107	109	108	-	-	-	-	-	-	-	6	105	97	98	100	108	105	107
*Gothic	9	108	102	116	111	111	111	14	118	100	98	108	104	105	-	-	-	-	-	-	-	107
*Arnie's Aim	21	96	104	103	107	108	107	-	-	-	-	-	-	-	-	-	-	-	-	-	-	107
*Clayt Hanover	111	102	110	112	106	107	107	192	124	105	110	106	105	106	211	116	106	113	105	106	107	107
V.I.P.	5	101	104	107	109	107	107	-	-	-	-	-	-	-	-	-	-	-	-	-	-	107
Near Me	5	100	103	101	105	107	106	6	101	106	110	107	109	108	5	96	96	103	105	109	107	107
*Impish Pride	14	95	105	100	98	102	101	22	93	108	115	108	110	109	21	87	112	111	107	109	108	107
Noble Action	13	103	106	106	101	110	108	7	96	107	110	108	108	108	7	101	110	108	105	99	101	106
*Leonard Hanover	15	100	118	109	111	109	109	15	100	108	108	106	101	103	13	120	101	107	99	105	105	106
*Keystone Patriot	36	94	105	103	104	102	103	62	118	106	107	108	109	109	40	118	108	111	106	105	107	106
Noble Wejover	6	98	104	102	103	103	103	10	95	110	104	105	108	107	15	115	109	111	105	106	107	106
*At Risk	27	102	105	114	107	105	106	25	105	104	110	107	108	108	19	98	117	110	98	100	101	105
*Court Recess	5	96	106	1054	103	106	105	-	-	-	-	-	-	-	-	-	-	-	-	-	-	105
Equileo	5	118	98	106	107	104	105	-	-	-	-	-	-	-	-	-	-	-	-	-	-	105
*Billy The Kid	6	101	104	103	103	101	102	6	95	109	107	103	111	109	-	-	-	-	-	-	-	105
*A.C's Orion	48	92	109	103	103	108	106	89	115	100	99	103	103	103	83	98	104	98	102	106	105	104
* Nevele Fever	7	109	101	103	107	105	105	5	102	95	97	99	103	101	-	-	-	-	-	-	-	104
*Christopher T.	14	101	104	103	104	104	104	-	-	-	-	-	-	-	-	-	-	-	-	-	-	104
*Ebby Lobell	36	107	102	103	103	104	104	32	118	99	99	100	106	105	12	103	88	94	97	103	101	104
Way To Fame	11	103	104	101	102	105	104	8	107	99	100	98	104	103	7	107	100	103	103	103	103	104
*Tic Collins	9	106	91	91	93	104	101	8	104	105	106	112	108	108	-	-	-	-	-	-	-	104

No = number of progeny
S1 = index for percentage of progeny of all progeny in age class
S2 = index for percentage of first placings in a year
S3 = index for percentage of first to third placings in a year
S4 = index for square root of annual earnings per start
S5 = index for best annual racing time on volt-start
SI = sire index (a combination of S1 to S5)
OI = overall index (a combination of the SIs)
* = used as a breeding stallion in Finland

BREEDING EVALUATION OF FRENCH TROTTERS ACCORDING TO THEIR RACE EARNINGS
1 - PRESENT SITUATION

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Summary

After a brief summary of French research on genetics of trotters an indexation method based on the use of race earnings is given in this report.

We propose the calculation of a yearly index which is rather similar to ESTES' "earning index" but normalized by a logarithmic transformation and expressed in points of mean 100 and standard deviation 20. Individual yearly average earning per start is expressed as a percentage of the variable for horses of the same age-sex-year group. The distribution of this ratio is then normalized, standardized for each age class and expressed in points.

These values are then used to index breeding animals by an adaptation of conventional methods related to random mating to unusual situations of assortative mating.

Stallions are estimated according to the mean of their own performances, the mean of their offspring and the mean of their mated mares; the mares are only estimated from their own performances and horses without any earning are estimated by a pedigree index computed from the indexes of their two parents.

We finally discuss the advantages and disadvantages of the proposed temporary solution while waiting for the use of animal model BLUP estimations which are commonly applied to sport horses in France.

Introduction

Research on quantitative genetics of the Trotter started at INRA in 1980 in a close co-operation with the National Studs, the "Société d'Encouragement à l'Elevage du Cheval Français" (SECF) and the "Groupement pour l'Amélioration de l'Elevage du Trotteur" (GAET). After some preliminary studies (Descoqs, 1976; de Richter, 1977) more or less widely diffused technical publications on this topic have been made (Théry, 1981; Langlois, 1982, 1983 a, b, and c, 1984 a and b, 1985 a, b and c). They show the advances in our knowledge in the field of genetic improvement of this population. Temporary selection indexes have also been calculated. Information has been collected from numerous specialists on the occasion of several meetings. We have now come to the definition of a routine method of objective qualification of breeding animals.

After a summary of obtained results, a simplified report on this routine method is given.

I. Summary of obtained results

Criteria available for evaluation of the performances of trotters derive either from timing or from earnings. Timings are given in best time record per kilometer depending on several factors. The horse age and sex, month and year of the race, harness race or mounted mode, autostart or voltstart, the length, the race track and especially the level of the race are very important factors. Nevertheless, it seems that the use of this information through the best time is efficient for selection (heritability between 0.25 and 0.35). It allows to suppress to a large extent the impact of the environmental effect mentioned before as each horse seems to have the possibility of giving the best of itself some time or other. Moreover, it should be noticed that according to the very small impact of rank effect on best time record per kilometer this criterion represents a level of the race rather than a direct measure of the animal's absolute potential. This estimation method is not fundamentally different from earnings. It gives an idea of the average level of the courses in which the horse is able to be placed.

As shown several times it must, however, be used in a logarithmic form in order to give an efficient indication of accomplished performances. After adjustment for the effects of year, age and sex the estimations of heritability of earning criteria ranged between 0.15 and 0.30. Yearly earning (log G) and especially the more heritable average earning per start (log G/D) thus seem suitable for the same reason as the best times to perform selection.

Genetic correlations between best time and earning criteria evaluated to about -0.80 are high, but still different from -1. The corresponding phenotypic correlation of about -0.70 is slightly lower, but remains high. These two criteria seem to give an account of the same ability.

In connection with this, genetic correlations obtained for one criterion at different ages with record times near to 1 are about 0.80 for yearly earnings (log G) and 0.90 for average earning per start (log G/D). In this case they are considerably higher than phenotypic correlations ranging around 0.80 for best times, 0.30 for earnings (log G) and 0.40 for average earning per start (log G/D).

It thus seems that the use of the life best time of the horse may give an account of the track career in terms of timing.

On the other hand, the use of all performance years available for earning criteria seems to be interesting given the importance of genetic correlations (0.80 - 0.90) and the relative weakness of phenotypic correlations (0.30 - 0.40).

Experimental use of indexation techniques for breeding animals on their own performances as well as on progeny and independently on life best time as well as average earning per start (log G/D) has led to the use of the average earning per start: more consistent results of the tested cross-checks and finally a higher accuracy of the estimates. Moreover, the ranks resulting from the use of either of the criteria do not seem fundamentally different. However, slight deviations are noticed. In fact, the best time only characterizes speed potential without taking into account other aspects like regularity and sporting longevity which are better taken into consideration by earnings. The earnings which depend to a larger extent on horses' adaptation to our race programmes indicate a little better our production objectives which are significantly different from those of standardbreds, directed towards speed and precocity.

Moreover, the development of an indexation method based on earnings gives another advantage, which is psychological and practical. Breeders of trotters have for a long time been accustomed to appreciate horses on their life best time. It is thus very difficult to change habits in this field even if it is justified. Earnings, which are very little used, would lead to development of a new, more performing methodology without the inertia of habits interfering with its accomplishment.

II. Indexation steps

a. Calculation of a yearly index

At the end of each race year an average earning per start (G/D) is calculated for each winning horse based on its earnings in the year (G) and on the corresponding number of starts (D).

Then, average earnings per start (G/D) are expressed as a percentage of the mean of this variable for horses of the same age class (2, 3, 4, 5 years, 6 years and more), sex (females, males and geldings) and year. The distributions of these yearly ESTES' average earning indexes are normalized (Fig. 1 and 2) by a logarithmic transformation and standardized per age class. To facilitate their use they are multiplied by 20, one 100 is added and the number is rounded of in order to obtain a whole number.

Figure 1. Distribution of Estes' earning index

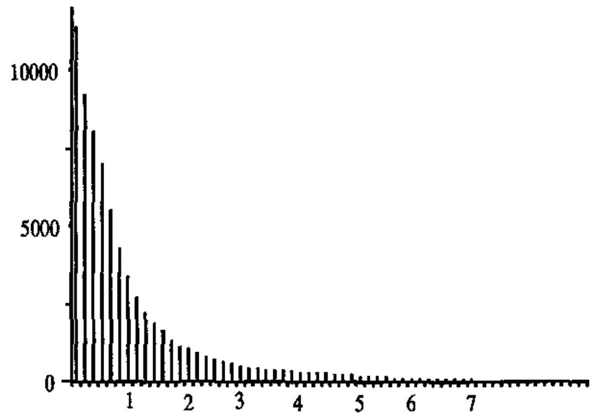
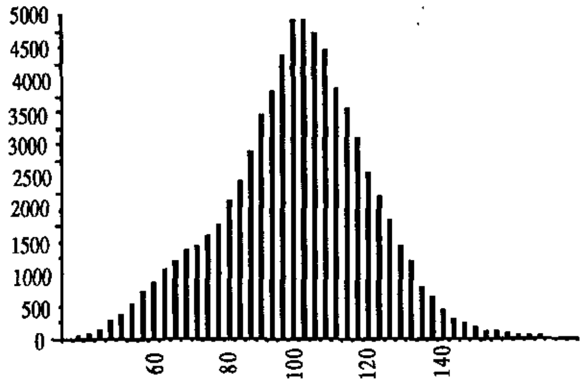


Figure 2. Distribution of our yearly index



The result of these transformations gives the "yearly index". In this presentation the horses are nearly equally distributed around the value of 100, a horse superior to 120 belongs to the upper 15% and a horse inferior to 80 belongs to the lower 15%. In this way obtained earnings at different ages can be compared over a very long period. The value of the index also allows an immediate comparison of the horse's performances to its contemporaries. The practical details of these calculations are given in Appendix I.

b. Indexation

It is known that information on the genetic value of a horse is placed chronologically in the following way: per origin (pedigree index), own performances (performance index), progeny performances (progeny index). It is also known that the accuracy of knowledge of this genetic value is increasing from the pedigree index to the progeny index and the weight of the first information shades more and more off as the new ones are taken into account.

In the case of a stallion with a large progeny group the phenotypic mean of his progeny generally contributes the most to the knowledge of his genetic value. On the other hand, the level of own performances of a brood mare whose progeny number is usually restricted generally constitutes the most interesting information. The pedigree index which assumes that the parents themselves are indexed is only interesting when no other information is available. This is the case of foals, yearlings and many mares.

Moreover, during progeny testing when the genetic average of the mates of a breeding animal is liable to substantially deviate from the mean this should be taken into account in the indexation. Therefore we suggest :

- to index a stallion according to the mean of his yearly indexes, the double of the mean of the means of yearly indexes of his progeny (*) and the mean of the means of yearly indexes of his mates.
- to index a brood mare only according to the mean of her yearly indexes. The average number of her known offspring is about 2.5 and therefore only gives little information which, in addition, should be adjusted for the value of corresponding stallions. It complicates the operations a great deal compared to the low gain in accuracy and therefore is not suitable.
- the elaboration of a pedigree index can then be undertaken from the parents' indexes.

When the choice of independent variables of the genetic value of one horse has been taken it is estimated by linear regression according to standard methods.

In the case where only one predictor is used as the mean P of the performances of the horse, the index I is written:

$$I = b\ (P-\bar{P})$$

where b is the regression coefficient of the genetic value A in its predictor P whose mean is P.

$$b = Cov(A,P)\ Var(P)^{-1}$$

Consider the case of 3 predictors for A, i.e. P, the mean of own

(*) each stallion only supplies half of the genetic value to each of his progeny performances, 2D, the double of the mean of progenies and M, the mean of mated mares, the expression

$$I = Cov(A,P)\ Var(P)^{-1}(P-\overline{P})$$

becomes a matrical equation where :

Cov(A,P) is the line vector (1x3) of the covariances of the predictors with the estimated genetic value.

$Var(P)^{-1}$ is the inverse of the variance covariance matrix of the predictors P, 2D and M.

$(P-\overline{P})$ is the column vector (3x1) of the deviations of the predictors from their mean.

The stallion's index is then established in the following form:

$$I = b_1\ (P-\overline{P}) + b_2\ (D-\overline{D}) + b_3\ (M-\overline{M})$$

where b_1, b_2 and b_3 are partial regression coefficients.

As it can be seen this method assumes that the variance covariance matrix of the chosen independent phenotypic variables and of the dependent genetic variable is known. Its determination includes two aspects:

-to explain according to a genetic model, the covariances of the genetic value to be predicted with its different phenotypic estimators.

-to express the other variances covariances according to the available number of horses for each animal and to a relatively restricted number of parameters measured once for all.

In Appendix II the method of calculation is given and, for methodological bases, we refer to former works (Langlois, 1981).

The parameters used are the following :

- those defining the quality of the information used. It concerns heritability ($h^2 = 0.21$ for log G/D) and repeatability ($r = 0.38$).

- a second group defines the structure of reproduction. It concerns the correlation between mates ($c = 0.15$) and the mean correlation of dams mated with one single stallion ($t_m = 0.11$).

- the mean correlation between progeny of one single stallion can be deduced from the former ones but it is preferable to estimate it in case of environmental effects common to all the progeny of one single sire. The evaluation gives $t_d = 0.06$.

In order to simplify the method it can be said that the horse's estimators are compared to their mean in the population. The observed deviations make it possible to decide the position of the animal. Then these deviations are multiplied by regression coefficients varying between 0 and 1 according to the available amount of information such as the number of years of performances, the number of progeny or dams included and the quality of this information expressed by coefficients like heritability and repeatability. The more information available, the higher the heritability and repeatability and the more coefficients are near to 1. The less information available, the lower the heritability and repeatability and the more the coefficients are near to 0. The observed deviations are brought back to the mean of the population as if they were "pulled by a rubber band". If much important information is available it will pull hard on the rubber band and the estimation by regression will be near to the observed deviations. On the other hand, if only little information is available the observed deviations will be strongly brought back to the mean.

Let us have a look on the results. They are expressed as yearly positive or negative index points representing the expectation conditioned by the information used of the genetic superiority or inferiority of the indexed animal. Half of this genetic value represents the expectation of the deviation from the mean of its progeny when mated at random.

This estimation is accompanied by a determination coefficient, i.e. a regression coefficient, which gives the degree of accuracy.

Knowing that the expectation of the genetic value of a horse equals half the value of its sire and half the value of its dam and that the indexes are un-biased estimators of the genetic value of the parents, a pedigree index having the following form can be suggested :

$$I_d = 1/2\ I_p + 1/2\ I_m$$

The pedigree index of the horse (I_d) equals half the index of its sire (I_p) plus half the index of its dam (I_m).

The determination coefficient of this index (R^2) which is a term of variance is established as a function of squares and it can be shown that if the correlation between Ip and Im is not too strong, we obtain

$$R_d^2 = 1/4\ R_p^2 + 1/4\ R_m^2$$

The determination coefficient of a horse pedigree index (R_d^2) equals a quarter of the coefficient of its sire (R_p^2) plus a quarter of that of its dam (R_m^2). If the dam is not indexed, $I_m = 0$ and $R_m^2 = 0$ allow a calculation to be made only as a function of the sire.

Discussion and conclusion

The present indexation method has the advantage of being very easy to use without major computer equipment. Only a matrix (3x3) has to be inverted. As it is based on the principle of regression it allows to generalize the conventional methods related to random mating to unusual situations of assortative mating. As far as the disadvantages are concerned it is pointed out that the method involves a separate treatment of fixed effects (year, age, sex...) which, for reasons of simplification, are not strictly treated by means of an analysis of variance. However, the use of average earning indexes are very practical and should allow breeders to better understand the adjustment method. Moreover, this approach should not deviate much from theoretically stricter methods as the number of horses per class is so high every year.

In the same way the level of a stallion's harem is estimated on the whole by the mean of the performances of the mates without relating them to each of their progeny : moreover, this level does neither take into account the paternal origins of the dams nor of their offspring, if any, which constitutes a loss of information.

Another handicap is the absence of a proposal for cumulating a pedigree index with a performance index except no longer taking into account the ancestors when performances are available. It would, however, be useful to exploit this lost information.

The application of an animal model BLUP-method would avoid these disadvantages. It is being studied at present (Tavernier, 1988) but it proves to need much more data processing than the solution proposed here. Accordingly, the solution suggested here may be useful and easily available before setting up of more consistent methods.

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APPENDIX I

Practical details of the calculation of yearly index

Calculate log G/D and subtract the adjustment factors given in Table 2 as a function of year and sex. They correspond to the logarithm of the mean of the variable G/D for horses of the same age, sex and year group. Then the values are standardized intra age according to the elements given in Table 1, i.e. subtract the mean, divide by the standard deviation, multiply by 20, add 100 and round off in order to obtain a whole number.

Table 1. Mean and standard deviation of log G/D adjusted for age, year and sex.

	mean	standard deviation
2 years	-0.36295	1.22588
3 years	-0.63587	1.33486
4 years	-0.58274	1.29576
5 years	-0.60910	1.28880
6 years and more	-0.69283	1.38169

Table 2 - Adjustment factors of Log G/D

	2 year		3 year		4 year		5 year		6 year and +	
	M+G	F	M+G	F	M+G	F	M+G	F	M+G	F
1947			9.1435	8.9309						
1948	9.3408	9.2576	9.4055	9.1929	9.4289	9.1695				
1949	9.2621	9.1789	9.3268	9.1141	9.3502	9.0908	9.3485	9.0924		
1950	9.4378	9.1784	9.4144	9.2018	9.3497	9.2665	9.4361	9.1801	9.3784	9.2378
1951	9.3898	9.3067	9.4546	9.2419	9.4780	9.2185	9.4763	9.2202	9.4186	9.2779
1952	9.6206	9.5374	9.6853	9.4727	9.7087	9.4493	9.7070	9.4510	9.6493	9.5087
1953	9.6501	9.5669	9.7148	9.5022	9.7382	9.4788	9.7365	9.4805	9.6788	9.5382
1954	9.7928	9.7096	9.8575	9.6449	9.8809	9.6215	9.8792	9.6232	9.8215	9.6809
1955	9.8900	9.8069	9.9548	9.7421	9.9782	9.7188	9.9765	9.7204	9.9188	9.7781
1956	9.9947	9.9115	10.0594	9.8468	10.0828	9.8234	10.0811	9.8251	10.0234	9.8828
1957	10.1904	10.1073	10.2552	10.0425	10.2786	10.0191	10.2769	10.0208	10.2192	10.0785
1958	10.3231	10.2400	10.3879	10.1752	10.4113	10.1518	10.4096	10.1535	10.3519	10.2112
1959	10.4227	10.3395	10.4874	10.2748	10.5108	10.2514	10.5091	10.2531	10.4514	10.3108
1960	5.9379	5.8547	6.0026	5.7900	6.0260	5.7666	6.0243	5.7683	5.9666	5.8260
1961	6.0953	6.0121	6.1600	5.9474	6.1834	5.9240	6.1817	5.9257	6.1240	5.9834
1962	6.3033	6.2201	6.3681	6.1554	6.3914	6.1320	6.3898	6.1337	6.3321	6.1914
1963	6.3993	6.3161	6.4640	6.2514	6.4874	6.2280	6.4857	6.2297	6.4280	6.2874
1964	6.4421	6.3590	6.5069	6.2942	6.5303	6.2708	6.5286	6.2725	6.4709	6.3302
1965	6.5425	6.4593	6.6072	6.3946	6.6306	6.3712	6.6289	6.3729	6.5712	6.4306
1966	6.6229	6.5398	6.6877	6.4750	6.7111	6.4516	6.7094	6.4533	6.6517	6.5110
1967	6.6464	6.5632	6.7111	6.4985	6.7345	6.4751	6.7328	6.4768	6.6751	6.5345
1968	6.5600	6.4902	6.7570	6.5444	6.7804	6.5210	6.7787	6.5227	6.7210	6.5804
1969	6.6045	6.5387	6.8270	6.4884	6.8560	6.5966	6.8544	6.5983	6.7967	6.6560
1970	6.6233	6.4833	6.7673	6.5729	6.7379	6.6042	6.8776	6.6216	6.8199	6.6793
1971	6.6835	6.5983	6.8841	6.6140	6.9388	6.6024	7.0503	6.7898	6.9411	6.8005
1972	6.7902	6.6858	6.9235	6.8191	7.0246	6.8063	7.1507	6.7866	7.0250	6.8843
1973	7.0809	6.9958	7.0725	6.9350	7.1826	6.8502	7.1201	7.0135	7.1056	6.9649
1974	7.0756	7.0969	7.2277	6.9198	7.1739	6.9238	7.2102	6.9642	7.1812	7.0406
1975	7.2895	7.1421	7.2884	7.1534	7.3243	7.1016	7.3690	7.0496	7.3107	7.1701
1976	7.3430	7.3467	7.4861	7.2168	7.4000	7.2976	7.4867	7.2833	7.4616	7.3478
1977	7.5262	7.4441	7.4523	7.2904	7.5117	7.2393	7.5315	7.3874	7.4974	7.3078
1978	7.6948	7.4913	7.5649	7.4122	7.6183	7.3275	7.6572	7.3745	7.5628	7.4321
1979	7.7062	7.7297	7.7153	7.4319	7.6799	7.4603	7.8055	7.5287	7.6784	7.4312
1980	7.7894	7.5978	7.7782	7.5210	7.8216	7.4861	7.8838	7.6870	7.7107	7.6108
1981	7.9046	7.8262	9.7953	7.6443	7.9408	7.5974	8.1043	7.7780	7.8606	7.7495
1982	7.9103	7.8818	7.8937	7.6530	7.9534	7.6737	8.1542	7.8182	7.9413	7.8433
1983	8.2167	7.9996	8.0703	7.7581	8.0707	7.8312	8.3081	7.9182	8.0745	7.9651
1984	8.1628	8.0656	8.1809	7.8639	8.2558	7.8491	8.2776	8.0412	8.2093	7.9866

APPENDIX II

Determination of variance covariance matrix of the chosen independent variables and of the dependent genetic variable

- The predictors

Let $P_{i.}$ be the mean of m_p yearly indexes of stallion i, $M_{i..}$ the mean of the means $M_{ij.}$ of n_m of its mates and $D_{i..}$ the mean of the means $D_{ij.}$ of n_d of its progeny.

$$P_{i.} = \frac{1}{m_p} \sum_{k=1}^{m_p} P_{ik}$$

$$M_{i..} = \frac{1}{n_m} \sum_{j=1}^{n_m} M_{ij.} \qquad \text{with} \qquad M_{ij.} = \frac{1}{m_m} \sum_{k=1}^{m_m} M_{ij'k}$$

$$D_{i..} = \frac{1}{n_m} \sum_{j=1}^{n_d} D_{ij.} \qquad \text{with} \qquad D_{ij.} = \frac{1}{m_d} \sum_{k=1}^{m_d} D_{ijk}$$

- The dependent value

It is the added genetic value (A) in a model where the phenotype (P) is the sum of this value and of a remainder (R) depending essentially on the action of environment.

$$P = A + R$$

suppose $cov(A,R) = 0$ let $var(P) = var(A) + var(R)$

put $var(P) = \sigma^2$ and $var(A) = h^2 \sigma^2$

- Determination of the vector of the covariances of the genetic value with its predictors

$$cov(A_p,P_{i.}) = cov(A_p,P) = h^2 \sigma^2$$

$$cov(A_p,D_{i..}) = cov(A_p,D) = cov(A_p,A_d) + \underbrace{cov((A_p,R_d)}_{=0}$$

$$= \frac{1}{2} \mathrm{Var}(A_p) + \frac{1}{2} \mathrm{cov}(A_p,A_m)$$

$$\mathrm{cov}(A_p,D_{i..}) = \frac{1}{2} h^2 \sigma^2 + \frac{1}{2} h^4 c \sigma^2 \quad \text{with} \quad c\sigma^2 = \mathrm{cov}(P,M)$$

$$\mathrm{cov}(A_p,M_{i..}) = \mathrm{cov}(A_p,M) = h^2 c \sigma^2$$

- Determination of predictors variance covariance matrix

The variances

$$\mathrm{Var}(P_{i.}) = \frac{1}{m_p} \mathrm{Var}(P_{ik}) + (1 - \frac{1}{m_p}) \mathrm{cov}(P_{ijk},P_{ijk'})$$

$$\mathrm{Var}(P_{i.}) = \frac{1}{m_p} \sigma^2 [1 + (m_p-1) r]$$

where r is the repeatability of performances. $\mathrm{Var}(D_{ij.})$ and $\mathrm{Var}(M_{ij.})$ are expressed in the same way.

$$\mathrm{Var}(D_{i..}) = \frac{1}{n_d^2} \sum_{j=1}^{n_m} \mathrm{var}(D_{ij.}) + \frac{1}{n_d^2} \sum_{j\neq j'} \mathrm{cov}(D_{ij.},D_{ij'.})$$

$$= \frac{1}{n_d^2} \sum_{j=1}^{n_m} \frac{1}{m_d} \sigma^2 [1 + (m_d-1) r] + \frac{1}{n_d^2} \sum_{j\neq j'} \mathrm{cov}(D_{ijk},D_{ij'k})$$

i.e., let $k_d = \frac{1}{n_d} \sum_{d=1}^{n_d} \frac{1}{m_d}$ and $t_d \sigma^2 = \mathrm{cov}(D_{ijk},D_{ij'k})$

$$\mathrm{Var}(D_{i..}) = \frac{1}{n_d} \sigma^2 [k_d + (1-k_d) r + (n_d-1) t_d]$$

where t_d is the paternal component of the variance. In the same way, let :

$k_m = \frac{1}{n_m} \sum_{m=1}^{n_m} \frac{1}{m_m}$ and $t_m \sigma^2 = \mathrm{cov}(M_{ijk},M_{ij'k})$

$$\mathrm{Var}(M_{i..}) = \frac{1}{n_m} \sigma^2 [k_m + (1-k_m) r + (n_m-1) t_m]$$

The covariances

$$\mathrm{Cov}(P_{i.}, D_{i..}) = \mathrm{cov}(P,D) = \frac{1}{2} h^2 (1 + c)\sigma^2$$

$$\mathrm{Cov}(P_{i.}, M_{i..}) = \mathrm{cov}(P,M) = c\,\sigma^2$$

$$\mathrm{Cov}(M_{i..}, D_{i..}) = \frac{n_c}{n_m n_d}\mathrm{cov}(M,D) + (1 - \frac{n_c}{n_m n_d})\mathrm{cov}(M',D)$$

In this expression M is D's dam and M' represents another dam mated with D's sire, n_c is the number of couples dam/progeny, n_m the number of dams intervening in the calculation of $M_{i..}$ and n_d the number of progeny intervening in the calculation of $D_{i..}$

$$\mathrm{cov}(M,D) = \frac{1}{2} h^2 (1 + c)\sigma^2$$

$$\mathrm{cov}(M',D) = \mathrm{cov}(A_d,M') + \underbrace{\mathrm{cov}(R_d,M')}_{=0}$$

$$\mathrm{cov}(M',D) = \frac{1}{2}\mathrm{cov}(A_p,M') + \frac{1}{2}\mathrm{cov}(A_m,M')$$

$$\mathrm{cov}(A_p,M') = \mathrm{cov}(A_p,M) = h^2 c\,\sigma^2$$

$$\mathrm{cov}(A_m,M') = h^2\,\mathrm{cov}(M,M') = h^2 t_m \sigma^2$$

where t_m is the paternal component of the variance of dams. After some simplifications we get :

$$\mathrm{cov}(M_{i..}, D_{i..}) = \frac{1}{2} h^2 \sigma^2 \left[\frac{n_c}{n_m n_d} + \left(1 - \frac{n_c}{n_m n_d}\right) t_m + c\right]$$

BREEDING EVALUATION OF FRENCH TROTTERS ACCORDING TO THEIR RACE EARNINGS
2 - PROSPECTS

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Summary

In order to benefit from the theoretical advantage of the BLUP animal model, an across herd evaluation system was developped which reduces computation cost for a routine application to a large horse population. For a long time, trotter horses have been submitted to selection and assortative matings. The animal model is the best approach to these problems.

The model used for the log of annual earnings per start (Langlois 1984) includes an individual additive genetic component, permanent environmental and "herd x dam" effects considéred as random and sex and age x year subclass effects as fixed. This "herd x dam" effect is due to the difference between the maternal and paternal components and represents the common environmental conditions shared by progeny of the same mother. The variance-covariance matrix includes the complete relationship matrix between all the animals whatever the kind of animal : recorded or non-recorded, parent or non-parent horse, males or females.

The problem is to solve the equations corresponding to all the animals after absorption of permanent environmental and herd x dam effects. The system is solved by using a particular structure of the inverse of the relationship matrix. Animals with no progeny are grouped by mare and their mares are then arranged into groups. A group of mares is made of a mare which has no identified dam, her daughers, her grand-daughters etc...The corresponding matrices are block-diagonal and are easily absorbed. The resulting system (fixed effects and stallions) is solved by iterations. An approximation of the coefficient of determination is then calculated by using matrix algebra. This evaluation system allows to compute the observed genetic change and the correlation between mates. This method is of a very great practical interest in Trotter horses :

- use of performance records in both sexes
- use of combined information from different relatives
- evaluation of all broodmares (with and without records)
- selection and assortative mating are taken into account.

Introduction

In France, trotters are indexed on earning per start using a selection index which for stallions combines own performances with those of progeny and mated mares and which is based on own performances for earning horses. It is possible to calculate a pedigree index for the other horses. Our aim is to improve these indexes, as for sport horses, by using an animal model BLUP method. At the same time, it allows us to give a more precise index and to simplify the index control by an uniform calculation method.

Material and methods

The applied calculation technique is the same as that used for sport horses (Tavernier, 1985), we shall therefore only briefly summarize it here. As far as criteria and variation factors are concerned we refer to the works of Langlois (1986).

1. Model

The used criterion is the average earning per start (Langlois, 1985). The sex and the combination of year and age class are fixed effects as the race endowment policy, which varies with time according to the age, combines with inflation effects. There are 5 age classes : 2, 3, 4, 5 years and 6 years and more. In France, a trotter may run from the age of 2 to the age of 10. Therefore, the repeatability of the trait will be taken into account. Moreover, in the same way as for sport horses (Tavernier, 1986), we showed a difference between the maternal and paternal component of variance. Because if the large number of herds with only one trotting mare (60%) it is not possible to distinguish between strict maternal effect and herd effect in this deviation. Therefore, we considered a random maternal-herd effect which represents the common environmental effect shared by all the progeny of one single dam. This gives one single effect for oofspring performances of one single mare.

The linear model is as follows :

$$y = Xb + Zu + Wm + Zp + e$$

where,

y	=	vector of observations (logarithm of yearly average earning per start)
b	=	vector of fixed effects (sex and age-year class)
u	=	vector of individual additive breeding values
m	=	vector of maternal-herd effects

p = vector of common environmental effects to the different performances of one single horse
e = vector of residual error
X, Z, and W = incidence matrices

The expectation vector is :

$$E \begin{bmatrix} y \\ u \\ m \\ p \\ e \end{bmatrix} = \begin{bmatrix} Xb \\ 0 \\ 0 \\ 0 \\ 0 \end{bmatrix}$$

The variance-covariance matrix is :

$$V \begin{bmatrix} u \\ m \\ p \\ e \end{bmatrix} = \begin{bmatrix} A\sigma_u^2 & 0 & 0 & 0 \\ 0 & I\sigma_m^2 & 0 & 0 \\ 0 & 0 & I\sigma_p^2 & 0 \\ 0 & 0 & 0 & I\sigma_e^2 \end{bmatrix}$$

where,

$$\sigma_u^2 = h^2 \sigma_y^2$$
$$\sigma_m^2 = v\, \sigma_y^2$$
$$\sigma_p^2 = (r\text{-}v\text{-}h^2)\, \sigma_y^2$$
$$\sigma_e^2 = (1\text{-}r)\, \sigma_y^2$$

A : relationship matrix
I : identity matrix
h^2 : heritability
r : repeatability
v : fraction of the phenotypic variance due to the maternal-herd component.

The relationship matrix contains all the animals, breeding or not, performing or not. The lines of matrix Z corresponding to non-performing animals only contain zeros.

2 - Equations and solution of the mixed model

The equations of the mixed model are :

$$\begin{bmatrix} X'X & X'Z & X'W & X'Z \\ Z'X & Z'Z+t_1A^{-1} & Z'W & Z'Z \\ W'X & W'Z & W'W+t_2I & W'Z \\ Z'X & Z'Z & Z'W & Z'Z+t_3I \end{bmatrix} \begin{bmatrix} b \\ u \\ m \\ p \end{bmatrix} = \begin{bmatrix} X'y \\ Z'y \\ W'y \\ Z'y \end{bmatrix}$$

where,

$t_1 = (1-r) / h^2$

$t_2 = (1-r) / v$

$t_3 = (1-r) / (r-h^2-v)$

"Common environmental" and "maternal-herd" effects are automatically absorbed as it is possible to calculate the result of their absorption directly from the number of performance years and from performances of each animal as well as the individual total and total per dam.

Then non-breeding animals and brood-mares are absorbed owing to the particular structure of the relationship matrix. Grouping the brood-mares born of one single "foundation" mare (without dam) leads to a brood-mare x brood-mare diagonal block matrix whose inversion is easy. Non-breeding animals are also grouped per dam.

Thus, the final matrix only includes fixed effects and stallions. It is solved by iteration. The solutions of absorbed brood-mares and non-breeding animals are obtained by back-solving of the equation using solutions for stallions and fixed effects.

The accuracy of these estimates is obtained by approximation of the block decomposition of the inverse of the final matrix.

If the inverse of the final matrix is denoted

$$\begin{bmatrix} H & B' \\ B & M \end{bmatrix}^{-1} = \begin{bmatrix} T & S' \\ S & F \end{bmatrix}$$

where H is the block corresponding to the close relationship of the stallion for which the estimation accuracy is to be calculated (sire, grandsires, half-sibs, male progeny and male grandprogeny).

Then : $T = H^{-1} + H^{-1}B'FBH^{-1}$

The upper bound of T is : $H^{-1} + H^{-1}B'ABH^{-1}$

The lower bound of T is : H^{-1}

The upper bound of T is approached by using the known structure of the block of relationship and the "average" relationship contained in A.

The accuracy of the estimations of brood-mares and non-breeding animals is simply obtained by the block decomposition of the inverse and by using the accuracy for stallions.

3 - Material

For many years, data on race earnings of trotters have been collected and published in annuals by the "Société d'Encouragement à l'Elevage du Cheval Français". These results have only been computerized since 1974, so it became necessary to enter earlier results. The performance file is now completed by births since 1966. Moreover, the performances of the parents of these horses are known but not those of their contemporaries. We therefore only included performances of horses born since 1966. The other performances clearly constitute a selected sample which, moreover, only contains a small number of aged parents. On the other hand, owing to the S.I.R.E. (1), the pedigree of these horses is available nearly up to the establishment of the Stud Book. We used this genealogical information as completely as possible including all the ancestors without performances.

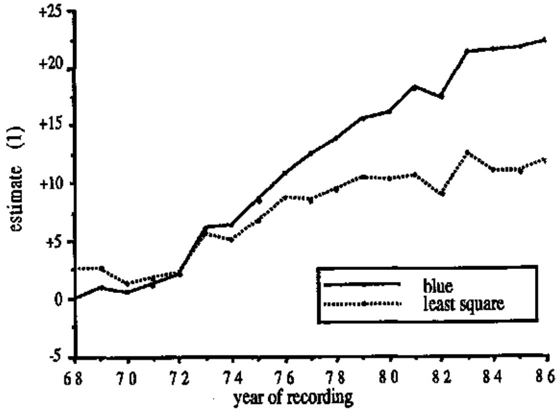
(1) Système d'Identification Répertoriant les Equidés (Identification system for equidae)

The final file (performing horses born after 1966 and all their registered ancestors) represents 61,012 horses with 42,263 performing horses and a total of 120,172 yearly performances, 2,828 stallions and 22,250 brood-mares. Among breeding animals born after 1966, i.e. 676 stallions and 10,083 brood-mares, 99.0% of the stallions and 56.1% of the brood-mares have been placed in races.

After calculations based on this useful file we made an estimation of all the trotting horses registered at the S.I.R.E. - i.e. all the births since 1974, winning or non-winning horses as well as their ancestors - by the mean of the estimations of their parents. It represents 140,107 French trotters of which 2,714 stallions and 35,091 brood-mares.

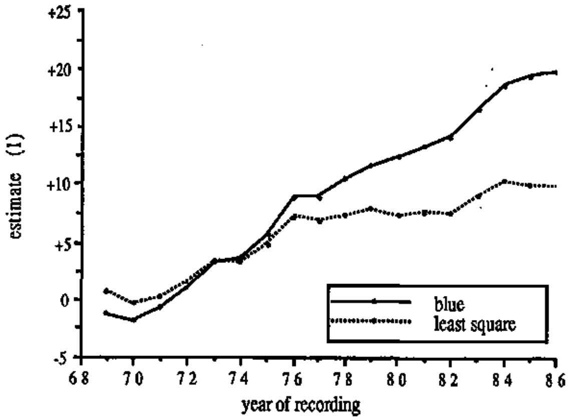
A new heritability estimation was made with reference to that reported by Langlois (1984, 1985). It was necessary to introduce the maternal component and use logarithms of yearly average earning per start previously adjusted by an estimation of the least squares of fixed effects rather than of ESTES' earning indexes. Moreover, our

Figure 1a. Estimates of fixed effects age-year : 2 years



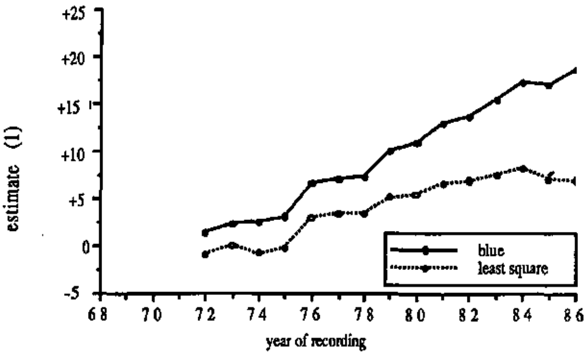
(1) "0" is class age 2 years - year of recording 1968 - Phenotypic Standard Deviation : 20 points

Figure 1b. Estimates of fixed effects age-year : 3 years



(1) "0" is class 2 years - year of recording 1968 - Phenotypic Standard Deviation : 20 points

Figure 1c. Estimates of fixed effects age-year : age 6 to 10



(1) "0" is class age 2 years - year of recording 1968 - Phenotypic Standard Deviation : 20 points

work was based exclusively on our file thus excluding the performances of horses born before 1966. The heritability was 0.26, the repeatability 0.36 and the maternal component 0.04.

Results

All the results were expressed as phenotypic standard deviation points. Phenotypic standard deviation was 20 points.

1 - Estimation of fixed effects

We compared the estimation of fixed effects obtained by the BLUP analysis to the estimation of least squares (Fig. 1). A clear difference was noted for recent years representing the deviation due to genetic progress. The BLUP estimation of the age-year effect for horses of 6 years and more was still definitely lower than the estimation of least squares. It may thus be assumed that horses which are still running at that age represent a selected population sample. This fact will be confirmed afterwards. In the same way, comparisonof the effects of two-year-olds and of four-year-olds shows that the sample of two-year-old winning horses tends to be selected whereas the estimation by least squares keeps an advantage of 3 points for the two-year-olds.

2 - Estimation of breeding values

The mean of all indexes calculated from the useful file was 2.1 expressed in units of the 20-point phenotypic standard deviation. The standard deviation was 7.8, the minimum -23.9 and the maximum +40.2. The mean of the determination coefficients was 0.50, the standard deviation 0.14 with a maximum of 0.98. These figures only allow to design index variations. Obviously, they correspond to different cases and a different evolution, as shown by the estimation of genetic progress.

Breeding value estimation by the BLUP method is supposed to be adjusted for effects due to selection provided that all data responsible for selection are included in the model and that genetic parameters are those of the basic population. Our basic population is made up of horses, most of them born before 1940. Moreover, it is rather small compared to the importance of the population today : 1,651 dams of non-registered sires and 828 stallions of non-registered sire and dam. The estimation of genetic parameters was based on a population born after 1966 and on methods not taking genetic progress into account. We are thus in a difficult situation which leads us to consider the introduction of genetic groups (Westell, 1984) according to the pedigree end or the introduction of in-breeding.

These modifications could easily be applied to the present programme structure. The representativeness of the population of ancestors, the introduction of their performances partly known as opposed to those of their contemporaries which are unknown and the estimation of genetic parameters by a REML could also be examined.

However, accuracy is obtained for all the horses and many of them have been indexed. By the former method 1,603 stallions had a combined index and 49,055 horses had a track career index. Now all the 140,107 trotters of the S.I.R.E. file are indexed.

3 - Comparison to selection indexes.

BLUP and selection indexes were compared. In the case of stallions, a comparison was made between BLUP and combined indexes : own performances - performances of progeny - performances of mated mares. For 1,534 stallions involved, the correlation value was 0.84 *** and average determination coefficients were 0.72 and 0.64, respectively for BLUP and combined indexes. It was thus rather high which could be expected for animals for which the main information was included in the selection index. In that case considerable deviations in the classification of stallions at the top. For horses with performances only, the comparison concerned the track career index. The correlation value was 0.78 (35,934 horses) with determination coefficients of 0.55 for the BLUP and 0.42 for the track career index. This high correlation shows the importance of performance testing in the selection of French trotters. The heritability was moderate (0.26) and the repeatability rather low (0.36). The average number of performances in the file was 2.8.

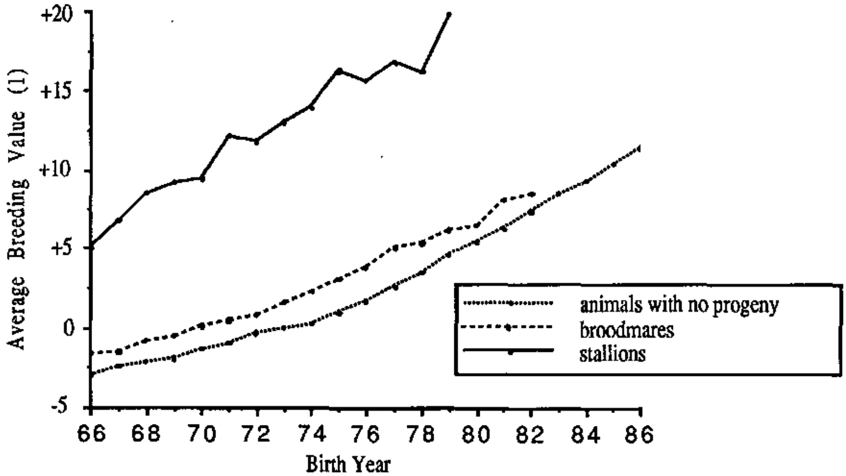
4 - Genetic progress

Genetic progress is measured by the regression of the BLUP index according to birth year. Fig. 2 summarizes these regressions in the overall population registered at the SIRE.

From 1974, the whole born population was concerned. Before 1974, all horses having started in a race since 1966, their ancestors and the ancestors of horses born since 1974 were registered at the SIRE. From the sixties, we are thus sure to have a good representation of the population of breeding animals as the generation interval of 12 years leads us to 1974. From 1966, we have a good representation of non-breeding animals having started in a race and from 1974 of the population as a whole.

Since the beginning of the seventies, the superiority of stallions compared with the non-breeding population was 14 points. It was 10 points from 1966 to 70. This superiority can almost only be explained

Figure 2. Genetic trends in "Trotteur Français"



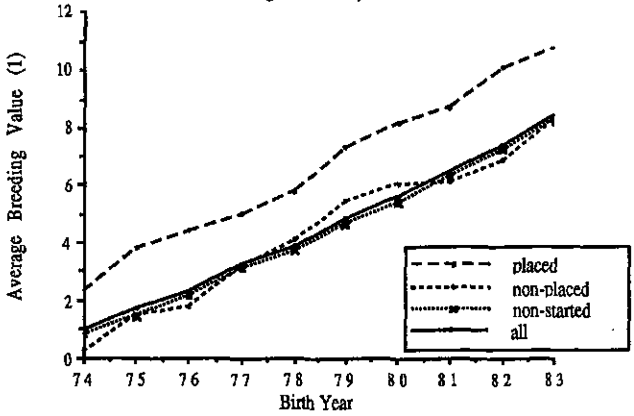
(1) Phenotypic Standard Deviation : 20 points

by their selection on own performances. The efficient rate of selection of males was 15% on one yearly performance (Langlois, 1985). For the overall performances, the genetic superiority of stallions was obtained by the mean of their track career indexes weighted according to the number of progeny. The mean value of these track career indexes was 13.5, therefore, the superiority of stallions was really due to selection on own performances.

Brood-mares showed a superiority around 1.5 points compared to non-breeding animals. However, they were not selected on own performances (Langlois, 1985), but probably on pedigree.

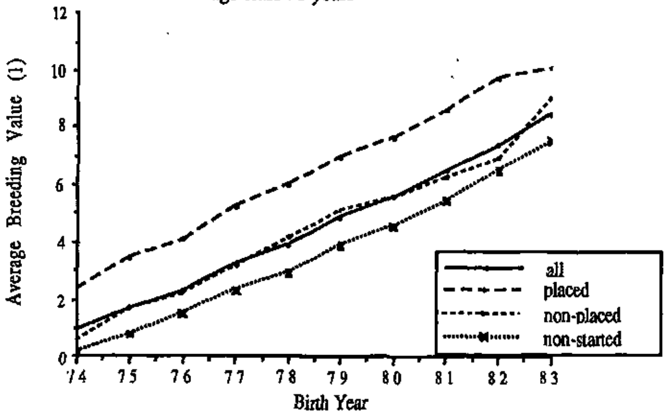
This selection led us to expect a yearly genetic progress of 0.7 points (generation interval of 11.6 years, Langlois, 1985). In fact, we did obtain this result : the regression coefficient of the BLUP on birth year for the SIRE population as a whole was 0.71 points (***) from 1966 to 1986, i.e. a 3.6% phenotypic standard deviation. This progress exceeded that obtained by sport horses in France : a 1.4% phenotypic standard deviation (Tavernier, 1987). It was, however, inferior to what could be obtained without thoroughly modifying the breeding system. Take the example of the population of French trotters born in 1983 which possibly was performance tested in 1986. The mean of the BLUP indexes was 8.4. With a selection rate of 50 and 1%, respectively for females and males, the mean of the BLUP indexes of future breeding animals was 13.3 and 27.6, respectively. The superiority of breeding animals was thus 4.9 points and 19.2 points, respectively. The generation interval was reduced by 2.6 years for males (maximum 2 years of performances versus 4.6 on an average) and by 0.8 years for females (2 years of performances versus 2.8 on an average). Expected genetic progress was 1.2 points per year, i.e. a 6% phenotypic standard deviation.

Figure 3a.Breeding value of placed, non-placed and non started horses
age class : 2 years



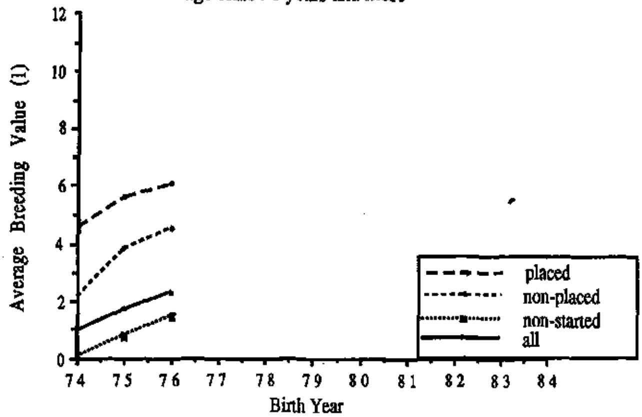
(1) Phenotypic Standard Deviation : 20 points

Figure 3b.Breeding value of placed, non-placed and non-started horses
age class : 3 years



(1) Phenotypic Standard Deviation : 20 points

Figure 3c.Breeding value of placed, non-placed and non-started horses
age class : 6 years and more



(1) Phenotypic Standard Deviation : 20 points

5 - Estimation of non-winning horses

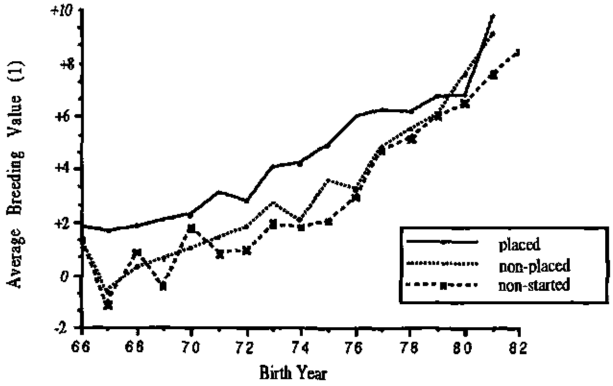
One of the problems attached to the earning criterion is that non-winning horses are not taken into account whether they started or not. By means of the BLUP method, it is now possible to obtain information about these horses and to compare them to the rest of the population.

Two-year-old winning horses representing only 6.5% of those born were 2 points superior to their contemporaries, even 2.5 points in the eighties. At this age it is not possible to distinguish between horses which did not win but started in a race (and were therefore qualified, 4.5%) and horses which did not start (Fig. 3). At the age of 3 which is representative of the trotter's average track career, 40% of the horses born started in a race and winning horses (29%) were still 2 points superior to their contemporaries, non-winning horses which did start (11%) were placed around the average and horses which did not start were slightly inferior to the rest of the population (-1 point). At the age of 6 and more, winning horses (15%) constituted the most selected sample with a 3.8-point deviation, non-winning horses (4%) had a 2-point deviation and non-starting horses -0.9. In every case genetic superiority of winning horses was very far from what could be expected from the number of horses. These results give a superiority which is slightly higher for winning horses than could be expected from the results obtained by Langlois (1985) on the selection of horses according to their age and previous or subsequent performances. At the age of 2, a genetic superiority of only 1 point could be expected (subsequent performances 105) and at the age of 6, 2 points (previous performances 108). There must be a slight selection before the race where only the best horses are allowed to start in races at their level which leads to earnings.

The second problem due to the lack of estimation of non-winning horses is the level of brood-mares whether performing or not. A distinction is made between qualified and non-qualified mares in the rules of mounting but it does not seem to correspond to a real quality deviation at the breeding level (Langlois, 1985).

In order to study the breeding stock of mares we analysed the dams of colts born in 1986. Winning brood-mares (whatever their age, 50.5% of the brood-mares) do have, like other winners, 2 points more than their female contemporaries with the exception of the younger ones. There are only few mares born in 81 and winning at the age of 2 or 3 and they have a superiority of 2 points. On the other hand, mares born between 1978 and 80, which have had the possibility of earnings from 2 to 6 years, are not superior to the others even though they represent an important quantity of performing mares intended for breeding. Starting mares which did not win (21.3%) had 1/2 point more. They joined the breeding stock earlier than winning mares and

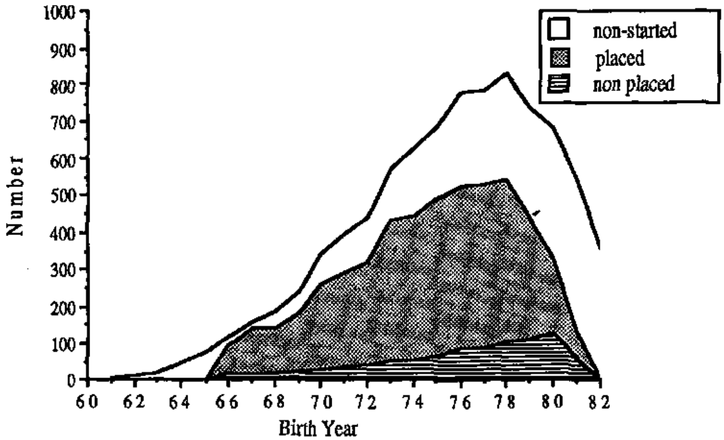
Figure 4. Breeding value of mares of colts born in 1986



(1) Phenotypic Standard Deviation : 20 points

as far as mares born in 1980 and 81 are concerned they were really superior even though they were similar to non-starting mares from 1978 and 1979 (Fig. 4). On the whole, these mares joined the breeding stock later than non-starting mares and they were kept longer for breeding. These 2 points only constitute hardly 3 years of genetic progress. The means of performing or non-performing mares were almost identical : the mean value of winning, non-winning and non-starting mares was 4.7, 4.5 and 4.5, respectively. Their average age was 11.5, 10.1 and 9.4 years, respectively (Fig. 5). At present, performance testing of mares is thus rather inefficient : winning mares are superior to their contemporaries, and only very slightly, as there is no real selection after performance testing. Moreover, they are penalized because they join the breeding stock later and those having a short track career are not the best. Such a method should not

Figure 5. Number of mares of colts born in 1986



be abandoned but its conception should be re-examined by actually taking into account short track careers, applying a real selection after the test (with a selection rate of 1/2, the superiority of winning brood-mares would be of 4 points for one performance year) and by a continuous comparison of old and young mares' competitiveness, using the BLUP index.

6 - Homogamy

The correlation between BLUP indexes of mates was 0.44 (136,753 couples) for average determination coefficients of 0.81 for stallions and 0.45 for brood-mares. The correlation ranges from 0.15 in 1966 to 0.34 in 1986. Rational mating is thus increasing. It is difficult to compare this result to those of phenotypic homogamy as it combines possible a priori information on breeding animals (only available in recent years) with a posteriori information given now by the index on former matings.

Conclusion

The advantage of an animal model BLUP index in horse populations is confirmed once again : general use of indexation at an earlier stage, taking all performances into consideration, estimation of horses remained in the herd. As far as selection of the French trotter is concerned the present inefficiency in the selection of mares on performances and the low selection of males compared to demographic possibilities, which is limited to a moderately demanding selection on performances, have been established. The BLUP index must be an appreciable selection tool as it allows early selection of females and males and it must increase the culling of old breeding animals which are exceeded by genetic progress or did not confirm their record times in the stud.

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SIRE EVALUATION IN THE GERMAN TROTTER (STANDARDBRED) POPULATION

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Summary

Since 1973, we are working on the breeding programme for the German trotter population. Following data are filed continually : all horses born since 1966 : name, age, date of birth, pedigree, (2 generations); at present, this file contains 40.005 horses. All racing performances since 1973 (name of horse, date of race, race course, rank at finish incl. disqualifications, earnings, racing time, racing distance, condition of race track, starting method, purse of the race); at present, this file contains 1.154.221 racing performances.

For sire evaluation, following traits are taken into account :
- average racing time per year of the two to seven year old horses; heritability estimates for own performance range from .23 to .44, depending on the age - concerning progeny performance the estimate amounts to .35.
- average racing time per year of the two and three year old progeny; heritability estimate is .50.
- money earnings per year of the two to seven year old horses; heritability estimates range from .14 to .27, depending on the age - concerning progeny performance the estimate amounts to .21.
- percentage of progeny raced at the age of two years; heritability estimate is .15.
- percentage of progeny raced at the age of two and three years; heritability estimate is .21.
- percentage of progeny not raced up to the age of five years (=culling rate); heritability estimate is .27.

After adjusting to the important environmental factors, breeding values are estimated by BLUP-method separately for own performance and progeny performance. Concerning progeny performance, the non-random mating structure is adjusted by means of the racing performance of the paternal half-sibs of the mated mares.

Furthermore, following selection indices are constructed :
- average racing time/money earnings per year.
- average racing time per year to the two and three year old progeny/percentage of progeny raced at the age of two and three years. This parameter displays the capacity to produce precocious progeny.

These indices are published annually in the official breeder's magazine both for own performance and progeny performance. As a supplementary information, the percentages of the progeny raced at the age of two years and the culling rates of the sires are also published.

In the very next future, scoring of the young sires will be done by the index for average racing time/money earnings (own performance), and culling of the sires beneath the average by the same index, but of course for progeny performance.

1. Introduction and material

Since 1973, we are working on a breeding programme for the German trotter population. Following data have been filed continually:
- all horses born since 1966 : name, date of birth, pedigree (2 generations), breed (German, US-Standardbred, French, others). At present, this file contains 40.005 single horses.
- all racing performances since 1973 : name of raced horse, date of race, race course, racing distance, condition of race track (fast, good, sloppy, muddy), starting method (flying start, volt start), purse of the race, rank at finish incl. disqualifications, racing time, earnings. At present, this file contains 1.154.221 single racing performances.

2. Methods

Racing performance can be measured by a lot of traits. For sire evaluation, we analyse following traits :

Average racing time per year :

- parameters : Total average time (all progeny included)
  Average time 2/3y. (only 2 and 3 year old progeny included
- restrictions : Minimum number of progeny per sire : 5
  Minimum number of racing times per progeny : 2 (2 year old progeny) resp. 4 (older progeny)

Accumulated earnings per year :

The parameters of earnings have the striking advantage, that all horses - wether they have raced or not - can be included in the evaluations; not raced progeny get the value zero. Thus, bias by different culling rates within the sires can be avoided.

On the other hand, the statistical handling gets more difficult, because the deviation from the normal distribution increases. Since the average culling rate amounts to appr. 30%, at least 30% of the included horses have the raw value zero - and this fact can not be removed by any statistical method. In order to diminish this skew distribution, we use the square root-transformation; to avoid computational breakdowns, we add the value one to all raw values.

- parameters : Total earnings (all progeny included)
Earnings 2/3y. (only 2 and 3 year old progeny included)
- restrictions : Minimum number of progeny per sire : 10

Percentage of raced progeny of all born progeny :
- parameters : Raced progeny 2y. (only 2 year old progeny included)
Raced progeny 2/3y. (only 2 year and 3 year old progeny included)
Culling rate (percentage of not raced progeny; all progeny up to 5 years included)
- restrictions : Minimum number of progeny per sire : 10.

All these traits are biased by several, more or less stronger environmental effects. The adjusting procedure to the quantifiable environmental effects and the analyse of the evaluated traits is displayed in Table 1.

Table 1. Used mixed model (simplified description)

y = Overall mean+ sire group (4 breeds/2 age-classes : 8 groups)
+ sire within group (random)
+ mother group (4 breeds/2 age-classes : 8 groups)
+ mother within group (random)
+ age (2 to 7 years)
+ sex (male, female)
+ racing year (15 years)
additionally for racing time
+ race course (10 courses)
+ racing distance (<1900m, 1900-2200m, >2200m)
+ track condition (fast, good, sloppy, muddy)
+ starting method (flying start, volt-start)
+ remainder

The effects of the mother are evaluated by the performances of their paternal half-sibs.

The genetic parameters are estimated by the traditional paternal half-sib-analysis (HENDERSON's method III).

Breeding values are estimated by the BLUP-method, which we have already published in detail (see references).

3. Results

3.1. Genetical analyses

The heritability estimates of the analysed parameters are displayed in Table 2.

Table 2. Heritability estimates

Trait	h^2
Total average time	.35
Average time 2/3y.	.50
Total earnings.21	
Earnings 2/3y.	.22
Raced progeny 2y.	.15
Raced progeny 2/3y.	.24
Culling rate	.27

Table 3 gives an excerpt of the correlations between the breeding values for the above displayed traits.

Table 3. Correlations between the breeding values

Total average time	*	Total earnings	.87
Average time 2/3y.	*	Raced progeny 2y.	.55
Average time 2/3y.	*	Raced progeny 2/3y	.60
Average time 2/3y.	*	Earnings 2/3y.	.79
Earnings 2/3y.	*	Raced progeny 2/3y	.88

$p < 0.001$ for all values

These results, combined with the heritability estimates, lead us to construct following indices :

- Total average time *Total earnings ("Total index") This index is used as the parameter for the total racing performance. The weighting-factors are 0.5 for both traits; they are determined by the breeding association and do - strictly spoken - not represent the genetic blackground in a proper way.
- Average time 2-3y. *Raced progeny 2-3y. ("Precocity index"). This index is used as the parameter for precocity. The weighting-factors are 0.5 for both traits; they are determined by the breeding association and do - strictly spoken - not represent the genetic blackground in a proper way.

3.2. Breeding practice

At present, following parameters are published annually :

- Total Performance Index
- Precocity Index
- Raced Progeny 2y.
- Raced Progeny 2/3y.

- Culling Rate.

Table 4 gives an excerpt of the correlations between the published parameters.

Table 4. Correlations between the published parameters

Total Index	*	Precocity Index	.83
Total Index	*	Raced Progeny 2y.	.59
Total Index	*	Raced progeny 2/3y.	.65
Total Index	*	Culling Rate	-.68
Precocity Index	*	Raced Progeny 2y.	.71
Precocity Index	*	Raced Progeny 2/3y.	.80
Precocity Index	*	Culling Rate	-.67

$p < 0.001$ for all values

The correlations give proof, that each published parameter gives new, supplementary informations.

Since 1987, selection of the sires is done by the Total Index : all sires with an Total Index lower 0.01 are deprivated of their covering license.

4. Discussion

Environmental effects

Generally spoken, we are capable to adjust to the bias by the environment in a sufficient degree (see references). A problem, not yet solved, are the effects of the stud, trainer and driver. In future, we will file these data and will try to quantify these undoubtedly important effects.

Traits

The most reliable trait is the average time, not only among the parameters of racing time, but even among all evaluated traits. The heritability estimate 0.50 for the average time of the 2 and 3 year-old progeny is very remarkable and should be utilized much more, than it is done at present.

The main advantage of the trait earnings - compared to the trait racing time - is the possibility to include all progeny.

On the other hand, our statistical methods are - strictly spoken - not absolutely suitable to evaluate this not normally distributed trait. Therefore, the achieved results can only be utilized with some caution.

The percentage of raced/not raced progeny is a simple and evident trait. It can utilized as an supplementary information and, furthermore, as a good adjusting factor in sire evaluation by parameters of the racing time.

Estimation of breeding values

The BLUP-method is very suitable, because the numerous different genetic groups and the rapid genetic progress are taken into account in a very good degree (see references).

The consideration of the effects of the mated mares (mother-effect) displays a much more reliable estimation than the estimation only on the basis of the sire-effects : the correlation between breeding values of the sires and of the mated mares without the consideration of the mother-effect is 0.30, and after consideration 0.04 (see references).

Construction of selection indices

We construct an index for the total racing performance and, in addition, an index for precocity. The precocity index is based on the performances of the 2 and 3 year-old progeny, although the consideration of only the 2 year-old progeny would display the precocity undoubtedly more clearer. But in the opinion of the breeding association, this index would emphasize the precocity in a too large degree. The weighting-factors are also given by the breeding association; therefore they represent much more economic than genetic weights.

Breeding practice

The most important parameter, the Total Index, is used for the ranking and selection of the sires. The other published parameters are useful supplementary informations. As to our knowledge, this is the first time, that selection is done by selection indices. This is a very important step on the way to a breeding programme based on genetical-statistical methods.

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APPLICATION OF A METHOD OF BREEDING VALUE ESTIMATION IN THE POPULATION OF TROTTERS IN THE GDR

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Summary

This text deals with problems arising in the analysis of times achieved by trotters in the German Democratic Republic.

789 progeny out of 40 different stallions were analyzed. Evaluation was based on the 25 744 races with took place at the trotting course Berlin-Karlhorst from 1974 to 1985. The following factors influencing racing time have been considered : year of birth, sex (*), breeder, frequency of starts, racing age (*), month of race (*), placing, distance (*), stable (*), trainer, race class (*), type of start, quality of soil (*), temperature. Interaction as well as confounding effects have been demonstrated among some factors (*). A complex linear methodology appears to be necessary to account properly for the joint influence of these factors. It is also shown that the adjusting method has a large influence on the ranking of animals according to their genetic merit.

Using an BLUP animal model with repeated records and the following fixed effects is proposed to improve genetic evaluation :

sex x quality of soil; distance x race classe; racing season and stable.

Due to the limited size of the population, solving this problem is feasible in practice.

Text

Breeding value estimate (Freund, 1974) have been done in the population of trotters in the GDR for 15 years. Traditionally, the estimates were performed by means of a modified form of the CC-test. The performances of the animals being compared were corrected by partial regression coefficients, which had been estimated beforehand. In the process of correction, the systematic influence factors :

- frequency of starts
- age
- sex
- month of race

- distance

were taken into account. This procedure was also followed by breeders in other countries.

The precision of the elimination of the environmental influences mentioned above as well as of breeding value estimation as a whole, however, did not meet present requirements any more. Therefore, new methods had to be developed. The advances made in the field of population genetics have provided methods, which allow the solution of quite a number of questions and, thus, to raise breeding value estimation in horses to a higher level.

Resulting from this state of affairs, the goal was set to develop a new method of breeding value estimation for use in the breeding of trotters in the GDR, which meets the following demands, and to suggest its practical implementation :

1. reliable elimination of all essential systematic nongenetic influence factors
2. use of all relevant kinship relations
3. elimination of the influence of assortative pairing
4. feasibility under the concrete conditions of practical breeding, performance testing as well as available computer technology.

This required a detailed population-genetic analysis of the stock of breeding and race horses, especially of the essential systematic factors, which can influence racing time.

On this basis, the following tasks had to be considered :

1. selection of the most essential systematic environmental influences to be eliminated in breeding value estimation
2. determination of orders of rank in the offsprings of stallions, depending on original racing time and relativized racing time
3. analysis of kinship and breeding relations in the population of trotters.

For the investigation, 789 horses - offsprings of 40 different stallions - were used. The evaluation was based on the 25.744 races,which without exception, took place at the trotting Berlin-Karlshorst in the years from 1974 to 1985. Table 1 shows the systematic influence factors on racing time that have been considered.

At the beginning of the investigations, a relativization according to the individual environmental factors was made, not taking into account interactions with other disruptive factors and possible effects of overlapping. The differences between the levels of the individual factors were used as a measure of the extent of the respective influence. In order to quantify the overlappings of several factors, a successive relativization according to different environmental effects was made at the end. The comparison of the absolute differences between the levels of the individual influence factors after simple and successive relativization is given in tables 2a and 2b.

Table 1. *Material used in the investigation*

age-groups 1972 to 1983
789 racehorses
25 744 races

FACTOR	CLASSES	FACTOR	CLASSES
year of birth	12	distance	5
sex	2	stable	22
breeder	3	trainer	2
frequency of starts	7	race class	2
racing age	3	type of start	3
month of race	3	quality of soil	5
placing	6	temperature	7

Table 2a. Range of differences between the levels within the influence factors (racing time in sec.)

Influence factor	N° levels	simple range (sec.)	relativization abs.diff. (sec.)	successive range (sec.)	relativization abs.diff. (sec.)
year of birth	12	+1.28 to -0.88	2.16	-	-
frequency of starts	7	+0.32 to -2.27	2.59	+0.30 to -1.92	2.22
racing age	3	+0.77 to -2.29	3.06	+0.74 to -2.04	2.78
stable	22	+1.40 to -1.27	2.67	+0.74 to -0.91	1.65
distance	5	+3.60 to -2.53	6.13	+2.33 to -1.21	3.54
race class	2	+2.47 to -0.13	2.60	+2.50 to -0.13	2.63
soil	5	+0.36 to -3.28	3.64	+0.36 to -3.05	3.41
placing	6	+0.82 to -1.05	1.87	+0.68 to -2.09	2.77

These results show clearly that distance with 6.13 sec., soil with 3.64 sec., racing age with 3.06 sec., stable with 2.67 sec. and race class with 2.60 sec. have to be regarded as being essential environmental effects.

Table 2b. Range of differences between levels within the influence factors (racing time in sec.)

Influence factor	N° levels	simple range (sec.)	relativization abs.diff. (sec.)	successive range (sec.)	relativization abs.diff. (sec.)
sex	2	+0.34 to -0.33	1.01	+0.33 to -0.32	1.01
breeder	3	+0.50 to -1.13	1.63	+0.45 to -0.99	1.44
month of race	3	+0.49 to -1.12	1.61	+0.40 to -1.73	2.13
trainer	2	+0.66 to -0.04	0.70	+0.19 to -0.01	0.20
type of start	3	+0.10 to -0.05	0.15	0 0	0
temperature	7	+0.61 to -0.86	1.47	+0.30 to -0.26	0.56

Relatively low differences, however, were observed with regard to trainer with 0.70 sec. and also with regard to sex (1.01 sec.).

To what extent breeder or stable contain genetic components cannot be quantified at the present stage of the investigations.

The existing distinctions in the absolute differences between simple and successive relativization suggest the existence of overlappings and interactions. This can be observed most clearly in the parameters :

- distance
- soil
- racing age
- stable
- race class
- month of race
- sex.

For an adequate depiction of the interplay of these factors, a joint estimation on the basis of a linear model is necessary.

The comparison of different relativization methods was also based on selected offsprings of stallions. The Table 3 shows the shifting in the order of rank for 12 groups of half brothers and sisters, using 3 methods of relativization, compared to the original racing time.

Table 3. Shifts in order of rank in offsprings of stallions ($\bar{x}$ /racing times), depending on the number of systematic environmental effects considered.

N°	Ranking			
	original racing time	rel. of 1 factor	rel. of 5 factors	rel. of 14 factors
1	12	3	3	13
2	3	12	12	1
3	16	36	16	39
4	17	16	36	14
5	36	17	17	3
6	26	26	26	21
7	21	21	21	26
8	1	1	13	36
9	39	39	1	16
10	14	14	39	17
11	13	13	14	12
12	23	23	23	23

It becomes apparent that the environmental factors play an important part in the racing time realized and they distort the estimated breeding value of the stallions. This has already been confirmed by the findings presented earlier.

Because of the existence of complex relationship structures, the analysis of which cannot be dealt with in detail here, the aim should be to use methods, which take these conditions into consideration. When methods based on half brothers and sisters' structures are used, a loss of information has to be accepted. Consequently, the use of a BLUP-method on the basis of an animal model was favoured. With this method, on the one hand, the questions already discussed above can be solved. On the other hand, a method like this is - under the given conditions including the limited size of the population - feasible in practice.

Following is the concrete model that has been chosen :

$$Y_{ijklmn} = \mu + a_i + b_j + c_k + d_l + g_m + p_m + e_{ijklm}$$

μ	a_i	b_j	c_k	d_l	g_m	p_m	e_{ijklm}
overall average	sex soil	distance race-class	racing season	stable	additive genetic effect	permanent environmental effect	residu[al] effect

The model presented here has been developed on the basis of the results gained so far. It has to be elaborated and specified by further investigations. Problems that have not yet been solved concern especially the influence of the stable, with its interplay of genetic and non-genetic components. A similar situation can be observed in connection with the frequency of starts.

The breeding values on the basis of the model described here are calculated using the BLUP-method by solving the respective Mixted-Model equation systems. In addition, a complete relationship matrix between all individuals contained in the material is built in. At the moment only one generation of ancestors is used. The intention is to go back 3 generations. For the application on the computer a program is used which has been developed at our department.

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RACES, IMPROVMENT AND RESEARCH IN HUNGARIAN TROTTER BREEDING

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Summary

Hungary the breeding of trotters has been practiced for more than 100 years. The official races began in 1983, however distance carriage races were organized much before.

There is only one international race course for trotters in Budapest, and three country race tracks. The main purpose of breeding is their supply with young horses. The entreprise of horse racing is profitable and belongs to the cultural and sports life of the Hungarian capital.

About 450-500 trotters of mixed age are in training here.

The breeding stock numbers 260 brood mares and 20 stallions in the hand of state farms, cooperative farms and private owners. Among the sires fifteen have a performance better than 1:20 and four stallions' records are under 1:15.

The standard breed is rarely used for crossbreeding.

The Hungarian trotter stock was badly damaged in World War II. From 1945-1950 to 1981-1984 the improvement of the main record of 2, 3, 4 and 5-year-old trotter reached 16.0, 10.9, 10.2 and 11.5 second respectively. The same advance can be stated for the best ten per cent of all the generations taken into account.

The genetic improvement is followed by calculating the main records for every generation, and the progeny of each sire is compared every year. This is the basis for selection beside the decisively important role of imported stallions and mares. The introduction of BLUP procedure for the estimation of genetic values of trotters is recently planned.

Scientists are dealing, among others, with the following problems : relationship between the performance of different age groups, the impact of sex on the performance of trotters, the heritability of records in trotter races, seasonal influence and the possible role of different methods in the evaluation of breeding values of sires and dams.

The history of trotter breeding and races in Hungary

At the end of the 19th century the horse population of Hungary was an English halfbred type with much Arabian blood. The breeding goal was to develop and select horses for fast trot because of great distances between the settlements. At the turn of century the famous Hungarian carriage horses were called "jukker". This fast trotter carriage horse and the driving culture were the basis for the developement of both the Hungarian trotter breeding and trotter races.

After some sporadic trials the first official trotter race was organised in 1883 in Budapest in the first permanent trotter race-course of the capital.

The place of trotter races changed three times and the third trotter course track was built in 1933. This one exists and is in function also at present.

From the end of the last century the Hungarian trotter breeders used more and more breeding material from the standard breed of USA for the improvement of the speed of horses.

The recent trotter races in Budapest

There is now only one international race-course for trotters in Budapest and there are also three country race tracks. The trotter /and gallop/ races are organised by the Hungarian Racing Association, established by the best Thoroughbred and Trotter studs of Hungarian large scale agricultural units 6 state farms and 2 cooperative farms.

This enterprise has been profitable for many years and the horse races are belonging to the cultural and sports life of the Hungarian capital.

About 450-500 trotters of mixed age are here being trained.

Table 1. Some characteristics of trotter races of Budapest

length of the track/m	:	1 000
races/year	:	950
race day/year	:	104
av. number of horse/race	:	10.3
number of visitors/year	:	250 000
total number of horses in training	:	470
total gain/Ft	:	9 400 000

The Trotter breeding at present in Hungary

The main purpose of trotter breeding is to supply the Budapest race-course with young horses. The standard breed is very rareley used for crossbreeding/exceptionally, trotter stallions were used in the Hungarian Halfbred and in the Nonius breed for trial just after World War II., Ocsag 1964.

In order to give a general information on the size of the Hungarian breeding stock Table 2, shows the most important figures.

Table 2. The Hungarian trotter stock in 1988.

	number of				
	studs	stallions	mares	foals	race horses
State farm	3	17	201	112	408
Cooperative farms	4	9	75	40	52
Private owners	11	-	19	6	8
Total	18	26	295	158	468

After the war the revival of the Hungarian trotter sport was possible only with imports.

The breeding stock after World War II. was based upon the following importations :

Table 3. Basis of the breeding stock after World War II

1947	34	trotters from	DENMARK
	8	trotters from	USA
1948	15	trotters from	USA
	12	trotters from	FRANCE

The improvement of such a small population like the Hungarian trotter stock in itself without imports is impossible. For this reason the Hungarian trotter studs permanently imported trotters from abroad. The quality of imported horses depends not only the competence and skill of importers but also on their purse.

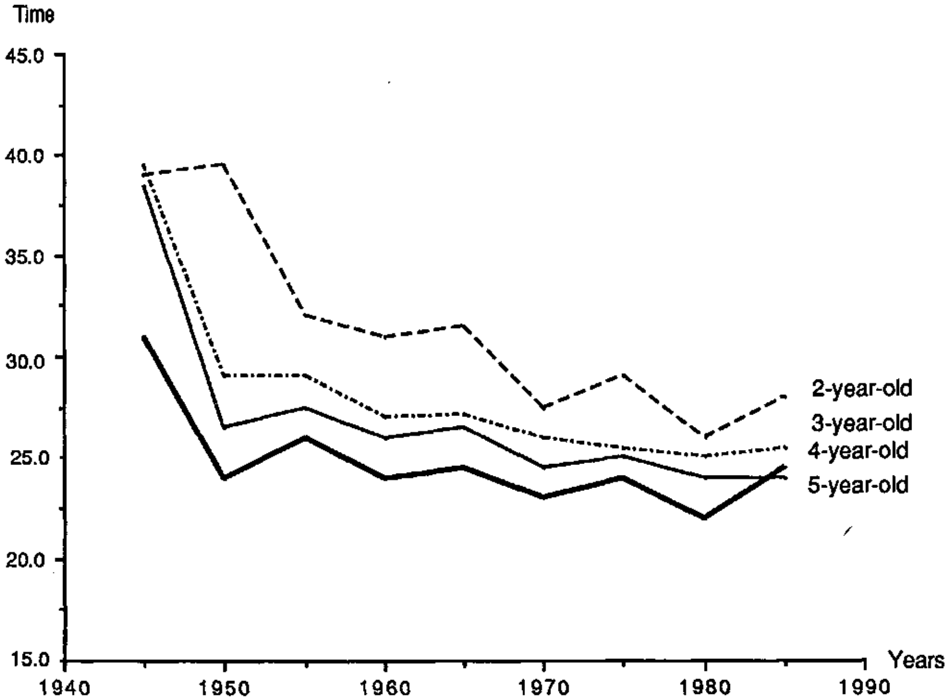
Table 4. gives some informations on the quality of imported trotters.

It is very difficult to judge the breeding value of the Hungarian trotter stock. Figure 1. shows the mean records and the records of the best 10.

Table 4. The most valuable imported trotters.

n	Name	Year of import	From	Sire - Dam	Best time	Number of progeny	Remarks		
1.	Aigle du Mou	1949	Fr	Huron II-Iole II	1.25.2	12	1951	Bp	2300m
2.	Calusar	1945	Ro	Lord Petaurist-Csalogány	1.26.1	71	1947	Bp	2260m
3.	Half Pint	1947	USA	Bill Gallon-Portia	1.23.0	156	1950	Bp	1650m
4.	Indian Guy	1947	USA	Guy Abbey-Indian	1.27.6	36	1950	Bp	2140m
5.	Never Stop	1948	USA	Guy Abbey-Fair Face	1.21.6	164	1951	Bp	1580m
6.	Platter Chatter	1947	USA	Phonograph-Katherine Palmer	1.23.1	75	1954	Bp	1660m
7.	Scot Palmer	1947	USA	Scotland-Katherine Palmer	1.23.0	32	1954	Bp	1660m
8.	The Skipper	1947	USA	Volomite-The Worthy Miss Moris	1.20.5	208	1946	Windsor	1600m
9.	Uli	1949	Fr	Kadé D-Maggy II	1.21.7	68	1950	Bp	1600m
10.	Uniforme	1949	Fr	Fourire-La Douceur	1.21.4	59	1949	Bp	1620m
11.	Boccaccio	1962	I	Mc Lin Hanover-Mischia	1.19.7	71	1957	Milano	1700m
12.	Calandrello	1962	I	Grand Parade-Saturnia	1.19.2	130	1956	Milano	1600m
13.	Gonio	1965	I	Bowman Hanover-Gorgia	1.18.7	50	1960	Milano	1600m
14.	Henribote	1963	Fr	Quiroga II-Rejane III	1.17.6	100	1958	Cagnes	1609m
15.	Let Him Roll	1974	USA	Speedster-Right Away	1.19.2	130	1968	USA	
16	Marradi	1971	I	Mighty Ned-Sulmona	1.19.1	71	1967	Bologna	1700m
17.	Ozark Hanover	1974	USA	Star's Pride-Olivia	1.16.8	143	1966	USA	
18.	Talent Scout	1969	USA	Demon Hanover-Rosalind Frost	1.15.8	136	1962	Vernon	1609m
19.	Diaspro	1967	I	Grand Parade-Saturnia	1.19.0	38	1960	Bologna	1700m

Figure 1. Evolution of mean records of best 10 horses of each early crop according to age



From 1945-1950 to 1981-1984 the improvement of the main record of 2-, 3-, 4- and 5-year-old trotters reached 16.0, 10.9, 10.2 and 11.5 seconds respectively. The advance for the best ten percent of the stock is very similar.

The interpretation of these data is difficult because one cannot compare the environmental and other influencing factors with those of other race tracks in the World. According to Csapó,1971, the difference between the records reached on the Budapest race-course is worse by 3 seconds compared to those reached in in the United States due to environmental conditions.

Some good results can also be mentionned : the races won abroad by trotters bred in Hungary :

In 1955 Bohóc, The Skipper-Cseled D, was first in Moscow,1600m

Kabala, Uli-Babona, won the Preis der Stadt Wien, in 1964, 1.19.8, and Pilvax, Boccaccio-Honleány, repeated this in 1960 and Api, Pacard-Stanci, in 1978.

Zápolya, Talent Scout-Bizalmas, reached a good time and won in Moscow, 1600m, 1.18.6, in 1978.

In Yugoslavia Lady Flame, City-Trotting Flame, Fickó, Kabala-Rosemary, Játszi, Célzat-Csalóka, Mágnás, Super Hanover-Acre's Magnus and Nikolett, Mill H.-Fatime, won races.

The last remarkable result was Lázálom's victory, Berlin, 1.17.2, in 1987.

The genetic improvement of the Hungarian standard breed stock and the products of different studs is followed by calculating the main records for every generation and the progeny of each sires can be compared. The introduction of "BLUP"-procedure is now planed. By this procedure a combined system of elaborating the time-records of races and their utilization in the evaluation of breeding value of brood mares and stallions is very suitable.

The only race-course of the country affords good possibility to computerize the racing system and at the same time to utilize the data for the evaluation of the horses in order to select them.

Scientific work in Hungarian trotters.

Here we want only to mention briefly some topics of Hungarian scientists. Ocsag and Toth, 1959, published an estimation of heritability of time-records of trotters in 1959. This was one of the first of such calculations. They got a very low value of $h^2 = 0.04$.

Csapó, 1968, has investigated the impact of seasons on the performance of trotters for a 14 years period. He could demonstrate the influence of the seasons and the improvement of performance with the growing age. The seasonal effect inlfuences the performances of elder horses markedly after the 5th year of age.

In 1976 Bodó calcultated the heritability estimates of the time-performance of trotters. Based upon the data of 10 years and used different methods, $h^2 = 0.32$, parent offspring regression, and $h^2 = 0.28$, response to selection/selection differential/ were obtained.

Borostyanköy, 1986, compared the time-performance of 2-3-4-5-year-old trotters and found that from the 3-4-year performances one can easily extrapolate the performance expectable at 5 years of age and when judging several age groups the same trend could be observed for the average, the best 10 per cent and the best record of the year.

In an other investigation the impact of sex differences on time-performance was investigated. Engel and Monori and Borostyankoy, 1985, could not observe significant difference between time-records of males and females.

Ocsag and Feher, 1983, carried out a factor-analysis, using 13 factors, and emphasized the role of the stud on the performance of trotters beside the impact of sire and dam.

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SOME ASPECTS OF TROTTER BREEDING IN ITALY

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Summary

The authors present a preliminary survey about some aspects of trotter breeding in Italy with particular reference to future plans : identification of the single and its correct genetical evaluation.

Text

In Italy, the surveillance on the horse races is under the responsibility of the Ministry of Agriculture and Forests, with the aid of the Equine Breed National Improvement Union (U.N.I.R.E.) and by other horse-organizations depending from it. The latter, for trotters are the Trotter Race National Organization (E.N.C.A.T.) and the Trotter Breeder National Association (A.N.A.C.T.). The E.N.C.A.T.'s aim is to promote the trotter and ambler improvement and selection as well as regulating and controlling trotter and ambler races in Italy; the A.N.A.C.T. defends the technical and economic interests of breeders together with controlling and identifying the horses, developing and increasing the breeding.

The trotter, in Italy, has a deep-rooted tradition and an important economic-productive aspect, and therefore a more careful and accurate selection is being carried out.

A general vision of the present situation may be briefly examined considering the following aspects.

Table 1 gives a global vision of the trotter population in Italy from 1978-1987.

Table 1. Trotter breeding

year	stallions	mares	offspring		
			males	females	total
1978	333	6037	1620	12548	3168
1979	354	5726	1615	1612	3227
1980	389	5665	1501	1593	3094
1981	401	5820	1619	1578	3197
1982	420	6320	1709	1632	3341
1983	431	6381	1762	1789	3551
1984	440	6160	1735	1768	3503
1985	448	6200	1746	1788	3534
1986	460	6120	1740	1812	3552
1987	492	6005	1642	1651	3293

Pie-charts 1, 2, 3, 4 and 5 demonstrate how in the past years a vast percentage of the horses imported in Italy came from the U.S. Swedish horse importation which was irrelevant until 1983, increased annually from then on. On the other hand the importations from France remained constant throughout the years.

In Figure 1 the sites of the 18 trotter- race tracks (Aversa, Bologna, Cesena, Florence, Follonica, Milan, Modena, Montecatini, Montegiorgio, Naples, Padua, Palermo, Ravenna, Rome, Taranto, Turin, Treviso, Trieste) in Italy are represented and the distribution of the breeders and the offspring is divided in the Northern, Middle and Southern areas (data 86).

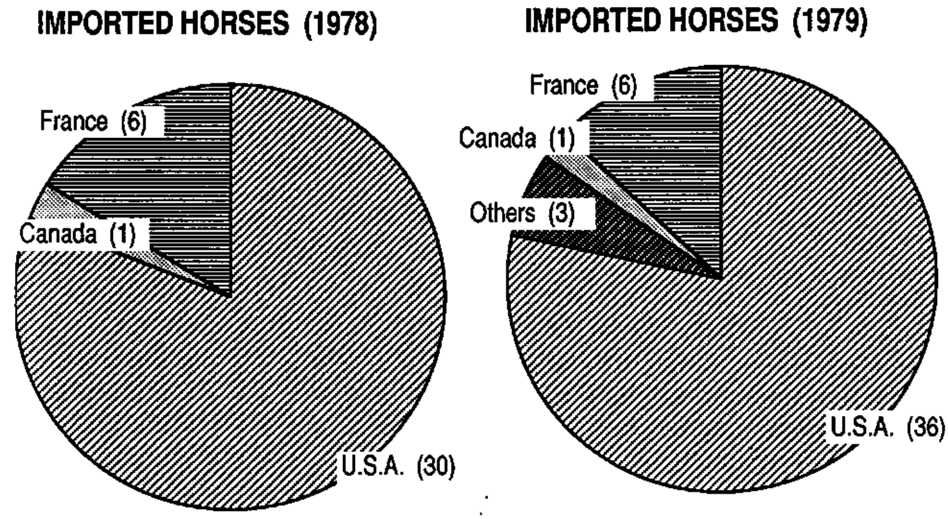
From this map the correlation between trotter-races-tracks, breeders and horse distribution is particularly evident, as well as the prioritary role played by the North in this activity.

Pie-chart 6 shows the offspring number per breeder in 1986 and that the class which occurs most frequently is the one with 1 or 2 offspring.

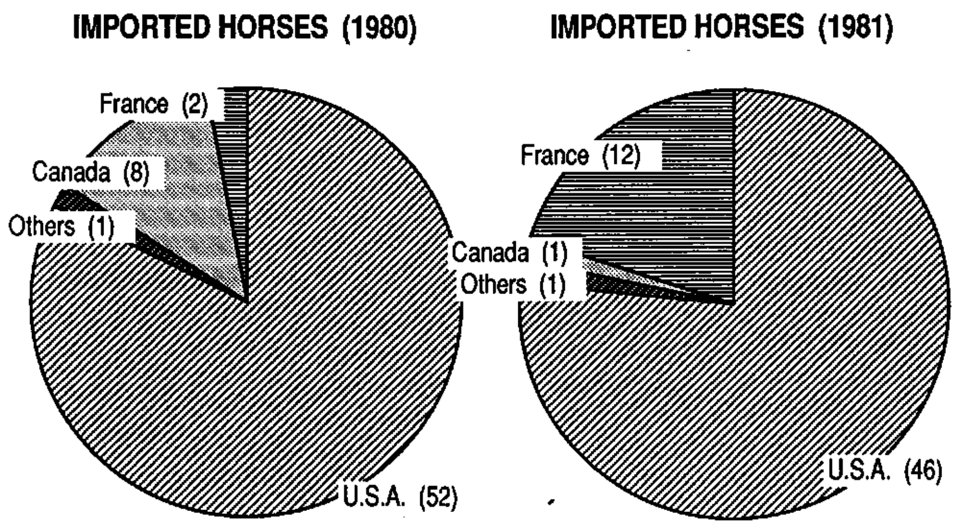
Reported in pie-chart 7 are mares per stallion (breeding season 1986) and in pie-chart 8 the relative live-born offspring per stallion in 1987. It is to point out that for some stallions a considerable difference in the male/female offspring ratio was noticed but these data analysed with the X^2 test never reached statistical significance.

The inbreeding coefficients and the ages of 126 horses randomly chosen from the selected group for the breeding season 1988 are reported in Figures 2 and 3 respectively.

Pie-chart 1

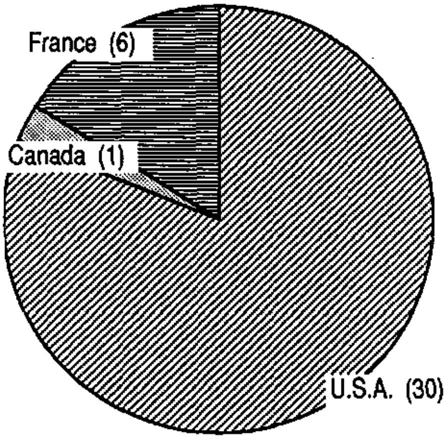


Pie-chart 2

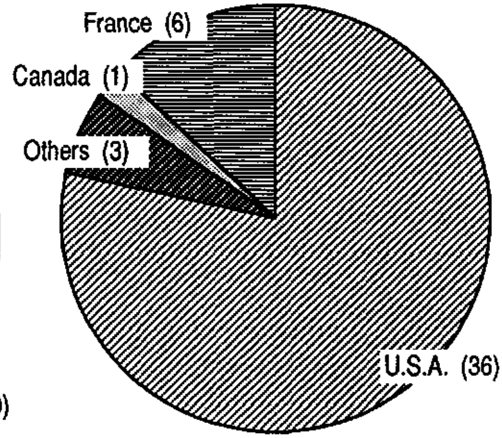


Pie-chart 3

IMPORTED HORSES (1978)

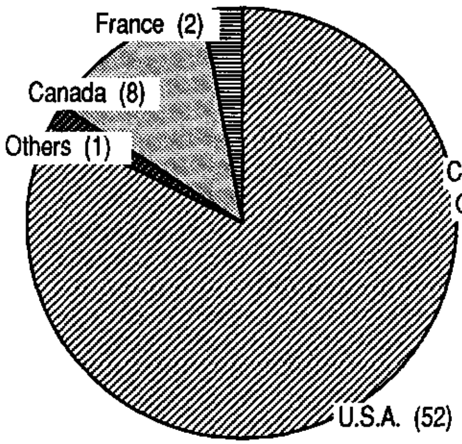


IMPORTED HORSES (1979)

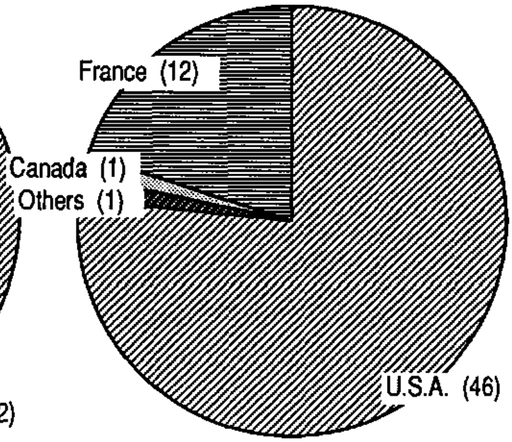


Pie-chart 4

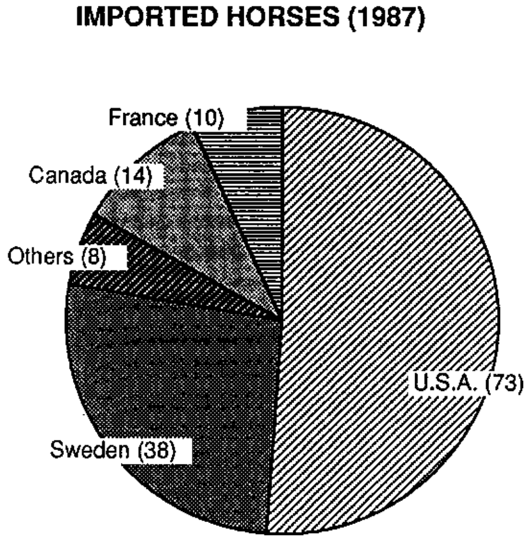
IMPORTED HORSES (1980)



IMPORTED HORSES (1981)



Pie chart 5



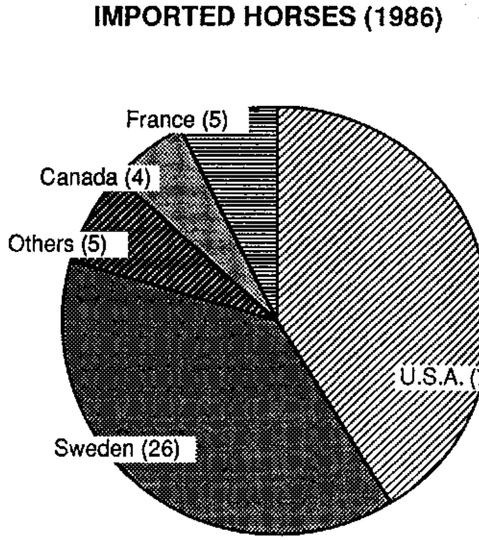
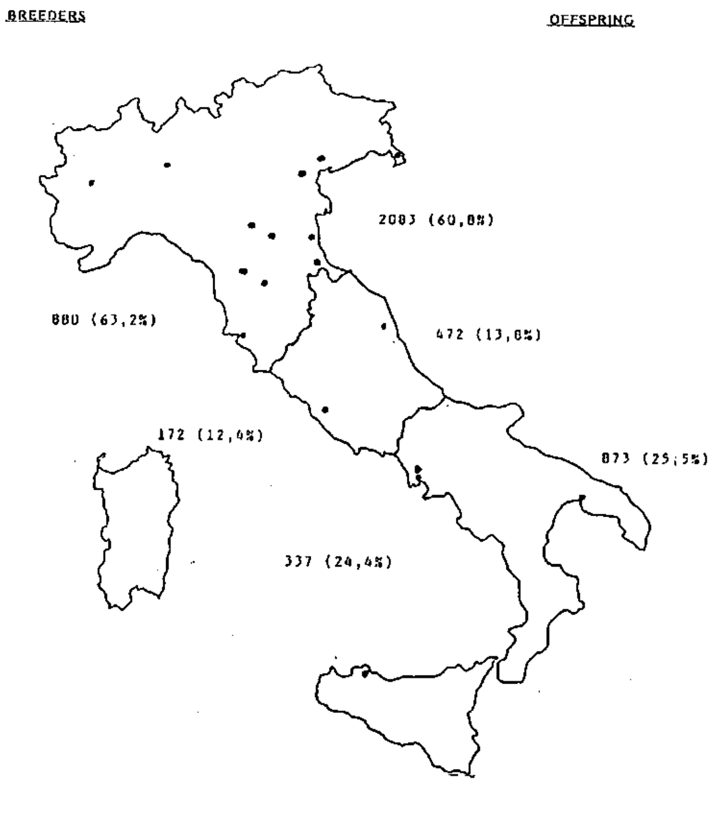
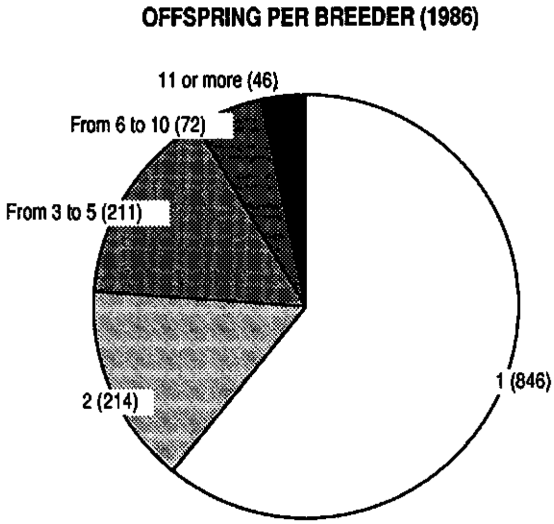


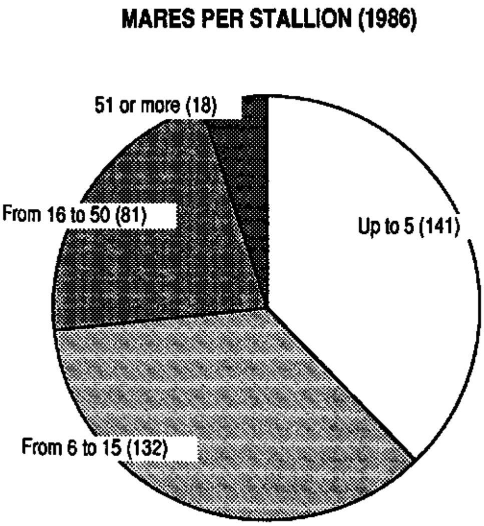
Figure 1. Trotter race-tracks (•), breeders (left) and offspring (right) distribution in Italy (data 86)



Pie-chart 6



Pie chart 7



Pie chart 8

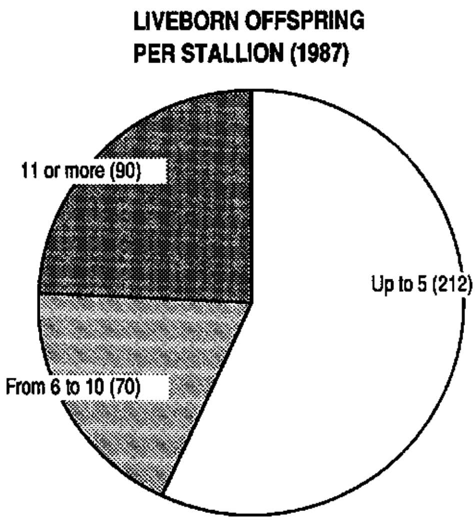


Figure 2. Distribution of inbreeding coefficients of 126 stallions

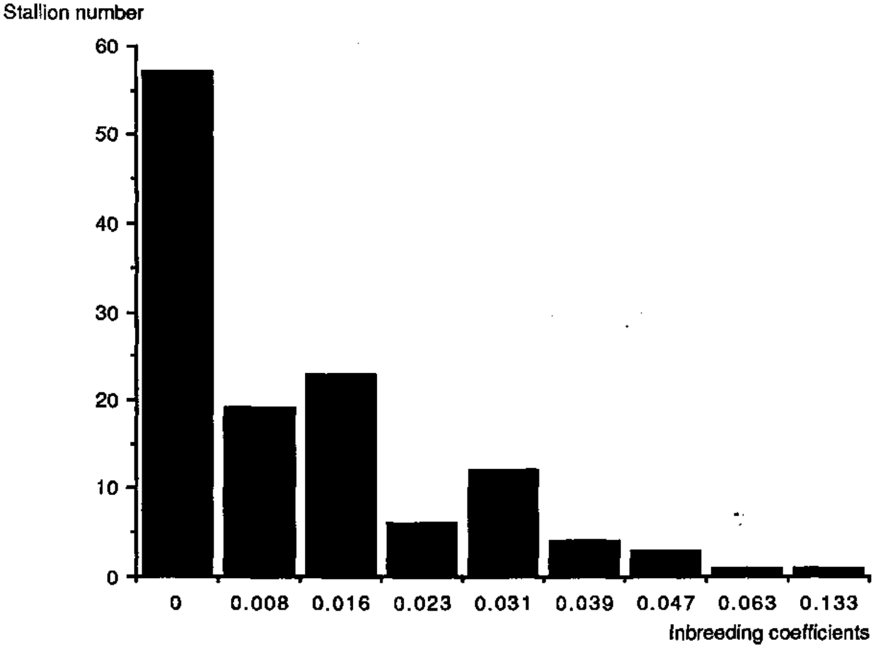
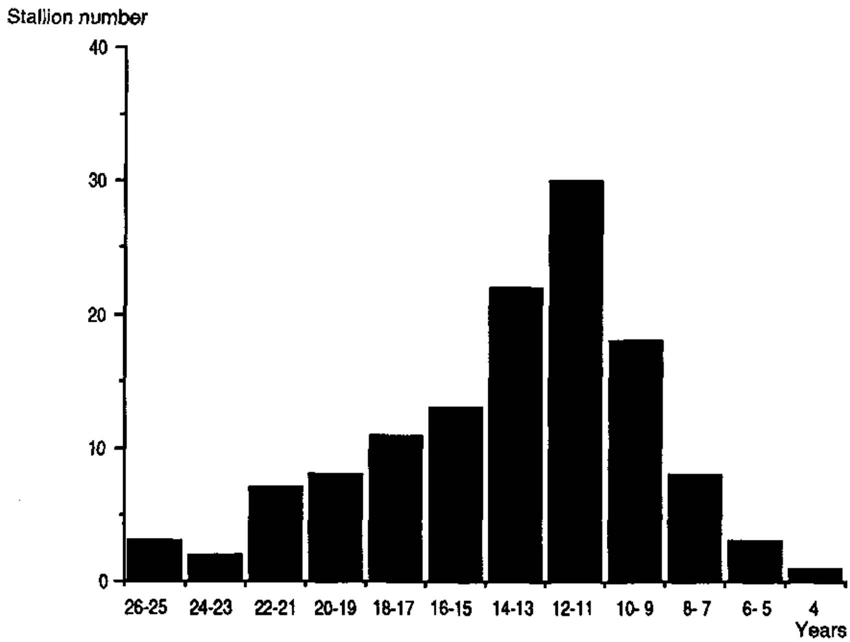


Figure 3. Age distribution of 126 stallions



In Italy, males and females are evaluated according to :

a) pedigree
b) conformation traits
c) performance (best racing time per life)
d) life time earnings

for the stallions also considered are :

e) progeny performances (best racing time)
f) progeny earnings
g) number of starts.

Nowadays attention is more and more payed to the genetic improvement of the population. Mainly two aims are important. Firstly, the identification of the horses by genetic markers (blood polymorphisms). Out of the whole population 700 horses were tested and therefore identified. We are planning to test most of the population within 1989, in order to constitute an archive to prevent fraud or mistake.

Secondly an accurate study of the most appropriate genetic evaluation methods for the sires. This is obviously necessary for the growing importance of some Italian trotter stallions, and because the artificial insemination technique is being widely used.

Further remarkable improvements in Italy can only be achieved by improving the evaluation schemes and breeding methods and this will positively influence future study approaches.

References

Data E.N.C.A.T.
Data A.N.A.C.T.

BREEDING VALUE ESTIMATION OF TROTTERS IN THE NETHERLANDS

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Summary

Since 1974 a breeding value index for trotter stallions is in use in the Netherlands, based on the selection index theory. The index was revised in 1981, when a genetic analysis of more recent data of trotter performances was completed.

The construction of the index and the genetic parameters involved are presented. The index is based on the earnings of the progeny, being in various stages of their trotting carreer. The earnings are corrected for yearly influences, for sex differences and for dam's performance. Furthermore the number of progeny and the age class to which they belong are taken into account.

Next to an index based on untransformed earnings an index based on the square root of earnings is calculated, which index has a somewhat higher reliability.

It is stressed that a growing need exists for a code of practice for computation and publication of breeding value estimates for trotters. Of particular interest is the problem how the genetic trend in performance data should be taken into account adequately and how the breeding values of trotters from different countries may be compared.

Introduction

In the Netherlands trotting racing has been popular for centuries. In 1879 breeders have founded a Stud Book and since then they have started with the improvement of the breed by selection and by importing good breeding horses from other countries, in particular from the U.S.A. and from France. International competitions provide a stimulus for the amelioration of the national trotting industry.

The importance of the Dutch Trotting industry is presented in Table 1.

Table 1. Importance of Dutch Trotting industry in 1987.

number of trotting tracks	9	
number of meetings	334	
number of trots	3,271	
number of starts	29,127	
number of trotters competing	2,005	
number of starts per trotter per year	14.5	
total prize money	11,540,520	Dutch guilders
breeding premium (10%)	1,143,933	Dutch guilders
total betting money	108,197,119	Dutch guilders
number of foals enregistered	733	
number of breeding stallions	51	
average age of breeding stallions	12.3	years

Although Galton already in 1898 pointed at " the existence in the registers of the American Trotting Association of a store of material most valuable to inquirers into the laws of heredity...", it lasted until the early sixties before the first genetic studies on trotter performance data were published. In the seventies breeding value estimation procedures, based on the knowledge of quantitative genetics, were introduced for the first time in trotter selection (Langlois, 1982).

In this paper a description of the breeding value estimation of Dutch Trotter stallions will be presented.

Selection of breeding stallions

Trotter stallions are licensed for breeding by a special committee of 3 members, appointed by the Studbook Committee of the Dutch Trotting Association (N.D.R.). One of the members must be a veterinarian. Stallion licensing takes place each year in November, so before the next breeding season.

A two-stage selection is applied. Trotter stallions are selected in the first stage on their own track performance, on their pedigree, on conformation and on a veterinary inspection. Furthermore, semen quantity and quality has to meet certain minimum requirements. These stallions are very intensively selected on their own performance. Only the best 3 to 5% are approved for breeding (Minkema, 1981). These stallions are allowed to cover a maximum of 100 mares per year during their first 3 years at the stud. After these 3 years, when 2 crops of foals and one crop of yearlings have been inspected during foal identification and registration or at the show competition for yearlings, stallions may be mated to a maximum of 150 mares per year.

In the second stage the stallions are evaluated and selected on the basis of the performance of their progeny. This selection takes place in the autumn of the year when their eldest progeny is 4 year-old, so when 3 yearly crops of progeny have trotted on the track. On average about one third of the stallions will surpass this selection stage.

Since 1974 a breeding value index for trotting sires is in use. This index is based on a genetic analysis of earnings of 2867 trotters born between 1929 and 1958 (Minkema, 1975) and is described by Minkema (1976). The index has been revised in 1981, after a genetic analysis of data from 5115 trotters born between 1959 and 1971 (Minkema, 1982).

The breeding value index of a stallion is based on the total lifetime earnings of his progeny. This means that the earnings of an offspring are accumulated over successive racing years. However, since female trotters are not allowed to trot after their 8th year of life, the earnings of male trotters (stallions and geldings) after their 8th year are ignored. Non-starters are included : their earnings are set to zero guilders. Only progency that die or that are exported before the age of 2 years are excluded.

To calculate these breeding value indexes, a data base has been set up, comprising all trotters born since 1929. For each trotter the sire, dam, year of birth, sex and for each racing year : earnings and best time record are recorded, and if relevant : year of death or export. Each year the new crop of trotters is brought in.

The index is calculated twice a year : firstly in the autumn before the licensing of the breeding stallions takes place, and secondly when the calender year has ended. For the first index the earnings won by the horses during the running year until the 1st of October are brought in. For the second index these part-year earnings are replaced by the total earnings up to December 31. The first index is used as an aid to the judging committee, the second index is published foregoing the breeding season.

For each stallion an index is calculated for (corrected) earnings and also for the square root of (corrected) earnings, since it was found (Minkema, 1975) that the frequency distribution of the square root of earnings is approaching better the normal distribution than the untransformed earnings. Nevertheless the class of non-starters will still provide a discontinuity.

<u>Corrections factors</u>

The earnings of the trotters are corrected for several influences.

a. influence of year of racing

The amount of money that can be won by an average trotter differs from year to year because of economic fluctuations (influencing the total purse money available) and because of yearly fluctuations in the number of trotters born or the number actually starting. In the former index (Minkema, 1976) the yearly earnings of a trotter were corrected to standard yearly earnings by means of a multiplication factor, based on the average amount of money available per trotter starting in that particular year. It turned out that the indices of younger sires were underestimated, due to the fact that the percentage of trotters starting (in relation to the number born) gradually decreased after 1958 (1958 : 90%; 1981 : 53%). This was caused by a fast growth of the trotter population.

In the revised index (Minkema, 1982) the conversion factors are based on the average amount of money available per trotter born. These factors are different for 2 year-old trotters and trotters of 3 years of age and older, because 2 year-old trotters are only racing against contemporaries. The earnings y_i of a 2 year-old trotter in year i are multiplied by

$$400 \Big/ \left(\frac{t_{i\ (2)}}{n_{i-2}} \right)$$

where :

400 = standard earnings in Dutch guilders for 2 year-old trotters (= average earnings of 2 year-old trotters in 1968)

$t_{i(2)}$ = total amount of money available for 2 year old trots in year i.

n_{i-2} = total number of trotters born 2 years earlier, so in year (i-2)

For trotters of 3 years and older the individual earnings y_i in year i are multilplied by

$$2300 \Big/ \left(\frac{T_i - t_{i\ (2)}}{n_{i-3} + n_{i-4} + n_{i-5} + n_{i-6} + n_{i-7} + n_{i-8}} \right)$$

where :

2300 = standard earnings in Dutch guilders for 3 years and older trotters (= average earnings of this category of trotters in 1968)

T_i = total amount of money available for all trots in year i.

n_{i-3} = number of trotters born 3 years earlier in year i - 3, etc..

The sum of the corrected yearly earnings of a horse in successive years yields his total corrected earnings. So the total corrected earnings Y3 of a 3 year old horse is the sum of his corrected earnings won as a 2 year old plus the corrected earnings won as a 3 year old trotter. These total corrected earnings, both untransformed and transformed (square root) are used in the breeding value estimation of sires. In Table 2 the corrected total earnings per age class, based on all trotters born between 1929 and 1971, are given for both sexes, for untransformed as well as for transformed earnings.

b. influence of sex

The sex distribution is usually unequal amongst the progeny of a sire. Besides male trotters win more money than female trotters. This difference becomes more pronounced with increasing length of trotting career. Therefore the progeny means have to be corrected for these differences. The earnings of male trotters are corrected to the level of female trotters by the multiplication factors listed in Table 2.

Table 2. Mean corrected total earnings per age class in Dutch guilders (based on all trotters born between 1929 and 1971).

age class	untransformed earnings			square root of earnings	
	♀♀ = $\overline{M}_{i♀}$	♂♂	sex ratio $\frac{♀♀}{♂♂}$	♀♀ = $\overline{M}_{i♀}$	♂
2 year old	409	436	.94	7.7	7.6
3 year old	2128	2329	.91	26.3	26.8
4 year old	4210	5050	.83	44.1	48.2
5 year old	6300	8198	.77	56.0	64.4
6 year old	8027	11010	.73	62.8	74.9
7 year old	9405	13301	.71	67.3	81.8
8 year old	10444	15103	.69	70.3	86.4
population mean	12774			78.4	

These factors are obtained for each age class as the ratio of the mean earnings of female trotters to the mean of male trotters, after having corrected these earnings for year influences. The multilplication factors are only derived for untransformed earnings, since the transformation is applied after correction for sex difference.

c. influence of age class and number of progeny

In the breeding value index of a sire the information of the different age classes of his progeny is combined and weighted to the number of progeny in each age class. So the progeny mean for each age class is estimated first after correction for year and sex. The total earnings of the older progeny give a more reliable picture of their trotting ability than those of the younger. This is reflected in the heritability values of the earnings of the various age classes, which are given in Table 3.

Table 3. Heritability values of earnings, based on trotters born between 1959 and 1971 (within sire regression of progeny mean on dam performance).

age class	untransformed earnings		square root of earnings	
	♀♀	♂♂	♀♀	♂♂
2 year old	.244 ± .069	.253 ± 075	.220 ± .057	.237 ± .057
3 year old	.199 ± .054	.281 ± .065	.221 ± .055	.307 ± 059
4 year old	.225 ± .058	.295 ± .075	.248 ± .059	.355 ± .065
5 year old	.216 ± .060	.351 ± .087	.252 ± .061	.393 ± .070
6 year old	.207 ± .064	.382 ± .097	.233 ±.,063	.408 ± .073
7 year old	.219 ± .065	.379 ± .099	.230 ± .063	.408 ± .073
8 year old	.226 ± .066	.373 ± .097	.228 ± .062	.404 ± .072

The genetic correlations between earnings of different age classes are represented in Table 4.

Table 4. Genetic correlations* between earnings of different age classes Y_i (based on arithmetic mean of the reciprocal intra-sire covariances of dam and mean of offspring).

	Y_2	Y_3	Y_4	Y_5	Y_6	Y_7	Y_8
Y_2		.98 .96	.84 .87	.68 .72	.56 .63	.42 .52	.39 .43
Y_3	.90 .91		1.00 .99	.92 .94	.85 .91	.78 .85	.74 .82
Y_4	.87 .89	1.00 1.00		.98 .99	.94 .98	.91 .95	.88 .95
Y_5	.74 .79	.98 .97	.98 .98		1.00 1.00	.99 .99	.97 .98
Y_6	.66 .73	.93 .96	.95 .97	.99 1.00		.99 .99	.99 .99
Y_7	.57 .67	.89 .93	.92 .95	.99 .99	1.00 1.00		1.0(1.0(
Y_8	.54 .62	.85 .91	.89 .94	.97 .99	.99 .99	1.00 1.00	

* above diagonal : untransformed earnings
bellow diagonal : square root of earnings
within each cell : upper figure : ♀♀
lower figure : ♂♂
based on trotters born between 1959 and 1971

Both heritabilities and genetic correlations are based on an analysis of earnings of trotters born between 1959 and 1971 (Minkema, 1982).

For each sire the appropriate weighting factors for each age class are derived by solving the index equation Pb = Av as will be mentionned later.

d. influence of performance of dam

The index also includes a correction for the performance of the dams of the trotters. Some stallions are mated to better mares than others. Therefore it is necessary to take the mean performance level of the dams of the progeny of a given sire into account. For each age class of progeny the average total earnings (corrected for year influences!) of their dams is computed. The deviation of dam's mean from the female population mean is a measure of dam's inferiority or superiority. The progeny means are corrected for these deviations by the within sire regression of progeny performance of a given age class on dam's total earnings. These regressions are estimated from the same material as the h^2 values and are given in Table 5.

Table 5. Within sire regression coefficients of part earnings of progeny on total earnings (Y_8) of dams, based on trotters born between 1959 and 1971)

age class	untransformed earnings		square root of earnings	
	♀♀	♂♂	♀♀	♂♂
Y_2	.006 ± .003	.005 ± .003	.025 ± .008	.021 ± .008
Y_3	.022 ± .009	.031 ± .009	.049 ± .016	.070± 016
Y_4	.032 ± .013	.061 ± .016	.063 ± .063	.107 ± .021
Y_5	.048 ± .019	.098 ± .025	.083 ± .024	.145 ± .026
Y_6	.068 ± .024	.130 ± .033	.095 ± .027	.171 ± .030
Y_7	.094 ± .029	.157 ± .041	.107 ± .029	.188 ± .033
Y_8	.113 ± .033	.186 ± .049	.114 ± .031	.202 ± .036

Breeding value index

In the breeding value index the information of the different age classes of the progeny is combined. The index developed is based on the selection index theory and is constructed in such a way that the correlation between the true breeding value for lifetime earnings and the index I is maximised.

$$I = \sum_{i=2}^{8}\left[b_i\left(\left(\overline{Y}_i - \overline{M}_{i♀}\right) - c_{i8}\left(\overline{D}_{8i} - \overline{M}_{8♀}\right)\right)\right]$$

where :

i = 2, 3, 4, 5, 6, 7, 8, referring to the age classes : 2 years old, 3 years old, etc.

b_i = weighting factor to be used for the i-th age class of a stallion's progeny.

$\overline{Y}_i$ = mean corrected total earnings of sire's progeny of the i-th age class (accumulated over years!).

$\overline{M}_{i♀}$ = mean corrected total earnings of all female trotters of the i-th age class.

c_{i8} = within sire coefficient of regression of total earnings of progeny of the i-th age class to the total lifetime earnings (Y_8) of the dams

$\overline{D}_{i8}$ = mean corrected total lifetime earnings (Y_8) of the dams of the progeny, belonging to the i-th age class.

$\overline{M}_{8♀}$ = mean corrected total lifetime earnings of all female trotters.

The weighting factors b_i are derived by solving the index equations Pb = Av,

where :

P = a 7 x 7 matrix of phenotypic covariance between the 7 progeny means $\overline{Y}_2, .. \overline{Y}_8$

The elements are for i = j : $\text{cov}(\overline{Y}_i, \overline{Y}_j) = \frac{1 + \{n_i - 1\}\, 1/4\, h_i^2}{n_i} \sigma_i^2$

$$\text{for } i \neq j : \text{cov}(\overline{Y}_i, \overline{Y}_j) = \tfrac{1}{4}\, r_{a_{ij}} h_i h_j \sigma_i \sigma_j$$

where :

n_i = number of progeny of sire in i-th age class.

h_i^2 = heritability of total earnings of trotters of i-th age class.

σ_i = standard deviation of total earnings of trotters of i-th age class.

$r_{a_{ij}}$ = genetic correlation between total earnings of i-th and j-th age class

b = vector of weighting factors $b_2, b_3 \ldots b_8$ to be used in the index I.

A = a vector of genetic covariances between the 7 progeny means $\overline{Y}_i$ and the additive genetic value for total earnings ($=X_8$); the elements are

$$\text{cov}(\overline{Y}_i, X_8) = \tfrac{1}{2}\, r_{a_{i8}} h_i h_8 \sigma_i \sigma_8$$

v = relative economic value of the trait involved in the true breeding value of sire for total lifetime earnings (X_8). As there is only one trait in the true breeding value, v is a scalar fixed to 1.

Reliability

The reliability of the breeding value index of a sire depends upon the number of progeny in the different age classes. The correlation R_{TI} between the true breeding value T of a stallion for total lifetime earnings and the index is a measure for the reliability of the index and can be computed as :

$$R_{TI}=\sqrt{\frac{b^1 Pb}{G}}$$

where :

b^1 = transpose of vector b (defined earlier)

P = defined earlier

G = a scalar, representing the genetic variance of the true breeding value T = X_8, so $G = h_8^2 \sigma_8^2$

In Table 6 the way in which the breeding values indices are published is given for the stallions in service in The Netherlands in 1988.

Discussion

Which trait should be chosen in the breeding value estimation of a trotter sire? In the Dutch breeding value estimation procedure only one trait is involved in the breeding goal, viz. total lifetime earnings. In the index the sum of the yearly earnings of an offspring is used, weighted, according to his age class. Earnings are preferred above (best) time records, since the first trait allows to take non-starters into account : their earnings are assumed to be 0 guilders. Other breeding goals and/or index traits may be desirable. However, for time records an analogous procedure is impossible, unless a chosen bad time record is attached to a non-starter, e.g. the population mean (or sire's mean) + 3 times the standard deviation for time records.

Nevertheless, in the analysis of earnings the class of non-starters provides a cluster, which causes a serious deviation from a continuous frequency distribution. Even with an appropriate transformation this cluster will not disappear. This cluster has biassed the means and standard deviations of earnings used in the Dutch

Table 6. Breeding value indices of trotter stallions in the Netherlands (at service in 1988).

name of stallion	progeny		earnings		square root of earnings	
	number	years of birth	index(1)	reliability %	index(1)	reliability %
Arden Al	190	1977-1985	+ 2611	96	-16.1	97
Brilliant H	19	1985	+ 9064	48	+44.7	55
Duke Iran	20	1982	+16751	69	+61.8	78
Evento	66	1980-1985	+ 3441	81	- 4.1	87
Formal Notice	282	1975-1985	+ 6753	92	+ 0.4	95
Gallant Prince	237	1973-1985	+ 6915	97	- 7.6	98
Heres	907	1972-1985	+29130	99	+88.0	99
Kameraad	43	1979-1985	+33980	80	+47.5	86
Keystone Master	21	1983-1985	+ 6187	62	_ 0.2	72
Manza Buitenzorg	120	1981-1985	+21545	85	+49.1	90
Mucho Pride	372	1973-1985	+ 6771	98	+ 9.6	98
Nevele Impulse	110	1982-1983	+28826	83	+95.2	89
Never Worry	42	1984-1985	- 3643	63	- 12.8	71
Noble David	51	1982-1985	+ 1884	75	+ 9.0	82
Orlow	76	1978-1985	+ 818	90	-12.8	94
Pyreus Berkenhof	32	1984-1985	- 654	60	-10.4	68
Robin Buitenzorg	4	1985	- 1424	26	-12.6	32
Speedy Gent	50	1980-1984	+ 3494	81	- 0.5	87
The Import Laren	8	1985	- 3077	35	-19.8	42
Volo Prise	2	1985	+26588	19	+64.7	23
Worthy Dean	110	1980-1985	+ 8112	84	+27.4	89

(1) deviation from population mean

index. Hypothetically, if there would have been plenty of starting possibilities for slow horses as well, the cluster could be regarded as the left end of a (normal) continuous frequency distribution. Under this assumption the mean and standard deviation can be adjusted (Minkema, 1981). This adjustment is a way to improve the index, currently in use.

In some countries different traits are included in breeding value estimation instead of or besides earnings, like earnings per start, time records (per start), percentage of starters as 2 or 3 year old trotters (as a criterion for precocity) or during lifetime, etc.. Sometimes the performance of each start is taken and corrected for various influences, e.g. track, track or weather conditions, season, type of race, type of starting method, length of race, etc..

Using earnings the necessity to proceed from the performances of individual starts and to correct these performances for the various influences mentioned is felt to be low in the Netherlands. This is justified by the fact that a trotter is starting at different tracks during his lifetime, since the distances between the tracks in the Netherlands are rather small. Furthermore, the amount of purse money for trots does not differ much between tracks.

In most trotter breeding populations a rather sharp selection is applied, in particular on the male side. This results in a positive genetic trend for performance. As a consequence the average breeding values of younger sires will be higher than those of older ones. However, since in the Dutch index earnings are corrected for yearly influences, also the genetic trend is taken away. This implies that the mean breeding value of all sires at any time will be zero. On the other hand the breeding value of a particular sire will fall with time when new yearly crops of progeny become available. When breeding values are computed and published at a certain moment, it should be borne in mind in which year the first crop of progeny of a stallion is produced and how long this stallion has been in service. Preferably these items should be published together with the breeding values.

When breeding values are computed each year the question remains which breeding value should be regarded as the most representative one of a particular sire. Is this the index of his first 3 yearly crops of progeny, since these are produced without prior knowledge of the performance of his progeny? Also the number of progeny is relevant. The reliability of a stallion's index depends upon the number and the age of his progeny. Therefore the index always should be published together with its reliability.

In several countries a more sophisticated procedure than the selection index method is, viz. the BLUP method. Probably, the application of this method will facilitate the comparison of breeding values of stallions from different countries. There is a growing need for this comparison because of increased exchange of breeding stock. Some sires have progeny in different countries and these stallions can provide the information necessary to compare the mean genetic levels of different countries. Hopefully in the near future a code of practice for breeding value estimation will be formulated, which will be followed by the countries with an important trotter breeding industry.

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NORWEGIAN TROTTER BREEDING AND ESTIMATION OF BREEDING VALUES

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Summary

The Norwegian Trotter and the Standardbred Trotter are both used for harness racing in Norway. The number of born foals in the two breeds have increased rapidly in the last five years. The number of horses started in races in 1987 compared to 1983 is relatively higher in the Standardbred Trotter than in the Norwegian Trotter :

	Foals born		Number of started horses	
	1983	1987	1983	1987
Norwegian Trotter	872	1240	1641	1955
Standardbred Trotter	687	1090	1790	2516

This development is due to an increased import of Standardbred Trotters.

Genetic evaluation based on accurate breeding values is an important tool to reduce the import and to improve the genetic progress in the two breeds.

Since 1985, the Norwegian Trotters have been evaluated genetically for speed. Repeated observations for the age classes three to five years have been analysed by an animal model. Estimated heritability for this trait is 0.17 ± 0.02 with a repeatability of 0.65.

In the Standardbred Trotter the same trait has low heritability (h^2=0.03 ± 0.007, r=0.46) and other traits has be used for genetic evaluation.

The following traits have been considered for further genetic evaluation in Norway :

- number of starts
- percent disqualifications
- percent of first and second placings
- percent placings
- earnings
- earnings per start
- best racing time in volt start.

A multitrait animal model and techniques for iteration on the

data have been developed for estimation of breeding values in both the Standardbred and the Norwegian Trotter.

Introduction

Totalizator races were allowed in Norway in 1928 and since then both the Norwegian trotter and the Standardbred trotter have been used for harness racing. The trotting industry has developed very intensively due to a new countrywide gambling system introduce in 1982. Table 1 shows this development. The number of foals born in the Norwegian trotter population increased 35% the last five years. In the Standardbred trotter this increase is 62%, but still there are born a higher number of foals in the Norwegian trotter than in the Standardbred trotter.

Table 1. Number of foals born in Norway between 1972 and 1987.

Breed	1972	1976	1980	1983	1984	1985	1986	1987	Total
Norwegian Trotter	538	775	866	909	1030	1159	1273	1233	13979
Standardbred Trotter	313	523	572	661	822	929	1057	1077	10126

One has to take the number of imported and exported trotters into consideration for a complete comparison of the relative size of the two trotter populations. Table 2 shows a considerable import of Standardbred trotters to Norway, and only a negligible export.

Table 2. Number of imported and exported trotters to Norway born between 1972 and 1987

Breed	Number of imported trotters	Number of exported trotters
Norwegian trotter	9	12
Standardbred trotter	1785	15

The overall breeding goal in Norway is to produce, within Norway, the need for trotters for the trotting industry. To meet this goal one has to produce trotters which are attractive in the market. First of all the norwegian Standardbred trotter population must have a genetic potential as high or ever higher than in the countries the import is coming from today. The genetic potential refers to soundness, trotting ability and temperament which were found to be the most important traits in an inquiry study performed in the Norwegian trotter (Klemetsdal and Halse, 1988). So far, the animal geneticists have concentrated mainly on traits expressing trotting ability.

Material

Records from single races.

Since 1983 data on performances have been recorded as racing time (per kilometer), placing, earnings, disqualification and qualifying points in each start. A wide specter of systematic environmental effects associated wich each start are also available. All horses born after 1972 have information on sire, dam, birth-year and sex. The Norwegian trotter have the same information on five ancestral generations. Information on the breeder is available for horses born after 1972.

Only performance traits associated with timing have been analysed in this material due to need for a normal distribution of the traits in analysis of variance and in prediction of breeding values. All qualifying races were excluded from the analysis. Records on foreign horses started in Norway or Norwegian horses started abroad, race records on horses that did not start, were disqualified or time not noted were all deleted from the final data sets. The distance was divided into three classes (<2000m, 2000-2500m, >2500m) and the sex effect into two classes, mares and stallions.

Annually summarized race records

They have been filed for Norwegian trotters born after 1972. An equal material is under preparation in the Standardbred trotter.

Since 1983 imported trotters have been given separate records in this databank to make possible a future nordic genetic evaluation of trotters. The best cumulative racing time was calculated for all horses and stored together with accumulated earnings, accumulated number of starts and the variable started/not started in ordinary races to ensure maximal use of the data on the Norwegian trotters.

Statistical methods use to estimate variance components.

Repeated racing time.

The analysis of variance of repeated racing times was done by Harvey's program LSMLMW (Harvey, 1985). First, racing time was preadjusted for age and sex effects estimated in an ordinary fixed model. Then the following nested model was applied to the data :

$$Y_{ijklmnop} = \mu + s_i + h_{ij} + t_k + d_l + b_m + c_n + r_o + e_{ijklmnop}$$

where

$Y_{ijklmnop}$ = racing time preadjusted for age and sex effects

μ = least squares mean

s_i = random effect of ith sire $\approx NID(0, \sigma_s^2)$

h_{ij} = random effect of jth horse nested within ith sire $\approx NID(0, \sigma_h^2)$

t_k = fixed effect of kth racetrack (k=1,2,..12)

d_l = fixed effect of lth distance (l=1,2,3)

b_m = fixed effect of mth starting method (m=1,2)

c_n = fixed effect of nth month of the year (n=1,2,..12)

r_o = fixed effect of oth race year (o=1983, 1984, 1985)

$e_{ijklmnop}$ = random error $\approx NID(0,\sigma_e^2)$

The heritability (h^2) and repeatability (r) estimates were calculated from variance components as :

$$h^2 = \frac{4\sigma_s^2}{\sigma_s^2 + \sigma_h^2 + \sigma_e^2} \quad \text{and} \quad r = \frac{\sigma_s^2 + \sigma_h^2}{\sigma_s^2 + \sigma_h^2 + \sigma_e^2}$$

Annually summarized race records

To approximate a marginal normal distribution of the phenotypical observations ($x_1, x_2, ..., x_n$) of earnings and number of starts one may choose the appropriate power λ which maximizes the expression (Box and Cox, 1964)

$$l(\lambda) = -\frac{n}{2}\ln\left[\frac{1}{n}\sum_{j=1}^{n}(x_j^{(\lambda)} - \overline{x^{(\lambda)}})^2\right] + (\lambda - 1)\sum_{j=1}^{n}\ln$$

$l(\lambda)$ was calculated for all values of λ between -1 and 1 for the two traits.

The accumulated earnings and number of starts were transformed to near normality. The genetic parameters for these two traits and best racing time in volt-start were estimated with a multivariate REML-procedure and a sire model which includes the relationship between sires in the analysis (Meyer, 1986). Starting frequency was analysed univariately with the same procedure. In all analysis, birth year and sex were included as correction terms. Only half sibs were used in the analysis

Results of variance component analysis

Repeated racing time

Heritability and repeatability estimates for repeated racing time are given in Table 3 for Norwegian trotter and in table 4 for Standardbred trotter.

Table 3. Heritability, repeatability, genetic variance and phenotypic variance for repeated racing time in Norwegian trotter

	Number of			Heritability	Repeatability	Variance	
Age	records	horses	sires	± st. error		genetic	phenotypic.
3-4	14393	1141	112	0.176 ± 0.027	0.65	2.40	13.65
3-5	26460	1490	130	0.166 ± 0.022	0.65	2.08	12.51
3-6	38008	1768	140	0.186 ± 0.022	0.64	2.22	11.92

Table 4. Heritability, repeatability, genetic variance and phenotypic variance for repeated racing time in Standardbred trotter

	Number of			Heritability	Repeatability	Variance	
Age	records	horses	sires	± st.error		genetic	phenotypic
3-4	13848	990	139	0.005 ± 0.006	0.46	0.028	5.18
3-5	24934	1310	159	0.034 ± 0.007	0.46	0.16	4.86
3-6	33645	1540	180	0.035 ± 0.006	0.46	0.16	4.71

Annually summarized race records

Both accumulated earnings and number of starts had a maximum in the given intervall for λ (Table 5).

Table 5. Appropriate transformations (λ) for accumulated earnings and number of starts in Norwegian trotter

	Accumulated	
age	earnings	number of starts
3	0.20	0.20
3-4	0.20	0.30
3-6	0.20	0.40

The transformed frequency distributions for the two traits were approximatively normal in all age groups.

Table 6, Table 7 and Table 8 show the correlation matrix with lower bound standard error between best racing time in volt start, transformed earnings and transformed number of starts in different age groups. The heritability estimates are on the diagonal, the lower triangle gives the genetic correlations. The upper triangle contain the phenotypic correlations. Basic information in each analysis is given in Table 9.

Table 6. Heritability estimates and genetic and phenotypic correlations between best racing time in volt start, $\sqrt[5]{\text{Earnings}}$ and $\sqrt[5]{\text{Number of starts}}$ for three years old Norwegian trotters

r_p / h^2 / r_g	Best racing time in volt-start	$\sqrt[5]{\text{Earnings}}$	$\sqrt[5]{\text{Number of starts}}$
Best racing time in volt-start	0.24 ± 0.06	-0.81 ± 0.01	-0.67 ± 0.01
$\sqrt[5]{\text{Earnings}}$	-0.93 ± 0.04	0.15 ± 0.04	0.73 ± 0.01
$\sqrt[5]{\text{Number of starts}}$	-0.64 ± 0.26	0.70 ± 0.24	0.02 ± 0.02

Table 7. Heritability estimates and genetic and phenotypic correlations between best racing time in volt-start, $\sqrt[5]{\text{Earnings}}$ and $\sqrt[3.33]{\text{Number of starts}}$ for three and four year old Norwegian trotters

r_p / h^2 / r_g	Best racing time in volt-start	$\sqrt[5]{\text{Earnings}}$	$\sqrt[3.33]{\text{Number of starts}}$
Best racing time in volt-start	0.27 ± 0.05	-0.86 ± 0.00	-0.77 ± 0.01
$\sqrt[5]{\text{Earnings}}$	-0.98 ± 0.01	0.23 ± 0.05	0.82 ± 0.01
$\sqrt[3.33]{\text{Number of starts}}$	-0.97 ± 0.04	0.96 ± 0.04	0.07 ± 0.02

Table 8. Heritability estimates and genetic and phenotypic correlations between best racing time in volt-start, $\sqrt[5]{\text{Earnings}}$ and $\sqrt[2.5]{\text{Number of starts}}$ of starts for three to six years old Norwegian trotters.

r_p / h^2 / r_g	Best racing time in volt-start	$\sqrt[5]{\text{Earnings}}$	$\sqrt[2.5]{\text{Number of starts}}$
Best racing time in volt-start	0.24 ± 0.05	-0.89 ± 0.00	-0.82 ± 0.01
$\sqrt[5]{\text{Earnings}}$	-1.00 ± 0.00	0.25 ± 0.05	0.86 ± 0.00
$\sqrt[2.5]{\text{Number of starts}}$	-0.93 ± 0.04	0.95 ± 0.03	0.10 ± 0.03

Table 9. Total number of sires, number of sires with progenies and total number of progenies included in the analysis of variance

Age	Total number of sires	sires with progenies	Number of progenies
3	447	202	2888
3-4	457	260	3752
3-6	419	190	3500

Starting frequency

Starting frequency is here defined as starting in ordninary race before a specified age.

Table 10 gives the heritability of starting frequency and information about the different analysis of variance performed.

Table 10. Heritability of starting frequency at different ages, total number of sires, number of sires with progenies and total number of progenies included in the analysis of variance

Age	Total number of sires	Number of sires with progenies	progenies	Heritability ± st.error
3	598	275	8918	0.09 ± 0.02
3-4	568	260	8038	0.15 ± 0.03
3-6	510	232	6541	0.20 ± 0.04

Prediction of breeding values

Repeated racing time.

Since 1986 a single trait multiple record animal model (Henderson, 1977) has been used to predict breeding values for repeated racing time in the Norwegian trotter population. Data on 3-5 years old trotters have been used. The breeding values have been appreciated by the horsemen and the chief inspector for horsebreeding has during 1987 introduced the calculated breeding values in selection of young stallions for practical breeding work.

Annually summarized race records - starting frequency.

A multiple trait single record animal model has been developed for calculating breeding values for transformed number of starts, best racing time in volt-start, transformed earnings and starting frequency. Data on 3-4 years old trotters has been choosen in the analysis due to the results from the analysis of variance.

A new computing strategy described for a multiple trait sire model by Schaeffer and Kennedy (1986) and for a multiple trait reduced animal model by Schaeffer and Wilton (1987) has been used to find the solution to the mixed model equations.

The starting frequency was assumed genetically and environmentaly uncorrelated with the other traits. This means that a single trait analysis is performed for starting frequency and a multiple trait analysis for the three other traits. Totally, breeding values were calculated for 11 600 animals. The computer programs read a datafile and a pedigree file in each Gauss-Seidel iteration. The convergency was very quick. The change in sums of squares of solutions was less than 1% for all four traits after 5 iterations and less than 0.01% after 15 iterations. The program is flexible and allows different fixed effects for each trait.

The frequency distribution of breeding values for starting frequency was approximately normal although starting frequency had a binomial distribution.

Annual genetic gain in starting frequency was 2.3% of the additive genetic standard deviation pr. year. Single trait analysis should be used to find the genetic trend in the three other traits included in the genetic evaluation. The indices for all traits will be presented standardized with a mean value of 100. This index has tradition in Norway and is appreciated by the horsemen.

Discussion

The litterature presents a large number of traits, all meant to express trotting ability. The traits may be based on :

1. Repeated measures in single races (e.g. racing time and earnings)
2. Repeated measures of annually summarized race records (e.g; earnings and best racing time in volt-start)
3. Repeated measures of annually average race records (e.g. average earnings pr. start and percent of placings 1-3)
4. A sum of annually summarized race records (e.g. earnings and best racing time in volt-start before five years of age)
5. The mean of the sum of annually summarized race records (e.g. earnings pr. start and percent placings 1-3 before five years of age.

Traits belonging to group 3 and 5 have been commonly used by scientists to estimate genetic parameters and predict breeding values in trotter populations. The heritability estimates from these analysis are heritability estimates of mean values. They are not directely applicable in single record animal models, sire models or selection indicies since these models assume that the genetic parameters are estimated on single records. In this way, animals with a small number of starts or sires with a small number of progenies will be regressed to little in the prediction of breeding values. These traits should be handled with care and if possible replaced by other traits or analyzed with models which allows repeated records. Another general problem is related to the approximation to normality of traits based on repeated measures in single races. The most appropriate way of handling these traits is probably to transform the right-hand side of the normal equations and keep the left-hand side untransformed in estimation of REML-variance components and prediction of breeding values with a multiple record animal model.

Another possibility would be to transform the single observations directely so that the sum of observations for each animal (right-hand sides of the normal equations for random effects) become approximatively univariate normal. The transformation of traits used for selection purposes in trotter breeding is often criticised. However, the transformations are necessary both from a genetical and statistical point of view, since the distributions of the three hidden genotypes are assumed normal and the REML-procedure assume approximatively normal distribution of the phenotypic values.

One special problem is related to environmental covariances between observations within animals. They are to some extent controlled in estimation of genetic parameters for repeated racing time due to separate estimation of variance components for horses. The inclusion of equations for permanent environmental effects and the inverse of the numerator relationship matrix have a similar effect in the multiple record animal model. For the same argument, the genetic parameters and predicted breeding values for annually summarized race records have been assumed independent of the environmental covariance within animals.

The heritability estimates in this study are probably biased upwards since the sire models does not controll assortative mating or preferential treatment of progeny groups. In addition, the heritability estimates for repeated racing time are biased upwards since data on full sibs were included in the analysis.

The heritability estimates for repeated racing time on Standardbred trotters are consistent but very low compared with the estimates on the Norwegian trotter. In Norwegian trotters, the genetic variance for repeated racing time is only 1/4 of the genetic variance for best racing time in volt-start (12.015 secunds). The repeated racing time absorb the tendency to breaking stride and is probably another trait than best racing time in volt-start. One may discuss which of these two traits that best expresses trotting ability but since :

° annually summarized race records includes traits traditionally appreciated by the horsemen.

° annually summarized race records exist for a longer period of time than records in single races.

° traits based on annually summarized race records show a high genetic correlation and some horses have missing values for best racing time in volt-start.

° annually summarized race records are easier to handle on a computer and in a statistical sence.

The developed multiple trait animal model is proposed for future genetic evaluation of trotters in norway. The multiple animal model will be extended to eight traits i.e. the mentionned four traits and the same traits on the last course of a year of horses which have available data from their three year season only. Genetic and environmental correlations between the traits in the two age groups have to be estimated and used in the prediction on breeding values.

In the near future all possible ancestors will be included in the genetic evaluation of the Norwegian trotter and genetic parameters will be estimated in the Standardbred trotter.

Repeated measures in single races should be further considered by scientists because important traits can only be treated statistically elegant that way.

Nordic genetic evaluation of trotters

About 8000 Standardbred trotter and 2500 Norwegian/North Swedish trotter foals are born annually in the nordic countries. This makes the Standardbred trotter population the most numerous population in the world. A nordic genetic evaluation of trotters would be an important tool to increase the genetic progress in the two breeds. Effort should be made to make this possible in the near future.

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GENETIC EVALUATIONS OF SWEDISH TROTTERS

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Summary

Swedish trotter are divided into two distinct populations, i.e. the Standardbred trotter and the North-Swedish trotter. Annually summarized racing records of trotters of both populations were analysed in order to get estimates of genetic parameters of performance traits and to identify important environmental factors affecting the racing performance of trotters. The following traits were selected for genetic evaluations of stallions : Best racing time, Total sum of earnings, Average earnings per start, Proportion of races placed 1-3, Number of races performed, Proportion of progenies starting at least in one race and Proportion of progenies starting at least in five races. Normal distributions of the phenotypic records were approximated by square-root and logarithmic transformations.

Standardbred stallions are at present routinely evaluated by a selection index based on their own racing performance and by the BLUP method based on progeny performance. The selection index weights the individual stallions deviations of transformed racing performance records from the contemporary averages. The sire model used for evaluation of sires having at least 5 offspring with racing records included fixed effects of birth year and sex together with the dam's selection index as a covariate.

Genetic evaluations of North-Swedish trotters are based on the BLUP method for an animal model using the complete genetic relationship, where the pedigree is traced at least 3 generations from the recorded individuals. The North-Swedish trotters of both sexes are evaluated simultaneously for the three following traits (transformed) : Best racing time, Average earnings per start and Proportions of races placed 1-3. Besides the random effects of the genetic value and the environmental deviation, the statistical model includes the fixed effects of sex and the year of birth. Annual genetic gain in the transformed racing performance traits of North-Swedish trotters amounts, on average, to 4% of the genetic standard deviation for respective traits.

Programs for evaluation of the Standardbred stallions and broodmares by animal model - BLUP are currently under development.

Introduction

Swedish trotters are divided into two distinct populations; the Swedish standardbred trotter and the North-Swedish trotter. The former is a light horse of mainly American and to a certain extent French origin, while the latter is a heavier domestic type, also used for forestry work. The number of Swedish standardbred mares serviced annually is about 8000, while the corresponding number is about 1000 for the North-Swedish trotter.

The breeding goal for the Swedish standardbred is a fast sound, sustainable, well tempered and good gaited racing trotter of international standard. The breeding goal of the North-Swedish trotter does also involve improvement of speed, soundness and sustainability, but in addition considerable emphasis is put on type, character and working ability which may cause an obvious restriction on the improvement in speed.

Competition results provide measures of some of the traits included in the breeding goal. The purpose of this study was : to identify practical measures of racing ability for Swedish trotters; to estimate genetic parameters for these traits ; to identify and estimate important environmental systematic sources of variation ; and to develope appropriate statistical models for genetic evaluation of breeding animals. Some of the results have previously been rapported (Arnason, Darenius and Philipsson, 1982; Arnason, Bendroth and Philipsson, 1984; Bendroth, Arnason and Philipsson, 1985).

Materials and methods

Estimation of genetic parameters and environmental factors affecting racing performance

I. The Swedish standardbred trotter

The material used in the analyses consisted of annually summarized racing records obtained before 1984 for 12 391 (6 906 ♂ and 5 485 ♀) Standardbred trotters born between 1973 and 1980.

The total material was further divided into four subsets as follows :

1. 2 051 horses that had been racing as 3- and 4-years old (1 196 ♂ and 855 ♀)
2. 4 026 horses that had been racing as 4- and 5-years old (2 421 ♂ and 1 605 ♀)
3. 1 229 horses that had been racing as 3- and 4- and 5-years old (779 ♂ and 450 ♀)

4. 9 654 horses that had raced any time before 6 years of age (5 426 ♂ and 4 228 ♀).

Only animals with at least 5 starts and a recorded racing time were included in the analyses.

The five following traits were studied using the transformations shown to right :

number of starts :	$(\text{number of starts})^{1/2}$
% placings 1-3	$(\%\text{placings } 1\text{-}3)^{1/2}$
total earnings :	$(\text{total earnings})^{1/4}$
earnings per start :	$\text{Log}_{10}\left[\frac{(\text{total earnings})^{1/2}}{\text{number of starts}} + 1\right]$
best racing time	$\text{Log}_{10}(\text{best racing time - 1 min})$

These transformations of the phenotypic records were found to give acceptable approximations to the normal distribution in this data (Arnason et al., 1982).

The data were analysed according to the following statistical model :

$$y_{ijkl} = \mu + s_i + k_j + f_k + b_1(x_{ijkl} - \bar{x}) + b_2(x_{ijkl} - \bar{x})^2 + e_{ijkl} \quad , \qquad (1)$$

where,

y_{ijkl} is the observation on the lth horse

s_i is the effect of the ith sire

k_j is the effect of jth sex (j = 1,2)

f_k is the effect of the kth birthyear (k = 1973, ... 1980)

b_1 and b_2 are the linear and quadratic regression coefficients on the dams' selection index value

x_{ijkl} is the selection index value of the dam to the lth horse

$\bar{x}$ is the average selection index value of dams, and

e_{ijkl} is a random residual term

The heritabilities, genetic- and phenotypic correlations were estimated by use of a standard form of paternal half-sib analysis where variance- and covariance components were estimated by Henderson's method 3, by use of the LSML76 program of Harvey (1977).

II. The North-Swedish trotter

The material used in the analyses of racing results of the North-Swedish trotter involved annually summarized racing records up to 6 years of age obtained before 1984 for 2 233 (1 199 ♂ and 1 034 ♀) individual horses born between 1970 and 1980.

Exactly the same traits were analysed for the North-Swedish trotters as for the Standardbred trotters by the application of the model in equation (1), with the exception of more birth years included in the model (j = 1970 - 1980) and the exclusion of the regressions on dam's index. The same transformations of phenotypic records were found to be appropriate and the same procedure was used for estimation of genetic parameters.

A set of data containing 4 929 individual horses (2 451 ♂ and 2 478 ♀) born 1970-1979 and sired by stallions having at least 5 registered offspring was analysed separately for starting frequency. Horses having at least one racing record were assigned the observation value of one, while non-starters were assigned the value of zero.

Estimation of breeding values

I. The Swedish standardbred trotter

Stallions which are candidates for approval as breeding stallions are routinely evaluated on the basis of their own racing performance by the following selection indices :

1) Individual selection index for results as 3-years to 5-years old :

$$I = (-0.32X_1 + 0.45X_2 + 15.26X_3 - 73.26X_4)\, k_1 + 100 \qquad (3)$$

$$R_{TI} = 0.60$$

2) Individual selection index for lifetime (up to 12 years of age) racing results :

$$I = (0.20X_1 + 0.54X_2 + 9.74X_3 - 62.46X_4)\, k_2 + 100 \qquad (4)$$

$$R_{TI} = 0.52$$

where, the X_is are the transformed racing performance variables (% placings 1-3, earnings, average earnings per start and best racing record, respectively), expressed as deviations from the average records of stallions belonging to the same age groups, and the k_is are constants scaling the variation in index values. The agregate genotype (T) involves the two traits earnings and % placings weighted by their respective phenotypic standard deviations.

Stallions having at least 5 offspring with racing records are routinely evaluated by the BLUP method for the following 5 traits (transformed as above) : number of starts, % placings 1-3, sum of earnings, earnings per start and best racing time. The material used in the BLUP analysis on racing results untill the end of 1987, consisted of the 3- to 5-years old racing results of 24 913 individual horses born in 1970-1984 and sired by 531 stallions. The sires were evaluated by the following statistical model :

$$y_{ijk} = f_i + s_j + b(x_{ijk} - \bar{x}) + e_{ijk} \qquad (5)$$

where,

y_{ijk} is the observation on the kth horse

f_i is the effect of the ith sex/birthyear subclass

s_j is the effect of the jth sire

b is a linear regression coefficient on the dam's selection index value

x_{ijk} is the selection index value of the dam to the kth horse Calculated according to equation (4) above

$\bar{x}$ is the average selection index value of dams and

e_{ijk} is a random residual term

The distribution of observations into the various sex/birthyear subclasses is shown in table 1.

Table 1. Distribution of observations included in the BLUP evaluation of Swedish standardbred stallions according to birthyear and sex classes

Year of birth	Stallions (and geldings)	Mares
1970	740	631
1971	810	614
1972	747	591
1973	747	578
1974	802	600
1975	783	685
1976	868	660
1977	975	755
1978	1025	827
1979	1082	827
1980	1096	916
1981	1231	951
1982	1192	1036
1983	1134	899
1984	608	503
	13840	11073

A single trait model was used for the sire evaluation of the trait number of starts, while a multiple trait model was used for the other four traits of racing performance. The set of genetic parameters : heritabilities, genetic- and phenotypic correlations are listed in Table 2.

Table 2. Genetic parameters for five variables of racing performance in Swedish standardbred trotters to be used in the BLUP analyses. Heritabilities on the diagonal. Genetic correlations above and phenotypic correlations below the diagonal.

	Number of starts	% placings 1-3	Earnings	Earnings per start	Best racing time
Number of starts	0.10				
% placings 1-3		0.22	0.84	0.81	-0.83
Earnings		0.64	0.27	0.78	-0.95
Earnings per start		0.57	-0.87	0.25	-0.75
Best racing time		-0.59	-0.87	-0.21	0.29

These values were actually obtained from the genetic analyses on dataset 4 as described above. The original values have been shrinked by the "bending" method (Hayes and Hill, 1981) in order to stabilize the effect of sampling variance on the variance/covariance structure of the highly intercorrelated performance traits. A bending factor of 0.3 was applied.

The BLUP analyses according to the multiple trait model were performed on canonically transformed variables as suggested by Thompson (1977) and applied by Arnason (1982, 1984). The canonical transformation is a special linear transformation of the records which creates a diagonal variance/covariance structure among the *n* traits involved and enables the multiple trait BLUP analyses to be performed as *n* single trait analyses.

In another BLUP analysis stallions which had at least 10 registered offspring were evaluated for starting frequency of their offspring. The material used in the BLUP analysis including the 1987 results consisted of 45 515 individual horses which were born in 1970-1984, and sired by 522 stallions. Two different starting frequencies were calculated as all- or non-traits. The first trait was defined as the frequency of having at least one racing record in the material. The second trait was defined as the corresponding frequency

Table 3. Distribution of observations according to sex and birthyear in BLUP analyses of start frequency in the Swedish Standardbred trotter. Proportions with a least one and five starts respectively.

	Stallions (geldings)			Mares		
		Proportions with			Proportions with	
Year of birth	Number	> 0 start	> 4 starts	Number	> 0 start	> 4 start
1970	1090	0.706	0.654	1130	0.581	0.512
1971	1208	0.704	0.649	1143	0.573	0.507
1972	1220	0.657	0.594	1225	0.521	0.466
1973	1169	0.682	0.618	1141	0.542	0.479
1974	1290	0.678	0.626	1214	0.524	0.474
1975	1335	0.640	0.580	1375	0.540	0.482
1976	1403	0.654	0.605	1378	0.517	0.462
1977	1530	0.678	0.628	1454	0.558	0.503
1978	1626	0.671	0.629	1582	0.548	0.503
1979	1674	0.685	0.637	1601	0.553	0.503
1980	1747	0.654	0.615	1726	0.557	0.504
1981	1894	0.674	0.630	1860	0.534	0.476
1982	1917	0.617	0.561	1888	0.547	0.483
1983	1996	0.565	0.473	1917	0.459	0.361
1984	1955	0.304	0.190	1827	0.276	0.158
Total	23054	0.627	0.567	11591	0.516	0.451

of at least five racing records. The same statistical model as above (equation 5) was used in the BLUP analysis of starting frequency. The heritability was set to 0.1 in line with the results of Klemetsdal, Swendsen and Vangen (1985) and two single trait BLUP analyses were performed for these two definitions of starting frequency. The distribution of observations according to sex and birthyear is shown in table 3, together with the observed starting frequencies.

The sire evaluations were performed without accounting for relationship among the stallions.

II. The North-Swedish trotter

The North-Swedish trotters are evaluated by an individual animal model on the basis of racing records. The material available at the end of 1987 consisted of : a) 5 162 individual trotters with at least 5 starts and a recorded time in the material, and 2) the pedigree part including 3 776 horses without own racing records. The pedigree was traced 3 generations for every individual with own records as defined above. Breeding values were evaluated for the following three traits (transformed) : % placings 1-3, average earnings per start and best racing time.

The following statistical model was applied to the data :

$$y_{ijk} = b_i + s_j + a_{ijk} + e_{ijk} \qquad (6)$$

where

y_{ijk} is the observation on the kth horse born in year i and of the jth sex

b_i is the effect of the ith birth year (i = 1960, ..., 1984)

s_j is the effect of the jth sex (j = 1, 2)

a_{ijk} is the effect of additive genetic merit of the kth horse, and

e_{ijk} is the random environmental effect affecting th kth horse

A multiple trait BLUP analysis was performed on canonically transformed variables. The set of genetic parameters used is shown in table 4. The inverse of the complete additive genetic relationship, accounting for inbreeding, was computed by the method of Quaas (1976).

Table 4. Genetic parameters for three variables of racing performance in the North-Swedish trotters to be used in the BLUP analyses. Heritabilities on the diagonal. Genetic correlations above and phenotypic correlations below the diagonal.

	% placings 1-3	Earnings per start	Best racing time
%placings 1-3	0.18	0.86	-0.78
Earnings per start	0.80	0.19	-0.93
Best racing time	-0.59	-0.68	0.25

The genetic trend in the racing performance was estimated by calculating the linear regression of average breeding values within birth years on the birth year.

Table 5. Distribution of observations into sex and birthyear subclasses and least-squares means (± standard errors). For the Swedish standardbred trotter for racing results before 6 years of age

	N	N° of starts	% placings 1-3	Earnings	Earnings per start	Best racing time
μ	9654	4.522 ± 0.026	4.874 ± 0.054	11.854 ± 0.114	0.910 ± 0.006	1.320 ±0.001
sex						
♂	5426	4.645 ± 0.030	5.201 ± 0.057	12.469 ± 0.119	0.930 ± 0.006	1.314 ± 0.001
♀	4228	4.399 ± 0.032	4.547 ± 0.059	11.238 ± 0.122	0.889 ± 0.006	1.326 ± 0.001
Birthyear						
1973	1033	4.861 ± 0.058	5.115 ± 0.087	11.713 ± 0.170	0.837 ± 0.009	1.336 ± 0.002
1974	1149	5.009 ± 0.054	5.161 ± 0.082	12.333 ± 0.162	0.863 ± 0.008	1.329 ± 0.002
1975	1226	5.007 ± 0.052	5.163 ± 0.079	12.692 ± 0.156	0.884 ± 0.008	1.319 ± 0.002
1976	1282	4.810 ± 0.050	4.987 ± 0.077	12.352 ± 0.153	0.890 ± 0.008	1.314 ± 0.002
1977	1445	4.810 ± 0.048	4.817 ± 0.075	12.281 ± 0.149	0.888 ± 0.008	1.311 ± 0.002
1978	1530	4.742 ± 0.047	4.649 ± 0.074	12.226 ± 0.148	0.892 ± 0.007	1.306 ± 0.002
1979	1310	3.931 ± 0.051	4.533 ± 0.079	11.166 ± 0.156	0.952 ± 0.008	1.315 ± 0.002
1980	679	3.009 ± 0.071	4.567 ± 0.101	10.066 ± 0.195	1.071 ± 0.10	1.327 ± 0.002

Results

Estimation of genetic parameters and environmental factors affecting racing performance

I. The Swedish standardbred trotter

The least-squares constants for the fixed effects included in model (1), when applied to dataset 4 (racing results up to 5 years of age), are shown in table 5. The effect of the quadratic regression on the dam's selection index value was not significant. All the other factors in the statistical model had generally significant effects on the variation observed in all traits studied. The estimates of heritabilities obtained for the five different sets of data are listed in Table 6. The estimated heritability for racing results (with the exception of number of starts) are fairly high ranging from 0.15 to 0.45. For the individual racing years 3- to 5-years old the heritability estimates decline with higher age. Similarily the heritability estimates are higher for racing results before 6 years of age than for tracing results before 6 years of age than for racing results before 13 years of age.

Table 6. Heritabilities (h^2) for different racing records (± standard deviation)

Results as 3-year old	h^2	Results before 6 years of age	h^2
1. N° of starts	0.07 ± 0.04	1. N° of starts	0.07 ± 0.02
2. % placings 1-3	0.32 ± 0.07	2. % placings 1-3	0.24 ± 0.03
3. Earnings	0.36 ± 0.07	3. Earnings	0.31 ± 0.03
4. Earnings per start	0.38 ± 0.07	4. Earnings per start	0.29 ± 0.03
5. Best racing time	0.45 ± 0.08	5. Best racing time	0.34 ± 0.04
Results as 4-year old		**Results before 13 years of age**	
1. N° of starts	0.04 ± 0.02	1. N° of starts	0.12 ± 0.08
2. % placings 1-3	0.22 ± 0.04	2.% placings 1-3	0.19 ± 0.02
3. Earnings	0.33 ± 0.05	3. Earnings	0.23 ± 0.03
4. Earnings per start	0.38 ± 0.05	4. Earnings per start	0.18 ± 0.02
5. Best racing time	0.37 ± 0.05	5. Best racing time	0.26 ± 0.03
Results as 5-year old			
1. N° of starts	0.02 ± 0.02		
2. % placings 1-3	0.15 ± 0.03		
3. Earnings	0.22 ± 0.04		
4. Earnings per start	0.30 ± 0.05		
5. Best racing time	0.35 ± 0.05		

Table 7. Corrélations between different racing records, both between and within years. Genetic correlations above and phenotypic correlations below the diagonal.

	Results as 3 year old					Results as 4 year old					Results as 5 year old				
	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
<u>Results as 3 year old</u>															
1. Number of starts	-	-0.10	0.39	0.03	-0.37	-0.79	-0.32	0.11	0.18	-0.01	0.20	-0.17	0.43	0.32	-0.13
2. % placings 1-3	0.07	-	0.85	0.96	-0.90	-0.34	0.82	0.86	0.96	-0.85	0.38	0.70	0.85	0.75	-0.98
3. Earnings	0.55	0.63	-	0.93	-0.99	-0.75	0.59	0.82	0.96	-0.80	0.08	0.48	0.84	0.82	-0.89
4. Earnings per start	-0.23	0.70	0.64	-	-0.91	-0.56	0.60	0.79	0.94	-0.81	-0.01	0.61	0.76	0.76	-0.91
5. Best racing time	-0.52	-0.53	-0.81	-0.47	-	0.60	-0.65	-0.86	-0.97	0.90	0.09	-0.49	-0.83	-0.87	
<u>Results as 4 year old</u>															
1. Number of starts	0.19	0.07	0.10	-0.03	-0.05	-	0.09	0.18	-0.07	-0.28	1.00	-0.14	0.07	-0.32	-0.23
2. % placings 1-3	-0.05	0.35	0.24	0.31	-0.22	0.17	-	0.87	0.95	-0.78	0.33	0.90	0.96	0.88	-0.87
3. Earnings	0.13	0.38	0.48	0.39	-0.38	0.59	0.66	-	0.95	-0.97	0.25	0.73	0.98	0.87	-0.95
4. Earnings per start	-0.05	0.36	0.41	0.46	-0.37	-0.28	0.64	0.57	-	-0.88	-0.03	0.81	1.00	1.00	-0.90
5. Best racing time	-0.23	-0.46	-0.56	-0.43	0.51	-0.58	-0.52	-0.81	-0.37	-	-0.30	-0.66	-0.92	-0.79	0.97
<u>Results as 5 year old</u>															
1. Number of starts	0.11	0.09	0.07	-0.00	-0.02	0.30	0.10	0.20	-0.05	-0.19	-	0.06	0.06	-0.26	-0.30
2. % placings 1-3	-0.02	0.32	0.23	0.29	-0.20	0.02	0.38	0.28	0.30	-0.12	0.32	-	0.91	0.89	-0.89
3. Earnings	0.06	0.32	0.34	0.32	-0.27	0.17	0.37	0.48	0.34	-0.19	0.63	0.74	-	0.95	-0.99
4. Earnings per start	-0.02	0.31	0.33	0.38	-0.30	-0.07	0.35	0.35	0.44	-0.05	-0.11	0.66	0.65	-	-0.89
5. Best racing time	-0.18	-0.46	-0.51	-0.42		-0.35	-0.46	-0.65	-0.38	0.44	-0.52	-0.56	-0.77	-0.46	-

Table 8. Distribution of observations into sex and birthyear subclasses and least-squares constant (± standard error) for North Swedish trotters

	N	Best racing time	% placings 1-3	Earnings	Earnings per start	Number of starts
μ	2233	2.614 ± 0.004	4.371 ± 0.126	9.091 ± 0.241	4.379 ± 0.077	4.335 ±0.158
sex						
♂	1199	-0.004 ± 0.001	0.129 ± 0.055	0.242 ± 0.086	0.058 ± 0.033	0.094 ± 0.045
♀	1034	0.004 ± 0.001	-0.129 ± 0.055	-0.242 ± 0.086	-0.058 ± 0.033	-0.094 ± 0.045
Birthyear						
1970	261	0.010 ± 0.005	0.208 ± 0.186	-0.889 ± 0.288	-0.678 ± 0.110	0.403 ± 0.151
1971	235	0.013 ± 0.005	0.236 ± 0.181	-0.522 ± 0.281	-0.504 ± 0.108	0.474 ± 0.148
1972	201	-0.007 ± 0.005	0.385 ± 0.195	0.578 ± 0.303	-0.169 ± 0.116	0.880 ± 0.159
1973	195	-0.005 ± 0.005	0.413 ± 0.194	0.621 ± 0.301	0.009 ± 0.115	0.610 ± 0.158
1974	237	-0.011 ± 0.005	0.102 ± 0.176	0.785 ± 0.273	0.152 ± 0.104	0.449 ± 0143
1975	232	-0.022 ± 0.005	0.389 ± 0.180	1.264 ± 0.280	0.523 ± 0.107	0.372 ± 0.147
1976	199	-0.023 ± 0.005	0.045 ± 0.187	1.213 ± 0.290	0.368 ± 0.111	0.415 ± 0.152
1977	233	-0.022 ± 0.005	0.014 ± 0.176	1.072 ± 0.273	0.306 ± 0.105	0.379 ± 0.144
1978	208	-0.003 ± 0.005	-0.267 ± 0.186	-0.112 ± 0.289	0.263 ± 0.111	-0.554 ± 0.152
1979	144	0.014 ± 0.006	-0.189 ± 0.230	-0.743 ± 0.358	0.248 ± 0.137	-1.158 ± 0.188
1980	88	0.055 ± 0.007	-1.337 ± 0.272	-3.267 ± 0.422	-0.501 ± 0.162	-2.272 ± 0.222

The phenotypic and genetic correlations between racing results within and between age from 3-year old to 5-year old are listed in table 7. The genetic correlations between number of starts and the other traits are generally fairly low. The genetic correlations between the other variables of racing performance are high or very high both within and between ages. The corresponding phenotypic correlations are moderately high to high.

II. The North-Swedish trotter

The fixed factors in the model affected the variation in racing results of the North-Swedish trotter in a very similar way as for the standardbred trotter. The least-squares constants for the fixed effects included in the material of racing results up to 6-years old are shown in table 8. The estimated heritabilities and genetic and phenotypic correlations are listed in table 9.

Table 9. Genetic parameters of racing results for North-Swedish trotters. Heritabilities and genetic correlations above and phenøtypic correlations below the diagonal.

	Best racing time	% placings 1-3	Earnings	Earnings per start	Number of starts
Best racing time	0.25	-0.79	-0.11	-0.93	0.44
% placings 1-3	-0.59	0.18	0.49	0.86	0.02
Earnings	-0.80	0.67	0.28	0.40	0.85
Earnings per start	-0.68	0.79	0.79	0.19	-0.12
Number of starts	-0.63	0.31	0.83	0.35	0.45

The estimates are quite different from those of the standardbred. A fairly high heritability estimate for the number of starts is noticed for the North-Swedish trotter contradictory to the low heritability estimate for the corresponding trait in the standardbred. Moreover, very high genetic and phenotypic correlations are noticed between earnings and the number of starts. In other words in the North-Swedish trotter earnings are to a much larger extent depending of the number of starts than is the case for the standardbred, and there is seemingly a large difference in the number of starts among progenies of different sires. It is very unlikely that this large difference between progeny groups is purely genetic. The heritability estimates for the number of starts are probably biased uppwards due to environmental covariance within progeny groups and the same phenomenon inflates the genetic correlation estimates between number of starts and earnings and even to some extent the correlation with best racing record. The objective of breeding in the population of the North-Swedish trotter is not so strictly related to the improvement of racing performance as it is in pure trotting breeds, like the Sandardbred trotter, since the former is also used as a working horse, mainly for forestry work. The probability of an individual horse to start frequently in races, and in that way earn money, may easily depend on environmental factors like location, owner or the reputation of the sire as racing capacity is concerned. The price money involved in the races of the North-Swedish trotter is considerably less than is the case for the Standardbred trotter. The matching of horses of high racing capacity into few high level races with high prices is comonly practiced in the standardbred trotting industry. This is not the case for the North-Swedish trotters where earnings apparently are very much depending on the number of starts.

The analysis of starting frequencies among North-Swedish trotters resulted in a heritability estimate of $\hat{h}_b^2$ = 0.10 (± 0.03) on the observable binomial scale. Using the adjustment term of Dempster, Lerner and Robertson (1950) and the observed frequency of starters in the material used for the analysis ($\underline{p}$ = 0.52) this corresponds to the heritability estimate of $\hat{h}_c^2$ = 0.16 on an underlying continous scale of the normal distribution. According to Van Vleck (1972) this transformation gives a reasonable unbiased estimate of the heritability on the normal scale for $\underline{p}$ close to 0.5.

Estimation of breeding values

I. The Swedish standardbred trotter

The BLUE (Best Linear Unbiased Estimates) of the fixed effects included in the models used for sire evaluations are revealed in table 10. Sires born between 1966 to 1975 with at least 20 offspring recorded in the analyses were defined as base sires and the estimated breeding values were scaled such that the average breeding value of the base sires equaled 100. The base is rolling, since the base next year will consist of stallions born between 1967 to 1976 with least 20 offspring. The current base for the five performance traits consists of 95 stallions with 87 offspring on average. The corresponding base for the estimated breeding values for frequency of offspring starting in a race includes 126 stallions with 126 offspring on average. The variation in the estimated breeding values were scaled such that one genetic standard deviation corresponded to 10 index units for each

Table 10. Best linear unbiased estimates (BLUE) of the fixed effects included in the mixed model used for genetic evaluations of Swedish standardbred trotters.

Effect	Number of starts	% placings 1-3	Earnings	Earnings per start	Best racing time	Start freq.(>0)	Start freq.(>4)
♂:							
Birthyear							
1970	4.763	5.319	11.032	.802	1.354	.747	.695
1971	4.720	5.161	11.034	.803	1.350	.739	.683
1972	4.663	4.970	11.088	.814	1.347	.681	.612
1973	4.450	4.913	10.996	.826	1.343	.702	.631
1974	4.618	4.909	11.689	.874	1.335	.688	.628
1975	4.567	4.998	11.929	.902	1.327	.653	.584
1976	4.566	4.934	11.967	.889	1.318	.654	.595
1977	4.565	4.620	11.805	.879	1.316	.662	.603
1978	4.511	4.583	11.859	.888	1.310	.629	.581
1979	4.540	4.477	12.109	.893	1.305	.620	.565
1980	4.420	4.464	12.193	.924	1.305	.581	.531
1981	4.307	4.328	12.338	.943	1.305	.592	.537
1982	4.148	4.349	12.558	.985	1.304	.521	.461
1983	3.291	4.222	11.251	1.063	1.315	.453	.359
1984	2.146	4.485	9.027	1.199	1.336	.179	.067
♀							
Birthyear							
1970	4.557	4.523	9.734	.734	1.370	.625	.553
1971	4.479	4.611	9.912	.767	1.363	.610	.540
1972	4.518	4.701	10.270	.784	1.355	.545	.481
1973	4.147	4.279	9.605	.775	1.356	.564	.491
1974	4.461	4.405	10.543	.803	1.347	.543	.481
1975	4.430	4.358	10.916	.848	1.336	.554	.485
1976	4.207	4.146	10.487	.848	1.333	.525	.458
1977	4.143	3.922	10.296	.836	1.332	.548	.481
1978	4.120	3.872	10.325	.840	1.325	.520	.468
1979	4.080	3.582	10.296	.842	1.320	.502	.442
1980	3.981	3.730	10.524	.883	1.318	.484	.420
1981	3.987	3.607	10.785	.898	1.315	.457	.388
1982	3.859	3.502	10.712	.907	1.317	.451	.383
1983	3.038	3.493	9.465	.980	1.328	.349	.248
1984	2.012	3.461	7.683	1.100	1.347	.147	.033
Regression on dam index							
	.021	.082	.180	.010	-.002	.007	.008

trait. The average, variation, and the range in estimated breeding values are shown in table 11.

Table 11. Averages, variation and range in estimated breeding values of Swedish standardbred stallions.

Traits	Minimum number of progeny	Number of stallions	Breeding values : Mean	SD	Minimum	Maximum
Number of	5	531	94.1	12.8	49	136
starts	40	173	97.2	6.7	81	115
% placings	5	531	96.5	9.3	63	139
1-3	40	173	98.3	6.7	86	115
Earnings	5	531	95.5	9.7	62	157
	40	173	98.0	7.5	83	128
Earnings	5	531	98.5	11.8	55	150
per start	40	173	99.6	7.3	84	120
Best racing	5	531	95.8	9.6	49	132
time	40	173	97.4	7.4	82	130
Start freq.	10	520	95.8	9.9	66	125
(>0)	40	287	96.5	7.8	73	117
Start freq.	10	520	95.0	10.1	67	130
(>4)	40	287	96.4	7.8	73	117

The correlations between estimated breeding values of the seven different traits included in both BLUP analyses are listed in table 12.

Table 12. Correlations between estimated breeding values of seven racing traits in Swedish standardbred stallions.

	% placings 1-3	Earnings	Earnings per start	Best racing time	Start frequency (>0)	Start frequency (>4)
Number of starts	.32	.69	-.10	-.47	.23	.48
% placings 1-3		.75	.71	-.67	.48	.47
Earnings			.54	-.83	.50	.61
Earnings per start				-.52	.38	.28
Best racing time					-.50	-.52
Start frequency (>0)						.89

II. The North-Swedish trotter

The BLUE (Best Linear Unbiased Estimates) of the fixed effects included in the animal model are listed in table 13. The average, variation, and the range in estimated breeding values are shown in table 14.

Table 14. Averages, variation and range in estimated breeding values by animal model in North-Swedish trotters.

		Breeding values			
Traits		Mean	SD	Minimum	Maximum
% placings 1-3	a)	102.2	5.6	73	129
	b)	103.5	6.1	73	121
Earnings per start	a)	99.6	3.7	74	124
	b)	99.8	4.2	74	119
Best racing time	a)	101.6	6.0	64	129
	b)	102.1	5.5	70	120

a) All 8.938 indivduals included
b) 5.162 indivudals with own records included

Table 13. Best linear unbiased estimates (BLUE) of the fixed effects included in the mixed model used for genetic evaluations of North-Swedish trotters.

effect	% placings 1-3	Earnings per start	Best racing time
Birthyear			
1960	4.524	1.320	2.606
1961	4.523	1.307	2.605
1962	4.562	1.349	2.604
1963	4.509	1.408	2.614
1964	4.089	1.395	2.624
1965	4.129	1.428	2.624
1966	4.453	1.508	2.612
1967	4.304	1.565	2.620
1968	4.293	1.608	2.612
1969	4.232	1.604	2.612
1970	4.441	1.774	2.602
1971	4.260	1.762	2.595
1972	4.160	1.738	2.583
1973	3.934	1.797	2.583
1974	4.079	1.928	2.576
1975	3.993	1.993	2.570
1976	4.034	2.061	2.571
1977	3.900	2.116	2.568
1978	3.739	2.167	2.571
1979	3.857	2.199	2.567
1980	3.853	2.378	2.572
1981	4.009	2.618	2.578
1982	4.170	2.833	2.593
1983	3.840	3.038	2.612
1984	4.151	3.646	2.637
sex			
♂	.100	.011	-.008
♀	-.100	-.011	.008

The variation in the estimated breeding values were scaled such that one genetic standard deviation corresponded to 10 index units for each trait. The base of breeding values for the North-Swedish trotter was not constrained to any specially defined group of breeding horses. Therefore, as inherent in the BLUP method for an animal model, the base (index value 100) refers to animals without both parents registered in the solution vector (Henderson, 1976). The correlations between estimated breeding values of the three racing performance traits are listed in table 15.

Table 15. Correlations between estimated breeding values of three racing traits in North-Swedish trotters.

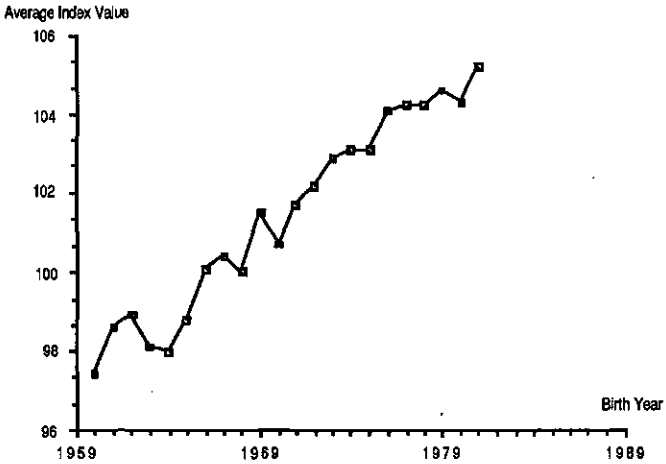
	Earnings per start	Best racing time
% placings 1-3	.85	-.94
Earnings per start		-.89

Table 16. Average estimated breeding values of three racing traits and a weighted total index within birth years in 5.162 North-Swedish trotters with own records, and regression coefficients (b) of annual average estimated breeding values on birht years.

year of birth	Number	% placings 1-3	Earnings per start	Best racing time	Total index
1960	104	98.0	97.0	97.3	97.4
1961	136	99.6	97.7	98.4	98.6
1962	168	100.0	97.8	99.0	98.9
1963	181	99.0	97.3	97.9	98.1
1964	184	99.1	97.3	97.7	98.0
1965	247	100.0	97.7	98.6	98.8
1966	287	101.5	98.3	100.4	100.1
1967	226	101.8	98.4	101.0	100.4
1968	236	101.2	98.3	100.4	100.0
1969	249	102.8	99.3	102.3	101.5
1970	245	102.0	98.8	101.3	100.7
1971	210	103.3	99.2	102.6	101.7
1972	193	103.6	99.7	103.2	102.2
1973	188	104.4	100.1	104.3	102.9
1974	237	104.5	100.2	104.2	103.1
1975	234	104.8	100.4	104.2	103.1
1976	219	106.0	100.7	105.5	104.1
1977	262	106.0	101.1	105.6	104.2
1978	248	105.9	101.2	105.5	104.2
1979	236	106.2	101.5	106.1	104.6
1980	234	105.9	101.3	105.9	104.3
1981	230	106.8	102.0	106.7	105.2
	b=	.42 (±.02)	.24 (±.01)	.47 (±.02)	.38 (±.02)

The estimated genetic trend for the three traits of racing performance and the weighted total index is shown in table 16 and in figure 1. The regression coefficient of the weighted total BLUP index values for the 5 162 individual trotters with own records in the material equaled to 0.38 index units. This may be considered as an estimate of the annual genetic trend in racing performance of North-Swedish trotter.

Figure 1. Genetic trend in racing performance (average index of three traits) of North-Swedish trotters



Discussion

The results of this study have already attained practical applications. The approval of Swedish trotter stallions for breeding is to a large extent based on their estimated breeding values, based on either the traditional selection indices or the BLUP - indices. In the end of the year the annual racing results of each horse are summarized at the STC's (Swedish Trotting Association) computer center. The annually summarized records are then merged with the data bank containing previous results and the pedigree information. The data bank is then splitted according to breed codes and the BLUP analyses are run separetely for the two different breeds. Currently the Standardbred stallions are only evaluated by a sire model, but an individual selection index is calculated for the young candidates for selection. An implementation of an animal model for the Standardbred is planed however. A research work comparing different computing strategies for solving the mixed model equations are under progress. In the relatively small population of North-Swedish trotters the mixed model equations are relatively easily solved by iteration explicitly (Henderson and Quaas, 1976) without too much computer effort. The equation set for a full animal model in the Standardbred, on the other hand, is too excessive for an explicit solution by iteration to be practical. An application of a reduced animal model (RAM) as described by Quaas and Pollack (1980) will be considered, and possibly other forms of equivalent models (Tavernier, 1987; Meinardus and Bruns, 1987). However the most promising alternative seems to be an indirect solution of mixed model equations by iteration on the data without setting up a system of equations. This procedure was invented by Schaeffer and Kennedy (1986a and b) and further investigated with respect to computational aspects by Misztal and Gianola (1987). Exactly which procedure and iterative method is most practical in any individual case will depend on both the data structure and the type of computer used to carry out the calculations. The methods have different demands concerning complexity in programming, running time, computer memory space, disk access space, etc. The choice of method may depend on whether the procedure will be run on a mainframe-, personal- or supercomputer.

The Swedish standardbred is a heterogenious breed with frequent import of American and some French horses (mainly stallions). This fact causes some problems as how to model the data. Moreover, the foreign stallions are selected on some criteria in their home countries which usually are not included in the Swedish data. The impact of this feature on the estimated genetic parameters and breeding values is a subject for further investigation, even if it can be difficult to tackle.

The North-Swedish trotter and the Norwegian trotter (Doele-horse) are closely related breeds with frequent mutual exchanges of genetic material. In particular Norwegian stallions are frequently siring horses registered as North-Swedish trotters. A considerable amount of information is lost by not making use of racing results of the Norwegian horses which do not have any racing records from Swedish tracks, and are therefore presently not included in the Swedish data bank for trotters. Probably it would be valuable, for all partners, to establish a common system for evaluation of trotters within the Scandinavian countries by use of animal models.

This study was initiated almost ten years ago. The analyses for estimating genetic parameters and to identify important sources of variation were based on methods which nowadays may be considered somewhat old fashioned. The rapid development in mixed model methodology during the last decade has turned the previously commonly used Henderson's method 3 for estimating variance components in unbalanced data out of date. The use of the restricted maximum likelyhood (REML) method (Patterson and Thompson, 1971) is becoming a standard method by animal breeders for estimating variance components for mixed models in unbalanced data. The discovery of a derivative-free procedure for estimating variance components in animal models by (REML) (Graser, Smith and Tier, 1987) opens very interesting possibilities of estimating genetic parameters by use of all relationship over many generations in populations undergoing selection. Reestimation of the genetic parameters for the traits included in this study by improved methods will hopefully be attained in not too remote future.

Meanwhile the estimates of genetic parameters of the present study will serve as a basis for the BLUP evaluation of Swedish trotter stallions and broodmares. As to be seen from table 5 the data used for the estimation of variances components are fairly balanced so the estimates obtained by Henderson's method 3 are presumably not in serious error, provided that the model is a reasonable description of the real world, there is negligable systematic environmental coviarance within the paternal half-sib groups and the selection is not too sever in the data.

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THE ENVIRONMENTAL EFFECTS OF PACE OF RACE AND PURSE FOR 2- AND 3-YEAR-OLD STANDARDBRED TROTTERS

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Summary

The objectives of this study were (1) to depict performance records of Standardbred trotters, with specific emphasis on the effects of non-random assignment of horses to races within the class-of-race system in the U.S., and (2) to identify a bias occurring when one or more of the indicators of class, e.g., purse and pace, varies with an individual horse's performance in that race. Data on 2- and 3-year-old Standardbred trotters entered in 1-mile (1.6 km) races at five tracks during the years 1975 through 1978 were obtained from the U.S. Trotting Association (USTA), Colombus, Ohio. Because of the class of race system, mean genetic differences in racing ability are expected to occur among horses chosen for inclusion in different races. Class of race appears to be a real and potentially significant source of variation. However, it is one that is poorly defined because it mixes genetic and environmental factors. The philosophy behind dividing horses by class of race suggests that differences in purse level and, presumably, in speed, may be associated with different classes. Therefore, we replaced class with two continuous variables, the within-horse effects of purse and pace, and included these separately and together as covariates in our statistical model. Purse and pace partially described the class of race. If pace (or purse) were totally environmental, the performance of a horse might be represented by a relatively simple linear model :

Racing time = sire effects$_1$ + horse effects$_1$ + pace + purse + other fixed effects + error$_1$

The interpretation of pace is complicated by the fact that the data reflect not only the performance of the horse but behavior of the racemates. When the horse is racing against faster racemates, it will have a faster time and vice versa. Thus, in order to depict that differences in pace also reflect differences in the average genetic merit of horses in the race, we need to have another equation and consider the two simultaneously. Some horses with the ability to race at higher speeds are given greater opportunities to win more

prestigious races having higher *purses than are their slower* contemporaries. These differences in opportunity reflect not only differences between horses but also differences in sire progenies. Breeders and owners believe that these differences in winnings are indicative of underlying differences in genotype. Therefore, we may want to combine all information into an interdependent system of three equations.

System :

Eq. 1 : Time = sire effects_1 + horse effects_1 + pace + purse + other fixed effects + error_1

Eq. 2 : Pace = sire effects_2 + horse effects_2 + other fixed effects + error_2

Eq. 3 : Purse = sire effects_3 + horse effects_3 + other fixed effects + error_3

This system of equations is consistent with descriptions of how breeders and owners seem to evaluate the racing ability of Standardbreds. We are primarily interested in the first equation in which time is the dependent variable. However, by adding a second or third equation to the system, we have defined pace or purse as a jointly dependent variable, i.e., a variable that can appear in the *diagram as either a covariate or a dependent variable.* The interpretation of pace or purse is complicated by the fact that the data reflect not only the performance of the horse but the decisions and behavior of the track officials, the driver, the owner, racemates, etc. To the extent to which pace, purse, or both are correlated with the error term in the primary equation (Eq.1), the estimators are biased and inconsistent. Potentially, the most popular and presumably genetically superior sires have some offspring competing at all purse and pace levels; however, offspring of lower quality sires would not likely compete for the most valuable purses nor would they race against very fast racemates. Thus, if we use ordinary least-squares methods, it is possible that parameter estimates of both covariates, as well as variance components, may be biased.

Introduction

Racing ability is a composite trait reflecting a horse's speed and its capacity to win against other horses with similar abilities. Objective measurement of racing ability is complicated by the fact that individual records are made in different races at different tracks and at different levels of competition. Thus, in genetic studies of Standardbreds, the question becomes "What is the real nature of the trait (racing ability) being selected?". After answering this question, geneticists can estimate the heritability and repeatability of the trait and compute breeding value estimates. In their breeding programs, breeders can use heritabilities and breeding value estimates as selection tools only to the extent that the breeders'subjective evaluations and the geneticists' objective measurements of true racing ability are consistent.

Choosing a trait that represents racing ability is a difficult task. A horse's racing time does not necessarily reflect the maximum speed at which that individual can trot or pace a specified distance. Instead, it is a measurement of an individual's ability to perform in a particular racing situation. Normally, every individual in a race has the potential to cover the distance at a faster rate, provided all environmental factors contribute perfectly to allowing the individual to achieve maximum speed. For each start, racing records provide other indicators of a horse's racing ability, including its placing, money won, and distance behind the winner.

Objectives of this study were (1) to depict performance records of Standardbred trotters, with specific emphasis on the effects of non-random assignment of horses to races within the class-of-race system in the U.S., and (2) to identify a bias occurring when one or more of the indicators of class, e.g., purse and pace, varies with an individual horse's performance in that race.

Materials and Methods

Description of the data.

Data on 2- and 3-year-old Standardbred trotter entered in 1-mile (1.6 km) races at five tracks during the years 1975 through 1978 were obtained from the U.S. Trotting Association (USTA), Colombus, Ohio. The tracks were Blue Bonnets, Montreal, Quebec, Canada; Saratoga Harness, Saratoga Springs, New York; Scioto Downs, Colombus, Ohio; Vernon Downs, Vernon, New York and Washington Trotting at the Meadows, Meadow Lands, Pennsylvania.

Only data from charted races were used. Charted races are those that provide detailed information on times and placings every 1/4 mile (.40 km), disqualifications, breaking, equipment failure, etc., for all horses in the race. The date, track condition, class of race (USTA, 1979), purse (total money awarded on the basis of horses' ranks at finish), and time of the winner (pace) were recorded for each race. The post position, final placing, and time at the finish (hereafter referred to as racing time or time) were recorded for each starter. Reported final times for horses other than the winner had been calculated by multiplying the number of lengths behind the winner by 0.2 s and adding this amount to the time of the winner (USTA, 1979). Sire, sex (stallion, mare or gelding), and foal year were recorded for each horse. The data were divided into subsets by age and track before being analyzed.

Editing the data.

Individual chart lines were reviewed. starts for horses that did not finish, were disqualified, or were distanced by 25 or more lengths were deleted. Horses that broke stride during the race were differentiated from those that did not with a breaking code (0 or 1). Only races occurring on tracks rated fast or good were included in the final data set. No upper limit was placed on purse size, but races with purses of less than $1,000 were deleted. Because of their nature, qualifying and matinee races (both of which are held primarily to allow the racing secretary to broadly evaluate the horses' abilities), and claiming races (which allow purchase of the horse after the race) were excluded. Remaining classes of races were maiden (for horses that have never won a race); stakes, futurities, early closings and late closings (all of which require early nomination and payment of sustaining fees); opens (which are open to all horses, but usually attract only relatively fast horses); and condition races (which restrict participation to horses that meet certain conditions; e.g., "3-yr-old fillies with winnings of less than $10,000"). A total of 4 765 records were included in the final data sets.

Statistical analysis.

Overall performance is the conceptual basis on which breeders make their decisions concerning the relative merits (abilities) of individual horses. Possible indicators of overall racing ability that may be obtained easily from the racing records included absolute time, time expressed as a deviation from the winner (Ferguson, 1980), money won, placing, best time (Ojala, 1981), and average time. Time, regardless of how it is measured, is an integral part of all other measurements. Although there appears to be a relationship between a horse's track earnings and its racing ability, money won has a bimodal distribution. Furthermore, over a period of several years, inflation and both genetic and environmental improvement of Standardbred horses may confounded. Placing ignores differences among racemates and categorizes a naturally continuous distribution. Best time and average time cannot be adjusted easily for environmental effects and may not provide an indication of overall ability. Therefore, actual racing time and time as a deviation from the time of the winner were chosen as dependent variables (indicators of a horse's overall merit). Throughout the remainder of this paper, horse's actual racing time will be called "time".

One of the most difficult problems with using racing performance records in genetic studies is that Standardbreds are not assigned at random to races. Instead, fields of horses are assembled in which individuals of similar abilities are matched and all starters theoretically have an equal opportunity of winning. Because of this system, class of race (or class) has become a variable connoting distinctions in genetic merit. However, class may also be considered an environmental effect because a horse may race in different classes of race (Henry, 1978; Hintz and Van Vleck, 1978). One may speculate that choice of class is contingent on both the performance history of the horse and the transient condition of the horse before entry in a particular race. Thus, mean genetic differences in racing ability are expected to occur among horses chosen for inclusion in different races.

In describing a horse's racing time, class of race appears to be a real and potentially significant source of variation (Henry, 1978; Hintz and Van Vleck, 1978; Tolley et al. 1983). If the class system is accurate in discriminating between horse's racing ability and if class of race provides additional information about a horse's racing time, then class is potentially useful in defining a horse's merit. However, using class as a variable in statistical models may not be appropriate for several reasons. (1) Class is a poorly defined variable because it mixes genetic and environmental factors. Because of this mixing, we must be careful to retain genetic differences associated with class in the sire and horse components of variance; we can do this by estimating the effects of class simultaneously with estimates of horse effects.This procedure also avoids biasing the estimate of the environmental part of the effect of class. For instance, bias of the effects of class may result from the tendency for "good" horses to compete in "higher quality" races. (2) There may be a great variation in exactly what class denotes at different tracks. (3) Because class is a subjective grouping, such a classification may divide a continuous distribution into arbitrary and possibly overlapping categories. Therefore, we searched for objective criteria that were less ambiguous for describing the variability attributable to class.

The philosophy behind dividing horses by class of race suggests that differences in purse level and, presumably, in speed, may be associated with different classes. previous reports by Henry (1978) and Sola (1969) tend to substantiate this relationship among class, average speed and purse. Therefore, we tested hypothesis that class could be replaced in statistical models by two objective continuous variable, the within-horse effects of purse and pace. The effect of class, the within-horse linear and quadratic regressions of purse, and the within-horse linear and quadratic regressions on pace were selectively added to our model. We concluded that purse and pace partially describe class of race and estimated heritabilities and repeatabilities with a model that included pace. Our statistical model for describing a horse's actual racing time has been presented previously (Tolley et al., 1983).

Results and discussion

Inclusion of covariates.

When the within-horse linear and quadratic effects of purse were used to replace class, both effects were statistically significant for 3-year-olds at most tracks. These estimated effects were generally consistent across tracks (table 1). The amount of total variation accounted for by the quadratic regression of racing time on purse did not appear to be practically important. However, we recognized that

Table 1. Pooled within-horse linear and quadratic regression coefficients of racing time on purse (sec/$1000) and pooled linear coefficients of racing time on pace (sec/sec) from analyses of trotter records from five tracks during 1975-1978.

Track	Purse[a]-linear	Purse[a]-quadratic	Pace[b]-linear
Blue Bonnets			
2-year-olds ***	-.14 ± .04	.006 ± .002	.58 ± .05
3-year-olds ***	-.13 ± .02 ***	.005 ± .001 **	.69 ± .03
The Meadows			
2-year-olds ***	-.11 ± .03	.013 ± .003	.65 ± .14
3-year-olds ***	-.12 ± .02 ***	.020 ± .001 **	.75 ± .03
Saratoga Harness			
3-year-olds ***	-.11 ± .03	-.006 ± .003	.64 ± .03
Scioto downs			
3-year-olds ***	-.06 ± .03	-.020 ± .005	.72 ± .04
Vernon Downs			
2-year-olds ***	.02 ± .01	.004 ± .002	.86 ± .06
3-year-olds ***	-.10 ± .02 ***	.002 ± .001	.77 ± .03

[a]Purse is expressed in thousands of dollars
*P < .05
**P < .01
***P < .001

the quadratic coefficient quantified a phenomenon that was biologically real. As a horse is entered in races having higher purses, it is first able to increase its speed in a nearly linear manner. However, beyond a certain point it is unable to continue increasing its speed linearly but instead increases its speed at a decreasing rate. Because the quadratic coefficient was so much smaller than the linear coefficient, we concluded that the linear effect of purse alone could be used to explain the majority of the variability associated with purse.

We have presented similar arguments for including only the linear effect of pace in our model (Tolley et al., 1983) (table 1).. The within-horse linear regression on pace adjusts records of Standardbred racehorses for the environmental effect associated with an individual's being matched with faster or slower racemates, as indicated by the time of the winner. We have shown that adjusting an individual's record by these within-horse regressions removes only environmental variation, and does not remove the additive genetic portion of the total variation that would be associated with pace (Tolley et al., 1981). Genetically similar horses tend to compete against each other. These differences in average quality of the racemates would be removed by a between-horse regression of pace, but in reality these should be retained in the between-horse and between-sire-progeny differences. If no adjustement for pace were made, the between-horse variance may be inflated because of environmental as well as genetic correlation between horse's time and pace.

Estimated correlations between purse and pace for 2-and-3year-olds at the five tracks are presented in table 2. Although all the estimates are negative, the strength of the relationship between purse and pace was not consistent for the two age groups at these tracks. The lack of consistency may be due to several factors : (1) interaction

Table 2. Estimated correlation coefficients between pace (s) and purse ($1000) for two- and three-year-old trotters at five tracks.

Track	2-year-olds	3-year-olds
Blue Bonnets	-.18	-.35
The Meadows	-.08	-.24
Saratoga Harness	-.13	-.50
Scioto Downs	-.28	-.30
Vernon Downs	-.37	-.40

between purse and pace within track-age subclasses, (2) differential responses to changes in purse and pace across tracks, or (3) differential levels of confounding between purse and pace among tracks. Most horses compete at one or at most only a few tracks during a racing year. The purse structure at a specific track tends to reflect the composition of the group of horses competing at that track. In addition, for attracting and maintaining this group of horses, track officials sponsor races with relatively large purses restricted to certain horses. Therefore, we concluded that adjusting time simultaneously for purse and pace could be misleading. Because the within-horse linear regression of pace accounted for more than 80% of the variation in horse's time originally attributed to class, we decided to replace class with the within-horse linear regression of pace (Tolley, 1983).

Causal models of racing ability.

As mentioned previously, one of our crucial considerations was interpretating and quantifying racing ability within the class of race system. We realized that breeders and owners evaluate horses based on this class system. They nominate young horses to stakes, early and late closing, and futurity races based on prior evaluation of racing ability and pedigree. Based on their evaluation of previous racing performance of racehorses, racing secretaries assist in the assigning of these racehorses to races in a non-random manner within the class system. Stratifying horses by class supports the formation of the hypotheses (1) that some of the differences attributable to class are genetic, and (2) because superior sire progenies compete in higher classes of races, the mean pace and purse associated with these classes reflect, in part, the mean genetic merit of the group of horses in that class of race.

Depicting a horse's racing time within this complex class of race system can be done with statistical models. If pace were totally environmental, time may be represented by a relatively simple linear model :

Eq. 1 Racing time = sire effects_1 + horse effects_1 + pace (linear) + other fixed effects + error_1

However, we must consider Eq. 1 in the context of how a horse's time was actually generated. From this perspective, we can see that the interpretation of pace is complicated by the fact that the data reflect not only the performance of the horse but behavior of the racemates. When the horse is racing against faster racemates, it will have a faster time and vice versa (Ferguson, 1980; Tolley et al., 1983). Thus, in order to depict that differences in pace also reflect differences in the average genetic merit of horses in the race, we need to have another equation and consider the two simultaneously. By adding Eq. 2, we have an interdependent system of equations that is theoretically more accurate because it takes into account the fact that the horse's time was the result of a race, not a time trial.

System A :

Eq. 1 Racing time = sire effects_1 + horse effects_1 + pace (linear) + other fixed effects + error_1

Eq.2 Pace = sire effects_2 + horse effects_2 + other fixed effects + error_2

Some horses with the ability to race at higher speeds are given greater opportunities to win more prestigious races having higher purses than are their slower contemporaries. These differences in opportunity reflect not only differences between horses but also differences in sire progenies. The purse structure within the class of race system is designed to magnify very small differences in racing ability between individuals and categorize horses as winners or losers of races. Winnings of individuals vary enormously. There are winners of large amounts, moderate amounts, small amounts, or nothing. Breeders and owners believe that these differences in winnings are indicative of underlying differences in genotype. Hintz and Van Vleck (1978) have demonstrated that a significant portion of the differences between horses for winnings are attributable to genetic and permanent environmental differences. We can depict this relationship with another interdependent system of equations.

System B :

Eq. 3 Racing time = sire effects_3 + horse effects_3 + purse (linear) + other fixed effects + error_3

Eq. 4 Purse = sire effects_4 + horse effects_4 + other fixed effects + error_4

Purse and pace partially describe the class of race system. Therefore, we may want to combine all information into an interdependent system of three equations.

System C :

Eq. 5 Racing time = sire effects_5 + horse effects_5 + pace + purse + other fixed effects + error_5

Eq. 6 Pace = sire effects_6 + horse effects_6 + other fixed effects + error_6

Eq. 7 Purse = sire effects_7 + horse effects_7 + other fixed effects + error_7

We are primarily interested in the equation in which time is the dependent variable (Eq. 1). However, by adding a second or third equation to the system, we have defined pace and purse as jointly dependent variables, i.e., variables that can appear in the system as either covariates or dependent variables. By constructing a system of equations, we have recognized that the interpretation of pace or purse is complicated by the fact that the data reflect not only the performance of the horse but the decisions and behavior of the track officials, the driver, the owner, racemates, etc. Using a system of more than one interdependent equations is consistent with our descriptions of how breeders and owners seem to evaluate the racing ability of Standardbreds.

As long as the covariates, purse and pace do not vary with changes in racing time of an individual horse, we can use ordinary least-squares for obtaining unbiased and consistent estimators of all parameters in our model (Johnston, 1972). To the extent to which pace, purse, or both are correlated with the error term in the primary equation (Eq. 1), the estimators are biased and inconsistent (Johnston, 1972). Increasing sample size will not correct either problem. The biological and non-biological relationships within which racing ability is evaluated result almost automatically in the average pace (level of competition) of a horse being correlated with its racing times. Potentially, the most popular and presumably genetically superior sires have some offspring competing at all purse and pace levels; however, offspring of lower quality sires would not likely compete for the most valuable purses nor would they compete against very fast racemates. Thus, if we use ordinary least-squares methods, it is possible that parameter estimates of both covariates may be inflated. Other parameter estimates may also be affected by a type of bias called simultaneous equation bias. Econometricians have developed several techniques that estimate parameters recursively (Johnston, 1972). If we use one of these regression procedures, we can avoid this types of bias and produce consistent and efficient estimators (Johnston, 1972). The SYSLIN procedure in SAS can be used whenever simultaneous equation bias appears to be a problem (SAS, Inc., 1984).

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