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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), $Y = \text{arcsin} (X)^{1/2}$, where X is a proportion (Sokal and Rohlf, 1969), and the logit transformation as

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

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

Item	Age of horse			
	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.

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 jth horse at the ith age;

μ is a general mean;

a_i is a fixed effect due to the ith age group;

h_j is a random effect due to the jth 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 jth horse at the ith 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 jth race record of the ith horse;

μ is a general mean;

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

e_{ij} is a random error effect, IID $(0, \sigma_e^2)$, unique to the jth record of the ith 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 jth offspring of the ith sire;

μ is a general mean;

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

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 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 kth race record made by the jth offspring of the ith sire;

μ is a general mean;

s_i is a random effect, IID $(0, \sigma_s^2)$, due to the ith sire;

h_{ij} is a random effect, IID $(0, \sigma_h^2)$, due to the jth offspring of the ith sire, and

e_{ijk} is a random error effect, IID $(0, \sigma_e^2)$, unique to the kth record made by the jth offspring of the ith 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 SET 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[a][b]		
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 (h²) 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 (h²) 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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