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USE OF RACE RECORDS FOR BREEDING EVALUATION OF TROTTERS IN FINLAND

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USE OF RACE RECORDS FOR BREEDING EVALUATION OF TROTTERS IN FINLAND

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DOCTORAL THESIS

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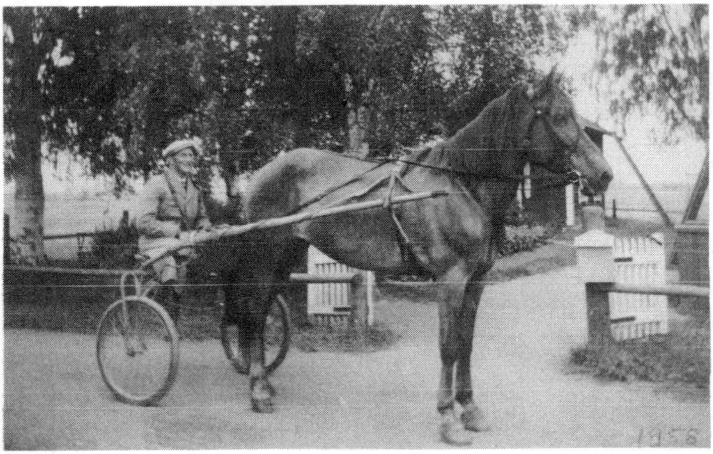

To the Finnish horsemen

ABSTRACT

The objective of this work was to gain the basic information necessary for improving the use of race records for breeding evaluation of trotters in Finland. The data analyzed were either the total data set consisting of individual race records on horses or the summary data set consisting of records summarized annually for each horse. Studies were concentrated on the latter type of data for 4-, 5- and 6-year-old Finnish Horses. Various measures of performance representing a horse's annual racing career based on number of starts, percentage of placings, earnings and best racing time were included.

Distribution of best annual racing time was approximately normal, and distributions of transformed earnings approached approximate normality. Age and sex of horse, race year, method of start and annual number of starts were important factors in influencing a horse's best annual racing time. The estimate of repeatability for best annual racing time over the three age groups was 0.69 ±0.03 and over the four age groups was 0.60 ±0.03. Averages of heritabilities weighted over the three ages were 0.10 for number of starts in a year, 0.16 for percentage of first placings in a year, 0.22 for percentage of first to third placings in a year, 0.27 for square root of annual earnings per start and 0.29 for best annual racing time on volt-start in the data for Finnish Horses. In Standardbred trotters, estimates for the previous traits were 0.06, 0.16, 0.18, 0.29 and 0.25, respectively. Estimates of phenotypic correlations among the annually summarized race records were all favorable with respect to a selection objective for trotters.

The individual and sire indexes have been constructed for routine breeding evaluation of trotters. The major emphasis is, through the best annual racing time, on improving a horse's capacity for maximum speed which is supplemented in the index by other characteristics of racing performance.

C O N T E N T S

PAPERS INCLUDED IN THE THESIS 1

INTRODUCTION 3

MATERIALS AND METHODS 5

RESULTS AND DISCUSSION 7

Summary of papers presented 7

Applications for breeding evaluation of trotters ... 10

General discussion 12

ACKNOWLEDGEMENTS 15

REFERENCES 16

SUPPLEMENT: Papers I - IV

PAPERS INCLUDED IN THE THESIS

The present thesis is based on the following papers which will be referred to by the Roman numerals I - IV.

I Ojala, M.J. 1982. Some parameters estimated from a restricted set of race records in trotters. Acta Agric. Scand. 32: 215-224.

II Ojala, M.J. and Van Vleck, L.D. 1981. Measures of racetrack performance with regard to breeding evaluation of trotters. J. Anim. Sci. 53: 611-619.

III Ojala, M., Van Vleck, L.D. and Quaas, R.L. 1986. Factors influencing best annual racing time in Finnish Horses. To be published.

IV Ojala, M. 1986. Heritabilities of annually summarized race records in trotters. To be published.

INTRODUCTION

Prediction of animals' breeding values is an important phase in selection program for genetic improvement of any species of domestic animals. This presupposes the definition of selection objectives and an analysis of the structure of data. In breeding trotters, the latter part of the statement includes elaboration of the measures of performance and variables influencing them, and estimation of genetic parameters for measures of performance.

Selection objectives for breeding trotters in Finland are stated broadly in the Stud Book regulations for Finnish Horses (SH, 1981a) and Standardbred trotters (SH, 1981b). To be qualified for the Stud Book, it is required, among others, that a horse possesses good racing records, sound conformation of legs and hoofs, and good movements and temperament. Best time in a year or in lifetime and total earnings have been the most important indicators of a horse's racing performance.

Trotters participating in races are continuously tested for racing performance. Large amounts of data are accumulated from trotting races and usually filed by trotting associations. Various choices exist to use these data for breeding evaluation of trotters. The size of data sets has, however, been insufficient for reliable estimates of heritability (h^2) for measures of racing performance in Finnish Horses (Lahdenranta, 1979; Papers I to III) and in Standardbred trotters in Finland (Hellman, 1978). Based on comprehensive reviews of literature (e.g., Ojala, 1979; Hintz, 1980; Langlois, 1982; Paper I; Katona, 1985; Tolley et al., 1985), genetic parameters for measures of racing performance have seldom been estimated from data sets of sufficient size.

The objective of this work was to gain the basic information necessary for improving the use of race records for breeding evaluation of trotters in Finland. This included elaboration of measures of trotting performance and factors influencing them, and estimation of heritabilities for measures of performance.

MATERIALS AND METHODS

Race records of Finnish Horses were filed up to 1970 by Suomen Ravirengas (the Finnish Trotting Association) only for horses placing first, second or third in a race. In the data of Paper I, originally collected and analysed by Ojala (1972), horses might have their best annual trotting times per kilometer in eight age groups on four lengths of race. The data included a total of 972 horses, the progeny of 24 sires. The number of records was small in most of the age - length of race subclasses. Therefore, analyses were performed using records from the classes with most numerous observations.

Individual race records for all horses raced have been filed by Suomen Hippos (the Finnish Trotting and Horse Breeding Association) since 1973. Race records were collected for Finnish Horses born in 1967 or 1968 that took part in trotting races at ages of 3 to 6 years. The original and complete set of data included 15 207 individual records in which a horse's racing performance was expressed in three forms: time at finish per kilometer, prize money won and placing at finish. In editing, two data sets were formed: the total data set (TDS) consisting of 13 000 individual race records on 554 horses by 206 sires, and the summary data set (SDS), with 1 378 records summarized annually for each horse (Ojala, 1979; Paper II). The traits in the TDS were the three basic expressions of racing performance and the square root transformation of prize money won. Due to transformations applied to annually summarized traits based on money won and placings, there were a total of 24 measures of performance in the SDS.

In paper III, the SDS was reanalyzed assuming more complete models and using the principle of least squares. The effects of the year of race, season of race, sex, method of start, annual number of starts, length of race and racetrack were evaluated on a horse's best annual racing time. Five models were assumed within the age groups from 3 to 6 years.

Annually summarized race records on 4-, 5- and 6-year-old Finnish Horses and 3-, 4- and 5-year-old Standardbred trotters from the years 1974 through 1983 were obtained on magnetic tapes from the files of the Finnish Trotting and Horse Breeding Association (Paper IV). The 13 transformed and untransformed traits represented a horse's annual racing performance based on number of starts, percentage of placings, earnings and best racing time. Variance components for estimating heritabilities of the traits were based on three methods. The number of horses and the number of progeny groups in one age class varied from 2 232 to 3 452 and from 138 to 198, respectively.

RESULTS AND DISCUSSION

Summary of papers presented

I. Some parameters estimated from a restricted set of race records in trotters

The objectives of the study were to estimate some parameters needed in breeding trotters, and to review the literature with respect to estimates of generation interval and heritabilities of speed, with a special emphasis on the size of and restrictions on the sets of data analyzed.

Generation interval between sire and progeny averaged 13.3 years. Excluding records on 4-year-old horses, frequency distributions for best trotting time in a year were approximately normal. Measured by best time in a year, males were superior to females at all ages; differences in means varied from 0.6 to 2.6 seconds. Simple correlations among a horse's best times at different ages averaged 0.55, implying a repeatability for best time in a year of about the same magnitude. Estimates of heritability for best time in a year varied from -0.06 ±0.07 to 0.23 ±0.11 through the six age groups. Based on the review of the literature, the majority of heritabilities for speed in trotting races was in the range of 0.20 through 0.30, representing a median of about 0.25. It was also observed that parameter estimates from most studies were associated with large standard errors.

Interpretation of results in this study suffered from the limited amount of data, and restrictions applied to the data. Filing of individual race records for all horses raced is the essential condition so that the data would be of use for estimation of genetic parameters and breeding evaluation of trotters.

II. Measures of racetrack performance with regard to breeding evaluation of trotters

The objective of the study was to examine some properties of different measures of track performance to determine whether data accumulated from harness races could be utilized in a simple, yet useful way for genetic evaluation of trotters.

The proportion of horses that started races and at the end of a race year had records different from those of unraced horses, i.e., different from zero, was 95, 82 and 40 through 77 % for measures of performance based on time, money and placings, respectively. Simple correlations between best and average time in a year were in excess of 0.90. Repeatabilities for time at finish during a year were about 0.70. Both estimates imply that time records of a horse are relatively consistent over an entire year. Estimates of heritability for best time in a year were about 0.30, whereas those for money and placing traits were small or even negative. The estimate of repeatability for best annual racing time over the three age groups was 0.69 ±0.03. The results from this study support the concept that best time in a year is the most useful measure for assessing sire breeding values based on progeny records.

III. Factors influencing best annual racing time in Finnish Horses

The objective of the study was to evaluate the effects of the year of race, season of race, sex, method of start, annual number of starts, length of race and racetrack on best annual racing time in Finnish Horses.

The effects of racetrack and length of race were regarded as inappropriate in these data. The annual number of starts method of start and season of race effects were interrelated. Increase in number of starts was associated with considerable improvement in a horse's best annual racing time. Records should not, however, be adjusted for effect of annual number of starts because it would simultaneously account for genetic differences among horses. Largest estimates of heritability were obtained for best annual racing time when the model included the fixed year-season and sex effects. Corresponding to this model, the estimate of repeatability for best annual racing time over the four age groups was 0.60 ±0.03. An example of best linear unbiased predictions (BLUP) of sires' breeding values based on progeny records in one or several ages was presented.

IV. Heritabilities of annually summarized race records in trotters

The objective of the study was to estimate distributional properties and heritabilities (h^2) of some annually summarized race records (traits) and phenotypic correlations among the traits.

The coefficient of variation (CV) for the square root of annual earnings per start was about 67 % in both breeds as compared with a CV of 7.7 and 5.9 % for best annual racing time on volt-start in Finnish Horses and Standardbred trotters, respectively. Frequency distributions for all traits departed ($P < 0.05$) from the normal frequency distribution. The distribution for best annual racing time was, however, approximately normal and distributions for transformed earnings approached approximate normality. Averages of h^2 weighted over the three ages were 0.10 for number of starts in a year, 0.16 for percentage of first placings in a year, 0.22 for percentage of first to third placings in a year, 0.27 for square root of annual earnings per start and 0.29 for best annual racing time on volt-start in the data for Finnish Horses. In Standardbred trotters, estimates for the previous traits were 0.06, 0.16, 0.18, 0.29 and 0.25, respectively. Standard errors of heritability for the traits ranged from 0.03 to 0.06 within an age group in the two breeds. Estimates of phenotypic correlations among the annually summarized race records were all favorable with respect to a selection objective for trotters.

Applications for breeding evaluation of trotters

The development and running of selection programs in animal breeding can be described systematically in several ways. An effective selection scheme was, for example, divided into six consecutive steps by Danell (1980) and into seven main phases by Arnason (1983). Only some of the phases of an overall selection scheme were the subject of the present work. The structure of data accumulated from harness races and consideration of practical measures of racetrack performance were dealt with in Papers I to IV. The effects of fixed factors on best annual racing time, and phenotypic and genetic parameters for measures of performance on trotters in Finland were estimated in Papers III and IV, respectively. Based on these studies, indexes for useful measures of racing performance and for a combination of them were constructed. Development of applications benefited also from similar work elsewhere (e.g., Rönningen, 1975; Minkema, 1976; Arnason et al., 1982a; Arnason et al., 1982b; Distl et al. 1982; Arnason et al., 1984).

A brief description of indexes based on either the individual's own or its progeny's race records will be used to illustrate the practical conclusions made from the present studies (Papers I - IV).

The individual index

The individual index is based on a horse's own race records within an age group. Separate indexes were constructed as described by Ojala (1985a) for the following five measures of performance:

1. square root of percentage of first placings in a year,
2. percentage of first to third placings in a year,
3. fourth root of annual earnings per start,
4. best annual racing time on auto-start, and
5. best annual racing time on volt-start.

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 using principles of the selection index (e.g., Van Vleck, 1974). Thus, a horse's annual number of starts, and estimates of heritability and repeatability of a trait were taken into account. Predicted breeding values for each trait were standardized to a scale with mean 100 and standard deviation 10.

Two combined indexes were either the sum of the weighted indexes of the first four traits, or the sum of weighted indexes of traits 1 to 3 and 5. The relative weights applied were 0.03, 0.05, 0.12 and 0.80 for indexes of the traits 1, 2, 3, and 4 or 5, respectively. The overall index, the individual index, was the average of the two combined indexes if a horse had raced under both methods of start. As implied by the weights of combined indexes, the major emphasis is on improving a horse's capacity for maximum speed which is supplemented by other characteristics of racing performance.

Indexes for 3- to 5-year-old Standardbred trotters and 4- to 6-year-old Finnish Horses having raced in 1977 to 1984 were calculated in the spring of 1985. Lists of horses with the best individual indexes were published grouped by age, sex and breed (Peltonen, 1985). Indexes will be calculated at the beginning of each year, and will be used by the jury in accepting horses for the Stud Book and by the breeding committee of the Finnish Trotting and Horse Breeding Association in awarding prizes.

The sire index

The sire index is based on progeny's race records within three age groups. Indexes predicting the relative genetic merit of sires have been published since the spring of 1984. In the spring of 1985, sire evaluations were calculated using progeny's race records from the years 1977 through 1984 for 3- to 5-year-old Standardbred trotters and for 4- to 6-year-old Finnish Horses (Ojala, 1985b).

Separate indexes were calculated in both breeds within each of the three age groups for the following five traits:

1. percentage of raced progeny of all progeny for a sire,
2. percentage of first placings in a year,
3. percentage of first to third placings in a year,
4. square root of annual earnings per start, and
5. best annual racing time on volt-start.

Earnings were preadjusted for inflation using multiplicative adjustment factors based on the wholesale price indexes published by Tilastokeskus (1982). 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 (e.g., Van Vleck, 1974). Sires' predicted breeding values for each trait were standardized to indexes with mean 100 and standard deviation 10. Indexes of the five traits were combined into subindexes within each age group using the relative weights of 0.05, 0.05, 0.05, 0.15 and 0.70, respectively. An overall index, the sire index, was the average of the subindexes. All indexes, jointly with the number of raced progeny at each age, were published for sires having at least 5 progeny in the youngest age group (Ojala, 1985b).

General discussion

The work presented in this thesis can be extended in various ways. Due to bimodal, peaked and skewed frequency distributions for traits based on placings, heritabilities should be estimated for various transformations of these traits. In addition to phenotypic correlations, genetic correlations among the traits within an age class should be estimated. The study should also include estimation of repeatabilities for a trait over the age classes, and genetic correlations of the same trait measured at different ages. This would help in deciding whether race records made at different ages should be treated as separate traits.

Completing the previously listed studies would add the basic information needed to refine the procedures presently used in breeding evaluation of trotters in Finland. However, the difficulty of explicitly defining the selection objective for trotters and the traits relating to it even then remains. This is, in part, due to the complex nature of a horse's trotting performance and the large number of variables influencing it. In addition, both genetic and environmental effects may be confounded in some of the variables contributing to the outcome of a horse's performance.

Approximate procedures were used in constructing the individual and sire indexes to supplement the two-stage selection process traditionally followed in Finnish horse breeding. In order to qualify for inclusion in the Stud Book, horses are evaluated by a jury for their racetrack performance, comformation of legs and hoofs, movements and temperament (SH, 1981a, b). The foregoing relates to the first stage of selection and is an important phase in breeding trotters. At this stage, selection may not, however, be intensive in a closed and relatively small population such as the Finnish Horse. Due to the long generation interval in horses, progeny testing, which relates to the second stage of selection, may be of some value only if accomplished also for sires with relatively few progeny.

Applications used or under development to predict stallions' breeding values in various countries differ both in traits included and methods used (e.g., Minkema, 1976; Arnason et al., 1982b; Distl et al., 1982; Arnason et al., 1984; Katona and Distl, 1985; Ojala, 1985b). In Finland, the information on relationships among male ancestors of progeny for stallions to be evaluated will be implemented, as described by Henderson (1975), into calculations in the near future. This will result in the use of mixed model equations and in best linear unbiased prediction (BLUP) of stallion's breeding value (Henderson, 1973). The use of relationships would especially improve the accuracy of breeding values for sires having only a few progeny. The bias due to selection of mates for the sires evaluated would also be reduced by including the maternal grandsire effect in a model. In addition to criteria directly based on racetrack performance, sire evaluation should also be supplemented by traits related to progeny's conformation, movements and temperament.

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I

Some Parameters Estimated from a Restricted Set of Race Records in Trotters

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Introduction

Animal breeding data do seldom comprise records of all individuals of the population. This is due to the use of samples, and also to the fact that all animals born will not necessarily make a record during their life. The latter part of the statement is especially true if records are from horse races. In the Netherlands and Federal Republic of Germany, for example, about 25% of trotters born never entered a race (Minkema, 1975; Katona, 1978). In other words, an apparently whole set of data (all race records) may, in fact, only represent records made by a preselected group of animals.

Besides being limited to a time period, race records may also have been subjected to at least the following three types of restriction: (1) the outcome (record) is filed only for top ranking horses in a race (say first through third); (2) only the records of the progeny of sires with the greatest number of offspring are included in the analyses; (3) only the records of horses with at least a certain number of starts during a year are included in the analyses. This implies that if a set of data is small, it obviously is also the result of restriction of some kind. It is generally known that parameters estimated from small samples are associated with large sampling variation. It is also apparent that restrictions on data may be regarded as equivalent to the presence of culling (or selection) in data. As shown by Robertson (1977) genetic estimates from data subject to selection are biased downward and associated with increased sampling variation. Due to these shortcomings, parameters estimated from restricted sets of data may be poor estimates.

The objectives of this study are to report some estimates of parameters needed in breeding trotters, and to review the literature with respect to estimates of generation interval and heritabilities of speed, with a special emphasis on the size of and restrictions on the sets of data analysed.

Review of Literature

Generation interval is defined by Johansson (1949) as the average age of parents at the time of birth of their progeny. Estimates of the generation interval are relatively uniform among different horse breeds (Table 1). The time between the birth year of a sire and its progeny, i.e., the generation interval on the male side, averages 11.4 years, and 10.4 years on the female side. The corresponding means are slightly larger in trotters, 13.4 and 11.2 years (Minkema, 1976; Lahdenranta, 1979; Darenius, 1980). The generation interval appears to be about one to two years longer on the male than on the female side.

Estimates of heritability for measures of racing performance in trotters and Thoroughbreds have recently been reviewed in several studies (e.g., Minkema, 1978; Langlois, 1980; Hintz, 1980). The bulk of heritabilities are reviewed also in this paper, but for a directly measured speed only. The main purpose is to illustrate the diversity of the measures of speed, and the size of and restrictions on sets of data analysed.

A horse's speed can be measured in several ways either directly based on time at finish, or indirectly, i.e., based on money won or rank at finish. In studies compiled (Tables 2 through 4), speed is measured directly using time which is an exact measure in seconds for each horse in a race. Speed may be expressed as time per unit distance or equivalently as distance per unit time. Another direct measure is the measure of relative speed. This corresponds to the performance rate which is an approximate time difference measured in horse lengths relative to the

Table 1. *Average generation interval in horses*

Author(s)	Breed[a]	Offspring in data	Generation interval in years: From sire to offspring	From dam to offspring	Overall
Steele (1944)	SB	389	–	–	12.4
	TB	1 983	–	–	12.1
	ASH	1 600	–	–	11.3
Fletcher (1945)	QH	409	9.5	7.9	9.0
Eriksson (1945)	AS	36 305	9.3	–	–
	AS	22 621	–	8.4	–
	NSH	9 465	10.3	–	–
	NSH	5 867	–	9.8	–
Johansson (1949)	WBH	2 195	10.4	10.7	–
Minkema (1976)	DT	2 867	15.8	12.1	–
Langlois (1976)	TB	930	–	–	10.5
Lahdenranta (1979)	FH	396	12.3	10.8	–
Cunningham et al. (1980)	HB	3 500[b]	–	12.5	–
Darenius (1980)	SBT	4 421	12.2	–	–
	SBT	9 344	–	10.8	–

[a] SB (Standardbred), TB (Thoroughbred), ASH (American Saddle Horse), QH (Quarter Horse), AS (Ardennes in Sweden), NSH (North-Swedish Horse), WBH ("Warm-blooded" horse in Sweden), DT (Dutch Trotter), FH (Finnish Horse), HB (Half-bred), SBT (Standardbred trotter in Sweden).
[b] Approximation.

winner in a single race. Even though direct measures of speed are used, expressions as speed, time or even best time may be incomplete. For example, heritability for best time in life time career may be the same as for best time in single year only if a horse's age has been properly accounted for.

Data sets are small in several studies reviewed. On account of this, it is to be expected that restrictions (or selection) have been applied as well. Restriction two, i.e., the requirement for a certain number of progeny per sire, has been applied to data in several studies. The restriction may have been applied on whole data sets while collecting the data (e.g., Bormann, 1966; Lahdenranta, 1979); or before performing analyses of the data. Restriction two is implied by the number of sires and offspring, and also by the method of estimation if based on paternal sibs (Tables 2 through 4). It is expected that

Table 2. *Estimates of heritability (h^2) for direct measures of speed in trotting tests*

Author(s)	Measure of speed[a]	Method of estimation[b]	No. of sires	No. of offspring	Age of horse	h^2
Lonka (1946)	TSB	OSC	74	179	4	.70
	TSB	OSC	47	96	5	.46
Vainikainen (1946)	TSB	OSC	762	762	≥4	.40
	TSB	ODC	–	557	≥4	.60
	TSB	OMC	489	489	≥4	.60
Varo (1965)	TSB	PHS	–	1 799	4	.35
	TSB	PHS	–	1 989	5	.40
	TSB	PHS	–	937	6	.47
	TSB	PHS	–	1 271	≥7	.53
Varo (1969)	TSB	PHS	173	1 609	≥4	.58
Árnason (1979)	THS	PHS	108	1 088	4–13	.20

[a] TSB (time in test for Stud Book), THS (time tested at horse show).
[b] OSC (offspring-sire correlation), ODC (offspring-dam corr.), OMC (offspring-midparent corr.), PHS (intra-class corr. of paternal half-sibs).

Table 3. *Estimates of heritability* (h^2) *for direct measures of speed in trotting races*

Author(s)	Measure of speed[a]	Method of estimation[b]	No. of sires	No. of offspring	Age of horse	h^2
Ócsag & Tóth (1959)	S	ODR	–	269	–	.04
Gopka (1971)	S	ODC	–	200	–	.32 to .48
	S	ODR	–	200	–	.04 to .13
Kalmykov (1973)	BTL	OMC	–	–[c]	≥3	.07 to .23
	BTL	OMR	–	–[c]	≥3	.15 to .59
	BTL	PHS	–	–[c]	≥3	.02 to .57
Linner & Osterkorn (1974)	ATY	PHS3	42	280	2	.22
	ATY	PHS5	26	223	2	.27
	ATY	PHS10	7	95	2	.21
	ATY	PHS3	65	558	3	.21
	ATY	PHS5	47	534	3	.21
	ATY	PHS10	23	371	3	.27
Minkema (1975)	BTY	ODRS	–	–	2	.17 to .55
	BTG	ODRS	–	–	2–3	.19 to .30
	BTG	ODRS	–	–	2–4	.24 to .32
	BTL	ODRS	–	2 867	≥2	.26 to .46
Rönningen (1975)	BTY	PHS	205	2 647	3–12	.12
Schwark & Freund (1976)	S	PHS	49	1 120	≥2	.21
Wrankmore (1976)	S	–	–	389	–	.38
Hellman (1978)	BTY	PHS9	20	299	3–12	.69
Dusek (1979)	BT	PHS	33	1 262	–	.20
	BT	PHS	53	3 050	–	.21
Georcescu et al. (1979)	S	PHS	13	260	2	.30
	S	PHS	13	260	3	.28
Katona (1979 *b*)	BTY	PHS	–	–[d]	2	.15
	BTY	PHS	–	–[d]	3	.31
	BTY	PHS	–	–[d]	4	.20
	BTY	PHS	–	–[d]	5	.16
	BTY	PHS	–	–[d]	6	.15
	BTY	PHS	–	–[d]	7	.14
Lahdenranta (1979)	BTY	PHS	17	284	4	.16
	BTY	PHS	17	303	5	.15
	BTY	PHS	17	278	6	.23
	BTY	PHS	17	210	7	.23
	BTY	PHS	15	172	8	.23
Ojala (1979)	BTY	PHS2	30	151	3	.31
	BTY	PHS2	44	259	4	.28
	BTY	PHS2	55	278	5	.33
	BTY	PHS2	63	321	6	.70
Árnason et al. (1980)	BTL	PHS	277	2 734	–	.26
Hintz (1980)	BWTL	OSR	137	219	2–12	.36
	BWTL	ODR	–	398	2–12	.16
	BWTL	PHS2	129	458	2–12	.53
	BWTL	PHS5	30	210	2–12	.49
	BWTL[e]	OSR	303	730	2–12	.24
	BWTL[e]	ODR	–	1 100	2–12	.22
	BWTL[e]	PHS2	298	1 414	2–12	.60
	BWTL[e]	PHS5	85	857	2–12	.39

[a] S (speed), BTL (best time in life time career), ATY (average time in a year), BTY (best time in a year), BTG (best time within an age group), BT (best time), BWTL (best winning time in lifetime).
[b] ODR (offspring-dam regression), ODC (offspring-dam correlation), OMC (offspring-midparent corr.), OMR (offspring-midparent regr.), PHS (intraclass corr. of paternal half-sibs), PHSn (PHS with at least *n* progeny per sire), ODRS (offspring-dam regr. within sires).
[c] 1855 in overall data.
[d] 9117 in overall data.
[e] Speed in pacing races.

Table 4. *Estimates of heritability (h^2) for direct measures of speed in flat races*

Author(s)	Measure of speed[a]	Method of estimation[b]	No. of sires	No. of offspring	Age of horse	h^2
Ócsag & Tóth (1959)	S	ODR	–	218	–	.06
Artz (1961)	TF	ODC	–	200	≥2	.24
	TF	PHS40	31	655	≥2	.19
Bormann (1962)	TF	PHS15	35	1 253	2	.17
	TF	PHS15	35	1 626	3	.09
	TF	PHS15	35	1 163	4	.17
	ATY	ODC	–	105	2	.31
	ATY	ODC	–	160	3	.16
	ATY	ODC	–	56	4	.20
Watanabe et al. (1965)	TF	PHS	47	677	3	.41
Bormann (1966)	ATY	PHS	39	753	2	.06
	ATY	PHS	39	753	3	.14
	ATY	ODR	–	162	3	.08
Watanabe (1969)	RT	PHS5	45	712	4	.12
Watanabe (1970)	RT	PHS5	45	551	4	.26
Pern (1970)	S	SM	–	–	–	.01 to .87
Pern (1971)	S	SM	–	–	–	.05 to .08
Foye et al. (1972)	PR	FS	39	78	–	.36
	PR	PHS	75	256	3	.68
Kieffer (1976)	PR	PHS	2 517	7 113[c]	3	1.43
	PR	PHS5	918	4 854[c]	3	1.14
	PR	PHS10	386	3 017[c]	3	.94
	PR	PHS	68	684[c]	3	.39
Watanabe (1974)	PR	PHS4	48	293	3	.64
Iorov & Kisov (1976)	S	–	–	–	–	.38
Neisser & Schwark (1979)	BSY	PHS8	41	1 565	3	.14

[a] S (speed), TF (time at finish in a single race), ATY (average time in a year), RT (racing time), PR (performance rate, defined as an annual average of a horse's speed in a race measured in horse-lengths relative to the winner), BSY (best speed in a year).
[b] ODR (offspring-dam regression), ODC (offspring-dam correlation), PHS (intraclass corr. of paternal half-sibs), PHSn (PHS with at least *n* progeny per sire), SM (several methods), FS (intraclass corr. of full-sibs).
[c] Data include colts and geldings.

restriction two reduces variability between sires; a marked effect is observed in the study by Kieffer (1976), but no effect in the study by Linner & Osterkorn (1974). Heritabilities are also expected to be underestimated if restriction is on the quality of a horse's own racing performance (type one restriction). The restriction is on 1st through 5th finishes in the studies by Bormann (1962) and Watanabe (1970), and on 1st through 3rd finishes in the study by Watanabe (1969). Records from first finishes only are included in the data in the study by Hintz (1980); this is the most severe kind of restriction one. Foye et al. (1972) apply a relatively severe restriction of type three, i.e., in order to be accepted in the data set, a horse is required to have raced during at least 3 years and have had at least 5 starts in a year. If any of the three types of restriction on data are severe, it obviously results in estimates of heritability biased downward.

The estimates of heritability of time in a test for Stud book (SB) increase with the age of a horse (Varo, 1965). A similar pattern cannot, in general, be verified in the studies reviewed (Tables 2 through 4). In contrast, heritabilities for best time in a year show a tendency for increasing when measured at early maturity (e.g., Minkema, 1975; Katona, 1979 *b*; Lahdenranta, 1979).

Depending on the set of data and the statistical model assumed, various other factors (e.g., sex, year, method of start, length of race etc.) may influence the estimates of heritability as well. In some studies (populations), large values of heritability have been obtained with certain methods of estimation (e.g., Kieffer, 1976; Hintz, 1980). Similar observations are reported by O'Ferral & Cunningham (1974) and Field & Cunningham (1976) with respect to heritability of timeform rating (an indirect measure of speed). However, if different methods of estima-

Table 5. *Number of horses for different age groups and length of race*

Length of race in meters	Age of horse in years 3	4	5	6	7–8	9–10	11–13	14–16
1 000[a]	101	473	10	31	35	33	36	3
1 609[a]	11	111	36	61	136	138	88	32
2 000 V	–	–	341	462	557	406	267	64
2 000 F	–	–	13	46	114	119	86	31
3 000[a]	–	–	–	4	10	15	12	6

[a] Starting methods: either V (volt-start) or F (flying start).

tion are used on the same body of data, heritabilities are not expected to be equal but a certain correlation structure exists among them (Hill & Nicholas, 1974). The correlation between the sire's phenotype and the environment of the offspring, and assortative mating are suggested as possible sources of an upward bias (e.g., O'Ferral & Cunningham, 1974; Kieffer, 1976). Some additional sources which tend to magnify h^2-values are discussed by Langlois (1980).

Due to the aspects discussed, estimates of heritability of speed are difficult to summarize. Based on 16 studies, the majority of heritabilities for speed in trotting races are in the range of 0.20 through 0.30 representing a median of about 0.25 (Table 3). The majority of heritabilities for speed in flat races are in a wider range of about 0.15 through 0.35 (Table 4); yet the median is about the same as for trotters. The median of heritabilities for time in the SB-test in Finnish Horses is about 0.45 (Varo, 1965, 1969), whereas the corresponding value for best time in a year made in trotting races is about 0.25 (Lahdenranta, 1979; Ojala, 1979). In general, racing speed appears to be moderately heritable, and heritabilities of about equal magnitude irrespective of breed or even the type of gait.

Data

Track records for Finnish Horses were collected from the files of Suomen Ravirengas (the Finnish Trotting Association, FTA). A record was filed by the FTA only if a horse had ranked first, second or third in a race. This corresponds to the restriction of type one. A record was the best trotting time per one kilometer made in any of the eight age groups on any of the four lengths of race (Table 5). In addition, two starting methods, flying start (F) and volt-start (V), were distinguished on the length of race of 2000 m. Flying start is also known as a group race, start behind a car or auto-start, and volt-start as a band-start or handicap race. Due to restriction one, a time record may, on rare occasions, not be a horse's best time in a year although assumed so in this study.

To restrict the data in this study, each horse was required to be the offspring of a sire having at least 10 filed progeny in at least one of the years 1960 through 1969. There were 24 sires which fulfilled this restriction of type two. Records in all age groups were collected for all of the progeny having at least one filed record during the mentioned ten-year period. A total of 972 horses, the progeny of the 24 sires, were sampled. The number of horses having a record made at a certain age and at a specified length of race are given in Table 5.

Methods

The number of records was small in most of the age-length of race classes. Therefore, analyses were performed using records from the classes with most numerous observations, i.e., records made at the age of 4 years at the length of race of 1000 m (either F or V), and at the ages of 5, 6, 7–8, 9–10 and 11–13 years at 2000 m (V). Thus, possible effects of method of start and length of race on the records were eliminated among the five oldest age groups. To remove the influence of a horse's age, heritabilities were estimated separately for each age group. This resulted in simple calculations of variance components since all other factors possibly influencing a horse's record were assumed absent. For justification of this procedure reference is made to the appropriate section of review of literature.

Estimates of heritability were calculated using the intraclass correlation of paternal half-sibs (e.g., Van Vleck, 1973). Approximate standard errors of heritability were estimated using the formula by Swiger et al. (1964). The linear model assumed in each of the age groups is:

$$Y_{ij}=\mu+s_i+e_{ij}$$

where Y_{ij} is the best time record in a year made by the jth offspring of the ith sire; μ is a general mean; s_i is a random effect due to the ith sire, and is assumed to be identically and independently distributed with mean zero and variance σ_s^2, IID $(0, \sigma_s^2)$; e_{ij} is a random error effect, IID $(0, \sigma_e^2)$, unique to the record made by the jth offspring of the ith sire. Sire and error effects were assumed uncorrelated.

Results and Discussion

General observations

Year of birth for the 24 sires varied from 1929 to 1952 with a mean of 1944 and a standard deviation of 5.7 years. The corresponding range for the 972 progeny was 1946 through 1966 with $\bar{x}=1957$ and $s=4.7$ years. *Generation interval* from sire to its progeny averaged 13.3 years. This agrees with the corresponding average reported for trotters (Table1), but is slightly larger than the estimate from a similar type of data set in Finnish Horses (Lahdenranta, 1979). Due to restriction two, the estimated generation interval in this study may be biased upward relative to the parameter for the population of all horses born.

Frequency distributions for best time in a year were slightly skewed toward inferior performances; in addition, the distribution was somewhat flat for 4-year-old horses. The histograms were, however, approximately normal for horses in the age groups of 5 through 11–13 years. This agrees with the results reported by Ojala (1979) using data free from restrictions one through three. Thus, the shape of frequency distributions for best time in a year appeared not to be affected by the restrictions set to these data, or at least the effect was negligible.

Means and standard deviations

Average speed at different ages. Regarding a horse's best time in a year, a general observation was that horses trot faster as they grow older (Table 6). A similar pattern has been reported in several studies. The difference in means for best time was marked between 4- and 5-year-old horses but diminished with increasing age. The superiority of horses at a certain age in comparison with those at the preceeding younger age was statistically highly significant in all pairwise comparisons except between the two oldest age groups. Thus, it appeared that an average horse reached its best time in the lifetime career by the age of 11 years. The differences between the means at the ages of 4 through 6 years were about the same magnitude in this study as in that by Ojala (1979), but the magnitude of the means themselves was about two seconds smaller than reported in the latter study. This phenomenon could be explained by the effect of restriction one to the data set in this study.

Restriction one creates some difficulties in interpreting the means. It is difficult to evaluate correctly the effect which the different number of horses may have had on the group means. It was assumed in this study that the observed frequency in a particular age group reflects the initial number of horses raced which depends partly on a preselection practised by horsemen. But due to restriction one, the frequency in a group also is in this data set the same as the fraction of horses which ranked among the first three at least in one race during a year. In other words, a low or high frequency in a group depends partly on the level of competition in a single race. This reasoning could explain the low frequency of 5-year-old horses because they raced against horses of all ages except 4-year-olds.

Average speed for different sexes. Measured by best time in a year, males were superior to females in all age groups (Table 6). The difference in means between females and males approximates the influence of sex. Differences varied from 0.6 to 2.6 sec through all age groups, but only in the three oldest age groups was the superiority of males statistically significant. Referring to the reasoning in the previous paragraph, the frequency of males was larger than that of females in all other age groups except the two oldest ones. The possibly more intensive preselection on females and/or restriction one may have inhibited the superiority of males from being statistically significant until the age of 7–8 years at which age frequencies for both sexes were about equal. The difference of 0.9 sec may, thus, be the best estimate for the influence of sex in this study. Several authors (e.g., Min-

Table 6. *Means ($\bar{x}$) and standard deviations (s) in seconds for best time in a year for different age groups and sexes*

Age and sex of horse	Number of horses *n*	%	$\bar{x}$	*s*	Differences between means[a]
4-year-olds	473	100	111.8	10.6	$\bar{x}_4-\bar{x}_5=7.8^{***}$
Males	212	45	111.2	10.3	
Females	193	41	112.6	11.1	$\bar{x}_f-\bar{x}_m=1.4^{ns}$
Geldings	68	14	111.1	10.5	
5-year-olds	341	100	104.0	5.8	$\bar{x}_5-\bar{x}_6=1.6^{***}$
Males	172	51	103.7	5.5	
Females	124	36	104.3	5.8	$\bar{x}_f-\bar{x}_m=0.6^{ns}$
Geldings	45	13	104.6	6.9	
6-year-olds	462	100	102.4	6.6	$\bar{x}_6-\bar{x}_{7-8}=2.5^{***}$
Males	221	48	102.0	6.8	
Females	179	39	102.8	6.2	$\bar{x}_f-\bar{x}_m=0.8^{ns}$
Geldings	62	13	102.8	6.8	
7–8-year-olds	557	100	99.9	5.9	$\bar{x}_{7-8}-\bar{x}_{9-10}=1.3^{***}$
Males	244	44	99.4	6.0	
Females	230	41	100.3	5.4	$\bar{x}_f-\bar{x}_m=0.9^{*}$
Geldings	83	15	100.8	6.9	
9–10-year-olds	406	100	98.6	5.6	$\bar{x}_{9-10}-\bar{x}_{11-13}=-0.1^{ns}$
Males	166	41	97.8	5.4	
Females	187	46	99.4	5.5	$\bar{x}_f-\bar{x}_m=1.6^{**}$
Geldings	53	13	98.6	6.1	
11–13-year-olds	267	100	98.7	5.9	
Males	105	39	97.2	5.3	
Females	127	48	99.8	6.2	$\bar{x}_f-\bar{x}_m=2.6^{***}$
Geldings	35	13	99.1	5.4	

[a] In subscripts numbers denote age groups, *f* females and *m* males; levels of statistical significance are for a one-tailed *t*-test with * ($p<0.05$), ** ($p<0.01$) and *** ($p<0.001$).

kema, 1975; Rönningen, 1975; Katona, 1979 *a*) have reported males to be superior to females.

Standard deviation for best time in a year was at the age of 4 years almost twice that at the other ages (Table 6). Thus, the assumption about equal variances among all ages is invalid. The variation of time records was also larger among young than among more mature horses in the studies by Minkema (1975) and Ojala (1979). This pattern may be caused by several factors such as differences in rate of reaching maturity as well as differences in opinions among horsemen concerning training and racing of young horses. Selection may also have influenced the results. In this study the magnitude of standard deviations was at all ages about 2 to 3 sec smaller than reported by Ojala (1979). This may be due to the type one restriction, i.e., the filing system of the records in this study.

Correlations

Simple correlations among a horse's best times at different ages were all positive and relatively large (Table 7). Correlations were largest in older age groups between best times made at adjacent years, but decreased with increasing time span between race years and with decreasing age of horse. This observation implies that the level of a horse's time record can be predicted with less confidence based on best times made at a younger age in comparison with time records made at a more mature age. A horse's best time for the next year can—naturally—be predicted more confidently than one further in the future. Correlations between best times were slightly smaller in this study than those reported for the corresponding ages by Minkema (1975) and Ojala (1979), but were of about the same magnitude as those reported by Katona (1979 *b*).

Correlations between measurements of the same trait at different ages can also be interpreted as the *repeatability* of two measurements. If more than two years are involved, the average of simple correlations among best times at different ages approximates the repeatability for

Table 7. *Simple correlations among a horse's best times at different ages*

Age of horse in years	4	5	6	7–8	9–10
5	.49 (246)				
6	.48 (254)	.68 (228)			
7–8	.41 (265)	.56 (235)	.69 (337)		
9–10	.33 (171)	.41 (140)	.54 (212)	.78 (312)	
11–13	.27 (104)	.35 (92)	.54 (122)	.66 (187)	.74 (206)

The number of pairs in calculations is given in brackets; all correlations are statistically significant with $p<0.01$ (Snedecor & Cochran, 1967).

best time in a year. The average of the correlations in Table 7 was 0.55 at ages of 4 through 6 years, and was also the same at ages of 4 through 7–8 years. The approximation of repeatability for best time was ~~larger~~ smaller than the corresponding estimates of repeatability reported by Katona (1979 *b*) and Ojala (1979).

Heritabilities

Estimates of heritability for best time in a year were variable. Heritability was smallest, −0.06 ±0.07, when estimated at the age of 5 years and largest, 0.23 ±0.11, in the age group of 7- to 8-year-olds (Table 8). Compared with the median value of heritabilities reviewed (Table 3), heritabilities in this study appear to be underestimated.

Due to restriction two, the sires sampled in these data obviously are the most popular service sires. In other words, selection practiced by horsebreeders, and restrictions applied in filing and analysing the data are obviously confounded with each other. A sire's track performance has apparently been one of the criterions in selection by breeders. Best time in lifetime on a distance of 2 000 m(V) averaged 1 min 32.6 sec per 1 000 m with a standard deviation of 3.1 sec. This suggests that fairly intensive selection has been practiced if best time was the criterion used. However, the range for best times was relatively wide, 1.28.0 through 1.38.0. It should be noted that the restriction of type two reduces the genetic variation among sires only if the most popular service sires also are genetically the best.

The low values of heritability in this study can primarily be explained through the combination of the sources enumerated in the review of literature, i.e., selection practiced by breeders, restrictions, and limited amount of data. All of these factors result in increased sampling variation as well. Ignoring year-effects, and in the older age groups sex-effects, may also have influenced the results. Consequently, the low values of heritability cannot be explained by increased sampling errors only, but heritabilities in this study obviously are also biased estimates relative to the parameter in the population of all horses raced. Moreover, if the target population is defined as all horses born (or registered), most estimates of heritability in this and other studies are biased.

Table 8. *Estimates of heritability (h^2) with their approximate standard errors (SE) for best time in a year*

Age of horse in years	h^2	SE	Number of sires	Number of horses
4	.08	.08	24	473
5	−.06	.07	24	341
6	.00	.06	24	462
7–8	.23	.11	24	557
9–10	.03	.08	24	406
11–13	.20	.16	23	267

Summary

A restricted set of track records in 972 Finnish Horses, the progeny of 24 sires, was analysed to estimate genetic and some other parameters. Generation interval from sire to its progeny averaged 13.3 years. Frequency distributions for best trotting time in a year were approximately normal at the ages of 5 through 11–13 years. An average horse reached its best time in lifetime by the age of 11 years. Measured by best time in a year, males were superior to females at all ages; differences in means varied from 0.6 to 2.6 sec. Simple correlations among a horse's best

times at different ages averaged 0.55 implying a repeatability for best time in a year of about the same magnitude. Estimates of heritability for best time in a year varied from -0.06 ± 0.07 to 0.23 ± 0.11 through the six age groups. Interpretation of results suffered from limited amount of data, and restrictions applied to data. Based on a review of the literature, it was concluded that parameter estimates from most studies are associated with large sampling variation, and obviously are also biased due to preselection of data.

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II

MEASURES OF RACETRACK PERFORMANCE WITH REGARD TO BREEDING EVALUATION OF TROTTERS

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Summary

Trotting records on the Finnish Horse were divided into two subsets: the total data set, with 13,000 race records on 554 horses by 206 sires, and the summary data set, with 1,378 records summarized annually for each horse. The purpose of the study was to determine whether these data could be utilized in a simple, yet useful way for the assessment of breeding value. A total of 24 measures of performance based on time at finish, money won and rank at finish were studied in the summary data set. The total data set included four traits compiled from records made at ages of 3 through 6 years. The proportion of horses that started races and at the end of a race year had records different from those of unraced horses, i.e., different from zero, was 95, 82 and 40 through 77% for measures of performance based on time, money and rank, respectively. Simple correlations between best and average time for a year were in excess of .90. Repeatabilities for time at finish during a year were about .70. Both estimates imply that time records are relatively consistent over an entire year. Estimates of heritability for best time were about .30, whereas those for money and rank traits were small or even negative. The results from this study support the concept that best time in a year is the most useful measure for assessing sire breeding values based on progeny records.

(Key Words: Race Track Traits, Repeatability, Heritability, Trotters.)

Introduction

A record system is needed to assess breeding values for any class of animal. Considerable data are being accumulated by horse racing associations. These records are necessary for supervision of parimutuel races, but also provide a source of information for the selection of breeding stock.

In Finland, the outcome of each harness race is recorded for each horse in three forms—time at finish, money won and rank at finish—each of which can be considered as an indicator of performance. Instead of using individual records for a horse (the total data set, TDS), the information is summarized annually for each horse (the summary data set, SDS). Various measures of performance (traits) can be derived from each of the three basic sources of information.

In both harness and flat racing, numerous traits derived from the same basic source of information are simultaneously reported to describe track performance. Thus, for selection purposes, estimates of genetic properties of the different traits should be known. A related question is whether best time in a year is representative of time records made by a horse in all starts during a year.

Horses that never enter a race create a problem when sire evaluation is based on progeny records. But many horses that have raced also may have records of zero, the same as for unraced horses, since they may not finish the race, win any money or have a rank recorded. The proportion of such horses depends on the measure of performance. For sire evaluation, the most useful trait will allow the greatest number of progeny to have a record different from zero or some other constant.

The purpose of this study was to examine some properties of different measures of track performance to determine whether data accumulated from harness races could be utilized in a simple, yet useful way for genetic evaluation.

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Materials and Methods

Data were collected from the files of Suomen Hippos, the Finnish Trotting and Horse Breeding Association. Records were made by Finnish Horses born in 1967 or 1968 that took part in trotting races at ages of 3 through 6 years. The Finnish horse is a general purpose breed such as the Døle in Norway, the North-Swedish Horse, the Breton in France and the Morgan in North America. At present, the Finnish Horse is used mainly for trotting sport, but is also a work and riding horse, whereas draft was the major usage in the past.

The original and complete set of data included 15,207 records. A record included race performance in three forms: time at finish expressed per unit of distance, prize money won and rank at finish. A record was accepted for analysis only if time and rank at finish were recorded. The absence of an entry for time at finish may, rarely, mean a failure in recording, but more commonly indicates, as was assumed in this work, that a horse was disqualified because it broke stride or because a driver interrupted the race. After editing, there were 13,000 records for 554 horses by 206 sires in the TDS, distributed by age as in table 1.

The records in the original data set also were summarized annually for each horse. The number of records in the SDS was 1,378, distributed by age as shown in table 1. The measures of performance are given in table 2.

Age is known to have a major effect on performance. To adjust for age effects, calculations were done separately, where applicable, for each age group. The simplest statistical models were assumed because they are the models assumed in sire evaluation in Finland at present.

Transformation of Variables. A measure of performance whose frequency distribution is not normal may follow an approximately normal distribution after transformation. Two transformations were applied to money traits: logarithmic, $Y = \ln (X + 1)$, and square root, $Y = (X)^{1/2}$, where X is the amount of money and ln is the natural logarithm (Snedecor and Cochran, 1967). A square root transformation of rank traits in the SDS was made as $Y = (X + 1)^{1/2}$, where X is the variable involving counts. Two other transformations were also applied to rank traits: the inverse of the sine (arcsin), $Y = \arcsin (X)^{1/2}$, where X is a proportion (Sokal and Rohlf, 1969), and the logit transformation as

TABLE 1. NUMBER OF RECORDS, HORSES AND SIRES FOR EACH AGE GROUP

	Age of horse			
Item	3 years	4 years	5 years	6 years
No. of records[a]	732	2,424	4,193	5,651
No. of horses	216	362	373	427
No. of sires	95	147	150	170

[a]Applies to the total data set only.

TABLE 2. MEASURES OF TROTTING PERFORMANCE IN TWO TYPES OF DATA SETS

I. Summary data set

(A) Measures based on time:
- (1) Best time per kilometer out of all starts in a year, abbreviated as best time
- (2) Average time
- (3) Poorest time

(B) Measures based on money:
- (4) Total money won in a year, total money (TM)
- (5) Log of TM
- (6) Square root of TM
- (7) Money won per start in a year, average money (AM)
- (8) Log of AM
- (9) Square root of AM

(C) Measures based on rank:
- (10) Number of times a horse finished first in a year, first rank (FR)
- (11) Number of times a horse finished first through fourth (FFR)
- (12) Number of times time at finish was not recorded, disqualified races (DR)
- (13) Percentage of FR races out of all starts in a year, FR-%
- (14) FFR-%
- (15) DR-%
- (16) Square root of FR
- (17) Square root of FFR
- (18) Square root of DR
- (19) Arcsin of FR
- (20) Arcsin of FFR
- (21) Arcsin of DR
- (22) Logit of FR
- (23) Logit of FFR
- (24) Logit of DR

II. Total data set

- (25) Time at finish per kilometer in a single race
- (26) Money won in a race, money
- (27) Log of money
- (28) Rank at finish in a race

used by Minkema (1975), $Y = \ln [(X + .5)/(100.5 - X)]$, where X is the variable consisting of proportions expressed as percentages.

Frequency distributions for all time traits were approximately normal. Among the other measures, distributions for logarithm and square root of average money (AM) and arcsin of number of times ranked first through fourth (FFR) were closest to normality. Frequency distributions for money and rank traits were approximately normal, at best, only if the fraction of horses (or records) with zero performance was deleted. Histograms for each measure were presented by Ojala (1979) for 5-year-old horses.

Estimation of Repeatabilities. Repeatability in the SDS is an estimate for annually summarized records. Each horse was required to have a time record in each of three age groups (4-, 5- and 6-year-olds). Thus, a mixed model analysis of variance for balanced data could be used to estimate the components of variance for the random effects (Sokal and Rohlf, 1969; Searle, 1971). The estimate of repeatability was the estimated intraclass correlation. The method of Swiger *et al.* (1964) was used to approximate the standard errors of the estimates. The linear model assumed in the SDS was:

$$y_{ij} = \mu + a_i + h_j + e_{ij},$$

where

y_{ij} is the annually summarized record of the j^{th} horse at the i^{th} age;

μ is a general mean;

a_i is a fixed effect due to the i^{th} age group;

h_j is a random effect due to the j^{th} horse, IID $(0, \sigma_h^2)$, and

e_{ij} is a random error effect, IID $(0, \sigma_e^2)$, unique to the record of the j^{th} horse at the i^{th} age.

Horse and error effects were assumed to be uncorrelated.

Repeatability calculated from the TDS represents an estimate for single records of a horse at a specific age. Each horse was required to have at least two starts in an age group. The linear model assumed in the TDS for each of the age groups was:

$$y_{ij} = \mu + h_i + e_{ij},$$

where

y_{ij} is the j^{th} race record of the i^{th} horse;

μ is a general mean;

h_i is a random effect, IID $(0, \sigma_h^2)$, due to the i^{th} horse, and

e_{ij} is a random error effect, IID $(0, \sigma_e^2)$, unique to the j^{th} record of the i^{th} horse.

Horse and error effects were assumed uncorrelated.

Estimation of Heritabilities. Since about two-thirds of the sires had only one progeny in each age group, records on offspring of those sires were deleted for heritability calculations. After the variance components were estimated, estimates of heritability were calculated by the intraclass correlation of paternal half sibs (e.g., Van Vleck, 1973). Approximate standard deviations for heritabilities were approximated by the method given by Swiger *et al.* (1964). The linear model assumed in the SDS for each age was:

$$y_{ij} = \mu + s_i + e_{ij},$$

where

y_{ij} is the annually summarized record made by the j^{th} offspring of the i^{th} sire;

μ is a general mean;

s_i is a random effect, IID $(0, \sigma_s^2)$, due to the i^{th} sire, and

e_{ij} is a random error effect, IID $(0, \sigma_e^2)$, unique to the record made by the j^{th} offspring of the i^{th} sire.

Sire and error effects were assumed to be uncorrelated.

For the estimation of heritabilities from the TDS, the same restriction was used in editing the data as for the SDS. Thus, the two edited data sets were identical in terms of horses and sires, but in the TDS an offspring of a sire might have had one or more records within an age group. The linear model assumed in the total data set for each of the age groups was:

$$y_{ijk} = \mu + s_i + h_{ij} + e_{ijk},$$

where

y_{ijk} is the k^{th} race record made by the j^{th} offspring of the i^{th} sire;

μ is a general mean;

s_i is a random effect, IID (0, σ_s^2), due to the i[th] sire;

h_{ij} is a random effect, IID (0, σ_h^2), due to the j[th] offspring of the i[th] sire, and

e_{ijk} is a random error effect, IID (0, σ_e^2), unique to the k[th] record made by the j[th] offspring of the i[th] sire.

Sire, horse, and error effects were assumed uncorrelated.

Results and Discussion

A Basic Property of the Measures of Performance. The proportion of horses that had raced and also had a record different from zero varied greatly depending on the measure of performance. The proportion of horses with racing records different from those of unraced horses averaged about 95, 82 and 40 through 77% for traits based on time, money and rank, respectively (table 3). Thus, measures of progeny performance based on time seem to be most useful for breeding evaluation of sires. The slight differences in percentages among age groups may be explained partly by differences in average number of starts per horse (3.5, 7.5, 12.5 and 14.5 for horses aged 3 through 6). The percentage of horses that earned some money agrees well with the 85% calculated from a large set of data on Thoroughbreds (Bloodstock Research and Statistical Bureau, 1979).

Relationships among Measures of Performance. Only simple correlations were calculated. The correlations in the SDS among time traits were large and similar for all age groups. Average correlations for best with average and poorest times were .96 and .76, respectively, and the correlation for average with poorest time was .88. It should be noted that the highest correlation was that between best and average time. Average correlations across the four age groups for best time with log of AM and arcsin of FFR were −.66 and −.35, respectively, and that for log of AM with arcsin of FFR was .76. Thus, favorable correlations existed among the traits in the three basic trait groups of time, money and rank. Complete tables of correlations among all traits were presented by Ojala (1979).

It was suspected that simple correlations among measures of performance in the SDS might not be the same if records on horses with only a single or a small number of starts in a year were deleted. Number of races in a year, however, seemed to have little or no effect on correlations between best and average time (table 4). The same pattern was observed for correlations among the other traits.

The results listed in table 4 indicate that time records in single races in a year are relatively repeatable. This result is supported by correlations of .83, .85 and .72 between best and average time in a year reported by Linner (1975, as cited by Minkema, 1978), Katona (1979) and Neisser (1976). The consistency of time records for individual races is further supported by results reported by Minkema (1975) and Katona (1979). Katona (1979) reported a correlation of .78 for time at finish in first race with average time for that year and of .93 for average time of first four races with average time of all races in a year. Minkema (1975) reported a correlation of .98 for best time in lifetime with average of five best times in lifetime. The absolute magnitudes of correlations among best time, log of AM and arcsin of FFR are slightly smaller than reported by Minkema (1975), but larger than the correla-

TABLE 3. THE FRACTION OF HORSES HAVING RECORDS DIFFERENT FROM THOSE OF UNRACED HORSES FOR SOME BASIC MEASURES OF PERFORMANCE

Measure of performance	% of horses by age group[a]			
	3 years	4 years	5 years	6 years
Measures based on time	95.2	93.5	93.5	96.2
Measures based on money	78.4	78.3	82.7	86.7
Measures based on first finishes	26.9	34.4	47.1	52.7
Measures based on first through fourth finishes	72.7	73.1	78.2	84.9
Measures based on disqualified races	18.1	51.7	63.7	60.6

[a]Number of horses in age groups 3 through 6 years was 227, 387, 399 and 444, respectively.

TABLE 4. SIMPLE CORRELATIONS BETWEEN BEST AND AVERAGE TIME IN A YEAR IN RESTRICTED SETS OF DATA

Minimum no. of starts per horse in a year	Correlations (r) and number of horses (n) at different ages							
	3 years		4 years		5 years		6 years	
	r	n	r	n	r	n	r	n
1	.96	216	.97	362	.95	373	.97	427
2	.95	173	.97	331	.95	356	.97	407
3	.94	132	.94	281	.94	339	.97	389
4	.92	92	.94	252	.94	314	.97	371
5	.92	60	.93	225	.94	295	.96	358
8	.95	19	.91	153	.94	250	.96	305
10	.94	6	.91	119	.93	216	.96	275
15	...	...	.86	55	.91	147	.96	196
20	...	...	.91	24	.91	85	.95	127
25	...	...	.91	5	.91	42	.93	81
30	...	...	....	2	.97	25	.94	55

tions from studies by Rønningen (1975) and Hellman (1978). A positive correlation between performance rate, which is an annual average of a horse's speed measured in horse lengths relative to the winner, and earnings per start was suggested in Thoroughbreds by the results of Gillespie (1971).

Large correlations for best time with average time in a year imply that best time is a satisfactory measure of average speed in a year. Correlations among annually summarized measures of performance based on time, money and rank were relatively large, supporting the obvious expectation that horses with superior best times tend to rank among the first four in a race and consequently tend to have larger average earnings per start.

Estimates of Repeatability. When the SDS is used, estimates of repeatability are for annually summarized records made at different ages. Repeatabilities for best time, log of AM and arcsin of FFR were about .70, .40 and .30 (table 5). The estimate of repeatability for best time was almost twice that reported by Rønningen (1975). Repeatabilities for best time and average time agree with those of .61 and .75 reported by Katona (1979). Repeatabilities for other traits were of about the same magnitude as corresponding estimates for trotters (Rønningen, 1975; Katona, 1979) and Thoroughbreds (Foye *et al.*, 1972).

Correlations between two measurements of the same trait at different ages can be interpreted as repeatability of the trait. The simple correlations were relatively consistent over an age range of 4 through 6 years, and their average approximated the estimate of repeatability. Correlations between best times at different ages were slightly larger than those reported for the Finnish Horse by Ojala (1972), but were of about the same magnitude as those reported by Minkema (1975). Correlations between average time in adjacent years agreed with those of Katona and Osterkorn (1977) but were slightly larger than those of Katona (1979).

Estimates of repeatability calculated from the TDS are for records of races in a year. Repeatabilities for time at finish were similar across age groups, varying from .60 to .70 (table 6). Repeatabilities for money and rank traits were smaller, about .15 through .25. Estimates of repeatability for time at finish were almost twice as large as estimates for Standardbred pacers (Solá, 1969; Hintz and Van Vleck, 1978) and Thoroughbreds (Bormann, 1962, 1966). Repeatabilities for other traits were slightly smaller than those reported by Solá (1969) and Hintz (1977).

The simple correlations and estimates of repeatability in the SDS suggest that performance measured by best or average time for a year is quite repeatable in successive years. The large estimates of repeatability in the TDS and the correlations between best and average times imply that performance measured by time at finish is relatively consistent during an entire year.

Estimates of Heritability. Heritability estimates from the SDS for best time in a year averaged about .30 (table 7). The heritability

TABLE 5. ESTIMATES OF REPEATABILITY (r) AND APPROXIMATE STANDARD ERRORS (SE) FOR ANNUALLY SUMMARIZED TROTTING TRAITS AND SIMPLE CORRELATIONS BETWEEN MEASUREMENTS OF THE SAME TRAIT AT 4, 5 AND 6 YEARS OF AGE

			Correlations between age groups[ab]		
Trait	r	SE[a]	4 *vs* 5 years	4 *vs* 6 years	5 *vs* 6 years
Best time	.69	.03	.73	.67	.79
Avg time	.76	.02	.80	.70	.86
Poorest time	.53	.04	.53	.48	.61
Total money (TM)	.28	.04	.56	.57	.49
Log of TM	.39	.04	.39	.45	.34
Square root of TM	.50	.04	.55	.58	.55
Avg money (AM)	.42	.04	.58	.60	.58
Log of AM	.38	.04	.37	.40	.37
Square root of AM	.49	.04	.49	.50	.53
No. of first place finishes (FR)	.40	.04	.45	.41	.39
No. of first through fourth place finishes (FFR)	.40	.04	.42	.41	.43
No. of disqualif. races (DR)	.24	.04	.36	.12	.25
FR-%	.34	.04	.39	.34	.32
FFR-%	.33	.04	.29	.35	.37
DR-%	.24	.04	.29	.17	.26
Square root of FR	.40	.04	.44	.40	.37
Square root of FFR	.41	.04	.40	.43	.42
Square root of DR	.26	.04	.36	.14	.28
Arcsin of FR	.30	.04	.34	.31	.27
Arcsin of FFR	.29	.04	.23	.33	.34
Arcsin of DR	.25	.04	.30	.17	.28
Logit of FR	.27	.04	.30	.29	.24
Logit of FFR	.23	.04	.17	.29	.28
Logit of DR	.24	.04	.30	.16	.26

[a]Data included on 226 horses that had a time record at 4, 5 and 6 years of age.

[b]Critical values of r at the 5 and 1% levels of significance are approximately r = .13 and r = .18 (Snedecor and Cochran, 1967).

for the 6-year-old group did not agree with estimates for the other age groups. Estimates of heritability for log of AM and arcsin of FFR were mostly small and varied markedly among the different age groups.

Heritabilities for time at finish estimated from the TDS averaged slightly over .30 for the four age groups (table 8). Estimates of heritability for other traits were mostly small and variable. Heritabilities for time at finish were of about the same magnitude as those for best and average times during a year.

TABLE 6. ESTIMATES OF REPEATABILITY (r) AND APPROXIMATE STANDARD ERRORS (SE) FOR MEASURES OF TROTTING PERFORMANCE FROM SINGLE RACES

	Age of horse[a]							
	3 years		4 years		5 years		6 years	
Measure of performance	r	SE	r	SE	r	SE	r	SE
Time at finish	.74	.03	.61	.02	.65	.02	.74	.01
Money won	.28	.04	.19	.02	.18	.02	.24	.02
Log of money	.38	.04	.22	.02	.14	.01	.13	.01
Rank at finish	.42	.04	.24	.02	.14	.01	.15	.01

[a]Numbers of records and horses in the four age groups were, respectively: 682 and 166; 2,372 and 311; 4,161 and 341, and 5,616 and 392.

TABLE 7. ESTIMATES OF HERITABILITY (h^2) AND APPROXIMATE STANDARD ERRORS (SE) FOR ANNUALLY SUMMARIZED TROTTING TRAITS

	Age of horse[a]							
	3 years		4 years		5 years		6 years	
Trait	h^2	SE	h^2	SE	h^2	SE	h^2	SE
Best time	.31	.29	.28	.21	.33	.21	.70	.23
Avg time	.27	.29	.30	.21	.45	.22	.74	.23
Poorest time	.08	.26	.19	.19	.21	.20	.67	.22
Total money (TM)	.75	.34	.29	.21	−.10	.16	−.22	.13
Log of TM	.04	.25	.22	.20	−.04	.17	.44	.21
Square root of TM	.34	.29	.41	.22	−.01	.17	.12	.18
Avg money (AM)	.20	.28	−.01	.17	−.05	.17	−.24	.13
Log af AM	−.04	.24	.12	.18	.03	.18	.45	.21
Square root of AM	.05	.25	.13	.19	.03	.18	.21	.18
No. of first place finishes (FR)	.63	.33	.38	.22	−.16	.15	.15	.18
No. of first through fourth place finishes (FFR)	.30	.29	.46	.23	−.20	.15	.23	.19
No. of disqual. races (DR)	−.32	.18	.02	.17	.22	.20	.10	.17
FR-%	.23	.28	.26	.20	−.20	.15	−.15	.14
FFR-%	.10	.26	.20	.20	.01	.18	.28	.19
DR-%	−.09	.23	.19	.19	.21	.20	−.04	.16
Square root of FR	.48	.31	.37	.22	−.05	.17	.23	.19
Square root of FFR	.21	.28	.49	.23	−.19	.15	.21	.19
Square root of DR	−.30	.19	.03	.17	.23	.20	.10	.17
Arcsin of FR	.16	.27	.25	.20	−.15	.16	.01	.16
Arcsin of FFR	.10	.26	.16	.19	−.03	.17	.34	.20
Arcsin of DR	−.16	.21	.15	.19	.24	.20	.08	.17
Logit of FR	.10	.26	.22	.20	−.13	.16	.14	.18
Logit of FFR	.10	.26	.13	.19	−.05	.17	.38	.20
Logit of DR	−.19	.21	.13	.19	.25	.20	.14	.18

[a]Number of horses and sires in the four age groups were, respectively: 151 and 30; 259 and 44; 278 and 55, and 321 and 63.

Studies based on the Studbook records of the Finnish Horse suggest a high level of heritability, about .40 through .50, for time in trotting tests (Vainikainen, 1946; Varo, 1965). Estimates for time traits based on trotting races range from .20 to .30 (Gopka, 1971; Ojala, 1972; Kalmykov, 1973; Linner and Osterkorn, 1974; Minkema, 1975; Rønningen, 1975; Schwark and Freund, 1976; Dusek, 1979; Katona, 1979). Thus, estimates of heritability for time traits in this study fall near the upper border of previous estimates. The range for

TABLE 8. ESTIMATES OF HERITABILITY (h^2) FOR MEASURES OF TROTTING PERFORMANCE FROM SINGLE RACES

	Age of horse[a]			
	3 years	4 years	5 years	6 years
Measure of performance	h^2	h^2	h^2	h^2
Time at finish	.41	.15	.39	.32
Money won	.26	.06	−.01	−.11
Log of money	.14	−.00	.02	.01
Rank at finish	.15	.01	.00	.01

[a]Numbers of records, horses and sires in the four age groups were, respectively: 499, 151 and 30; 1,853, 259 and 44; 3,240, 278 and 55, and 4,387, 321 and 63.

time traits based on flat races is about .10 through .30 (Artz, 1961; Bormann, 1962, 1966; Watanabe *et al.*, 1965; Watanabe, 1969, 1970; Kieffer, 1973; Neisser, 1976).

Estimates of heritability for untransformed money traits generally range from .20 to .30 (Pirri and Steele, 1951, 1952; Langlois, 1975; Minkema, 1975), whereas the corresponding range for transformed money traits is .30 to .40. Excluding 3-year-olds, heritabilities for money traits were lower in this study than those in the literature. No distinct effect of transformation on the magnitude of heritabilities for money traits was observed in this study.

Estimates of heritability reported in the literature are difficult to summarize because of the great variability in magnitude. In addition, descriptions of size and structure of data sets and even definitions of measures of performance are often insufficient for summarization. In general, estimates of heritability for time traits seem to be similar for both trotters and Thoroughbreds, perhaps slightly smaller for Thoroughbreds. No definite conclusion can be made about the relative sizes of heritabilities for traits based on time, money and rank, because only a few studies included all three or even two of these traits.

General Discussion

Most horses that have raced have a time record, but not necessarily a money won or rank at finish record, different from that of unraced horses. Thus, for purposes of sire evaluation, a measure of performance based on time at finish is more useful than a measure based on money won or rank at finish. This conclusion contradicts that of Minkema (1975).

Time at finish in single races was relatively consistent for a horse during a year. Thus, best time during a year may be the most useful measure of track performance. In addition, estimates of repeatability and heritability were consistently larger for time traits than for traits based on money and rank. Money and rank traits may have been affected more than time traits by not being adjusted for fixed factors other than age.

By this reasoning, it follows directly that if best time is used for genetic evaluation, single race records are not needed since the summary data are sufficient. On the other hand, if average time or a money trait is used, the total data set should be utilized because the single records should be adjusted for some of the fixed factors. Some of the adjustments required e.g., year (inflation) and racetrack (amount of purse), may be large in the case of money traits. The number of adjustment factors also may be numerous for time at finish. In contrast, best time in a year has some useful properties since the importance of environmental factors such as weather, track and other conditions influencing best time may be minimized if a horse had a chance to start a sufficient number of times. Future research will focus on a horse's best time.

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III

FACTORS INFLUENCING BEST ANNUAL RACING TIME IN FINNISH HORSES[1]

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Summary

The effects of the fixed year of race, season of race, sex, method of start, annual number of starts, length of race and racetrack were evaluated on best annual racing time in Finnish Horses. Data included 1 378 records for 554 horses by 206 sires. Five models were assumed within the age groups from 3 to 6 years. The effects of racetrack and length of race were regarded as inappropriate in these data. The annual number of starts, method of start and season of race effects were interrelated. Increase in number of starts was associated with considerable improvement in a horse's best annual racing time. Records should not, however, be adjusted for effect of annual number of starts because it would simultaneously account for genetic differences among horses. Largest estimates of heritability were obtained for best annual racing time when the model included the fixed year-season and sex effects. Corresponding to this

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model, the estimate of repeatability for best annual racing time over the four age groups was .60 ±.03. An example of best linear unbiased predictions (BLUP) of sires' breeding values based on progeny records in one or several ages was presented.

(KEY WORDS: Variance Components, Heritability, Repeatability, Fixed Effects, Racing Time, Trotter, Horse.)

Introduction

In most countries racing associations routinely summarize individual race records for each horse on an annual basis and on the basis of the whole racing career. If data consisting of race records are used to select individuals for breeding purposes, records should be adjusted for pertinent environmental effects.

Data consisting of individual race records on trotters have been analyzed by several authors (e.g., Linner and Osterkorn, 1974; Katona and Osterkorn, 1977; Hintz and Van Vleck, 1978; Katona, 1979; Tolley et al., 1983) for effects influencing the records. The studies show that numerous effects contribute to the outcome of a race. It is not obvious, however, for which effects and how these data should be adjusted when the object is breeding evaluation of trotters. When the data have been summarized on an annual basis, the number and the interpretation of the factors influencing the best annual racing time obviously differ from those influencing time records in individual races.

The objective of this study was to evaluate the effects of the year of race, season of race, sex, method of start, annual number of starts, length of race and racetrack on best annual racing time in Finnish Horses.

Materials and Methods

The Data. The original set of data consisted of individual race records made by Finnish Horses born in 1967 or 1968 that took part in trotting races at ages of 3 to 6 years. The information in individual race records was summarized annually for each horse. A record used in this study was a horse's best annual racing time. There were a total of 1 378 records for 554 horses by 206 sires in the data. The numbers of horses having a record at 3, 4, 5 or 6 years of age were 216, 362, 373 and 427.

In addition to a horse's age, the following information about fixed factors, which may influence a horse's best annual racing time, was available in this set of data:

1) year of race: two years within each age group;
2) season of race: coded from originally reported month of race as winter (months 1 to 4), summer (6 to 9), and fall and spring (10 to 12 and 5);
3) sex: stallion, mare and gelding;
4) method of start: auto-start which is a flying start behind a car, and volt-start in which horses are handicapped, based on total lifetime earnings or sometimes on best time in lifetime, by increments of 20 meters behind the base distance;
5) annual number of starts: coded in six groups as 1, 2, 3 and 4, 5 to 9, 10 to 19, and ≧ 20 starts;
6) length of race: coded as < 2 000 m and ≧ 2 000 m;
7) racetrack: 11 tracks, and 10 track groups formed on the basis of the location in the country.

<u>Estimation of Variance Components due to Sire and Residual Effects.</u> The summary data set (N = 1 378) was edited so that each sire was required to have at least two progeny in an age group. This resulted in a data set with 1 009 records. The numbers of horses in the four age groups were 151, 259, 278 and 321, respectively. There were, on average, 5 to 6 progeny per sire within an age group. These data were previously analysed by Ojala and Van Vleck (1981) for 24 traits under the assumption of simple statistical models.

To estimate sire and residual variances, the data were analyzed using five different models. The linear model assumed within each age group was in general form:

$$\underset{\sim}{y} = \underset{\sim}{X}\,\underset{\sim}{b} + \underset{\sim}{Z}\,\underset{\sim}{s} + \underset{\sim}{e} \qquad [1]$$

where

$\underset{\sim}{y}$ is a N x 1 vector of horses' best annual racing times;

$\underset{\sim}{X}$ and $\underset{\sim}{Z}$ are known incidence matrices with N rows and p and q columns, respectively;

$\underset{\sim}{b}$ is a vector of unknown fixed effects of length p;

$\underset{\sim}{s}$ is a q x 1 nonobservable vector of random sire effects representing one half of sires' breeding values;

$\underset{\sim}{e}$ is a N x 1 nonobservable vector of random residual effects.

It was assumed that the random vectors have null means and

$$\text{var}\begin{bmatrix}\underset{\sim}{s}\\ \\ \underset{\sim}{e}\end{bmatrix} = \begin{bmatrix}\underset{\sim}{I}\,\sigma_s^2 & \underset{\sim}{0}\\ \\ \underset{\sim}{0} & \underset{\sim}{I}\sigma_e^2\end{bmatrix}.$$

The five models studied differed in the fixed part of equation [1] as follows:

<u>Model 1</u> (full model): $\underset{\sim}{b}$ consisted of year-season subclass, sex, method of start - length of race subclass, annual number of starts and racetrack effects;

Model 2: $\underset{\sim}{b}$ consisted of year-season subclass, sex, method of start and annual number of starts effects;

Model 3: $\underset{\sim}{b}$ consisted of year-season subclass, sex and method of start effects;

Model 4: $\underset{\sim}{b}$ consisted of year-season subclass and sex effects;

Model 5 (simple model): $\underset{\sim}{b}$ consisted of general mean only.

Components of variance were estimated using least squares (LS) equations in [2] based on equation [1]:

$$\begin{bmatrix} \underset{\sim}{X}'\underset{\sim}{X} & \underset{\sim}{X}'\underset{\sim}{Z} \\ \underset{\sim}{Z}'\underset{\sim}{X} & \underset{\sim}{Z}'\underset{\sim}{Z} \end{bmatrix} \begin{bmatrix} \underset{\sim}{b} \\ \underset{\sim}{s} \end{bmatrix} = \begin{bmatrix} \underset{\sim}{X}'\underset{\sim}{y} \\ \underset{\sim}{Z}'\underset{\sim}{y} \end{bmatrix} \qquad [2]$$

In order to perform calculations, sire effect ($\underset{\sim}{s}$) was temporarily considered fixed. Estimates of variance components are free from the effects of fixed factors in the model. Thus, variance components are estimates of Henderson's method 3 (e.g., Seare, 1971). Using estimates of sire and residual variances, heritabilities (h^2) of best annual racing time were estimated based on the intraclass correlation of paternal half sibs. Approximate standard errors of heritabilities were calculated applying formulas 10.12 and 10.15 in Falconer (1981).

Estimation of the Effects of Fixed Factors. In order to estimate effects of fixed factors and to obtain correction factors for preadjusting the data, the LS-equations in [2] were modified. A ratio of estimated variances (σ_e^2/σ_s^2) was added to the diagonal elements of the $\underset{\sim}{Z}'\underset{\sim}{Z}$ submatrix relating to the random sire effect in the equation [1]. This ratio of variances can be accounted for if an estimate of heritability for the trait is known. Heritability of .25 for best annual racing time was assumed. The modified LS-equations, called the mixed model (MM) equations according to Henderson (1974), yield the same solutions as the generalized least squares (GLS) method. Consequently, estimable functions of the fixed effects in the model are best linear unbiased estimates (BLUE). The estimable function of interest in this study was a difference between the levels within a fixed factor, i.e., the effect of a level of a factor. These will be called differences later in this paper. The difference between two levels of a fixed factor was tested for statistical significance by the two-tailed t-test (Snedecor and Cochran, 1967). Variances of differences were calculated using the inverse of the coefficient matrix for MM-equations.

Estimation of Variance Components due to Horse and Residual Effects. The summary data set (N = 1 378) was edited so that each horse was required to have at least two records, i.e., a record in two or more of the four age classes. The data set for estimating horse and residual variances and repeatability of best annual racing time included 1 244 records on 420 horses. Components of variance were estimated for both preadjusted and unadjusted best annual racing times. Records were preadjusted for all other fixed effects in models 2 to 4 except for year-season effects. Additive adjustment factors were obtained by reversing the sign of the differences in solutions (e.g., table 3). The equation of the model was:

$$\underset{\sim}{y} = \underset{\sim}{X}\,\underset{\sim}{b} + \underset{\sim}{Z}\,\underset{\sim}{h} + \underset{\sim}{e} \qquad [3]$$

where

$\underset{\sim}{y}$ is a vector of preadjusted best annual racing times on horses aged 3 to 6 years;

$\underset{\sim}{X}$ and $\underset{\sim}{Z}$ are known incidence matrices;

$\underset{\sim}{b}$ is a vector of fixed age-year-season subclass effects;

$\underset{\sim}{h}$ is a vector of random horse effects representing the genetic effects and permanent environmental effects associated with a horse;

$\underset{\sim}{e}$ is a vector of random residual effects.

It was assumed that the random vectors have null means and

$$\text{var}\begin{bmatrix} \underset{\sim}{h} \\ \underset{\sim}{e} \end{bmatrix} = \begin{bmatrix} \underset{\sim}{I}\sigma_h^2 & \underset{\sim}{0} \\ \underset{\sim}{0} & \underset{\sim}{I}\sigma_e^2 \end{bmatrix} .$$

In computing the components of variance, horse effect was temporarily considered fixed. Estimate of repeatability (r) for best annual racing time was the estimated intraclass correlation. Approximate standard error of repeatability was calculated according to Falconer (1981).

Predictions of sires' breeding values within an age group were obtained jointly in the context of estimating differences between the levels of fixed factors. As obtained from the MM-equations, predictions of one half of sires' breeding values are best linear unbiased predictions (BLUP) (Henderson, 1974).

An overall prediction of a sire's breeding value may be obtained using repeated records on progeny. The model, based on Henderson (1977), was:

$$\underset{\sim}{y} = \underset{\sim}{X}\,\underset{\sim}{b} + \underset{\sim}{Z}_1\,\underset{\sim}{s} + \underset{\sim}{Z}_2\,\underset{\sim}{p} + \underset{\sim}{e} \qquad [4]$$

where

$\underset{\sim}{y}$ is a vector of preadjusted best annual racing times on sires' progeny for any of the ages of 3 to 6 years;

$\underset{\sim}{X}$, $\underset{\sim}{Z}_1$ and $\underset{\sim}{Z}_2$ are incidence matrices for fixed effects, sires and progeny, respectively;

$\underset{\sim}{b}$ is a vector of fixed age-year-season effects;

$\underset{\sim}{s}$ is a random vector of one half of sires' additive genetic values;

$\underset{\sim}{p}$ is a random vector representing the genetic effects not accounted for in $\underset{\sim}{s}$ and permanent environmental effects associated with the progeny of sires;

$\underset{\sim}{e}$ is a random vector of residual effects.

The random vectors, $\underset{\sim}{s}$, $\underset{\sim}{p}$ and $\underset{\sim}{e}$, were assumed to have null means and variance-covariance matrices $\underset{\sim}{I}\,\sigma_s^2 = \underset{\sim}{I}\,\frac{1}{4}\,h^2\,\sigma_y^2$, $\underset{\sim}{I}\,\sigma_p^2 = \underset{\sim}{I}\,(r - \frac{1}{4}\,h^2)\,\sigma_y^2$ and $\underset{\sim}{I}\,\sigma_e^2 = \underset{\sim}{I}\,(1 - r)\,\sigma_y^2$, respectively. It was also assumed that cov $(\underset{\sim}{s}, \underset{\sim}{p}') =$ cov $(\underset{\sim}{s}, \underset{\sim}{e}') =$ cov $(\underset{\sim}{p}, \underset{\sim}{e}') = \underset{\sim}{0}$.

Estimates of $h^2 = .25$ and $r = .50$ were assumed. Thus, the following ratios of variances $\sigma_e^2 / \sigma_s^2 = 8$ and $\sigma_e^2 / \sigma_p^2 = 1.143$ were added in diagonal elements of sire by sire and progeny by progeny submatrices on the left hand side of the normal equations as shown by Henderson (1977).

Results and Discussion

Estimates of Sire and Residual Variances. Model 1 represented the full model in this study including the following fixed effects: year-season, sex, method of start - length of race, number of starts and racetrack. Model 1 resulted in the smallest residual variance for best annual racing time (table 1). Omitting the racetrack and length of race effects from model 1 increased the estimate of residual variance only slightly. The same tendency was observed in all of the four age groups. Sire variances were similar in magnitude for models 1 and 2. Omission of the number of starts effect from model 2 resulted in a marked increase in both sire and residual variances. This implies that the annual number of starts effect is associated with both additive genetic and environmental effects influencing a horse's best annual racing time. Omitting the method of start effect from model 3 resulted in a slight increase in both sire and residual variances. Residual variance for best annual racing time was largest when the model included no other fixed effects than the general mean.

As implied through the estimates of sire and residual variances, ratios of the variance components as represented by estimates of heritability were the most favorable based on models 3 and 4. In other words, the magnitude of heritabilities was the largest, about .50 on average, when models included year-season and sex or these and method of start as fixed effects (table 2).

Estimates of heritability were associated with large standard errors (table 2). Consequently, the estimated heritabilities are of little value as estimates of parameter values. The merit of the estimated variance components and heritabilities in this study is that they give intimations about the nature of influences of the fixed factors included in the model.

Effects of Fixed Factors. Racetrack and length of race effects did not account for much of the variation in best annual racing time (table 1). This is in accord with the fact that track effect does not apply well to data consisting of horses' best annual racing times. This is partly due to the specific feature attached to a horse's best annual racing time: it is required that several of the favorably contributing factors occur simultaneously, timing of a horse's peak performance obviously has the major influence. Thus in such data, the track effect mainly represents the quality of horses to which races are being offered on a particular track. Horses' best annual racing times improved as the length of race increased. Only a contrary result would have supported adjusting for this effect. The discrepancy is partly explained by the fact that a large number of horses had achieved their best annual racing time at a long distance on volt-start. For previous reasons, no adjustment for racetrack and length of race could be justified.

The annual number of starts effect was one of the major factors influencing a horse's best annual racing time (table 3). An increase in the number of starts was associated with a decrease, i.e., an improvement, in a horse's best annual racing time. This result is obvious because horses with several starts had more chances to express their potential speed than horses with a single or only a few starts. But the statement may also be reversed, i.e., poor quality horses acquire, in general, only a few starts. Some other reasons contributing to differences in annual number of starts for a horse are differences in soundness among horses, and in expertise and enthusiasm among owners and trainers of horses. Thus, both genetic and environmental effects obviously cause the number of starts among horses to vary as implied through models 2 and 3 in tables 1 and 2. In order to avoid removing additive genetic differences among horses, the number of starts effect was excluded from model 3.

Auto-start as a method of start was superior to volt-start (table 3). Although there is no doubt about the general validity of the result, it should be noted that not all horses had the opportunity to race on both methods of start. In addition, more races are being offered on volt-start than on auto-start. This is also implied in this study through the number of horses having achieved their best annual racing time on the two methods of start. Although the influence of the method of start effect was substantial on best annual racing time (table 3), its influence on the magnitude of sire and residual variances (table 1) and heritabilities (table 2) was negligible as implied through models 3 and 4. Another and perhaps a more appropriate way to account for the method of start effect would have been to treat best annual racing time based on the two methods of start as separate traits.

Of year-season and sex effects, only the season effect had a statistically significant influence on a horse's best annual racing time (table 3). The purpose of having the season effect in the model was to account indirectly for track condition. This effect would, however, apply better to a set of data consisting of individual race records. But when the data comprise race records summarized annually for horses, inclusion of the season effect in the model may no longer serve its original purpose sufficiently. This statement is partly based on the relationship between the annual number of starts and season effects. It is unlikely, for example, that horses with several starts in a year achieve their best annual racing time during the early part of the year. Connection between the two fixed effects was also implied through a marked increase in differences for year-season effects in model 3 after excluding the number of starts effect from model 2 (table 3). The method of start effect is also partially connected to the number of starts and season effects for the previous reasons. The results in the other age groups were consistent with those for five-year-old horses in table 3.

Estimates of Horse and Residual Variances. The smallest estimate for residual variance was obtained when horses' best annual racing times were preadjusted for sex, method of start and number of starts effects (table 4). Preadjusting best annual racing time for these effects resulted also in the smallest estimate of horse variance. Thus, the number of starts effect accounted for both genetic and environmental differences in horses' best annual racing times. The most favorable ratio between these two components of variance, as represented by estimate of repeatability, was obtained when the records had been preadjusted for sex. In this case the estimate of repeatability for best annual racing time was .60 ±.03.

The Model of Choice. Prediction of sires' breeding values requires the records on progeny to be adjusted for appropriate fixed effects. For applications, the model should be as simple as possible. In selection of the model, the bias resulting from deleting factors from the model as well as the magnitude of the variances of the estimates should also be considered (e.g., Hocking, 1976).

The data in this study were not suitable for obtaining reliable estimates of genetic parameters, but may serve as a quide to achieve a better understanding of the nature of such data. The results were quite similar in the four age groups studied. Choosing the appropriate model from the different alternatives was complicated by the fact that both genetic and environmental effects were confounded with certain factors. The effect of number of starts had a major influence on both genetic, including the additive genetic, and environmental variation. If selection is for improving a horse's capacity for speed as characterized by best annual racing time, horses with an increasing number of starts in a year would be favored. This is fully in accord with a proper selection goal in breeding trotters.

Year and sex effects did not exert a significant influence on best annual racing time in this study. These effects should, however, be included in the model if evaluation of sires' breeding values is within an age group. The method of start effect should also be properly accounted for. This conclusion agrees with results for models used by Rönningen (1975) and Langlois (1984) in analysing similar data.

Predictions of sires' breeding values within each age group were obtained simultaneously with the estimation of effects of fixed factors for models 2 to 4. Ranking of sires based on BLUP for one half of sires' breeding values was quite consistent within an age group for the three models. Slight differences occurred between ranking of sires within the four age groups for model 4 (table 5). Sire evaluation, which was based on a combination of records at all ages, was parallel to those based on records of 5- and 6-year-old progeny.

Evaluations for sires were made both within age groups and combining the progeny records in the four age groups (table 5). Both within age group and overall evaluations of sires are obviously useful for horsemen. This is supported by observations on a recent sire evaluation in which substantial differences occurred between the within age group evaluations for some sires (Ojala, 1985).

Additive relationships among the male ancestors of the progeny will be implemented, as shown by Henderson (1975), in the evaluation procedure in the near future. This would increase the accuracy of evaluations for sires having small progeny groups. The bias due to selection of mates for the sires evaluated would also be reduced by including the maternal grandsire effect in a model. In addition, sire evaluations should also include other measures of racing performance, as traits based on earnings and placings, to supplement the best annual racing time.

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TABLE 1. ESTIMATES OF SIRE AND RESIDUAL VARIANCES FOR BEST ANNUAL RACING TIME

Model[a] and source of variance	Estimates of variance components (sec^2) by age of horse			
	3 years	4 years	5 years	6 years
Model 1: (A, B, C, D, E)				
sire	3.2	2.8	0.9	6.7
residual	62.4	41.2	24.8	26.0
Model 2: (A,B,D,F)				
sire	1.1	2.6	1.0	6.0
residual	76.4	47.4	25.8	29.1
Model 3: (A, B, F)				
sire	9.3	8.3	3.4	16.0
residual	106.7	83.3	45.6	46.8
Model 4: (A, B)				
sire	9.5	8.9	5.4	16.7
residual	105.8	86.3	52.9	59.1
Model 5: (G)				
sire	8.8	11.4	6.0	15.3
residual	104.4	149.6	66.2	72.8

[a] Fixed effects in the models are: year-season (A), sex (B), method of start - length of race (C), number of starts (D), race track (E), method of start (F), general mean (G).

TABLE 2. ESTIMATES OF HERITABILITY (h^2) AND APPROXIMATE STANDARD ERRORS (SE) FOR BEST ANNUAL RACING TIME

Model[a]	Age of horse								
	3 years		4 years		5 years		6 years		Average of
	h^2	SE	h^2	SE	h^2	SE	h^2	SE	h^2
Model 1: (A, B, C, D, E)	.20	.27	.25	.20	.15	.19	.82	.23	.36
Model 2: (A, B, D, F)	.06	.24	.21	.19	.15	.19	.69	.22	.28
Model 3: (A, B, F)	.32	.28	.36	.21	.28	.20	1.02	.24	.50
Model 4: (A, B)	.33	.28	.37	.21	.37	.21	.88	.23	.49
Model 5: (G)	.31	.28	.28	.20	.33	.21	.70	.22	.41

[a] Fixed effects in the models are: year-season (A), sex (B), method of start - length of race (C), number of starts (D), race track (E), method of start (F), general mean (G).

TABLE 3. DIFFERENCES BETWEEN TWO LEVELS IN A FIXED EFFECT AND STANDARD ERRORS OF DIFFERENCES (SE) FOR BEST ANNUAL RACING TIME IN FIVE-YEAR-OLD FINNISH HORSES

Fixed effect with the levels	No. of horses	Model 2			Model 3			Model 4		
		Difference[a]	SE	t-test	Difference[a]	SE	t-test	Difference[a]	SE	t-test
Year-season										
1972 winter	13	6.21	1.63	***	11.69	2.12	***	13.95	2.27	***
summer	78	0.0			0.0			0.0		
fall	33	1.10	1.09		1.90	1.46		4.10	1.55	**
1973 winter	16	4.61	1.50	**	10.51	1.96	***	12.73	2.09	***
summer	100	1.27	0.79		1.92	1.07		1.69	1.15	
fall	38	2.14	1.05	*	3.56	1.40	*	4.76	1.51	**
Sex										
stallion	116	0.0			0.0			0.0		
mare	115	0.36	0.69		0.42	0.92		0.72	1.00	
gelding	47	-0.58	0.92		-1.78	1.23		-1.14	1.33	
Method of start										
auto-start	93	0.0			0.0					
volt-start	185	4.12	0.72	***	6.49	0.94	***			
Annual no. of starts										
1	12	8.22	1.67	***						
2	11	11.04	1.73	***						
3 and 4	27	6.68	1.20	***						
5 to 9	59	0.0								
10 to 19	102	-3.08	0.85	***						
20 or over	67	-7.27	0.95	***						

[a] Differences are in seconds relative to the level indicated by 0.0; statistical significance is denoted by * $P < .05$, ** $P < .01$ and *** $P < .001$.

TABLE 4. ESTIMATES OF HORSE AND RESIDUAL VARIANCES, AND REPEATABILITIES (r) FOR BEST ANNUAL RACING TIME (BEST TIME)

Trait and model[a]	Estimates of variance due to			
	Horse	Residual	r	SE
Best time preadjusted for B, D and F	17.8	23.9	.43	.03
Best time preadjusted for B and F	36.7	32.8	.53	.03
Best time preadjusted for B	44.4	29.8	.60	.03
Best time (not preadjusted)	43.8	30.2	.59	.03

[a] Model including the fixed age-year-season effect was fitted on records preadjusted within age groups for the fixed sex (B), number of starts (D) and method of start (F) effects from model 2, for B and F from model 3 and for B from model 4, respectively.

TABLE 5. EXAMPLE OF BLUP FOR ONE HALF OF SIRES' BREEDING VALUES BASED ON PROGENY'S BEST RACING TIMES AT FOUR AGES

Sire	Age of progeny														
	3 years			4 years			5 years			6 years			3 to 6 years[a]		
	No. of prog.	BLUP in sec.	Rank	No of prog.	BLUP in sec.	Rank	No. of prog.	BLUP in sec.	Rank	No. of prog.	BLUP in sec.	Rank	No. of prog.	BLUP in sec.	Rank
Vilperi	19	-1.0	2	28	-3.1	1	28	-2.6	1	28	-3.9	1	35	-4.3	1
Erilo	26	-1.1	1	42	-1.2	3	37	-2.0	2	41	-2.3	2	47	-2.9	2
Uusi Veto	10	-0.7	3	20	-0.5	4	16	-1.3	3	15	-0.8	3	22	-1.7	3
Ero Lohko	17	2.8	5	22	-0.2	5	24	1.6	5	26	1.1	5	29	0.5	4
Ponnen Muisto	10	0.2	4	11	-1.3	2	12	1.5	4	11	1.0	4	20	0.7	5

a Based on the model allowing for repeated records on progeny.

IV

HERITABILITIES OF ANNUALLY SUMMARIZED RACE RECORDS IN TROTTERS[1]

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Summary

Race records of 4-, 5- and 6-year-old Finnish Horses and of 3-, 4- and 5-year-old Standardbred trotters from the years 1974 to 1983 were used to estimate distributional properties and heritabilities (h^2) for 13 traits, and phenotypic correlations among the traits. Traits represented a horse's annual racing performance based on number of starts, percentage of placings, earnings and best racing time. The number of horses and the number of progeny groups in one age class varied from 2 232 to 3 452 and from 138 to 198, respectively. The coefficient of variation (CV) for the square root of annual earnings per start was about 67% in both breeds as compared with a CV of 7.7 and 5.9% for best annual racing time on volt-start in Finnish Horses and Standardbred trotters, respectively. Frequency distributions for all traits departed ($P < .05$) from the normal frequency distribution. Distribution of best annual racing time was, however, approximately normal and distributions of transformed earnings approached approximate normality. Averages of h^2 weighted over the three ages were .10 for number of starts in a year, .16 for percentage of first placings in a year, .22 for percentage of first to third placings in a year, .27 for square root of annual

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earnings per start and .29 for best annual racing time on volt-start in the data for Finnish Horses. In Standardbred trotters, estimates for the previous traits were .06, .16, .18, .29 and .25, respectively. Standard errors of heritability for the previous traits ranged from .03 to .06 within an age group in the two breeds. Estimates of phenotypic correlations among the annually summarized race records were all favorable with respect to a selection objective for trotters.

(KEY WORDS: Heritability, Phenotypic Correlations, Racing Performance, Trotter, Horse.)

Introduction

Data accumulated from harness racing provide a basic source of information for the selection of breeding stock. It is not, however, obvious nor generally accepted how to use these data for genetic evaluation. The data may be used in at least three different forms: 1) as basic data consisting of individual race records for a horse, 2) as data in which individual records have been summarized on an annual basis for a horse, and 3) as data in which individual records have been summarized over a horse's whole racing career up to a certain age.

It is generally known that the outcome — placing, money won and time per unit distance — in an individual race for a horse may be influenced by a host of factors. In processing the summarization, the factors influencing individual race records are, however, ignored. This is the same as if the factors were assumed to have a random influence on the outcome of an individual race. Drawing on the results from the previous study (Ojala et al., 1986) and the data readily available, data consisting of race records summarized on an annual basis for a horse was used in this study.

The objective of this study was to estimate distributional properties and heritabilities of some annually summarized race records (traits) and phenotypic correlations among the traits.

Materials and Methods

The Data. Race records on Finnish Horses and Standardbred trotters from the years 1974 through 1983 were obtained on magnetic tapes from the files of Suomen Hippos (the Finnish Trotting and Horse Breeding Association). There are about 650 racedays annually issued by some 45 tracks of which about one half issue at least 10 racedays in a year. Each raceday consists of 10 to 12 races from which about one half are issued separately for horses of the two breeds. Some 6 000 horses race at least once a year.

The ages during which horses are qualified to race are from 3 to 16 years for Finnish Horses and from 2 to 14 years for Standardbred trotters. Three-year-old Finnish Horses and two-year-old Standardbreds may start racing the first of July. In general, young horses are not trained or raced much in Finland. Consequently, about 7 % of all Finnish Horses racing annually are 3-year-olds, and 2 % of all Standardbred trotters racing are 2-year-olds. Two starting methods are used: volt-start, known also as handicap race; and auto-start, flying start or start behind a car. One race is restricted to a maximum of 16 horses. Money prizes are issued for at least one half of the horses in one race. Time is recorded for each horse finishing the race. Time is not recorded and no money paid if the driver interrupted the race, or the horse was disqualified due to breaking stride or to some other reasons.

Since 1974, individual race records have been summarized annually by the Finnish Trotting and Horse Breeding Association for each horse having at least one start in a year. The data in this study were restricted in both breeds to include records only in the three youngest age groups in which the number of horses raced was the largest. The fractions of horses relative to all horses raced were 14, 15 and 14% for 4-, 5- and 6-year-old Finnish Horses, and 15, 20 and 18% for 3-, 4- and 5-year-old Standardbred trotters, respectively. It was required that a horse had annually at least one qualified time record on either volt- or auto-start. About 90% of 4-year-old, and 95% of 5- and 6-year-old Finnish Horses fulfilled the set condition. The corresponding percentages for 3-year-old, and 4- and 5-year-old Standardbred trotters were 95 and 97%. respectively.

For estimation of heritabilities, data were further restricted to include only records on the offspring of sires having at least 5 progeny (table 1). This condition reduced the number of horses by about 20% in all other ages except in 3-year-old Standardbred trotters of which about 30% of the horses were omitted. Estimates of parameters regarding the distributional properties of the traits studied (e.g., tables 2 and 3) were quite similar both in the restricted and unrestricted sets of data. Thus, the data used may be regarded as a random sample of all data for the age groups studied.

Description of Traits Studied. Numerous possibilities exist to summarize the information of a horse's race records on an annual basis. For example, a study by Ojala and Van Vleck (1981) included a total of 24 traits of which 15 traits were based on placings alone. To reduce the number of traits in this study, no transformations were applied to traits based on placings. A total of 13 traits were included in this study (e.g. table 2).

Sound conformation is an essential prerequisite for a horse to be able to race many times in a year and for several years. The number of starts may be regarded as a possible indicator of the soundness of a horse's basic conformation. This does not apply in general, but it is true that an unsound horse is unable to start frequently. It may also be argued that the number of times a horse starts during a year is partly a function of its recent racing career. The square root transformation was also applied to the number of starts.

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.

Earnings in a year reflects a horse's level relative to that of all horses raced. To account for the skewness of the distribution of this trait, square root, fourth root and logarithmic transformations were applied.

Earnings per start is a more precise trait than earnings because the number of starts has been accounted for.

Best racing time on either volt- or auto-start reflects the maximum speed a horse may achieve on a distance of at least 1 600 m. Best racing time also indicates a horse's level relative to that of all horses raced.

Due to two starting methods being used, all horses may not have a time record in a year on both volt- and auto-start. About 91 to 97 % of Finnish Horses and 96 or 97 % of Standardbred trotters possessed a time record on volt-start (table 1). The percentage of horses having time record on auto-start was rather small, 37 to 55 % for Finnish Horses, but was somewhat larger, 57 to 71 % for Standardbred trotters. For all other traits, all horses had a record which could be used in analyses. This is because zero-values were used as records for all horses which had never won a race, had not placed among the first three in a race or had won no money.

Estimation of Variance Components and Heritabilities. Race records on Finnish Horses were analysed within age groups assuming the following linear model:

$$y_{ijk} = \mu + a_i + s_j + e_{ijk} \qquad \text{(model 1)}$$

where

y_{ijk} is the annually summarized race record of the k^{th} horse;

μ is the general mean;

a_i is the fixed effect of the i^{th} year-sex subclass (sex was coded as 1 for stallions and geldings, and 2 for mares);

s_j is the random effect of the j^{th} sire assumed to be uncorrelated and distributed with mean zero and variance σ_s^2;

e_{ijk} is the random residual effect, NID $(0, \sigma_e^2)$.

Sire and error effects were assumed to be uncorrelated.

The genetic structure of the Standardbred trotter population in Finland is heterogeneous due to the frequent imports from the Soviet Union in the 1960's, and later on from Sweden, Denmark and the United States. It should be noted, however, that the majority of the horses have American Standardbreds in their pedigrees. In addition to the effects in model 1, model 2 included the fixed country of birth effect for a horse when race records on Standardbred trotters were analyzed.

Estimates of variance components for best annual racing time on volt-start were computed using three methods, the TYPE1, MIVQUE0 and ML of the VARCOMP procedure in the Statistical Analysis System (SAS, 1979). Estimates of variance components for all other traits studied were computed using the TYPE1 and MIVQUE0 methods only.

Estimates of variance components on the TYPE1 method are computed in the SAS using the forward solution of the Abbreviated Doolittle (Gaylor et al., 1970). In this procedure the components of variance in the expected mean squares for the least squares analysis of variance are obtained by the method of fitting constants. Thus, the TYPE1 method is equivalent to Henderson's Method 3 (e.g., Searle, 1971). Both model 1 and model 2 included only one random effect in addition to the fixed effects. Consequently, the sum of squares due to the sire effect is adjusted for the preceding fixed effects in the model. The MIVQUE0 method in the SAS is based on the algorithm by Hartley et al. (1978). This algorithm for the estimation of variance components is a special case of MINQUE (e.g., Searle, 1979). The ML estimates of variance components are computed in the SAS using the W-transformation developed by Hemmerle and Hartley (1973). To start iteration for ML, initial values are obtained using MIVQUE0. Depending on the breed and age group, 5 to 7 rounds of interation were required to reach the convergence criteria assumend in the SAS.

Estimates of heritability (h^2) for the traits studied were calculated based on the intraclass correlation of paternal half sibs. Standard errors of heritabilities were computed using the method by Swiger et al. (1964).

Results and Discussion

Distributional properties of the annually summarized race records (traits). Excluding the means, distributional properties of traits studied were similar in the three age groups within both breeds. Five-year-old Finnish Horses were inferior to four-year-old Standardbred trotters in all traits studied (tables 2 and 3). Differences in the means of the time traits characterize the level of trotting ability of horses in the two breeds. Differences in the means of the other traits studied imply the policy in offering races for horses of the two breeds.

Standard deviations and coefficients of variation for the traits were similar in both breeds (tables 2 and 3). Variation for the traits based on placings and earnings was enormous as compared with variation for the time traits. This is obviously due, in part, to the bimodal frequency distributions of the traits based on placings and earnings. Applying square root and logarithmic transformations to the traits based on earnings resulted in a great reduction in the variation. The coefficient of variation (CV) for square root of earnings per start was about 67% in both breeds as compared with CV of 7.7 and 5.9% for best racing time on volt-start in Finnish Horses and Standardbred trotters, respectively (tables 2 and 3).

Due to the transformations for traits based on earnings, the form of the distributions was altered toward being less skewed and peaked (tables 2 and 3). Excluding one case, frequency distributions for all traits departed ($P < .05$) from the normal frequency distribution when tested by the t-test (Sokal and Rohlf, 1969) for skewness and kurtosis parameters.

Based on best annual racing time on either volt- or auto-start, horses in the youngest age group were inferior to more mature horses (table 4). The pattern was similar in both breeds, but the magnitude of differences between the means was larger in Finnish Horses than in Standardbred trotters.

Variation of best annual racing time was somewhat larger in Finnish Horses than in Standardbred trotters (table 4).

This may be due, in part, to genetic differences between the two breeds. Improvement of trotting ability has not been the only selection criterion in Finnish Horses. The results in table 4 allow an assumption that the variance and the mean of best annual racing time are not entirely independent of each other. Variation of best annual racing time was slightly larger for horses in the youngest age group than for more mature horses. As compared with the previous study (Ojala, 1979), standard deviations of best annual racing time for Finnish Horses at the three ages were much more uniform in this study.

Estimates of variance components for best annual racing time on volt-start were quite similar in magnitude when based on the three methods in estimating the variance due to residual effects (table 5). Estimates of variance due to sire effects were also similar if based on TYPE1 and ML methods. The MIVQUE0 method tended to yield estimates of variance smaller in magnitude than those based on the other two methods.

As already implied through estimates of standard deviation (table 4), estimates of variance components due to both sire and residual effects were smaller in Standardbred trotters than in Finnish Horses (table 5). Model 2 for records in Standardbred trotters included the fixed effect accounting for a horse's country of birth in addition to the effects in model 1 assumed for Finnish Horses. When model 1 was assumed also for records in Standardbred trotters, estimates of variance components due to residual effects remained equal to those in table 5. Estimates of sire variance were, however, at least twice as large as those in table 5. Thus, the fixed country of birth effect in the model seemed to account satisfactorily for genetic differences among Standardbred horses born in different countries.

Estimates of heritability for best annual racing time on volt-start were quite similar if based on TYPE1 and ML methods (table 6). In contrast to the previous ones, estimates of heritability based on the MIVQUE0 method were slightly smaller. The relation with regard to the methods of estimation was also the same for other traits studied.

Due to the previous observations, estimates of h^2 based on the TYPE1 method only are to be presented in the three age groups within the two breeds for all traits studied. Although slight differences occurred in the magnitude of estimates of heritability for the same trait at different ages, any general pattern could not be noticed. Averages of h^2 for all traits were .23, .21 and .18 at the ages of 4, 5 and 6 years in Finnish Horses, respectively (table 7), while the corresponding averages for 3-, 4- and 5-year-old Standardbred trotters were .19, .17 and .25, respectively (table 8). Although some differences occurred in the magnitude of h^2 for the 13 traits in the three age groups within the breeds, average heritabilities of .21 in the Finnish Horse and of .20 in the Standardbred trotter were quite similar. Standard errors of h^2 were about the same for individual traits in the three ages in both breeds. Heritabilities for 5-year-old Finnish Horses and 4-year-old Standardbred trotters may, however, be the most representative because most horses race at these ages.

Estimates of heritability were the smallest for number of starts. Heritabilities for number of starts and square root of number of starts were of equal magnitude. Excluding best racing time on auto-start, estimates of heritability were the largest for best racing time on volt-start and for square root of earnings per start. Estimates of heritability for earnings per start were larger than heritabilities for earnings. Transformations applied to traits based on earnings increased the magnitude of heritabilities. Weighted averages of h^2 were .10 for number of starts, .16 for percentage of first placings, .22 for percentage of first to third placings, .27 for square root of earnings per start and .29 for best racing time on volt-start in the data for Finnish Horses (table 7). In Standardbred trotters, weighted averages of h^2 were .06 for number of starts, .16 for percentage of first placings, .18 for percentage of first to third placings, .29 for square root of earnings per start and .25 for best racing time on volt-start (table 8). Standard errors of heritability for the previous traits ranged from .03 to .06 within an age group in the two breeds (tables 7 and 8).

Estimates of h^2 for best racing time in this study agree well with those summarized in literature reviews for trotting speed (e.g., Hintz, 1980; Langlois, 1982; Ojala, 1982; Katona, 1985; Tolley et al., 1985). In this study estimates of heritability for earnings per start were larger than those for earnings, and h^2 were larger for transformed than untransformed variables of earnings. These observations are in agreement with results by Minkema (1975), Rönningen (1975), Katona (1979), Arnason et al. (1982), Langlois (1984), Bendroth et al. (1985) and Katona and Distl (1985). Estimates of h^2 for percentage of first placings and percentage of first to third placings were slightly smaller in this study than those reported by Rönningen (1975), Arnason et al. (1982) and Bendroth et al. (1985). The magnitude of estimates of h^2 for untransformed variables based on placings suggest that transformed variables as used by Ojala and Van Vleck (1981) should have been included in this study as well. Estimates of h^2 for number of starts were the smallest of all traits in this study. This agrees with the results reported by Arnason et al. (1982) and Bendroth et al. (1985).

It should be noted that the type of data set, definition of variables, or transformations applied on variables were seldom identical in the studies previously referred to. In this study a horse's racing performance was summarized on an annual basis. Similar data sets were used by Rönningen (1975) and Langlois (1984), but traits for earnings were different in the latter study. Another summarized type of data set, as used by Minkema (1975), Arnason et al. (1982) and Bendroth et al. (1985), consists of records summarizing a horse's whole racing career up to a certain age. The difficulty connected with this type of data set is that not all horses race at every age during a given age interval. A third choice, as used by Katona (1979) and Katona and Distl (1985), is the basic data consisting of a horse's individual race records during a year.

Estimates of phenotypic correlations among the annually summarized race records were all favorable with respect to a selection objective for trotters; in addition, some of the correlations were quite large (table 9). Correlations between number of starts and the other traits were the smallest. The pattern for correlations among the traits was also the same in other age groups in both breeds. The magnitude of correlations was, in general, slightly smaller in Standardbred trotters.

The correlation of -.67 between number of starts and best racing time on volt-start verifies the obvious relation that the more often a horse starts the better are its chances to achieve a good racing time. Similarly, the relationship between number of starts and earnings is also obvious. But a favorable relationship exists between number of starts and earnings per start, too. Favorable relationships of number of starts with traits describing a horse's racing performance may, in part, be explained by the fact that racing success is almost a precondition for the increase in number of starts. Estimates of phenotypic correlations among the traits in this study are in general agreement with simple correlations among the same traits in Finnish Horses (Ojala, 1979). The general pattern of correlations among the traits in this study was also supported, where applicable, by the studies by Minkema (1975), Rönningen (1975), Arnason et al. (1982), Distl et al. (1982), Langlois (1984) and Bendroth et al. (1985).

Conclusions and Applications. Applying results of this and previous studies, indexes based on a horse's own race records were constructed within an age class for 3- to 5-year-old Standardbred trotters and 4- to 6-year-old Finnish Horses. The previous individual indexes as well as sire indexes, based on progeny records at earlier ages, will be calculated routinely in the beginning of each year, and will be used by the breeding committee of The Finnish Trotting and Horse Breeding Association.

In 1985, separate indexes were calculated for traits based on percentage of first placings in a year, percentage of first to third placings in a year, annual earnings per start and best annual racing time on both volt- and auto-starts. An overall index within an age group was a combination of the separate indexes, the largest weight being on best annual racing time. This relates to the selection objective in which a trotter's capacity for maximum speed on a distance of at least 1 600 m is valued the most and is supplemented by other characteristics of racing performance.

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TABLE 1. NUMBER OF HORSES AND SIRES IN THE RESTRICTED SET OF DATA

Breed and age of horse	Number of horses[a]					Number of sires
	Total	With qualified time record				
		On volt-start		On auto-start		
		No.	%	No.	%	
The Finnish Horse						
4 years	2 968	2 706	91	1 107	37	139
5 years	3 275	3 132	96	1 600	49	139
6 years	3 018	2 914	97	1 670	55	138
Standardbred trotter						
3 years	2 232	2 133	96	1 267	57	142
4 years	3 452	3 360	97	2 363	68	195
5 years	3 132	3 031	97	2 233	71	198

[a] Data were restricted to include offspring of sires having at least 5 progeny.

TABLE 2. DISTRIBUTIONAL PROPERTIES OF ANNUALLY SUMMARIZED RACE RECORDS (TRAITS) IN 5-YEAR-OLD FINNISH HORSES

Trait	No. of horses	Mean	Stand. dev.	Coeff. of variation	Skewness	Kurtosis
Number of starts	3 275	14.7	9.5	64.7	0.7	0.4
Percentage of first placings	3 275	8.5	12.0	141.1	1.9	4.2
Percentage of first to third placings	3 275	24.0	20.1	84.0	0.6	-0.2
Earnings in Finnish marks	3 275	5 297.0	9 262.7	174.9	5.1	43.0
Square root of earnings	3 275	56.4	46.0	81.4	1.5	3.9
Fourth root of earnings	3 275	6.7	3.4	51.3	-0.3	0.1
Natural logarithm of earnings	3 275	6.9	2.9	41.5	-1.5	1.3
Earnings per start, EPS	3 275	277.2	387.9	140.0	4.6	33.2
Square root of EPS	3 275	13.8	9.3	66.9	1.1	3.1
Fourth root of EPS	3 275	3.4	1.5	45.7	-0.8	0.7
Natural logarithm of EPS	3 275	4.6	2.0	42.1	-1.4	1.2
Best racing time on volt-start[a]	3 132	104.0	8.0	7.7	1.2	2.4
Best racing time on auto-start[a]	1 600	98.8	6.0	6.1	0.9	1.7

[a] Expressed in seconds per kilometer.

TABLE 3. DISTRIBUTIONAL PROPERTIES OF ANNUALLY SUMMARIZED RACE RECORDS (TRAITS) IN 4-YEAR-OLD STANDARDBRED TROTTERS

Trait	No. of horses	Mean	Stand. dev.	Coeff. of variation	Skewness	Kurtosis
Number of starts	3 452	17.2	10.5	61.4	0.5	-0.2
Percentage of first placings	3 452	9.9	12.8	128.8	1.7	3.2
Percentage of first to third placings	3 452	28.0	20.9	74.6	0.4	-0.4
Earnings in Finnish marks	3 452	9 190.0	15 611.3	169.9	5.0	39.5
Square root of earnings	3 452	75.6	59.0	78.0	1.5	3.9
Fourth root of earnings	3 452	7.9	3.7	47.1	-0.2	0.4
Natural logarithm of earnings	3 452	7.6	2.7	35.7	-1.8	2.7
Earnings per start, EPS	3 452	449.0	718.2	160.0	5.9	55.3
Square root of EPS	3 452	17.6	11.9	67.6	1.6	5.8
Fourth root of EPS	3 452	3.9	1.6	41.8	-0.6	1.4
Natural logarithm of EPS	3 452	5.1	1.9	36.6	-1.6	2.3
Best racing time on volt-start[a]	3 360	85.4	5.0	5.9	1.7	4.9
Best racing time on auto-start[a]	2 363	82.2	3.7	4.5	1.3	3.3

[a] Expressed in seconds per kilometer.

TABLE 4. DISTRIBUTIONAL PROPERTIES OF BEST ANNUAL RACING TIME FOR HORSES IN THREE AGE GROUPS WITHIN THE TWO BREEDS

Breed and age of horse	No. of horses	Mean	Stand. dev.	Coeff. of variation	Skewness	Kurtosis
	Best annual racing time on volt-start[a]					
The Finnish Horse						
4 years	2 706	109.0	9.0	8.3	1.0	1.5
5 years	3 132	104.0	8.0	7.7	1.2	2.4
6 years	2 914	101.8	7.8	7.7	1.2	2.4
Standardbred trotter						
3 years	2 133	88.0	5.7	6.5	1.5	3.5
4 years	3 360	85.4	5.0	5.9	1.7	4.9
5 years	3 031	84.4	4.7	5.6	1.7	5.8
	Best annual racing time on auto-start[a]					
The Finnish Horse						
4 years	1 107	102.6	7.3	7.1	1.4	4.1
5 years	1 600	98.8	6.0	6.1	0.9	1.7
6 years	1 670	97.3	5.8	6.0	0.7	0.9
Standardbred trotter						
3 years	1 267	84.1	4.4	5.2	1.5	5.0
4 years	2 363	82.2	3.7	4.5	1.3	3.3
5 years	2 233	81.3	3.5	4.3	1.4	4.9

[a] Expressed in seconds per kilometer.

TABLE 5. SIRE AND ERROR COMPONENTS OF VARIANCE FOR BEST ANNUAL RACING TIME[a] BASED ON THREE METHODS[b] OF ESTIMATION

Breed and age of horse	Sire variance estimated by			Residual variance estimated by		
	TYPE1	MIVQUE0	ML	TYPE1	MIVQUE0	ML
The Finnish Horse						
4 years	6.2	4.9	6.6	72.0	73.3	71.8
5 years	4.3	4.5	4.2	58.6	58.3	58.2
6 years	4.1	3.4	4.3	52.7	53.5	52.4
Standardbred trotter						
3 years	1.6	1.7	1.3	26.4	26.3	26.2
4 years	1.2	0.7	1.1	20.5	21.0	20.5
5 years	1.4	1.0	1.4	18.0	18.4	18.0

a Best annual racing time on volt-start, expressed in seconds per kilometer.

b See text for details.

TABLE 6. ESTIMATES OF HERITABILITY (h^2) AND STANDARD ERRORS (SE) FOR BEST ANNUAL RACING TIME[a] BASED ON THREE METHODS OF ESTIMATION

Breed and age of horse	Methods[b] of estimation					
	TYPE1		MIVQUE0		ML	
	h^2	SE	h^2	SE	h^2	SE
The Finnish Horse						
4 years	.32	.06	.25	.05	.34	.06
5 years	.27	.05	.29	.05	.27	.05
6 years	.29	.05	.24	.05	.30	.05
Standarbred trotter						
3 years	.23	.06	.24	.06	.19	.05
4 years	.22	.04	.13	.04	.21	.04
5 years	.29	.05	.20	.05	.29	.05

a Best annual racing time on volt-start, expressed in seconds per kilometer.

b See text for details.

TABLE 7. ESTIMATES OF HERITABILITY[a] (h^2) AND STANDARD ERRORS (SE) OF ANNUALLY SUMMARIZED RACE RECORDS (TRAITS) IN FINNISH HORSES

Trait	Age of horse						Weighted[b] average of h^2
	4 years		5 years		6 years		
	h^2	SE	h^2	SE	h^2	SE	
Number of starts	.13	.04	.11	.03	.05	.03	.10
Percentage of first placings	.15	.04	.18	.04	.14	.04	.16
Percentage of first to third placings	.23	.05	.23	.05	.21	.05	.22
Earnings in Finnish marks	.11	.04	.09	.03	.07	.03	.07
Square root of earnings	.24	.05	.23	.05	.19	.04	.22
Fourth root of earnings	.27	.05	.25	.05	.19	.04	.24
Natural logarithm of earnings	.24	.05	.20	.04	.14	.04	.19
Earnings per start, EPS	.09	.03	.15	.04	.14	.04	.13
Square root of EPS	.28	.05	.28	.05	.24	.05	.27
Fourth root of EPS	.27	.05	.25	.05	.21	.05	.24
Natural logarithm of EPS	.26	.05	.22	.04	.18	.04	.22
Best racing time on volt-start	.32	.06	.27	.05	.29	.05	.29
Best racing time on auto-start	.45	.10	.26	.07	.29	.07	.32
Average of all traits	.23		.21		.18		.21

[a] Based on variance components estimated by TYPE1 method.

[b] Weighted by the number of horses in an age group, see table 1.

TABLE 8. ESTIMATES OF HERITABILITY[a] (h^2) AND STANDARD ERRORS (SE) OF ANNUALLY SUMMARIZED RACE RECORDS (TRAITS) IN STANDARDBRED TROTTERS

Trait	Age of horse						Weighted[b] average of h^2
	3 years		4 years		5 years		
	h^2	SE	h^2	SE	h^2	SE	
Number of starts	.06	.04	.03	.03	.09	.04	.06
Percentage of first placings	.20	.05	.16	.04	.13	.04	.16
Percentage of first to third placings	.22	.05	.16	.04	.16	.04	.18
Earnings in Finnish marks	.07	.04	.13	.04	.29	.05	.17
Square root of earnings	.19	.05	.19	.04	.27	.05	.22
Fourth root of earnings	.18	.05	.15	.04	.23	.05	.19
Natural logarithm of earnings	.12	.05	.10	.03	.15	.04	.12
Earnings per start, EPS	.20	.05	.21	.04	.34	.06	.25
Square root of EPS	.31	.06	.25	.05	.33	.06	.29
Fourth root of EPS	.23	.06	.18	.04	.25	.05	.22
Natural logarithm of EPS	.17	.05	.13	.04	.19	.04	.16
Best racing time on volt-start	.23	.06	.22	.04	.29	.05	.25
Best racing time on auto-start	.25	.08	.31	.06	.24	.06	.27
Average of all traits	.19		.17		.23		.20

a Based on variance components estimated by TYPE1 method.

b Weighted by the number of horses in an age group, see table 1.

TABLE 9. ESTIMATES OF PHENOTYPIC CORRELATIONS[a] AMONG SOME ANNUALLY SUMMARIZED RACE RECORDS (TRAITS) IN 5-YEAR-OLD FINNISH HORSES

Trait	1.	2.	3.	4.	5.	6.	7.	8.
1. Number of starts								
2. Percentage of first placings	.23							
3. Percentage of first to third placings	.38	.76						
4. Earnings	.54	.54	.55					
5. Square root of earnings	.74	.64	.73	.90				
6. Earnings per start, EPS	.35	.69	.67	.89	.85			
7. Square root of EPS	.52	.74	.83	.79	.92	.89		
8. Best racing time on volt-start	-.67	-.47	-.61	-.54	-.76	-.54	-.75	
9. Best racing time on auto-start	-.52	-.47	-.55	-.57	-.73	-.55	-.69	.91

[a] Based on residuals from a model including a fixed year-sex subclass effect.

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