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Inheritance of racing performance of trotter horses: An overview

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ABSTRACT

Harness racing is a form of horseracing in which the horses race in a specified gait (trot or pace). In contrast to the Thoroughbred, the trotter is not an international breed. In this type, the horses are raced with trotting or pacing gait. Breeds specialized for racing at trot or pace are indigenous to many countries. Separate breeds of light harness horses, generally designated as trotters have evolved for racing purposes in several countries. The important horse breeds used for harness racing in different parts of the world are the Standardbred, French Trotter, Swedish Trotter, Orlov Trotter, Russian Trotter, Finnhorse, Icelandic Toelter, Dole horse and North-Swedish cold-blooded horses. The trotter ranks worldwide second to the Thoroughbred in popularity as a racehorse. Racing performance in trotters, in contrast to Thoroughbred is characterized by qualifying tests before entering the races, inclusion of more than one breed in international races only and greater duration of racing career. An intensive selection of stallions on the basis of phenotypic racing performance has been practised in many trotter populations for quite a long time. Unlike Thoroughbreds, improvements have been observed in different trotter populations and this is attributed to both genetic and environmental changes. Environmental changes include enhanced training methods, as well as improved tracks, harness and sulkies. As a result of selection, racing time of trotters has been reduced over the years. The estimated annual genetic progress in racing performance traits of Swedish Standardbred horses corresponds to 5% of the phenotypic standard deviation, 3.6% in French Trotters and 5% in Dutch Trotters. According to the recent selection for speed in trot, this trait remains heritable and genetic improvement is observed in most countries. Correlations between earnings and times are negative and high, and hence favourable. As a result, selection based on times and earnings are quite effective. A multiple trait approach avoids potential biases of one particular measure, even if the objective of all traits is much the same. Since racing performance may be evaluated in both males and females and repeated observations can be obtained on the same animal, mass selection based on performance tests would be the selection procedure of choice. In the future, interest in the possible use of marker-assisted selection (MAS) for enhanced genetic improvement in horses is likely to increase. MAS is likely to be a valuable complement to selection of horses based on estimated breeding values (EBVs) obtained by the Best Linear Unbiased Prediction (BLUP) method, rather than as a replacement for EBVs.

1. Introduction

Racehorse populations provide examples of breeds, which have been selected over relatively longer period of time. The two breeds mostly used for gallop racing are the Arab and the Thoroughbred. Arab horses are being used in the shorter range of Thoroughbred or for endurance racing. The other type of racing is generally called harness racing. It is a form of

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racing in which the horses run in a specified gait (trot or pace). Trot is a two-beat gait in which the diagonal limbs move together synchronously whereas in pace, the lateral limbs move together simultaneously. In harness racing the horses usually pull two-wheeled carts called sulkies (Sulky is a light two-wheeled cart equipped with bicycle wheels. The driver carries a long light whip, which is chiefly used to signal the horse by tapping and to make noise by striking the sulky shaft), although races with saddle are also conducted. Races can be conducted in differing gaits; trotting, pacing and toelting. In the Continental Europe races are conducted exclusively between trotters, whereas in Australia, Canada, New Zealand, the United States of America (USA) and the United Kingdom racing is also held for pacers. In contrast to the Thoroughbred, the trotter is not an international breed. In this type the horses are raced with trotting or pacing gait. Breeds specialized for racing at trot or pace are indigenous to many countries. Separate breeds of light harness horses, generally designated as trotters have evolved for racing purposes in several countries. The trotter ranks worldwide second to the Thoroughbred in popularity as a racehorse. Harness racing is an important sport event in Canada, Iceland, Norway, Sweden, Finland and Russia. It is also of importance in the USA, France, The Netherlands, Belgium, Germany, Italy and some central European countries. Now it is also developing in the United Kingdom and Spain. The important horse breeds used for harness racing in different parts of the world are the Standardbred, French Trotter, Swedish Trotter, Orlov Trotter, Russian Trotter, Finnhorse, Icelandic Toelter, Dole horse and North-Swedish cold-blooded horses. Reviews on the trotting performance were previously done by Minkema (1978), Hintz (1980) Langlois (1982, 1984a) and Tolley et al. (1985). Later, Ricard et al. (2000) also compiled the performance of trotters. In this review a detailed description of different breeds involved in trotting races have been presented along with a compilation of the genetic parameters and a description of the breeding evaluation and genetic improvement of the trotters.

2. International trotter breeds

2.1. Standardbred

It was developed from the Thoroughbred, Norflok Trotter, Barb, Morgan and Canadian pacing ancestors in the USA. This included both trotters and pacers. The name Standardbred was derived from the original standard for speed, which was adopted in 1879. For a horse to be registered, it had to trot a mile in 2′ 30″ min or pace it in 2′ 25″ min. The current standard is 2′ 20″ min for 2-year-old and 2′ 15″ min for older horses, although horses are now only rarely registered on the basis of these standards. The horses range in height from 14.2 to 16.2 hands; the range in weight is 850 to 1150 lb. Early breeders tended to favour horses whose length exceed their height. Standardbreds have proportionally shorter legs than Thoroughbreds and longer bodies. The predominant coat colour of the Standardbred horses is bay but chestnut, black and grey are also found. The founding sire of today's Standardbred horse was Messenger, a grey Thoroughbred brought to the America in 1788 and then purchased by Henry Astor. From Messenger came a great-grandson, Hambletonian 10 (1849–1876), who gained wide following for his racing prowess. All Standardbred horses of today can be traced back to four sons of Hambletonian10 (Evans et al., 1995).

MacCluer et al. (1983) observed that although Standardbred breeders tend to avoid very close inbreeding, nearly all horses with complete pedigrees were inbred within the first five ancestral generations. Inbreeding coefficients increased markedly with increasing pedigree depth, levelling off only after 10 to 12 generations. When completeness of pedigree was taken into account there was little evidence for an increase in inbreeding through time. A preliminary analysis of inbreeding as a function of gait suggested that trotters were more highly inbred than pacers. Further, Cothran et al. (1984) stated that relationship between reproductive performance and inbreeding was not consistent between trotters and pacers of Standardbred horses. For trotters ($F=0.103$) there was a trend for an increase in conception and foaling rates with increased inbreeding, while for pacers ($F=0.074$), reproductive performance decreased with increased inbreeding. Hence, overall, they concluded that inbreeding does not appear to be a significant factor influencing reproductive performance of Standardbred horses.

2.2. French Trotter

It is also called Trotteur Français, Anglo-Norman Trotter and Norman Trotter. They originated from the Norman Coach Horse by crossbreeding with the Thoroughbred, Hackney and American Standardbred (Mason, 1996; Hendricks and Dent, 2007). The development of French Trotter was a result of the establishment of the sport of harness racing in France. The first racing took place at Cherbourg in 1836 and the studbook was opened in 1922. In 1937, to protect the qualities of the breed (which can beat world-class harness-racers) the French Trotter studbook was closed to non-French bred horses. Recently, however, it was partly opened to let in a few French/Standardbred crosses. The predominant coat colours of these horses are bay and brown and have average height ranging between 15.1 and 16.2 hands. The average coefficient of inbreeding for offspring born from 1989 to 1992 was 1.86%. From 1974 to 1992, the rate of inbreeding in percentage points per year was +0.052. The distribution of genetic contributions of founder animals was unbalanced and 25 founder animals only accounted for half the actual gene pool of French Trotter (Moureaux et al., 1996). Langlois and Blouin (2004b) observed that the numerical productivity progressed in France more for draught breeds than for saddle breeds and trotters. They further stated that a high performance level of the mare was positively associated with higher productivity in sport and trotting horses and showed no significant difference for galloping horses.

2.3. Orlov Trotter

It is a historic breed of trotting horse and was founded in 1777 by Count Alexis Grigoroevich Orlov at Khrenovskoy Stud Farm, Bobrov, Russia. It was developed by crossing mares mainly of Dutch, Danish, English and Mecklenburg harness breeds with Arabian stallions. It is the most famous Russian horse and has features like hereditary fast trot and outstanding speed and stamina. The Orlov Trotter resembles the Arabian horse but is generally taller, ranging in height from 16 to 17 hands. Due to its Arabian origin, many Orlovs are grey in colour. Selection for trotting ability made the breed world famous. Orlov Trotters were used mainly for riding and harness racing by the Russian nobility. In 1834, a Trotting Society was established in Moscow and then regular races began. In 1877, Harness Racing Totalizator emerged in Russia and this led to crucial changes in breeding of Orlovs. To protect Orlovs, in 1997, the International Committee for the Protection of Orlov Trotter was established (Jones, 1982; Dmitriev and Ernst, 1989).

2.4. Russian Trotter

It was established in Russia to create a horse with a faster trotting speed than the older Russian Orlov Trotter. This breed was developed by crossing the Orlov Trotter with the American Standardbred horses. The crossbreeding began in the 1890s. A total of 156 Standardbred stallions and 220 mares imported from USA between 1890 and 1914 were used for crossbreeding. Breed characteristics of this breed were fixed in 1950, and the breed was officially recognised. In 1960 a second cross to the American Standardbred was made to improve speed, and the crossbreeding still continues. Modern Russian Trotter is a typical harness horse. It is easy to train, quiet, yet energetic when needed. The usual colour is bay, but can be chestnut, black or grey. The Russian Trotters stand between 15.3 and 16.0 hands high (Dmitriev and Ernst, 1989; Hendricks and Dent, 2007).

2.5. Icelandic Toelter

The Icelandic Toelter horses are descended from horses brought to Iceland by settlers during the years 870 to 930. It is believed that the Icelandic horses mostly came from Norway and they originated from Norwegian Landrace breeds such as Norwegian Fjord horses. The Icelandic Toelter is a small and sturdy animal but not light in build and thus often lacking in elegance. It has a wide range coat colours. The best qualities of the horse are the riding skills and is multi-gaited. Most breeds of horses have only three gaits; walk, trot and gallop, whereas, the Icelandic Toelter has in addition toelt gait (It is a four-beat gait in which the horse moves its feet in the same order as in the walk). Organisation of breeding started in the beginning of the 20th century. Legislation was passed in 1891 and the establishment of the Agricultural Society of Iceland (which employed the first State Consultant in Animal Breeding in 1902) resulted in the establishment of horse breeding organisation throughout the country. The first breed society for the Icelandic Toelter horse was formed in 1904 with the first register being created in 1923. Since 1951, the official breeding goal has given emphasis to the improvement of the special characters of the breed as a multi-gaited riding horse (Árnason and Bjarnason, 1994; Hugason, 1994; Sveinsson, 2003).

2.6. Dole Trotter

Dole Trotters originated from Norway's Gudbrandsdal valley (an area connecting the Oslo region with the North Sea Coast). Dole horses were descended in part from the Dutch Friesian and there is similarity between the two. The Dole horses of today are found in two types — the heavy horse and the light draft horse (the cold-blooded trotter) and are most widespread in Norway. This lighter sporting type of draft horses (i.e. Dole Trotter) was derived from Dole Gudbrandsdal (heavier type of Dole horse) in the 19th century. The Dole Gundbrandsdal was crossed with imported trotting stallions, usually, the Swedish or the Thoroughbred for creating the Dole Trotter. These horses were developed mainly for harness racing, which is a popular sport in Scandinavia. Dole Trotters are tough and hard horses with a great trotting ability. They generally stand 14.1 to 15 hands high and are usually bay, brown or black in colour. In 1928, trotting races were organised at the Bjerke trotting tract of Norway. Of the trotting racers, 50% are for warm-blooded trotters (Standardbred and so forth) and 50% for cold-blooded trotters. The Dole horse is one of the smallest cold-bloods. It contributed greatly to formation of North-Swedish horse, another excellent trotter (Bongianni, 1988; Mason, 1996; Hendricks and Dent, 2007).

2.7. Finnhorse

Finnhorse (Finnish horse) is the only native horse breed of Finland. It is of similar type as the North-Swedish horse and the Norwegian Dole horse, but somewhat lighter. It is a descendant of the northern European domestic horse. The Finnhorse is a multi-purpose breed as it is used for trotting races, work and riding (Árnason et al., 1994). The studbook of the Finnish horses was officially approved by a statue in 1905. Since 1973 Finland's Hippos is the Central National Organisation of the horse sports and is responsible for the registration and breeding of horses in Finland. The Finnhorse is among the fastest and most versatile cold-blooded horses in the world. It is typically 15 to 17 hands high and the dominant colour is chestnut. Finnhorse harness races have been held in Finland since the second half of the 19th century, with the official annual Finnhorse racing championship starting in 1924, and it continues to be a popular spectator (and betting) sport. Internationally, Finland lies among the 5 to 6 major trotting countries in Europe. Finnish Trotter stallions had to meet minimum best time of 1′37″, 1′ 34″, 1′ 32″ and 1′ 30″ min at 4-, 5-, 6- and 7-years and older horses respectively and earnings per start about 1000 FIM or the individual index of 108 for entry in the studbook. This breed is also called Finnish Universal, as it is able to fulfil all needs of horses in Finland, from draft to speedy trotting races and riding. In races, about 40% of the starts are for Finnhorses (Ojala, 1989; Hendricks and Dent, 2007).

2.8. North-Swedish cold-blooded horses

Horse racing and riding are quite popular sports in Sweden and the horse racing is dominated by trotting. Swedish trotters are divided into two distinct populations: the Standardbred Trotter and the North-Swedish Trotter. The former is a light horse of mainly American and to a certain extent French origin, while the latter is a heavier domestic type also used for forestry work. Horse breeding in Sweden has been under regular government control since 1874. An open studbook for Swedish riding horses was established in 1918 (Árnason et al., 1989, 1994; Klemetsdal, 1999). The North-Swedish cold-blooded horses are medium-sized and they have ancient origin. These horses are closely connected to their neighbour, the Dole horse from Norway. There has been a lot of crossbreeding and the more uniform type of this breed was produced after the establishment of the breed society at the end of the 19th century. They are tractable and robust horses and like the Dole horses they are good trotters. Horses are with any basic colour and usually stand 15.0 to 15.2 hands high.

2.9. Other breeds

In Norway, in addition to the Dole and the Standardbred, Norwegian Trotters are also used for harness racing. In Norway, close to 50% of all totalizator races have been reserved for Norwegian Trotters. In the Netherlands, trotting racing has been popular for centuries. In 1879, breeders founded a studbook and since then they started with the improvement of the breed by selection and by importing good breeding horses from the USA and France (Minkema, 1989). The breeding of trotters in Hungary has been practised for more than 100 years. The first official trotter race was organised in 1883 in Budapest (Bodó et al., 1989). Trotter racing is also very popular in Belgium, where the first society "Federation des hippodromes de grands champs" has been created before 1900. In 1976, the name of the society has been changed to "Federation Belge du Trot" (Leroy et al., 1989).

3. Types of trotting race

The different types of trotting race are matinee race (held primarily to allow the racing secretary to broadly evaluate the horses' racing ability), qualifying race (race upon which there is no betting and staged solely to establish minimal performance standards in order to make a horse eligible for entry for races at a particular track), claiming race (allows purchase of horses after the race), maiden race (for horses that never won a race), open race (open to all horses, but usually attracts only relatively faster horses), and condition race (restricts participation to horses that meet certain conditions (for example 3-year-old fillies with winnings of less than $10,000 etc.) (Physick-Sheard, 1986). In trotting races, there are two starting methods; they are volt-start (the horses start the race in circled group (voltage) on command. This type is practised in oval tracks) and auto-start (also called as flying start or start behind a car. Major races are often started behind a car with wings).

4. Racing performance of trotters

Racing performance in trotters, in contrast to Thoroughbreds is characterized by

i) qualifying tests before entering races,
ii) inclusion of more than one breed in international races only,
iii) greater duration of racing career. The ages during which horses are allowed to race are from 3 to 16 years for Finnish Trotter and 2 to 14 years for Standardbred trotters and 2 to 10 for French Totters. But most horses are starting in races between 3 and 5 years of age (Langlois, 1985; Ricard et al., 2000).

4.1. Measures of racing performance in trotters

a. Time traits: Racing time is expressed as the inverse of a speed i.e., the time taken to cover 1 mile (Standardbreds) or to cover a kilometre (in Europe). A horse can be evaluated through its average time or more commonly by its lifetime best time. In this case some indications are also given about age, racetrack, type of start, harnessed or mounted are generally given. It will be explained later on these various factors.

b. Earnings: In a race the four or five placed horses receive a prize money. Allocation is nearly made as follows. If the first receives X, the second receives (0.5) X, the third $(0.5)^2$X, the fourth $(0.5)^3$X, and if $(0.5)^4$X is not negligible the fifth will receive it (Langlois, 1983a). This mechanism explains why the very skewed distribution of earnings can be normalised by a log transformation or other similar functions for stabilising variance (shrinking the extremes toward the mean) as the different roots.

Accumulated earnings over the years by age are by extension transformed in the same manner. The same is done for the yearly average earnings per start. The same procedure can be applied to the whole career accumulated earnings.

c. Perfect gait: For trotting races there are judges observing the faults i.e., going from trot into the gallop or going to trot into the pace. Perfect gait is a score, which takes into account the number of faults made by a horse during his career.

d. Number of starts can be considered including or excluding the zero starts. It can be considered according to age or for the whole career. For statistical reasons its study is often limited to earning horses.

e. Rank in races

i) Percentage of first placings: It reflects a horse's temperament, its spirit and willingness to win (Ojala, 1989).
ii) Percentage of first to third placings: It reflects a horse's level relative to that of the mates in the same race (Ojala, 1989).
iii) According to the rank and to the number of horses starting in the same race a normal score can be attributed. For trotters the square root of the rank is often used to approach the true solution.

f. Qualification status: It is a career trait; each trotter needs to pass a qualification test before entering the racing circuits. Once a trotter has passed this test, it will be qualified for life (Langlois and Vrijenhoek, 2004). Starting status and earning status are all-or-none criteria of the same kind highly correlated with it.

4.2. Adjustment of records to evaluate trotting performance

Trotting performance measured by annual or career earnings has been adjusted for age, sex and year. These effects are largely dependant on the policy of the racing society. Race earnings and ranks are generally corrected for an individual race effect. When measured by time criteria, age, sex, year, racing distance, racetracks, track condition, temperature, class of race, starting method, post position, season, region, prize money, pace and harness versus mounted effect are often considered. (Katona, 1979; Árnason et al.,1982; Langlois, 1983b; Tolley et al., 1985; Langlois, 1989a,b, Petzold et al., 1989; Minkema, 1989; Klemetsdal, 1989; Tolley et al., 1989). Because most of these numerous effects are included in the individual race effect, it is therefore recommended to adjust for it. When using time criteria, Bugislaus et al. (2005a,b) also opined that in order to avoid bias in estimation of genetic parameters individual race effect should be considered in the statistical model.

Age and gender effects will be examined further, as will be the year of racing with the genetic progress. Effect of racing distance on the speed is observable in countries having a wide range of distances in races. This effect can bias the estimation of the effect of age because younger horses race on shorter distances. It can also increase the difference between volt-start and auto-start because auto-start is not needed for longer race distances. In mean, adding 100 m results in increasing the time/km by 0.10 s (Langlois, 1983b). Racetrack effect results from some physical conditions such as the type of ground (grass slower than the sand), shape of the curves and evenness and length of the straight lines. It also results from the reputation of the racetrack, which attracts special quality in horses.

Racing results are not directly reflective of the maximum speed at which an individual can cover a given distance. Instead, this measures an individual's ability to respond to a given set of circumstances. Slow pace would slow all members of the field, while a fast pace would exert a drag effect (all horses in a race tend to go faster if the leader's time is fast) on even for the slowest member. Pace accounted for more than 80% of the variation attributable to class of race (Katona and Osterkorn, 1977; Linner and Osterkorn, 1974; Rönningen, 1975; Tolley et al., 1989). Type of start had an influence on best racing time and the best racing time was the best on auto-start (near 1 s/km lower time). The same difference (1 s/km) was observed in favour of harness races over mounted races. Pace races were also quicker than trotting races because they were almost as fast as the gallop races.

4.2.1. Effect of month of birth

Saastamoinen and Ojala (1991a) observed that the effect of birth-month on racing performance was more pronounced in Standardbreds than in Finnish trotters. The influence of birth-month was expressed most clearly in 3-year-old Standardbreds. Horses born in January to March were faster, had greater earnings and a larger number of both 1st placings and 1st to 3rd placings than their race mates born later. With regard to performance over the whole career, the most advantageous time of birth was January to May for Standardbreds and March to June for Finnish Trotters. The poorest performance in both breeds was observed for horses born in late summer or in the fall. Langlois and Blouin (1997a,b), confirmed this observation for French Trotters.

4.2.2. Effect of age

Younger animals have slower times at finish; a 3.2 s/km difference was observed between 2- and 10-year-old German Trotters (Katona and Osterkorn, 1977). In addition, older animals (7 to 12 years) have advantage over younger animals (3 to 6 years) in percentage of races won, percentage of races disqualified, percentage of races not ranked and money won/start (Rönningen, 1975). The age-wise winning time of Canadian Standardbred is presented in Table 1. The author concluded that the best recorded time was achieved at 2.7 years of age (Physick-Sheard, 1986). The conditions seem quite different in France where a monthly exponential like decrease in time per kilometre with age was precisely described (Langlois, 1983b). A difference of 5.7 s/km was observed between 2- and 6-year-olds and only 3.4 s/km between 3- and 6-year-olds.

Table 1
Age-wise winning time (over a mile) of Canadian Standardbred trotters.

Age (years)	*n*	Mean mark (min)	Best mark (min)
2	75	2′11.4″	1′95.0″
3	203	2′12.9″	1′94.0″
4	90	2′12.8″	1′99.3″
5	30	2′14.3″	2′05.0″
6	10	2′11.8″	2′04.7″

Source: Physick-Sheard (1986).

The mean best-recorded time of Canadian Standardbred is presented in Table 2. Best racing time of Finnish Trotter populations diminishes with age (Ojala, 1982; Ojala and Hellman, 1987; Leroy et al., 1989). The ability to begin the career early and show good performance at an early age is a desirable feature of horses in the trotting sport. Horses starting their career early have been reported to be superior to other individuals as racehorses and to have longer careers (Physick-Sheard, 1986; Saastamoinen, 1991a,b; Saastamoinen and Ojala, 1991b; 1994). Saastamoinen (1991a,b) observed that the trotters broken at 1 or 1.5 years of age and racing by 3 years of age were significantly faster (by 2.1 s), had a greater number of starts and higher earnings by 5 years of age than those broken at 2 or 3 years. Trotters broken and trained by professional trainers tended to perform better than those broken and trained by breeders and owners. The author concluded that, in general, young age at first start was associated with superior performance and the performance in one season at a young age was highly correlated with the performance in the first three years. Subsequently, Saastamoinen and Ojala (1994) also observed that the horses starting their racing career young and racing during several consecutive years were superior to other horses. Horses racing only as 3-year-old had 5.6 s/km slower career times than those racing at 3-, 4- and 5- year-olds. These differences are respectively 7.5 and 6.4 s/km for the horses racing only as 4- and 5-year-olds.

The genetic correlation between early and mature performance was found to be high for performance measured as earnings or earnings per start (0.76 to 1.00). For age-based trait analysis in French Trotters (Langlois, 1984b) these correlations remained high i.e. 0.89 between 2- and 3-year-olds, 0.96 between 3- and 4-year-olds and 0.77 between 2- and 4-year- olds. This indicated that early performance seems to be a good predictor for selection of a mature horse (Árnason et al., 1989; Klemetsdal, 1994). However, Saastamoinen and Nylander, (1996a,b) and Ricard et al. (2000) reported that the early performance (age at first start) had very low heritability (0.14 to 0.16), which indicated that early start of a career depends mainly on environment.

4.2.3. Effect of sex

Males held advantage over females in best times (1.6 s), times at finish (1.2 s) and money won per year. Males were

Table 2
Mean (±SE) best recorded time (over a mile) of Canadian Standardbred Trotters.

Sex	n	Time (min)
Male	128	2′10.3″ ± 0.006
Female	222	2′13.9″ ± 0.005
Geldings	153	2′10.8″ ± 0.005
Pooled	503	2′12.0″ ± 0.003

Source: Physick-Sheard (1986).

also superior to females in percentage of races won, percentage of races ranked and money won per start (Rönningen, 1975; Katona and Osterkorn, 1977; Minkema, 1989). However, Minkema (1975) observed that in Dutch Trotters the 2-year-old fillies won more money than 2-year-old colts and geldings. For the 2- to 3-year-old trotters only a slight advantage in favour of the fillies was felt. According to Langlois (1983b) males were 0.4 s/km faster than females. This advantage diminished after 5 years and disappeared at 7 years of age due to selection phenomena; only best females were remaining in races. For the best time record the advantage in speed of colts and geldings over fillies was 1.2 s (Table 3). The superiority of males over females was also reported by Langlois (1982) in his review. Further, Ojala and Hellman (1987) observed that males were superior to females with regard to best racing time of Standardbred horses in Finland and Finnish Trotters. However, Ojala et al. (1987) obtained different results but on a smaller set of data. However, subsequent report by Leroy et al. (1989) stated that the Belgian Trotter males were superior to castrated males and females. Males were 0.498 and 0.385 s faster than the females and castrated males respectively while geldings were 0.113 s faster than females. Similarly, Langlois and Vrijenhoek (2004) reported that best time decreased as the age advanced as seen before for meantime and the values observed in French Trotters as 2-, 3-, 4-, 5- and 6-years of age were 1′24.7″, 1′23.2″, 1′21.5″, 1′20.5″ and 1′19.9″ min/km respectively. The career total races for males, females and geldings were 49 to 56, 24 to 29 and 46 to 58 respectively. The mean number of races per year for males, females and geldings were 15.6, 12.3 and 15.9 respectively (Physick-Sheard, 1986). In French Trotter, Langlois and Blouin (2008) reported that the females had a lesser probability than males to appear in races and when they started they had a lesser number of starts.

Table 3
Means and standard deviations of time records (min) for kilometre per age class of Dutch Trotters.

Age/character	Sex	n	Mean	Standard deviation
Time at finish				
2-year-old	Male	315	1′42.9″	11.3
	Female	361	1′42.6″	11.7
2 to 3-years-old	Male	612	1′36.8″	9.1
	Female	719	1′36.9″	9.1
2 to 4-years-old	Male	808	1′33.4″	8.0
	Female	910	1′33.9″	8.1
2 to 5-years-old	Male	868	1′31.5″	7.8
	Female	968	1′32.1″	7.9
2 to 6-years-old	Male	876	1′30.4″	7.7
	Female	980	1′31.4″	8.0
2 to 7-years-old	Male	885	1′29.9″	7.9
	Female	986	1′31.0″	8.1
2 to 8-years-old	Male	887	1′29.6″	8.2
	Female	989	1′30.8″	8.3
Average time	Male	887	1′30.9″	8.7
	Female	993	1′32.2″	9.0
Best time	Male	887	1′29.6″	8.1
	Female	993	1′30.8″	8.4

Source: Minkema (1975).

Table 4
Summary of heritability estimates of trotters of earnings and time.

Criterion	Range	Average estimate	Weighted average
Log of earnings	–	0.41 (1)	0.41 (1)
Time	0.04–0.48	0.31 (10)	0.34 (10)
Best time	0.18–0.36	0.24 (3)	0.25 (3)
Earnings	0.00–0.26	0.16 (3)	0.20 (4)

Source: Hintz (1980).
Figures in parentheses are the number of estimates.

4.3. Genetic parameter estimates for different measures of trotting performance

Minkema (1978), Langlois (1982, 1984a) and Hintz (1980) reviewed the heritability estimates of trotters and reported (Table 4) that log of earnings is highly heritable (0.41) and time, best time and earnings are moderately heritable (0.34, 0.25 and 0.20 respectively). Hence, genetic improvement of trotting performance can be accomplished via selection based on the animal's own record, particularly if log of earnings information is used. Árnason et al. (1982) stated that the heritability estimates (Table 5) for best racing time and earnings were found to be almost equal and the genetic correlations between these traits were very strong (0.96). The authors concluded that studies on heritability of racing performance traits based on earnings, speed or rank functions with few exceptions yielded estimates in the range of 0.2 to 0.4. Heritability of number of starts was 0.1. Racing measures based on time, earnings and ranks were found to be mutually highly genetically correlated. One can remark that these three measures are in fact nearly the same one at the race level when the data are corrected for the individual race effect. Indeed, only the unit of between ranks measurements is changing. With earnings, the log transformation is stabilizing the difference between two consecutive ranking to nearly log 0.5. With ranks this quantity is one or fraction of one when one considers the variation in number of starts by using normal order statistics. With time measures this quantity is expressed in seconds. However, one has to consider that the breeder's goal is to win money. To have a fast horse is for him only a tool. Given the much lower phenotypic correlation between earnings and time, it is important not to

Table 5
Heritability estimates of different racing performance traits of Swedish Standardbred Trotters.

S. no	Trait	Heritability (±SE)
1	Log_{10} (Best racing time)	0.31 ± 0.06
2	Number of starts	0.08 ± 0.04
3	√ Number of starts	0.10 ± 0.04
4	Per cent races won	0.22 ± 0.05
5	Per cent races placed 1st to 3rd	0.26 ± 0.05
6	√ Per cent races placed 1st to 3rd	0.27 ± 0.05

Source: Árnason et al. (1982).

forget this situation, particularly for breeds that are running on longer distances. This explains for example the choice of French indexing on earnings because they are running for 2400 m compared to the Standardbred preferring the time because they run for 1600 m. On longer distances discrepancies between time and earnings have indeed greater chance to appear.

4.3.1. Time traits

a. Time at finish: A natural choice to measure a performance trait for a racing horse is to measure its ability to run fast. For each horse, in each race, the time is officially recorded and converted to the average time per 1000 m, unless the horse breaks its gait and starts to gallop and is going to be disqualified. Racing time has frequently been used as a measure of racing performance in trotters (Rönningen, 1975; Katona and Osterkorn, 1977; Ojala and Van Vleck, 1981; Tolley et al., 1983). The heritability estimates for time at finish are presented in Table 6.

The repeatability estimates of speed between 2 and 3, 3 and 4, and 2 and 4 years were 0.59, 0.55 and 0.31 respectively (Nikolaeva and Rozhdestvenskaya, 1979). Ojala and Van Vleck (1981) calculated repeatability and heritability estimates for 24 traits based on time, earnings and rank in Finnish Trotters and concluded that the repeatabilities and heritabilities for time traits were higher than for other traits and the measure based on time at finish would be more useful than one based on money or rank. Langlois (1983b) reported that the repeatability estimates of racing time at 2, 3, 4, 5 and 6 years of age were 0.54, 0.73, 0.70, 0.73 and 0.72 respectively. Tolley et al. (1983) observed that the repeatabilities of racing time for 2- and 3-year-old trotters were 0.40 and 0.38 respectively. Klemetsdal (1989) stated that the repeatability estimates for repeated racing times at 3 to 4, 3 to 5 and 3 to 6 years were 0.65, 0.65 and 0.64 respectively for the Norwegian Trotter. The estimates for Standardbred Trotters were 0.46, 0.46 and 0.46 respectively.

Röhe et al. (2001) observed a genetic correlation of 0.81 between rank and racing time. In addition, both traits were highly correlated with earnings (correlations of earnings with ranking and racing time were −0.98 and −0.89 respectively). They concluded that the most important trait for selection of racing performance was the racing time due to its

Table 6
Heritability estimates for time at finish in trotters.

Age (years)						Method of estimation	Country	Breed	Reference
2–2 1/2	2–3/3	4	5	6 and above	Mixed				
–	–	–	–	–	0.04	ODR	–	–	Öscag and Toth (1959)
–	–	–	–	–	0.06–0.92	OSC	USSR	Orlov and Russian Trotters	Gopka and Derev'yanchuk (1970)
					0.20–0.70				
–	–	–	–	–	0.24	ODC	USSR	Orlov Trotter	Gopka (1971a)
					0.40	–			
					0.08	PHS			
–	–	–	–	–	0.48	–	USSR	Orlov Trotter	Gopka (1971b)
–	0.34	–	–	–	–	–	USSR	Orlov Trotter	Kalmykov (1973)
0.22 ± 0.18	0.21 ± 0.11	–	–	–	–	–	Germany	German Trotter	Linner and Osterkorn (1974)
0.25	0.36	–	–	–	–	–	Germany	German Trotter	Linner (1975)
0.170 ± 0.196*	0.304 ± 0.100*	–	–	–	0.321 ± 0.096*	ODR	Netherlands	Dutch Trotter	Minkema (1975)
0.546 ± 0.220*	0.192 ± 0.115*				0.235 ± 0.076*				
0.168 ± 0.187**	0.327 ± 0.097**				0.320 ± 0.090**				
0.516 ± 0.222**	0.203 ± 0.116**				0.214 ± 0.080**				
–	–	–	–	–	0.15–0.59	OMR	USSR	Orlov Trotter	Kalmykov (1975)
–	–	–	–	–	0.21	–	Germany	German Trotter	Schwark and Freund (1976)
0.42 ± 0.18	0.47 ± 0.16	0.32 ± 0.11	0.32 ± 0.11	0.15 ± 0.09	0.20 ± 0.04	PHS	Germany	German Trotter	Katona and Osterkorn (1977)
0.30	0.28	–	–	–	–	–	Romania	Romanian Trotter	Georgescu et al. (1979)
–	0.41	0.15	0.39	0.32	–	PHS	Finland	Finnish Trotter	Ojala and Van Vleck (1981)
0.02 ± 0.19	0.10 ± 0.04	0.30 ± 0.05	0.42 ± 0.06	0.27 ± 0.06	–	–	France	French Trotter	Langlois (1983b)
0.45 ± 0.07^{+}	0.25 ± 0.04^{+}	–	–	–	0.31 ± 0.03^{+}	PHS	USA	Standardbred	Tolley et al. (1983)
0.31 ± 0.20^{++}	0.10 ± 0.09^{++}	–	–	–	0.16 ± 0.09^{++}				
	0.005 ± 0.006		–	–	0.034 ± 0.007 [a]	PHS	Norway	Standardbred	Klemetsdal (1989)
–					0.035 ± 0.006 [b]				
	0.176 ± 0.027				0.166 ± 0.022 [a]			Norwegian Trotter	
					0.186 ± 0.022 [b]				
–	–	–	–	–	0.23–0.28	–	Finland	Finnhorse and Standardbred	Thuneberg-Selonen et al. (1999)
					0.29	–	Germany	German Trotter	Röhe et al. (2001)
–	–	–	–	–	0.23	REML	Germany	German Trotter	Bugislaus et al. (2002)

ODC — Offspring–dam correlation, ODR — Offspring–dam regression, OMR — Offspring mid-parent regression, OSC — Offspring–sire correlation, PHS — Paternal halfsibs, REML — Restricted maximum likelihood. *Untransformed, ** Transformed., $^{+}$ Pacer, $^{++}$Trotter.

[a] Age — 3 to 5 years.

[b] Age — 3 to 6 years.

Table 7
Heritability estimates for average time and best time for trotters.

Age (years)						Method of estimation	Country	Breed	Reference
2–2 1/2	3	4	5	6 and above	Mixed				
Average time									
–	–	–	–	–	0.411 ± 0.090* 0.281 ± 0.070* 0.407 ± 0.084** 0.306 ± 0.073**	ODR	Netherlands	Dutch Trotter	Minkema (1975)
0.26 ± 0.10	0.49 ± 0.09	0.38 ± 0.08	0.30 ± 0.06	0.26 ± 0.06	0.30 ± 0.03	PHS	Germany	German Trotter	Katona (1979)
–	0.27 ± 0.29	0.30 ± 0.21	0.45 ± 0.22	0.74 ± 0.23		PHS	Finland	Finnish Trotter	Ojala and Van Vleck (1981)
		0.23 to 0.44			0.35	–	Germany	Standardbred	Katona and Distl (1989)
0.50	–	–	–	–					
Best time									
–	–	–	–	0.15 0.28 0.12	–	– OMR OMC	USSR	Orlov Trotter	Kalmykov (1973)
–	–	–	–	–	0.455 ± 0.096* 0.264 ± 0.072* 0.434 ± 0.089** 0.303 ± 0.073**	ODR	Netherlands	Dutch Trotter	Minkema (1975)
–	–	–	–	–	0.12 ± 0.03	PHS	Sweden	Swedish Trotter	Rönningen (1975)
–	–	–	–	–	0.09		Germany	German Trotter	Katona and Osterkorn (1978)
–	–	–	–	–	0.21 0.20	PHS	Italy	Hungarian and Italian Trotters	Dusek (1979)
0.15 ± 0.07	0.31 ± 0.06	0.20 ± 0.04	0.16 ± 0.04	0.15 ± 0.04	–	PHS	Germany	German Trotter	Katona (1979)
–	0.31 ± 0.29	0.28 ± 0.21	0.33 ± 0.20	0.70 ± 0.23	–	PHS	Finland	Finnish Trotter	Ojala and Van Vleck (1981)
–	–	–	–	–	0.26 ± 0.05	PHS	Sweden	Swedish Trotter	Árnason et al. (1982)
–	–	0.08 ± 0.08	−0.06 ± 0.07	0.00 ± 0.06	0.23 ± 0.11 [+] 0.03 ± 0.08 [+++] 0.20±0.16 [+++]	PHS	Finland	Finnish Trotter	Ojala (1982)
–	–	–	–	–	0.25	–	France	French Trotter	Langlois (1984b)
–	–	0.32 ± 0.06	0.27 ± 0.05	0.29 ± 0.05	–	Henderson-3	Finland	Finnish Trotter and Standardbred	Ojala (1987)
–	–	0.34 ± 0.06	0.27 ± 0.05	0.30 ± 0.05	–	ML			
–	0.23 ± 0.06	0.22 ± 0.04	0.29 ± 0.05	–	–	Henderson-3			
–	0.19 ± 0.05	0.21 ± 0.04	0.29 ± 0.05	–	–	ML			
–	0.20 ± 0.27	0.25 ± 0.20	0.15 ± 0.19	0.82 ± 0.23	0.36	PHS-Model 1	Finland	Finnish Trotter	Ojala et al. (1987)
–	0.06 ± 0.24	0.21 ± 0.19	0.15 ± 0.19	0.69 ± 0.22	0.28	PHS-Model 2			
–	0.32 ± 0.28	0.36 ± 0.21	0.28 ± 0.20	1.02 ± 0.24	0.50	PHS-Model 3			
–	0.33 ± 0.28	0.37 ± 0.21	0.37 ± 0.21	0.88 ± 0.23	0.41	PHS-Model 4			
–	0.31 ± 0.29	0.28 ± 0.21	0.33 ± 0.21	0.70 ± 0.23	0.40	PHS-Model 5			
–	0.45 ± 0.08	0.37 ± 0.05	0.35 ± 0.05	0.34 ± 0.04	0.26 ± 0.03 0.25	PHS	Sweden	North-Swedish Trotter and Standardbred	Árnason et al. (1989)
–	0.24 ± 0.06	0.27 ± 0.05	–	–	0.24 ± 0.05	REML	Norway	Norwegian Trotter and Standardbred	Klemetsdal (1989)
–	–	–	–	–	0.09 to 0.52	REML	Finland	Finnish Trotter and Standardbred	Saastamoinen and Ojala (1991b)
					0.27 ± 0.05	REML	Finland	Finnish Trotter and Standardbred	Saastamoinen and Nylander (1994)
–	–	–	–	–	0.27 ± 0.03 [a] 0.25 ± 0.02 [b] 0.20 ± 0.03 [a] 0.21 ± 0.01 [b]	REML	Finland	Standardbred Finnhorse	Saastamoinen and Nylander (1996a)
–	–	–	–	–	0.29–0.49	–	Finland	Finnhorse and Standardbred	Pöso and Ojala (1997)
–	–	–	–	–	0.35	–			
0.28	0.33	0.35	0.37	0.30	–	ODR	France	French Trotter	Langlois and Vrijenhoek (2004)

ODR — Offspring-dam regression, OMC — Offspring mid-parent correlation, OMR — Offspring mid-parent regression, PHS — Paternal halfsibs, REML — Restricted maximum likelihood, ML — Maximum likelihood. [+]7–8 y, [++]9–10 y, [+++] 11–13 y. *Untransformed, ** Transformed.

[a] Single trait analysis.

[b] Multi-trait analysis.

substantial higher heritability and its high genetic correlation with earnings. Additionally, rank at finish could be included in the breeding goal because it reflects more the potential of trotters to win at finish and accounts for records without earnings. Similarly, Bugislaus et al. (2002) reported a racing time of 1′19.6″ min/km in German Trotters. Since the heritability of racing time (0.23) was higher than rank at finish (0.07) and log earnings (0.09), it may be used for genetic improvement of trotters. Subsequently, Bugislaus et al. (2005a,b) opined that racing time per kilometre was the most important trait for selection because it represented the highest heritability of all analysed racing performance traits. However, Tolley et al. (1989) stated that the racing ability was a composite trait reflecting horse's speed and its capacity to win against other horses with similar objectives. Choosing a trait that represents racing ability was a difficult task. A horse's racing time did not necessarily reflect the maximum speed at which that individual could trot or pace as at specified distance. Instead, it was a measurement of an individual's ability to perform in a particular racing situation.

According to recent selection for speeding trot, this trait remains heritable and genetic improvement is observed in most countries. Speed is only one quality of racehorse; its capacity to adapt to race conditions and to win at a certain pace is the complete goal. Individual race time doesn't perfectly reflect the genetic ability of an individual to trot or pace at maximum speed. Many factors such as track condition, track shape, racing strategy and quality of race mates may modify the expression of true speed. Hence, search for other traits to record performance is necessary (Ricard et al., 2000).

b. Average time: The heritability estimates for average time and best time are presented in Table 7. Katona and Osterkorn (1977) analysed racing time of German Trotters and reported that the repeatability estimates of average racing time ranged between 0.63 and 0.84. In a subsequent study, Katona (1979) found that the heritability estimates for average racing time/year ranged from 0.55 to 0.79 for the various age groups. The author concluded that 3-year-old records were suitable for selection purpose because estimates of heritability (0.49) and repeatability (0.68) were among the highest. Katona and Distl (1989) analysed different performance traits in German Trotter (Standardbred) and stated that among different traits studied, the most reliable was the average time. The authors were of the view that the heritability estimate of 0.50 for the average time of the 2- and 3-year-old progeny was very remarkable and should be utilized much more, than it was done at present. They further studied other traits viz. percentage of progeny raced at 2 and 3 years and percentage of progeny not raced up to the age of five years and observed heritability estimates of 0.21 and 0.27 respectively and concluded that these two traits were simple and evident traits and could be utilized as supplementary information.

c. Best time or mark: Mark refers to a horse's best (fastest) winning time for a mile in official races in a year. Career mark or career best is the fastest winning time for its career (Physick-Sheard, 1986). Best racing time expressed as s/km indicates a horse's level relative to that of all horses raced. The heritability estimates for racing time (Table 7) ranged between 0.03 and 0.70 and were mostly in the range of 0.2 to 0.3. Langlois and Vrijenhoek (2004) estimated the heritability for all-or-none

Table 8
Heritabilities of binary and performance traits for different age groups in French Trotters.

Character	Age (years)				
	2	3	4	5	6
Binary traits					
Starting status	0.28	0.43	0.40	0.36	0.32
Placing status	0.31	0.43	0.38	0.35	0.32
Best time status	0.36	0.39	0.38	0.36	0.32
Performance traits					
Total number of starts	0.13	0.07	0.07	0.10	0.11
Earning index	0.31	0.26	0.28	0.20	0.13

Langlois and Vrijenhoek (2004).

(binary) traits and performance traits and found that the estimates by dam–offspring regression were generally moderate to high (Table 8). However, sire and dam components (Langlois and Blouin, 2008) demonstrated considerable influence of common environments on theses criteria indicating that the chance to appear in races is not equally distributed among dams and stallions. The genetic correlations of best time with other traits (−0.76–0.37) were high except with number of starts.

4.3.2. Earnings

The heritability estimates of earning traits are presented in Tables 9, 10 and 11. Minkema (1975, 1976a) observed that the heritability estimates for lifetime performance were 0.26 for total earnings and 0.36 for the best time record. A square root transformation of earnings increased the heritability to 0.40. For selection purpose, the author recommended the use of earnings above time records, since the former allows to include non-starters in the breeding value estimation of horses. However, this makes the distribution of the criteria away from normality as it happens with the number of starts when zero starts are included.

Subsequently, some authors suggested that money earnings were a logical measure of racing performance for trotters (Katona, 1979; Langlois, 1983a, 1984a, 1989a,b; Saastamoinen and Nylander, 1996a). In many research studies, heritability of earnings was moderate and was sufficient to facilitate selection. Correlation between earnings and times were negative and high (Table 12) and so were favourable. Therefore selection based on times and earnings would be quite effective. Langlois (1989a,b) opined that the best time only characterizes speed potential without taking into account other aspects like regularity and sporting longevity, which were better taken into consideration by earnings. The development of indexation method based on earnings gives other advantages, which were psychological and practical. To approach normality, different authors used different forms of transformation of earnings. They were square root transformation (Katona, 1979), (lifetime earnings)$^{1/2}$, (lifetime earnings)$^{1/4}$ (Árnason et al., 1982), log of earnings per start (Langlois, 1983a, 1989a,b), $\log_{10}$ [(annual earnings + 1) / number of starts] (Silvestrelli et al., 1995), (cumulated earnings)$^{0.20}$ (Klemetsdal, 1994) and (annual earnings)$^{1/4}$ (Saastamoinen and Nylander, 1996a).

4.3.3. Perfect gait

It is the percentage of the correct ranking performance among all races. To normalize the perfect gait arcus-tangens-

Table 9
Heritability estimates for total earning of trotters.

Age (years)						Method of estimation	Country	Breed	Reference
2–2 1/2	3/2–3	4	5	6 and above	Mixed				
Total earnings/earnings per year									
0.00 ± 0.13	0.00 ± 0.08	–	–	–	–	–	Germany	German Trotter	Linner and Osterkorn (1974)
0.134 ± 0.067	0.248 ± 0.060	–	–	–	0.296 ± 0.056	ODR	Netherlands	Dutch Trotter	Minkema (1975)
0.139 ± 0.071	0.258 ± 0.065				0.215 ± 0.073				
–	–	–	–	–	0.14 ± 0.03	PHS	Sweden	Swedish Trotter	Rönningen (1975)
–	0.75 ± 0.34*	0.29 ± 0.21*	−0.10 ± 0.16*	−0.22 ± 0.13*	–	PHS	Finland	Finnish Trotter	Ojala and Van Vleck (1981)
	0.26**	0.06**	−0.01**	−0.11**					
–	–	–	–	–	0.30 ± 0.06	PHS	Sweden	Swedish Trotter	Árnason et al. (1982)
0.75 ± 0.34	0.29 ± 0.21	–	–	–	–	–	Finland	Finnish Trotter	Ojala (1982)
–	–	0.11 ± 0.04	0.09 ± 0.03	0.07 ± 0.03	–	PHS	Finland	Finnish Trotter and Standardbred	Ojala (1987)
–	0.07 ± 0.04	0.13 ± 0.04	0.29 ± 0.05	–	–				
0.244 ± 0.069	0.199 ± 0.054	0.225 ± 0.058	0.216 ± 0.060	0.207 ± 0.064	0.20–0.36	ODR	Netherlands	Dutch Trotter	Minkema (1989)
0.253 ± 0.075	0.281 ± 0.065	0.295 ± 0.075	0.351 ± 0.087	0.382 ± 0.097					
–	–	–	–	–	0.05 to 0.09	–	Finland	Finnhorse and Standardbred	Thuneberg-Selonen et al. (1999)

PHS — Paternal halfsibs, ODR — Offspring–dam regression, *Annually summarized, **Single races.

transformation was used. The heritability estimate of 2–2 1/2 year-old trotters was 0.17 ± 0.04 (Katona, 1979).

4.3.4. Number of starts

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 might be regarded as a possible indicator of the soundness of a horse's basic conformation. Health and endurance may be assessed by studying number of starts. Langlois and Vrijenhoek (2004) stated that the number of starts observed in French Trotters at 2, 3, 4, 5 and 6 years of age were 3.2, 8.1, 10.7, 12.2 and 13.6 respectively and the career total number of starts was 30.3.

Klemetsdal (1989) observed that the heritability estimates in Norwegian Trotters for transformed number of starts at 3, 4 and 3 to 6 years of age were 0.02, 0.07 and 0.10 respectively and the corresponding estimates for starting frequency were 0.09, 0.15 and 0.20 respectively.

Árnason et al. (1989) also reported low heritability estimates for number of starts at 3-, 4-, 5- and 6-year-olds and the estimates were 0.07, 0.04, 0.02 and 0.07 respectively in Swedish Standardbred Trotters. The genetic correlations between number of starts and the other traits were generally fairy low. However, the estimates in North-Swedish Trotter were quite different from those of the Standardbred. A fairly high heritability (0.45) and very high genetic (0.85) and phenotypic (0.83) correlations were observed between earnings and the number of starts.

Saastamoinen and Ojala (1991b) estimated heritabilities for number of starts, earnings and time traits and they ranged between 0.02 and 0.13 in Standardbred and Finnish Trotters. The number of starts had lower heritability among the different traits studied. In another study, Saastamoinen and Nylander (1994) also obtained low heritability estimates of 0.13, 0.09, 0.14 and 0.11 for number of starts, age at first qualifying start, age at passed qualifying start and age at first race respectively in Standardbred Trotter. Further, the same authors (Saastamoinen and Nylander, 1996a,b) reported that the traits viz. age at qualifying start, age at passed qualifying start and age at first race had high correlations with best time (0.38 to 0.43); earnings (−0.64 to −0.75) and number of starts (−0.71 to −0.79) in Finnish Standardbreds and Finnhorses. Age at first qualifying start, age at passed qualifying start and age at first start were highly correlated genetically and phenotypically. In, Finnish Standardbred Trotters, positive genetic correlations were found between the age traits and best career time. Whereas in Finnhorse, these correlations had higher estimates but with an opposite sign. The heritability estimates observed for (number of starts)$^{1/2}$ were 0.13 and 0.04 for the Standardbreds and Finnhorses respectively. From the results the authors concluded that the use of the age traits in the selection scheme was more reasonable than the use of number of starts and selection based on the results of an early career was likely to result in younger ages at qualifying start and first start. Pöso and Ojala (1997) reported that the heritability estimate for number of starts ranged between 0.08 and 0.18.

Langlois and Blouin (2007) analysed the racing careers of 2-, 3-, 4-, and 5-year-old French Trotters born in France between 1995 and 1999. The horses were evaluated on a set of traits, with particular attention to annual or career earnings and number of starts. The percentage of horses placed and the mean earnings for each age were combined to estimate the economic weights for each age class. The economic weights for the French Trotters at 2-, 3-, 4-, and 5-year-olds were 0.00, 0.21, 0.40, and 0.39 respectively.

4.3.5. Rank in races

It reflects a horse's temperament, its spirit and willingness to win. Rank at finish has been used by several authors (Árnason et al., 1982; Katona, 1985; Ojala, 1987). Transformations may improve the distributional properties of rank at finish. The reported heritability estimates (Table 13) ranged

Table 10
Heritability estimates for transformed earning traits of trotters.

Age (years)						Method of estimation	Country	Breed	Reference
2–2 1/2	3	4	5	6 and above	Mixed				
Log of total earnings									
0.137 ± 0.079	0.409 ± 0.068	–	–	–	0.456 ± 0.070	ODR	Netherlands	Dutch Trotter	Minkema (1975)
0.221 ± 0.082	0.318 ± 0.069				0.355 ± 0.077				
–	0.14*	−0.00*	0.02*	0.01*	–	PHS	Finland	Finnish Trotter	Ojala and Van Vleck (1981)
	0.04 ± 0.25**	0.22 ± 0.20**	−0.04 ± 0.17**	0.44 ± 0.21**					
–	–	–	–	–	0.20	–	France	French Trotter	Langlois (1984b)
–	–	0.24 ± 0.05	0.20 ± 0.04	0.14 ± 0.04	–	PHS	Finland	Finnish horse	Ojala (1987)
–	0.12 ± 0.05	0.10 ± 0.03	0.15 ± 0.04	–	–			Standardbred	
–	–	–	–	–	0.39 ± 0.06	REML	Finland	Finnish Trotter and Standardbred	Saastamoinen and Nylander (1994)
0.31	0.26	0.28	0.20	0.13	–	ODR	France	French Trotter	Langlois and Vrijenhoek (2004)
Log of earnings (0.20, 0.25, 0.50) and square root of earnings									
0.26 ± 0.12	0.15 ± 0.06	0.18 ± 0.06	0.09 ± 0.06	0.08 ± 0.08	0.11 ± 0.02	PHS	Germany	German Trotter	Katona (1979)
–	0.05 ± 0.25 [a]	0.13 ± 0.19 [a]	0.03 ± 0.18 [a]	0.21 ± 0.18 [a]	–	PHS	Finland	Finnish Trotter	Ojala and Van Vleck (1981)
	0.34 ± 0.29 [b]	0.41 ± 0.22 [b]	−0.01 ± 0.17 [b]	0.12 ± 0.18 [b]					
–	–	–	–	–	0.36 ± 0.06	PHS	Sweden	Swedish trotter	Árnason et al. (1982)
					0.33 ± 0.06				
	0.36 ± 0.07	0.33 ± 0.05	0.22 ± 0.04	0.31 ± 0.03	0.23 ± 0.03	PHS	Sweden	Swedish Trotter	Árnason et al. (1989)
					0.28				
–	0.15 ± 0.04	0.23 ± 0.05	–	–	0.25 ± 0.05	REML	Norway	Norwegian Trotter and Standardbred	Klemetsdal (1989)
0.14 to 0.27					0.21	–	Germany	German Trotter	Katona and Distl (1989)
0.22									
0.220 ± 0.057	0.221 ± 0.055	0.248 ± 0.059	0.252 ± 0.061	0.233 ± 0.063	–	ODR	Netherlands	Dutch Trotter	Minkema (1989)
0.237 ± 0.057	0.307 ± 0.059	0.355 ± 0.065	0.393 ± 0.070	0.408 ± 0.073					
–	–	–	–	–	0.14, 0.22	–	Norway	North-Swedish and Norwegian Trotters	Klemetsdal (1993)
–	0.14	–	–	–	0.20^{+}	REML	Norway	Norwegian Trotter	Klemetsdal (1994)
					0.23^{++}				
					0.22^{+++}				
					0.39 ± 0.03 [c]	REML	Finland	Standardbred	Saastamoinen and Nylander (1996a)
					0.33 ± 0.03 [d]				
					0.36 ± 0.01 [e]				
–	–	–	–	–	0.19 ± 0.03 [c]			Finnhorse	
					0.16 ± 0.03 [d]				
					0.17 ± 0.01 [e]				
–	–	–	–	–	0.32	–	Finland	Finnhorse and Standardbred	Pöso and Ojala (1997)
					0.33				
–	–	–	–	–	0.21				
					0.24				
–	–	–	–	–	0.36	–	Sweden	Standardbred	Árnason (1999)

ODR — Offspring–dam regression, PHS — Paternal halfsibs, REML — Restricted maximum likelihood. * Single races, ** Annually summarized, $^{+}$3–4 years, $^{++}$3–5 years, $^{+++}$3–6 years.
[a] Square root of average money.
[b] Square root of total money.
[c] Single trait analysis with starters.
[d] Single trait analysis along with non-starters.
[e] Multi-trait analysis.

between 0.12 and 0.25. Bugislaus et al. (2005a,b) concluded that because the trait log of earnings per race showed high bias it could be eliminated. The rank at finish was highly genetically correlated with the trait log of earnings per race and could be used as a good estimate for log of earnings.

4.3.6. Breaking stride

Breaking stride had an extreme effect on all measures of performance (Hintz and Van Vleck, 1978). Pöso and Ojala (1997) reported a heritability estimates of 0.14–0.23 for this trait.

4.3.7. Pooled estimates

Ojala (1987) reported that the heritability estimates for 3-, 4- and 5-year-olds Standardbred Trotters pooled over time, earnings and placing traits were 0.19, 0.17 and 0.23 respectively and the estimates for Finnish horses at 4-, 5- and 6-year-olds were 0.23, 0.21 and 0.18 respectively.

Table 11
Heritability estimates for average earnings per start of trotters.

Age (years)						Method of estimation	Country	Breed	Reference
2–2 1/2	3	4	5	6 and above	Mixed				
Average earnings per start									
–	–	–	–	–	0.27 ± 0.05	PHS	Sweden	North-Swedish Trotter	Rönningen (1975)
–	–	0.09 ± 0.03	0.15 ± 0.04	0.14 ± 0.04	–	PHS	Finland	Finnish Trotter	Ojala (1987)
	0.20 ± 0.05	0.21 ± 0.04	0.34 ± 0.06					Standardbred	
Transformed earnings/start (Log 0.20, 0.25, 0.50)									
0.34 ± 0.13	0.13 ± 0.06	0.11 ± 0.05	0.11 ± 0.07	0.13 ± 0.09	0.25 ± 0.04	PHS	Germany	German Trotter	Katona (1979)
–	–	–	–	–	0.68 ± 0.08	PHS	Sweden	Swedish Trotter	Árnason et al. (1982)
–	–	–	–	–	0.30	–	France	French Trotter	Langlois (1984b)
–	0.38 ± 0.07	0.38 ± 0.05	0.30 ± 0.05	0.29 ± 0.03	0.18 ± 0.02	PHS	Sweden	Swedish Trotter	Árnason et al. (1989)
					0.19				
–	–	–	–	–	0.26	–	France	French Trotter	Tavernier (1989a,b)
–	–	–	–	–	0.19	–	Italy	Standardbred	Silvestrelli et al. (1995)
					0.10				
					0.38, 0.44	–	Finland	Finnish Trotter and Standardbred	Pöso and Ojala (1997)
					0.24, 0.30				
					0.09	–	Germany	German Trotter	Röhe et al. (2001)
–	–	–	–	–	0.09	REML	Germany	German Trotter	Bugislaus et al. (2002)

PHS — Paternal halfsibs, REML — Restricted maximum likelihood.

4.4. Breeding evaluation of trotters

For the evaluation of the performance of horses in general and trotters in particular, breeding values are calculated. These are based on a combination of different traits that together are supposed to represent the ability to perform. In several European countries, trotters are genetically evaluated routinely for traits measuring racing performance by the BLUP (Best Linear Unbiased Prediction) method (Árnason, 1982; Árnason and Van Vleck, 2000). Large-scale genetic evaluations are run routinely for trotters, riding horses and Icelandic horses. The application of BLUP animal model for estimating breeding values of horses had been reported for various breeds at least in 10 European countries and for the Quarter Horse in the USA. Breeders had access to the estimated breeding values (EBVs) through publications and computerized databases. The United States equine industry, unlike many European breed associations, had been slow to adopt genetic evaluation as a tool for animal selection (Burns et al., 2004).

Table 12
Genetic and phenotypic correlations between time and earning traits.

Genetic correlation	Phenotypic correlation	Country	Breed	Reference
−0.86/−0.95	−0.59/−0.69	France	French Trotter	Langlois (1984b)
−0.88/−0.91/−0.93	−0.37/−0.46/−0.68	Sweden	Standardbred and North-Swedish Trotter	Árnason et al. (1989)
−0.93 /−1.00	−0.81/−0.89	Norway	Norwegian Trotter	Klemetsdal (1989)
−0.98/−0.98	−0.81/−0.88	Finland	Standardbred and Finnhorse	Saastamoinen and Nylander (1996a)

The use of selection index principles for genetic evaluation of horses started in the mid-1970s with Langlois (1975) for French Riding Horses and with Minkema (1976a) in the Netherlands for racing trotters. The BLUP method was first introduced to horse breeders with a simple example by Van Vleck and Hintz (1976). The first application of the BLUP method with real data appears to have been in the Icelandic horse (Árnason, 1980) and in German trotters (Distl et al., 1982) and was based on sire models (progeny tests). The implementation of BLUP with the animal model in horse breeding was initiated by Árnason (1984) and Árnason et al. (1984) for Icelandic and Swedish Trotters respectively.

Different authors suggested different traits for indexation. Minkema (1975, 1976a) recommended the use of earnings above time records, since the former allows to include non-starters in the breeding value estimation of horses. Similarly, Langlois (1984b) recommended the use of annual average earnings per start for indexation of French Trotters instead of the usual criterion of absolute best time. Ojala et al. (1987) suggested inclusion of other measures of racing performances viz. earnings and placings along with best annual racing time for better evaluation. Klemetsdal (1989) reported that the traits, average earnings per start, percent of placings 1 to 3, earnings per start and per cent placings 1 to 3 before five years of age have been commonly used by scientists to estimate genetic parameters and to predict breeding values in trotter populations. Tavernier (1991) evaluated French saddle horse based on ranks in competitions and suggested that this method could be applied to an "individual animal" as well as to a "sire" model. Although use of ranks might seem to lead to loss of information compared to physical measure, it was sometimes more reliable. In the case of horse races, ranking was absolutely necessary, as real physical measure was not identifiable.

In 1989 an overview was published (Langlois, 1989a) on the state of breeding evaluation in different trotter populations in Europe. The trotters in Belgium, Norway, Germany and the USA were evaluated based on best time (Leroy et al., 1989;

Table 13
Heritability estimates of rank in races and transformed values.

Traits	Age (years)					Country	Breed	Reference
	3	4	5	6	Mixed			
Number of first place finishes	0.63 ± 0.33	0.38 ± 0.22	−0.16 ± 0.15	0.15 ± 0.18	–	Finland	Finnish Trotter	Ojala and Van Vleck (1981)
Number of first fourth place finishes	0.30 ± 0.29	0.46 ± 0.23	−0.20 ± 0.15	0.23 ± 0.19	–			
Square root of first place finishes	0.48 ± 0.31	0.37 ± 0.22	−0.05 ± 0.17	0.23 ± 0.19	–			
Square root of first fourth place finishes	0.21 ± 0.28	0.49 ± 0.23	−0.19 ± 0.15	0.21 ± 0.19	–			
Percentage of first placings	–	0.15 ± 0.04	0.18 ± 0.04	0.14 ± 0.04	–	Finland	Finnish Trotter	Ojala (1987)
Percentage of first to third placings	–	0.23 ± 0.05	0.23 ± 0.05	0.21 ± 0.05	–			
Percentage of first placings	0.20 ± 0.05	0.16 ± 0.04	0.13 ± 0.04	–	–		Standardbred	
Percentage of first to third placings	0.22 ± 0.05	0.16 ± 0.04	0.16 ± 0.04	–	–			
Percentage of first to third placings	0.32 ± 0.07	0.22 ± 0.04	0.15 ± 0.03	0.24 ± 0.03	0.18 ± 0.02	Sweden	Standardbred	Árnason et al. (1989)
Square root of rank at finish					0.25	Finland	Finnish Trotter and Standardbred	Pöso and Ojala (1997)
					0.13			
Square root of rank at finish	–	–	–	–	0.05	Germany	German Trotter	Röhe et al. (2001)
Square root of rank at finish	–	–	–	–	0.07	Germany	German Trotter	Bugislaus et al. (2002)

Klemetsdal, 1989; Petzold et al., 1989; Tolley et al., 1989). Evaluation in France and the Netherlands used only earnings (Langlois, 1989b; Tavernier, 1989b; Minkema, 1989) and in Germany, Finland and Sweden multiple traits (per cent 1st placings)$^{1/2}$, (per cent 1st to 3rd placings)$^{1/2}$ and (earnings)$^{1/4}$ were used (Katona and Distl, 1989). Silvestrelli et al. (1989) reported that in Italy the male and female trotters were evaluated according to pedigree, conformation traits, performance (best time per life) and lifetime earnings. In addition, for stallions, progeny performance (best racing time), progeny earnings and number of starts were also considered for genetic evaluation.

In France index values based on the yearly average earnings per start adjusted by a repeatability animal model (BLUP) have been available routinely since 1986. In Sweden, index values based on a multiple trait animal model have been available to the breeders of the Standardbred Trotter since 1992. The traits included in the index were number of races, percentage of races ranked 1st to 3rd at the finish, earnings per race, total earnings, best racing time per kilometre and racing status. All traits were based on accumulated racing results as 3- to 5-year-olds. The traits were transformed in order to approximate the normal distribution before being included in the BLUP analysis (Árnason, 1994a).

About 40% of Swedish Standardbred trotters do not enter races as 3- to 5-year-olds and receive a start status of zero. Start status is genetically correlated with racing performance and is therefore a correlated pre-selection criterion for performance. Ignoring such a culling process can result in substantial selection bias (Klemetsdal, 1992). Árnason (1999) described computational procedure for multiple trait evaluation of the all-or-none trait, racing status and five continuous racing performance traits. Based on stochastic simulation studies the author concluded that the selection bias in EBV due to pre-selection of records is efficiently reduced by inclusion of the all-or-none trait racing status in the multiple trait animal model procedure together with the correlated performance traits. Langlois and Blouin (2008) reported that in trotters estimation of breeding values was not biased by selection of only earning horses. This was due to the fact that 89% of starting horses were earning some money. They concluded that correction of the selection bias expected from the introduction of none or all variables in the estimation of breeding value of trotters is probably not as important as it was thought previously.

A problem in genetic evaluation of trotters has been to find good normally distributed measures of performance, which are appropriate for use in the framework of linear models. Various mathematical transformations of records have been used to approximate normal distribution. The alternative but computationally demanding non-parametric ranking methodology for genetic evaluation of competition traits has been developed and has potential for practical applications in horse breeding, due to the dramatic improvement in computer technology (Tavernier, 1991).

Breeding values of French Trotters are estimated using a single trait animal model using log of earnings per start. But the four major disadvantages of this model are:

i. Earnings-based model excludes the horses without any earnings, which results in considerable loss of horses and supposes that horses with earnings are representative from the born horses.
ii. Status of the event depends on prize money, which is not necessarily equal to the true level.
iii. Quotient of earnings and number of starts does not sufficiently correct for performance at both extremities of the normal distribution, i.e. a similar performance (quotient) could be obtained with different numbers of starts; and
iv. There is a considerable risk of neglecting other traits when selection is based on a single trait and this could increase the risk in inbreeding (Ricard, 1997; Langlois and Vrijenhoek, 2004).

These four aspects indicate that a multiple trait model could be advantageous. Indeed, Árnason (1999) showed that bias was considerably reduced since the introduction of a multi-trait-based genetic evaluation of Swedish Trotters. The selection bias in estimated breeding value due to pre-selection of records was efficiently reduced by inclusion of the all-or-none trait i.e. racing status in a multiple trait frame work with the correlated performance traits.

In recent publications, models were developed that were based on individual race results, instead of annually summarized results. This allows the inclusion of specific environmental effects in the model, which makes assumptions about absence of pre-adjustment for these effects unnecessary (Röhe et al., 2001; Thuneberg-Selonen et al., 2001; Bugislaus et al., 2005a,b; Langlois and Blouin, 2008). Langlois and Blouin (2007) analyzed the racing careers of 2-, 3-, 4 and 5-year-old French Trotters and evaluated based on annual or career earnings and number of starts. They inferred that these race performance criteria have advantage among others (year and career performance traits) of avoiding the difficulties due to the variation in number of starts.

Based on the results of the study made on French Trotters, Vrijenhoek (2002) and Langlois and Vrijenhoek (2004) opined that an animal repeatability model based on earnings per start used currently for evaluation of French Trotters should be revised for better approximation to reality. A multivariate model that separates the performance of 2- to 6-year-olds would probably lead to higher accuracy of the breeding value estimates. An all-or-none trait per age should be included in the index together with earnings to better correct for the selection effects that influence a trotter career. Furthermore, a correction by regression of the number of starts could improve the present method, in which simple division was used. The authors proposed a model based on sex, year of birth, year of performance and year of indexation as fixed effects. The indexation would be based on

i. all-or-none traits, most probably qualification status,
ii. total earnings (transformed and standardized),
iii. best time, and
iv. number of starts.

Including best time in this model was not really necessary, but results in a better adaptation on the demands of the breeders; they have the possibility to select on both of the performance traits instead of only one of them. The three advantages of the proposed model were

i. it was closer to reality; since it was the total career performance that counts for the breeders,
ii. it gave a possibility to include qualification status as all-or-none trait, which measured early in trotter career; and
iii. the number of starts could be included in the index.

Subsequently, Rose et al. (2007) studied four variables viz. starting status, number of starts, number of starts without the zeros and number of starts of earning horses. The heritability estimates (Table 14) were much higher when zeros were included and decreased when zeros were excluded. They recommended using two principal traits; the qualification status and the career earnings, adding optionally the best time for facilitating the comparison between countries. Number of starts was proposed as an important correction factor for earnings (and best time) but not as a selection criterion. However, the correction of the selection bias expected from the introduction of all-or-none variables in the estimation of breeding values of the trotters was probably not as important as it was thought. They concluded that the previous estimations of breeding values made on earnings were not much biased.

Langlois and Blouin (2004a) opined that predicting the performance through breeding value evaluation at the moment of conception over-evaluated the level of performance actually achieved by 21% in trotting races. The breeding value estimation at the moment of conception had a correlation of 0.26 and it was lower than the expected correlation of 0.33. In another study, Langlois and Blouin (2007) evaluated horses based on a set of traits, with particular attention to annual or career earnings and number of starts and concluded that the use of logarithm of the annual earnings per start represents a relatively good compromise for measuring performances. They further stated that current breeding evaluation was based everywhere on continuous variables — mostly earnings — which basically excluded horses with no performance (zero earnings). To include these horses in the breeding evaluation, a variable like placed/not placed, could be added.

The increase in international trade of sport horses and breeding stock has created a need for genetic evaluation of

Table 14
Heritabilities of binary and performance traits for different age groups in French Trotters.

Variables	Model	Age							
		3-year-old		4-year-old		5-year-old		2- to 5-year-old	
Starting status	Sire	0.456		0.514		0.451		0.450	
	Sire–Dam	0.442	0.370	0.502	0.390	0.440	0.296	0.559	0.430
Number of starts, zero included	Sire	0.104		0.133		0.095		0.160	
	Sire–Dam	0.097	0.205	0.124	0.215	0.090	0.144	0.148	0.244
	Animal	0.123		0.150		0.099		0.176	
Number of starts, zero excluded	Sire	0.070		0.034		0.023		0.054	
	Sire–Dam	0.067	0.383	0.034	0.230	0.022	0.252	0.052	0.219
	Animal	0.070		0.027		0.022		0.047	
Number of starts of earning horses	Sire	0.112		0.056		0.038		0.060	
	Sire–Dam	0.106	0.512	0.053	0.420	0.037	0.312	0.058	0.291
	Animal	0.121		0.057		0.040		0.050	

Source: Rose et al. (2007).

breeding horses across countries. Therefore, there is growing interest in the development of international genetic evaluations of horses. Inter-Nordic genetic evaluation of Nordic trotters and Icelandic horses (Árnason et al., 1994; Árnason and Sigurdsson, 1997; Árnason et al., 2006) has already begun. The breeding horses could be fairly compared across country on basis of EBVs. Inspection of the estimated genetic and environmental levels across country could be very valuable.

The BLUP index must be an appropriate selection tool as it allows early selection of females and males and it must increase the culling of old breeding trotters (Tavernier, 1989a). The advantages of using BLUP animal model are information from many different sources may be used and many breeding values can be estimated. In addition BLUP method takes into account assortative mating and selection. Hence, selection based on BLUP EBVs with the animal model is by far the most effective way of changing genetic merit of horse populations. The uses of EBVs for planning matings and to predict potential genetic and phenotypic values of the candidate progeny are also of great value to the individual breeder. The BLUP method will facilitate the comparison of breeding values of stallions from different countries. There is a growing need for this comparison because of increased exchange of breeding stock. Some sires have progeny in different countries and these stallions can provide the information necessary to compare the mean genetic levels in different countries (Tavernier, 1988; Árnason and Van Vleck, 2000). The BLUP method takes into account all records of all relatives of a horse and environmental effects such as maternal herd effect, age, sex, year of recording and permanent environmental effect. The BLUP evaluation should become the selection tool and would give, with shorter generation interval, a genetic trend with over 50% improvement (Tavernier, 1989a).

Modern animal breeding requires dynamic breeding schemes in which the accumulation of new knowledge demands continuous methodological development of the procedures used for genetic evaluation of breeding animals. Future improvement of the system for genetic evaluation of trotters will probably involve improved modeling of the joint analysis of ordered categorical and normally distributed traits. Alternative genetic models including non-additive genetic effects, genetic groups, quantitative traits loci (QTL), finite number of loci, nonparametric ranking methodology, etc., might give a closer fit to the real data. Presumably some precautions should be taken to reduce the rate of inbreeding in the population before the effective population size becomes too small with loss in fitness as well as in genetic variation of performance traits and eventually a decreased rate of genetic response as the inevitable consequence (Árnason, 1999).

In the future, interest in the possible use of marker-assisted selection (MAS) for enhanced genetic improvement in horses is likely to increase. Genetic markers are DNA sequences that can be identified easily in individual animals. As the gene map of the horse becomes more complete there is increase in the chances of finding genetic markers closely linked to major genes affecting some important quantitative traits included in the breeding goal. The only indication of a plausible marker for a quantitative trait in horses found in literature was the report of Anderson et al. (1987) on an association between different alleles at the serum esterase locus (Es) and racing status (all-or-none trait depending on whether the horse has started in a race or not) in Swedish Standardbred Trotters. MAS is likely to be a valuable complement to selection on EBVs obtained by the BLUP method, rather than as a replacement for EBVs. The use of MAS in horse breeding schemes could be particularly useful for traits that are expressed late in the horse's life because the genetic markers will become known in the foal. The effect of MAS would be to shorten the generation interval and thereby increase the rate of genetic progress. At present, evidence for the existence of QTL with large effects (major genes) in horses is scarce. Traits, however, such as the lateral gaits, pace and toelt and other unusual behavioural characteristics related to special movements affecting trotting could quite probably be influenced by major genes (Árnason and Van Vleck, 2000).

5. Genetic improvement in trotter populations

The American Trotter best time over 1 mile decreased by 34.5 s from 1806 to 1856 and 29.25 s from 1857 to 1906 but did not change from 1938 to 1955 (Anderson, 1921; Hamori and Halasz, 1959). Selection for speed in Orlov Trotters from 1958 to 1972 resulted in only slight decrease in average time over one mile for offspring of progeny tested sires (Nikolaeva and Rozhdestvenskaya, 1979). Minkema (1981) demonstrated that racing times had steadily declined in Dutch Trotters between 1929 and 1958. The best time recorded decreased from 1′ 35.40″ min/km in 1929 to 1′ 26.85″ min/km in 1958 with an annual genetic progress of 0.307 ± 0.028 s. The estimated genetic progress per year was 0.479 ± 0.360 s/km for best time and 5.39 ± 3.24 for transformed earnings. The author attributed this improvement to simultaneous modernisation (especially track surface and flying starts) and genetic change due to selection and importation of superior sires. The author concluded that 0.24 to 0.31% of the total genetic improvement in racing time was attributable to genetic changes, most of which was effected by selection in males used for breeding. Langlois (1983b) showed a differential tendency according to the age of the record. If for 8-year-olds the decrease in time/km over years was low between 1968 and 1980, it was at the opposite very strong for the two-year-olds and progressively intermediate for the other ages.

The estimated annual genetic progress in racing performance traits of Swedish Standardbreds corresponds to 5% of the phenotypic standard deviation, 3.6% in French Trotters and 5% in Dutch Trotters (Minkema, 1981; Tavernier, 1989b; Árnason, 1994a). Klemetsdal (1994) showed a genetic trend of 3.2% of phenotypic standard deviation per year in Norwegian Trotters selected based on accumulated transformed earnings.

Árnason (2001) studied the trends and asymptotic limits for racing speed in Swedish Standardbred Trotters and predicted that the population average best time of 1′15″ min/km would be attained around the year 2015 and a racing time record below 1′10″ min/km (1.8″ s/km in auto-start) would be accomplished before the middle of the 21st century. The author concluded that the reliability of the prediction equation was dependant on the estimated asymptotic constants and the time span of the data. Future accumulation of additional data would provide information for more reliable predictions. Árnason (1994b) presented a non-linear polynomial genetic model (geometric progression) for a finite number of independent loci. Strictly this model is inconceivable for an infinite number of loci. In reality the unknown number of loci with segregating genes, which affect racing performance in trotters, is presumably large, but not infinite. The real genetic mechanism is far more complex, but this independent loci would explain the apparent asymptotic limits for genetic improvement of racing speed of horses (Árnason, 2001).

The implementation of an index based on BLUP with an animal model has increased greatly the selection intensity for both stallions and mares (Árnason, 1997). The annual rate of genetic response increased by 40% from 1988 to 1996 and corresponds to about 6% of one phenotypic standard deviation in racing performance. For trotters, racing speed, winning ability and earnings are highly positively correlated traits. Selection for racing performance, where earnings are the main component, has resulted in substantial genetic as well as phenotypic improvement in racing time. Genetic improvement is estimated to account for about 60% of the phenotypic change (Árnason and Van Vleck, 2000).

5.1. Generation interval

Trotters are having longer racing career hence the generation interval of mares and stallions were 12.1 and 15.8 years respectively (Minkema, 1976b). Ojala (1982) reviewed literature on generation interval of trotters and found an average generation interval of 11.4 and 10.4 years for males and females respectively. Langlois (1985) reported an average generation interval of 11.6 years for French Trotters.

6. Conclusions

Harness racing is a form of horseracing in which the horses run in a specified gait (trot or pace). Trotter ranks worldwide second to the Thoroughbred in popularity as a racehorse. The important horse breeds used for harness racing in different parts of the world are Standardbred, French Trotter, Swedish Trotter, Orlov Trotter, Russian Trotter, Finnhorse, Icelandic Toelter, Dole horse and North-Swedish cold-blooded horse. The performance of trotters is actually recorded as best times per kilometre and transformed earnings. These traits are moderately heritable and the estimates range between 0.20 and 0.40. An intensive selection of stallions on the basis of phenotypic racing performance has been practised in many trotter populations for quite a long time. Unlike the Thoroughbreds, improvement has been observed in different trotter populations and this is attributed to both genetic and environmental changes. Environmental changes include enhanced training methods, as well as improved tracks, harness and sulkies. A large but sometimes overlooked part of the 'environmental' improvement is however advanced genetic capacity of the competitors, which boosts the racing speed.

In several European countries, trotters are genetically evaluated routinely for traits measuring racing performance by the BLUP method. Large-scale genetic evaluations are run for trotters, riding horses and Icelandic horses. Breeders had access to the EBVs through publications and computerized databases. The increase in international trade of sport horses and breeding stock has created a need for genetic evaluation of breeding horses across countries. Therefore, there is growing interest in the development of international genetic evaluations of horses.

A problem in genetic evaluation of trotters has been to find good normally distributed measures of performance, which are appropriate for use in the framework of linear models. Various mathematical transformations of records have been used to approximate normal distributions. The alternative but computationally demanding non-parametric ranking methodology for genetic evaluation of competition traits has been developed. It has the potential for practical applications in horse breeding due to the dramatic improvement in computer technology. Recent selection for speed in trot indicates that the times and earnings traits remain heritable and genetic improvement is observed in most countries. Correlations between earnings and times are negative and high, and so desirable. Therefore, selection based on these are quite effective. However, a multiple trait approach avoids potential biases of one particular measure.

The racing performance of horses may be evaluated in both males and females and repeated observations can be obtained on the same animal. Hence, individual selection based on performance tests would be the selection procedure of choice. Information on racing performance of 2- and 3-year-old progeny could also be used, as becomes available, to increase the accuracy of sire selection; but progeny testing that would unreasonably increase the generation interval should be avoided.

Modern animal breeding requires dynamic breeding schemes in which the accumulation of new knowledge demands continuous methodological developments of the procedures used for genetic evaluation of breeding animals. Alternative genetic models including non-additive genetic effects, quantitative trait loci (QTL), nonparametric ranking methodology, etc., might give a closer fit to a real data. At present, evidence on the existence of QTL with large effects in horses is limited. Hence, further research in this aspect is needed to identify the major genes affecting some important quantitative traits related to trotting performance. These findings are likely to be a valuable complement to selection on estimated breeding values obtained by the BLUP method.

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