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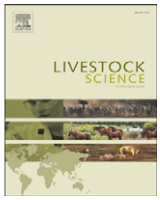

Inheritance of racing performance of Thoroughbred horses

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A B S T R A C T

Horse racing is a contest between horses, usually held for the purpose of betting. Thoroughbred horse racing is the most diffused form of horse racing throughout the world. Thoroughbred is one of the most versatile of horse breeds and has influenced the development of many other breeds. Thoroughbred horses served as a foundation stock for the development of the light horse breeds. The two types of horse racing are flat racing and jumping races/steeplechases. The measures of racing performance are broadly classified into three categories. They are time and its several variations, handicap or similar performance ratings and earnings. One common measure of the performance of racehorses evaluated genetically is racing time or final time. The heritability estimates differed according to method of estimation, age, sex, track and distance. Time measure generally had a heritability in the range of 0.1 to 0.2 with the higher values for shorter races. For handicap and earning measures the heritabilities reported were generally higher in the range of 0.3 to 0.4; hence these may be considered in genetic evaluation of racing performance of Thoroughbred horses. The average generation interval of Thoroughbred horses was 11.2±4.5 and 9.7±3.8 years for males and females respectively, which limits the genetic progress in racing horses. However, the major advantage is that the racing performance may be evaluated in both males and females and repeated observations can be obtained on the same animal in relatively short periods. These factors coupled with the reasonable heritability of some measures of racing performance, suggest that mass selection based on performance tests would be the selection procedure of choice to improve the racing performance of Thoroughbred horses. In general, the inbreeding at the rate that is usually practised in Thoroughbred population does not enable much gene fixing. However, practice of close inbreeding may be avoided, even though it still fascinates breeders at subconscious level.

1. Introduction

For thousands of years horses have been linked to humankind, as beasts of burden and in war. In most recent times, the emphasis of use has been on sport and recreation. Nowadays, horses are companion animals, providing people as riders or spectators, with such pleasurable pursuits as hacking, hunting, show jumping, racing, trotting, three-day eventing, dressage etc. Every day throughout the world, thousands upon thousands of men and women devote their energies to breeding, rearing, maintaining and working horses of one breed or another. The horse has become a national pastime in many countries, and the activities provide job security and income for many individuals employed in catering, journalism, advertising, gambling networks, farriery, saddlery, transport by air, road and sea and of course in the veterinary profession (Rossdale, 1995). Evidence of selective breeding of horses for both riding and draught purposes exists from ancient Elam in 2800 BC (Amschler, 1935). By 400 BC, selection standards remarkably similar to those used for selection of modern riding and racing horses had been defined for cavalry horses (Xenophon, 36?BC; Evans et al., 1995). However, despite the long recorded history of unidirectional selection and clearly defined selection goals within breeds, genetic research involving horses has been

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minimal compared with the amount of research devoted to the improvement of the meat and dairy species of livestock.

Racehorse populations provide examples of breeds, which have been selected over relatively longer periods of time. Historically, an individual horse's racing merit has been established by inexact indexing methods assigning relative, and perhaps trendy, valuation to performance and pedigree according to the collective perceptions of elite breeders. Development of racing breeds has been founded on the intuitive notion that a horse's ability to cover a specific distance in a relatively short time is determined in part by genetic components. The plausibility of this notion has been corroborated by subsequent specialization of racing stocks (Tolley et al., 1985). Some important characteristics of horse populations regarding breeding aspects are complete and deep pedigree registration, important traits measured on both sexes, low rate of reproduction, long generation interval, widely overlapping generations, non-random mating, large differences in price of the horse depending on expected breeding values and large proportion of the animals born are submitted to the control of one's performance (Arnason, 1998). Horse racing is a contest between horses, usually held for the purpose of betting. Thoroughbred horse racing is the most diffused form of horse racing throughout the world. However, in North America, American Quarter Horse racing is also popular.

Thoroughbred is one of the most versatile of horse breeds and has influenced the development of many other breeds. Thoroughbred horses served as a foundation stock for the development of the light horse breeds. Thoroughbred horses are primarily running horses but are also used for hunting, jumping, dressage, three-day events, polo, fox hunting, cow horses and so on. Thoroughbred horses have been developed for speed at intermediate distances. No other breed can match the Thoroughbred at racing distances of 6 furlongs (3/4 mile) to 1 1/2 miles the so so-called classic distance (2400 m). Most of the running Thoroughbreds are 15.1 to 16.2 hands high and weigh from 900 to 1200 lb (408 to 544 kg). The modern Thoroughbred is nearly two hands taller than the foundation Thoroughbreds of about 1750 (Evans et al., 1995). As early as the reign of King James I (1603–1625), Arabian horses were imported into England and were crossed with native light horses. During the reign of Charles II (1660–1685), the so-called Royal mares (foundation mares of the breed) were imported. Byerly Turk, Darley Arabian (or Barb) and Godolphin Barb (or Arabian) are the foundation sires of the Thoroughbred horses. They were brought to England between 1689 and 1728. The first part of these stallions' name refers to stallion's British owner; the second part is an indicator of horse's origin. Byerly Turk reached England in 1689 followed by Darley Arabian (1705 or 1706) and then Godolphin Barb around 1728 to 1730. All English and American Thoroughbreds trace their lineage in the male line from these three studs. All racehorses are inbred. Every name in pedigree traces in tail female to one of some 50 foundation mares (Royal mares) and in tail male to one of three patriarchs, *Matchem* (foaled in 1748), grandson of *Godolphin Barb*; *Herod* (foaled in 1758), great-great-grandson of Byrely *Turk* and *Eclipse* (foaled in 1764), great-great-grandson of *Darley Arabian* (Willett, 1975; Wright, 1989; Evans et al., 1995). According to a study by Cunningham et al. (2001), 95% of male lines trace back to this stallion. The first recording of Thoroughbreds in England was made in 1791 by James Weatherby Jr. in his introduction to a General Stud Book. The first volume appeared in 1793 and revisions were made in 1803, 1808, 1827, 1858 and 1891 (Wright, 1989). Thoroughbreds are primarily for racing under saddle at the gallop. Thoroughbreds that are born in the Northern Hemisphere technically become a year older on January first. Those born in the Southern Hemisphere turn one on July first and August first. These artificial dates have been set to enable the standardization of races for horse in certain age groups. Thoroughbred racing traces its foundation to the establishment of the Jockey Club in Newmarket, England about 1750 (Wright, 1989).

In racing the term horse includes stallion, mare, filly, gelding, colt, donkey or mule. For horseracing a trainer, who is hired by the horse's owner, would train horses for a particular event and also enters horses into races that would suit the horse. Trainers also have professional relations with jockeys, who ride the horse and give feed back to the trainer after every run. Horse racing is being held at different gaits (Wright, 1989; Evans et al., 1995; Rossdale, 1995). Research in to the genetics of Thoroughbred performance has been made in selected countries with a handful of researchers being responsible for the bulk of studies. Most investigations have been aimed at obtaining heritability estimates of performance, and they have been summarized in papers reported by Hintz (1980), Langlois (1980) and Tolley et al. (1985). Langlois (1996) has discussed this topic further. This review has been made to give complete and up-to-date details on racing performance of Thoroughbred horses.

2. Types of horse racing

The two types of horse racing are flat racing and jumping races/steeplechases.

2.1. Flat racing

Flat racing is a term commonly used in the United Kingdom to denote a form of horse racing which is run over a predetermined distance and in which the horses are not required to jump over obstacles such as hurdles or fences. This form of racing is a test of speed and stamina. Flat races in the United Kingdom are run over a variety of distance from five furlongs (1006 m) to over 2 miles (3219 m) and are generally called sprints, mile and classic distances or stayer's races. However, flat racing generally involves a racing distance of 1000–2500 m and animals may start racing at 2 years of age (Young et al., 2005).

2.2. Jumping races and steeplechases

They are called as National Hunt racing in the United Kingdom and Ireland. They are run over long distances, usually from 2 miles (3200 m) up to four-and-a-half miles (7200 m). National Hunt racing is distinguished between hurdles races and chases. The former is run over low obstacles and the latter over larger fences that are more difficult to jump. Horses involved in National Hunt racing have a longer racing career than those running on the flat. These horses begin racing at 3 to 5 years of age and reach their athletic peak between 6 and 11 years of age.

2.3. Other classes

Between the two types, there are other classes of races, which have been classified based on prize money, weight assigned etc. They are graded stakes or condition race, handicap, maiden, allowance and claiming races.

2.3.1. Graded stakes or condition race

It is a higher class race for bigger prizes. It is called as graded stakes race in United States and condition race in England and France. This often involves competitions that belong to the same gender, age and class. In these races, weights are adjusted only according to age, whereas in handicap racing, weights adjusted according to the racing performance. In condition races, all horses carry the same weight. The other set conditions such as having won certain number of races or races of a certain value. It is top quality race in which the owners pay nominating fee, entry fee and starting fee (Evans, 1989).

2.3.2. Handicap race

In handicap race, the runners would be handicapped according to their performance in other races. Theoretically, all horses have an equal chance of being competitive in a race that is correctly handicapped. In handicap racing, the racing secretary takes entries, evaluates the horse's past performance and assigns weights to be carried so that all horses have an equal chance of winning. The horses with better records or potential carry more weights than those with poorer records (Evans, 1989). Handicap weight is the total weight carried by the horse including the jockey, tack and extra weight assigned by the racetrack secretary. Heavier weights are assigned to horses that are considered to be faster and lighter weights are assigned to slower horse (Buttram et al., 1988a,b).

2.3.3. Maiden race

It is the one in which the runners have never won a race and maiden races can be among horses of many different age groups. It is similar to a stakes race in the respect that horses all carry similar weights and there are no handicapped penalties. This is the primary method for racing a 2-year-old for the first time.

2.3.4. Allowance race

It is one in which the runners are for a higher purse than in a maiden race. These races usually involve conditions such as “non-winner for their lifetime”. They usually are for a horse which has broken its maiden but not ready for stakes company.

2.3.5. Claiming race

The runners' run for a tag and anyone may claim a runner via the claim box. All horses entered are for sale at the price they are entered. They may be claimed or purchased by any owner who has started a horse at that race meeting (Evans, 1989).

3. Barrier gate and draw

Draw is more important in flat racing than National Hunt racing. It is significant in certain courses for sprints, races of five furlongs (1006 m) up to a mile (1609 m). The horses have less distance to make up if they start from inside barrier (called stall in the United Kingdom and Ireland) such as post-position one, rather than on outside such as post-position 15. In general, inner locations (one and two) are normally considered to be more favourable in Thoroughbred race. Mota et al. (2005) reported that in 1000 m, post-position one was significantly faster than the positions above four. At distance of 1300 m and 1400 m, post-positions one and two were significantly superior to the other post-positions. Post-positions one and two do not differ significantly from one another for any of the distance evaluated (1000 to 1600 m). At 1000 m post-position one was significantly faster than the post-positions above four (Martin et al., 1996). In National Hunt racing, horses do not have a draw because they are started by flag and line up behind a tape.

4. Measures of racing performance

A great abundance of data are available for racing performance at the gallop and the heritability of racing ability has received more attention than any other performance traits of the horse. However, the criteria available for measuring them are not, for the most part, really objective (Langlois et al., 1983). In order to evaluate genetically the racing performance of horses it is necessary to have a measure of performance. The measures of racing performance are broadly classified into three categories. They are:

a. Time and its several variations
b. Handicap or similar performance ratings
c. Earnings

a. Time and its several variations
   The different time traits considered are:
   i. Final time
   ii. Best time
   iii. Average time
b. Handicap or similar performance ratings
   i. Handicap weight/best handicap weight/timeform rating
   ii. Performance rates (length behind winner)
   iii. Position or ranking rates
   iv. Weight performance
c. Earnings
   i. Earnings
   ii. Annual earnings
   iii. Earnings/start
   iv. Average earning index (AEI)
   v. Standard starts index (SSI)
   vi. Log of earnings
   vii. Log of earnings/start
   viii. Tapered earning or prize-money rating.

4.1. Time

4.1.1. Final time

One common measure of racehorses' performance evaluated genetically is racing time or final time. It indicates the number of seconds a horse takes to complete a race. It is the direct measure of animal speed, however, it was influenced by all circumstances associated with that trait (Tolley et al., 1985). Previously it was measured only for the winner and for others it is estimated from the length behind the winner. Oki et al. (1994) reported racing time of Japan Thoroughbred horses in turf and dirt tracks for five distances viz. 1000, 1200, 1400, 1600 and 1800 m (Table 1). The racing time was less on turf than on dirt and there was a consistent increase in differences as the distance became longer. Mota et al. (2005) reported lower mean racing time of Brazilian Thoroughbred horses for distances of 1000 and 1600 m than Oki et al. (1994) and are presented in Table 2. Taveira et al. (2004) reported that the means for speed at 1000 m and 2000 m were 16.76 m/s and 15.91 m/s. Track type had significant effect on racing time and best racing time. Thoroughbred horses were faster on turf track than dirt track (Oki et al., 1994; Ekiz and Kocak, 2005). Mota (2006) stated that the mean number of starts per horse in lifetime was 10.9 (range 1 to 121) with 50% of the animals participating up to 7 races and 95% up to 32 races and only four horses started more than 100 times. The mean numbers of horses per race for the distances of 1000, 1100, 1200, 1300, 1400, 1500 and 1600 m were 8.3, 7.3, 7.1, 7.5, 7.3, 7.2 and 7.2 respectively.

4.1.2. Best time

It is the horse's fastest time over a given distance. It is defined as the fastest time out of several races won by the same horse. Best time achieved during a year or the lifetime best time may also be used as a selection criterion (Hintz, 1980; Ekiz and Kocak, 2005). The best racing time of an animal within a given period of time (year, life) reflects the maximum velocity of a horse, indicating its level in relation to all other animals that raced during the same period of time (Saastamoinen and Ojala, 1991).

4.1.3. Average time

It is the average of all the horse's times over a given distance. It indicates only the relative speed of the horse (Hintz, 1980).

4.2. Handicap or similar performance rating

4.2.1. Handicap weight/timeform rating

Thoroughbreds are handicapped by assigning increasingly heavier weights to the horse as supposed racing merit increases. Stepwise increases in weight carried have the average effect of slowing the speed of an individual over a given distance (Hintz, 1980). Handicap weights are established by specialists who, at the end of each race, determine the weights that would have allowed each horse to arrive in the same position as the others. It is generally assumed that 5 to 6 races allow the determination of the reference values of a horse (Langlois et al., 1983). At the end of each year, these handicap weights are published in the form of rating and are called handicap rating. This was used to rank the relative performance of all horses at a given point of time. These measurements are subjective though several researchers have used handicap as an indicator of performance level. Timeform rating is simply the merit of the horse expressed in pounds and it is obtained by careful examination of its running against other horses using a scale of weight for distance which ranges from around 3 lb a length for five furlongs, 2 lb a length for a mile and 1/4 to 1 lb for 2 miles. At the end of each racing year, final weight assignments for all the horses in training are determined at weight-for-age. Additionally, adjustments are made to the general level of the handicap so that all the ratings are kept at the same standard level from year to year.

Table 1
Racing times of Thoroughbred horses in Japan on turf and dirt tracks

Distance (m)	Turf (s)	Dirt (s)
1000	60.23±0.02 (4102)	62.32±0.02 (7620)
1200	72.36±0.01 (17,805)	74.82±0.01 (26,944)
1400	85.51±0.02 (13,761)	87.91±0.02 (12,407)
1600	98.20±0.01 (26,495)	100.75±0.02 (8384)
1800	111.84±0.01 (23,379)	115.75±0.01 (29,763)

Number of observations are in parentheses.
Source: Oki et al., 1994.

Table 2
Racing time (s) of Thoroughbred horses in Brazil

Distance (m)	Number of observations	Mean	Minimum	Maximum
1000	29,036	58.84	53.90	79.50
1100	30,414	69.06	58.60	85.90
1200	33,220	75.45	69.20	96.80
1300	51,879	81.13	74.30	104.40
1400	39,418	87.49	80.60	107.20
1500	27,429	93.66	86.80	105.40
1600	27,494	99.63	92.40	108.90

Source: Mota et al. (2005).

4.2.2. Performance rates

It is calculated from lengths behind the winner (Porter, 1971) and is also called handicap length. The performance rate expresses each horse's ability in terms of how many lengths it would be expected to finish from the average horse in the population. It is expressed in terms of lengths better or worse than the average race (Kieffer, 1975). The measure of lengths that a horse finishes ahead of or behind an average horse is really representative of its performance. It is defined as an estimate of how many lengths in front or behind the horse would finish compared to an average horse in an average race for a particular year. The advantage of performance rate over handicap is that the former is objective measure based on actual performance (Langlois, 1980). Foye et al. (1972) reported that performance rate has much more validity in measuring racing performance than money earnings since numerous horses finish out of the money because they race with high quality animals. The major advantages of this method are that it is an objective measure and uninfluenced by prize mode. However, it has disadvantages like, the beaten margin influenced by race distance and track condition. One very bad defeat can overwhelm all the horse's other good performance and it also reflects only the relative performance but does not indicate speed.

4.2.3. Position or ranking rates

It is based on finishing position within a race rather than margin. The level of rank is the difference between one's performance and those of the others. Rank at finish reflects relative performance but does not indicate speed. It is similar to performance ratings relying on finishing position rather than margins, will remove some of the problems associated with different lengths and track conditions, single unusual poor performance and problems with non-normality of the performance criterion (Langlois, 1980; Williamson and Beilharz, 1996, 1998; Belhajyahia et al., 2003; Sobczynska and Lukaszewicz, 2004; Svobodova et al., 2005; Bokor et al., 2007).

4.2.4. Weight performance

Weight performance used the prize money on offer to indicate the quality of race. The competitors (horses) are rated based upon the rating of the race (based upon prize money for the race, finishing position and number of starters), and their beaten margin adjusted for weight. Subjective appraisal of this system of measuring performance, by comparing the resultant ratings to relative merits of some of the horses, as assessed by weight performance, showed a high degree of concordance. It is a system analogous to position rates, relying upon finishing position rather than margin (Williamson and Beilharz, 1996).

4.3. Earning measures

Proponents advocating the use of earnings as the indicator of performance presented cogent arguments i.e. all individuals had equal opportunity, but not ability to win and earnings indicated what an individual was able to do in actual competition and therefore the level of earnings implied level of performance (Tolley et al., 1985). The value of information on racing ability supplied by the earnings is absolutely comparable to that of the various handicap systems. In addition, earnings do not require supplementary data management since, they are also subjected to accounting. Furthermore, the amount of information accumulated definitely exceeds that from other criteria (Langlois, 1980). At the end of race, money is allotted to the horses according to their ranking in the race. The different types of earning measures are as follows.

4.3.1. Annual earnings

The total earning of a horse in a year will be calculated for assessing its performance. The earning in a year reflects a horse's level of performance relative to that of all horses raced.

4.3.2. Cumulative earnings

Money is distributed in every race but the quality of a race must be measured on its entire career. It may be appropriate as a cumulated success over a year or a life and is called as cumulated earnings. Cumulative performance is combination of regularity, longevity and level of races won (Ricard et al., 2000).

4.3.3. Earnings per start

It is a measure of earnings in terms of number of starts. It is a more precise trait than earning because number of starts has been accounted for (Ricard et al., 2000).

4.3.4. Average earning index (AEI)

It is calculated from money won from racing. Estes (1948) introduced this type of performance measure and is calculated based on money won from racing. It is the yearly earnings of a horse or its average progeny.

$$\text{Actual amount won by horse or its progeny} = \frac{\text{Actual amount won by sire's progeny}}{\text{Number of starters} \times \text{Average entitlement of each starter}}.$$

(Wright, 1989)

This economic index ranked sires based on progeny performance in terms of amount earned per starter per year. Estes and Baumohl (1960) compared AEI of stallions and concluded that there was sufficient agreement to justify selection of sires and dams based on AEI.

4.3.5. Standard starts index (SSI)

It is the modified form of AEI, proposed by Clark (1977). In AEI bias occurs when a sire is represented by one highly successful money earner among few starters. In SSI, this bias has been removed by separation of earnings of fillies from those of colts and geldings and additionally 2-year-olds were ranked separately from older horses (Tolley et al., 1985).

4.3.6. Transformed earnings

Since many horses have little or no earnings, its distribution is extremely skewed. To make the distribution more normal and less skewed, logarithmic or square root transformation of earnings are often made. Some of the transformed measures are i) Log of earnings and ii) Log of earnings/start (Langlois, 1975; Langlois et al., 1983; Svobodova et al., 2005).

4.3.7. Tapered earnings or prize-money rating

It is based on combining prize money for the race, finishing position and number of starters (Williamson and Beilharz, 1996, 1998). Essentially it is simply a prize-money ratings, but with a distribution ensuring that all starters receive some money for each race. This approach greatly reduces the variation in earnings between winning and coming second or third, etc. It also ensures that every competitor receives some reward for running in difficult events. This should more accurately reflect ability than actual prize money.

4.4. Factors affecting racing performance

The factors affecting racing performance of Thoroughbred horses are age, sex, handicap weight, track condition, year, season, class of race, post-position, distance, trainer effect, jockey effect and race effect (Hintz, 1980; Langlois, 1990; Tolley et al., 1985; Oki et al., 1994; Evans et al., 1995; Bowling, 1996).

4.4.1. Effect of age

Age of the animal had significant influence on the performance. Laughlin (1934) found that peak racing performance of stallions, mares and geldings in the United States occurred at the age of 4, 2.5 and 5.5 years respectively. The estimated differences in handicap weight of colts minus fillies and colts minus geldings were 4.2 and 5.1 kg respectively. Several authors also confirmed the above findings and reported significant effect of age on racing performance of

Table 3
Least-squares means of racing time and best racing time at different ages in Thoroughbred horses

Age (year)	Racing time (s)			Best racing time (s)		
	Dirt ***	Turf ***	Entire ***	Dirt ***	Turf ***	Entire ***
2	110.7 (4371)	108.4 (4911)	108.9 (9282)	96.5 (1750)	95.9 (1786)	94.6 (2245)
3	109.7 (14,661)	106.9 (13,979)	107.6 (28,640)	95.3 (2619)	94.2 (2529)	93.1 (2857)
4	108.9 (9822)	106.3 (7864)	107.0 (17,686)	94.8 (1651)	93.6 (1411)	92.4 (1813)
5	108.8 (5593)	106.0 (4096)	106.8 (9689)	94.6 (871)	93.6 (713)	92.2 (975)
6	108.9 (3073)	106.0 (2068)	106.9 (5141)	94.8 (469)	93.2 (339)	92.3 (525)
7 and above	109.8 (3041)	106.4 (1586)	107.5 (4627)	95.5 (442)	93.8 (280)	92.8 (491)

Source: Ekiz et al. (2005).
Number of observations are in parentheses.
*** $P<0.001$.

Thoroughbred horses (Hintz, 1980; Moritsu et al., 1994; Oki et al., 1994; Langlois and Blouin, 1998; Mota et al., 2005; Ekiz and Kocak, 2007). However, Oliveira (1989) and Mota et al. (1998) reported non-significant effect of age if the analysis was made only for winning horses. However, subsequent analysis by including all participants (Mota et al., 2005) in the race revealed a significant effect of age on the racing performance of Thoroughbred horses. The authors concluded that excluding the 1100 m distance, animals of 4 years of age were significantly faster (0.13 s) than those of the other ages for all distances analysed i.e. 1000, 1200, 1300, 1400, 1500 and 1600 m. The superiority was marked at longer distances 1500 m (0.164 s) and 1600 m (0.22 s). Ekiz et al. (2005) observed that there was a decline in racing time and best racing time from young to intermediate age and an increase through seven years and older (Table 3). Horses 7 years and older showed lowest performance for rank and earnings per start. Although the annual earnings of 2-year-old horses were lower than those of 3-, 4-, 5- and 6-year-old ones, the differences among these age groups for earnings per start were not significant.

4.4.2. Effect of sex

Thoroughbred horse racing is carried out with males (colts, stallions and geldings) and females (fillies and mares). Several studies indicated that the sex of the horse played a major role in racing performance (More O'Ferrall and Cunningham, 1974; Langlois, 1975; Mota et al., 1998, 2005; Svobodova et al., 2005; Ekiz et al., 2005). Stallions have better racing performance, as measured by earnings and log of earnings (Langlois, 1975; Ekiz et al., 2005; Svobodova et al., 2005) and by handicap weight (More O'Ferrall and Cunningham, 1974). However, Oki et al. (1994) reported that the overall effects of sex were not large in Japanese Thoroughbred. They observed mixed results on turf and dirt tracks; mares were faster than stallions on turf at all distances but on dirt track stallions were faster than mares except for 1200 m. However, in the study of Moritsu et al. (1994) the effect of sex was non-significant for a distance of 1200 m and significant for distance of 1800 m. Subsequently Mota et al. (1998) observed that the males were significantly superior to females (0.39 s). The differences in racing time between sexes normally reflect different physiological characteristics of males and females while racing (Jelinek, 1988). In another study the authors (Mota et al., 2005) found that males were significantly superior to females at all distances. The contrast mean at all distances (0.30 s) corresponded to a difference of 1.5 body length between sexes. Svobodova et al. (2005) also reported significant effect of sex on earning and other traits in Thoroughbred horses of Czech Republic. Ekiz et al. (2005) concluded that the sex effect of the time traits was significant and males were much faster than females (Table 4). Males were also superior to females for rank, annual earnings and earnings per start.

4.4.3. Environmental source of variation

Different environmental components affect the racing performance of Thoroughbred horses. Oki et al. (1994) studied (Table 5) the effect of various non-genetic factors on racing performance in turf and dirt races and concluded that the individual race differences contribute to most of the variance. Hence, the removal of these effects was considered essential for performance evaluation. Subsequently, Oki et al. (1995b) reported that the race, jockey and weight carried were found to have highly significant ($P<0.01$) effects on racing time. The skill of jockey was an important source of variation in racing time across distances, track types and therefore, it should be considered in deriving adjustment factors, estimating genetic parameters and predicting genetic values for racehorses. Langlois and Blouin (1997, 1998) observed that the horse's month of birth had significant effect on annual phenotypic indices (calculated based on

Table 4
Least-squares means of racing time and best racing time of male and female

Sex	Racing time (s)			Best racing time (s)		
	Dirt ***	Turf ***	Entire ***	Dirt ***	Turf ***	Entire ***
Male	109.1 (24,617)	106.5 (17,492)	107.1 (42,109)	94.8 (4337)	93.9 (3716)	92.7 (4878)
Female	109.9 (15,944)	106.9 (17,012)	107.7 (32,956)	95.7 (3465)	94.2 (3342)	93.2 (4028)

Source: Ekiz et al. (2005).
Number of observations are in parentheses.
*** $P<0.001$.

Table 5
Environmental sources of variation of racing performance

Source of variation	1000–1800 m	
	Dirt (%)	Turf (%)
Race course	0–14.1	3.2–6.5
Years	0–2.5	1.1–4.5
Months	3.8–16.4	6.8–17.7
Days	0–6.7	3.2–19.0
Races	15.6–53.2	18.8–44.9

Source: Oki et al. (1994).

earnings), annual earnings and earnings per start. This difference might mainly be due to the effect of real age differences in the same 'administrative' age class. This effect can be supposed to decrease with advancing age. They recommended that the effect of horse's months of birth should definitely be taken into account for breeding value estimation.

Different workers considered different non-genetic factors and adjusted the significant effect for estimation of genetic parameters and performance evaluation. The adjustment of data depends on the kind of measurement of different racing traits. Some of the factors adjusted were animal age and sex, handicap weight, type of track, distance, jockey effect and month of racing (Langlois, 1975; Oki et al., 1994, 1995a,b; Langlois and Blouin, 1997, 1998; Mota et al., 1998, 2005; Ekiz et al., 2005; Bugislaus et al., 2005; Sobczynska, 2006).

5. Genetic parameters

5.1. Final time/winning time

For estimating genetic parameters of the trait several authors adjusted data for various systematic sources of variation. The heritability estimates for final time by several authors are presented in Table 6. The heritability estimates differed according to estimation method, age, sex, track and distance and it ranged between 0.06 and 0.84 (Oscag and Toth, 1959; Williamson and Beilharz, 1996). In most of the studies the heritability is lower than 0.20. Oki et al. (1995a) studied racing performance of Thoroughbred horses in Japan by REML (Restricted Maximum Likelihood Method). The average race records per horse at 3 years and above was 6.7. The values of heritability and repeatability on turf and dirt are almost similar (Table 7) and the heritability values decreased as the distance increased. They also suggested that racing time at different distances might be regarded as different

Table 6
Heritability estimates of final time/average time

Distance (m)	Age (years)					Method of estimation	Reference
	$2–2^{1/2}$	3	4	5 and above	Mixed		
–	–	–	–	–	0.06	ODR	Oscag and Toth (1959)
					0.04		
–	–	–	–	–	0.194	PHS	Artz (1961) (average corrected time)
1000–2000	–	–	–	–	0.243	ODR	
–	0.173	0.087	0.166	–	–	PHS	Bormann (1964) (average corrected time)
–	–	–	–	–	0.251	ODRS	Dusek (1963)
					0.448	ODRD	
–	–	–	–	–	0.195#	PHS	Dusek (1965)
					0.250##		
–	0.06 ± 0.01*	0.14 ± 0.02*	–	–	0.08**	PHS and ODR	Bormann (1966)
1600	–	–	0.12	–	–	PHS	Watanabe (1969) (average corrected time)
–	–	–	–	–	0.49	PHS	Pern (1970)
					0.53	ODR	
–	–	–	–	–	0.05 to 0.08	–	Pern (1971)
	–	–	–	–	0.10–0.78	–	Pern (1973)
–	0.16 ± 0.04	0.57 ± 0.04	0.28 ± 0.02	–	0.27 ± 0.02	Sire	Williamson and Beilharz (1996)
	–	–	0.47 ± 0.09	–	0.37 ± 0.05	Dam	
	0.27 ± 0.10	0.84 ± 0.08	0.18 ± 0.04	–	0.23 ± 0.02	Damsire	
–	–	–	–	–	0.08	–	Taveira et al. (2004)
–	–	–	–	–	0.232 ± 0.025¢	REML	Ekiz et al. (2005)
–	–	–	–	–	0.396 ± 0.029£		
–	–	–	–	–	0.317 ± 0.022¥		
1200	–	–	–	–	0.353 ± 0.035	REML	Ekiz and Kocak (2007)
1300	–	–	–	–	0.309 ± 0.055		
1400	–	–	–	–	0.265 ± 0.030		
1500	–	–	–	–	0.228 ± 0.046		
1600	–	–	–	–	0.248 ± 0.034		
1700	–	–	–	–	0.228 ± 0.069		
1800	–	–	–	–	0.214 ± 0.065		
1900	–	–	–	–	0.255 ± 0.039		
2000	–	–	–	–	0.227 ± 0.054		
2100	–	–	–	–	0.212 ± 0.048		
2200	–	–	–	–	0.180 ± 0.052		
2400	–	–	–	–	0.177 ± 0.056		

ODRS — regression of son on dam, ODRD — regression of daughter on dam, ODR — offspring–dam regression, PHS — paternal halfsib. # male, ## female. * paternal halfsib, ** offspring–dam regression. ¢ = turf track, £ = dirt track, ¥= entire (turf+dirt).

Table 7
Heritability and repeatability estimates of final time of Thoroughbred horses in Japan

Distance (m)	Heritability		Repeatability	
	Turf	Dirt	Turf	Dirt
1000	0.254	0.191	0.700	0.669
1200	0.160	0.217	0.579	0.645
1400	0.096	0.121	0.507	0.509
1600	0.121	0.086	0.581	0.556
1800	0.087	0.165	0.432	0.671
2000	0.081	–	0.586	–

Source: Oki et al. (1995a).

traits when the horse was evaluated genetically. Oki et al. (1997) reported that the genetic correlation between racing times on turf and dirt tracks ranged from 0.31 to 0.69 (average of 0.51). In both tracks, the genetic correlations between the nearest distances increased as the distances increased. These results indicated that the racing time per 100 m could be used in the genetic evaluation of the horses considering of the high estimated genetic correlation (mean of 0.85 for distances 1000 to 2000 m).

Ekiz et al. (2005) reported moderate to high heritability estimates of 0.465, 0.293 and 0.359 for racing time of Thoroughbred horses at dirt, turf and combination of both tracks. Ekiz and Kocak (2007) reported that the heritability and repeatability estimates ranged from 0.177 to 0.353 and 0.289 to 0.404 respectively depending on the racing distances. They concluded that a moderate level of genetic progress was possible for racing time if selection was based on the phenotypic value of the horses. Mota (2006) opined that racing time at 1000 m seems to be an interesting trait to be applied in breeding program, since in addition to representing the first performance record of most animals in Brazil, it shows higher heritability (Table 8) and direct selection based on 1000 m may lead to higher genetic gains than those obtained by indirect selection for large number of traits (e.g. performance at 1300, 1400, 1500 and 1600 m).

However, Chico (1994) reported that the speed was not the proper selection criterion for selection program for Spanish Thoroughbred population since the heritability and repeatability estimates obtained for this trait was close to zero. Similarly, Taveira et al. (2004) reported that the heritability of winning time was low and hence small response was possible for this trait if selection was based on the phenotypic value of the animals. Information about collateral relatives and progeny may help in identification of genetically superior horses, although waiting for progeny information will further increase the generation interval.

Table 8
Heritability and repeatability estimates of final time of Thoroughbred horses for races at different distances in Brazil

Race distance (m)	Heritability*	Repeatability*	Heritability**
1000	0.29	0.63	0.32
1100	0.21	0.47	0.25
1200	0.15	0.38	0.20
1300	0.10	0.24	0.14
1400	0.06	0.20	0.11
1500	0.04	0.15	0.10
1600	0.05	0.19	0.10

Source: *Mota et al. (2005). **Mota (2006).

The heritability and repeatability estimates tend to decrease with increasing racing distances (Oki et al., 1995a; Williamson and Beilharz, 1998; Mota et al., 2005; Mota, 2006), indicating that selection based on racing time becomes less effective when the racing distances increase. With increasing racing distances, more factors, probably environmental ones, influence racing performance. In a relatively short distance (1000 m), horse can run fast instinctly and jockeys have no great influence on the performance. As races get longer, jockey contributes indirectly to the temporary environmental source of variation. Hence, racing time at 1000 m may be used as selection criterion for improving the performance of animals considering distances from 1000 to 1600 m.

5.2. Best (racing) time

The heritability estimates for best time are presented in Table 9. In general, the heritability estimates of best time were low (0.10 to 0.18) and hence selection based on the phenotypic value may induce only small genetic changes in this trait (Neisser, 1976; Neisser and Schwark, 1979; Mota et al., 1998). However Ekiz et al. (2005) observed moderate to high heritability and repeatability values for this trait. The repeatability estimates at dirt, turf and entire tracks were 0.531, 0.373 and 0.500 respectively. Among the different time and earning traits, best racing time yielded the highest estimate of heritability. Hence selection for this trait might result in higher genetic improvement than other traits.

5.3. Average time

The heritability estimates for average time ranged between 0.087 and 0.243 (Table 6). Neisser (1976) reported that the average time was not influenced by track-by-track

Table 9
Heritability estimates for best time(s)

Distance (m)	Age (years)			Reference
	$2–2^{1/2}$	3	Mixed	
200	0.58* 0.77**	0.32* 0.40**	0.23	Yorov and Kissyov (1976)
1000	–	–	0.18	
1200			0.13	
1600			0.28	
2000			0.28	
2400			0.13	
–	–	–	0.13	Neisser (1976)
–	–	–	0.10	Neisser and Schwark (1979)
–	–	–	0.12	Mota et al. (1998)
–	–	–	0.286 ± 0.035¢	Ekiz et al. (2005)
–	–	–	0.491 ± 0.045£	
–	–	–	0.467 ± 0.044¥	

*ODC — offspring–dam correlation, **ODR — offspring–dam regression. ¢ = turf track, £ = dirt track, ¥ = entire (turf+dirt).

condition and month of race. The average time was highly significantly (0.72) correlated with best time.

5.4. Handicap rating or timeform rating

The heritability estimates of handicap weight are presented in Table 10. More O'Ferrall and Cunningham (1974) studied timeform ratings and reported that selection for performance was effective in sire and stated that the heritability by paternal halfsib was less biased. Further, Field and Cunningham (1976) analysed timeform ratings of 3-year-olds and reported that there was reduction of heritability estimates indicating reduction of additive genetic variance. The most comprehensive study on timeform ratings were made by Gaffney and Cunningham (1988) and they concluded that sire-based estimates were likely to be biased upwards. This might be due to that the highly rated stallions have very high stud feed and their offspring receive above-average treatment such as quality of the trainer and training. The speed and handicap had a correlation of 0.98 and 0.99 for 1600 m and 2400 m respectively. Handicap expressed as a standardised deviation value was the most accurate measure of racing performance (Dusek, 1977a,b). Moritsu et al. (1999) analysed the rating scores of Thoroughbred horses used by the Japan Racing Association and reported that the heritability values at turf and dirt tracks were 0.09±0.04 and 0.18±0.02 respectively. The authors stated that the values were higher than the racing time and suggested that the rating score used could be the most desirable criterion for evaluating the performance of racehorses in Japan and the results were similar to those based on timeform ratings in England.

Table 10
Heritability estimates for handicap weight/timeform rating (TR)/general handicap score (GHS)/general compensation weight (GCW)

Sex	Age (years)			Method of estimation	Reference
	$2–2^{1/2}$	3	Mixed		
Male	–	0.25	–	ODR	Dusek (1963)
Female	–	0.45	–		
Male	–	0.19	–	PHS	Dusek (1965)
Female	–	0.25	–		
–	0.33	0.51	–	ODR	Bormann (1966)
–	0.61	0.60	–	ODR	Schwark and Neisser (1971) (GCW)
–	–	0.35±0.11	–	PHS	More O'Ferrall and Cunningham (1974) (TR)
–	–	0.56±0.20	–	OSR	
–	–	0.34±0.08	–	OMR	
–	–	0.36±0.10	–	ODR	
–	0.40*	0.23*	0.33**	ODR	Hecker (1975) (*GHS; ** Best handicap weight)
–	–	0.57±0.02	–	PHS	Field and Cunningham (1976) (TR)
–	–	0.93±0.13	–	OSR	
–	–	0.38±0.08	–	ODR	
–	–	0.39±0.06	–	OMR	
Male	0.17	0.25	–	–	Dusek (1977b)
Female	0.30	0.45			
–	–	0.39±0.01	–	ODR	Gaffney and Cunningham (1988)
–	–	0.76±0.02	–	OSR	
–	0.29	0.30	0.32	POR	Bodo (1976)
–	–	0.51	0.46	PHS	
–	–	0.45	0.34	FS	

POR — parent–offspring regression, ODR — offspring–dam regression, OMR — offspring–mid-parent regression, OSR — offspring–sire regression, FS — fullsib, PHS — paternal halfsib, GCW — general handicap weight, TR — timeform rating, GHS — general handicap score.

5.5. Rank at finish/position rates

For analysis of rank at finish/position rates, square root transformation is applied to normalise the data. But the simplest way is to use normal order statistics to get the best fit to normality. Neisser and Schwark (1979) reported a heritability estimate for 2 to 2 1/2, 3 and 4-year-old Thoroughbred horses as 0.20, 0.16 and 0.14 respectively and for all racing distances these values were 0.24, 0.37 and 0.08 respectively. Fedorski (1977) reported that the heritability estimates for normalised ranking at 2, 3 and 4 years of ages were 0.20, 0.16 and 0.14 and 0.24, 0.37 and 0.08 for first and all races respectively. Chico (1994) reported that the heritability and repeatability estimates obtained by REML method ranged from 0.07 to 0.10 and 0.21 to 0.26 respectively. Rank and earning were similar traits since the genetic correlation between these traits are close to one. Among the different traits studied (speed, log of earning and rank) rank appears to be the most important Thoroughbred performance evaluation criterion. Williamson and Beilharz (1996) reported that the position rates were highly heritable and could be used for improving the racehorse performance. Belhajyahia et al. (2003) stated that the heritability and repeatability values for normalised ranking were 0.12±0.01 and 0.35±0.01 respectively. They concluded that the heritability of log of earning estimates was substantially low and the genetic correlation of 0.97±0.01 and phenotypic correlation of 0.779±0.01 between the ranking value and log of earning suggested that the ranking value was the best one for breeding evaluation of horses. The heritability and repeatability of placing amounts to 0.18 and 0.33 respectively and hence placing seems to be a better measure than log of earnings because its variance can be estimated more precisely (Sobczynska and Lukaszewicz, 2004).

Bokor et al. (2005) found that earnings and ranking had high genetic correlation of 0.94 to 0.97. They further stated that ranking value was normally distributed and had a great advantage of comparison between countries, because the rank is same across the countries. This is not the case with earnings, which depends on national policies. Svobodova et al. (2005) also reported a genetic correlation estimate of 0.98±0.003 between ranking value and log of earning per race and the respective heritability and repeatability values for rank were 0.162±0.011 and 0.347±0.014. They suggested that earnings and ranking values are two appropriate criteria to select the English Thoroughbred horse for racing ability in the Czech Republic. Bokor et al. (2007) also obtained a heritability and repeatability estimates of 0.170±0.012 and 0.347±0.029 respectively in France and 0.067±0.007 and 0.223±0.016 in the United Kingdom and concluded that ranking value after statistical normalization has a great advantage for comparison between the countries.

However, Ekiz et al. (2005) found that the heritability and repeatability values for rank at dirt, turf and both were 0.133±0.019, 0.152±0.020 and 0.132±0.016 and 0.225, 0.232 and 0.215 respectively. The lowest heritability was estimated for this trait when compared to different time and earning traits. Similarly, Sobczynska (2006) studied individual animal placing at the finish and reported that the heritability values at 1000, 1200, 1300, 1400, 1600, 1800 and > 1800 m were 0.16, 0.04, 0.09, 0.07, 0.07, 0.04 and 0.06 respectively and the corresponding repeatability estimates were 0.39, 0.27, 0.19, 0.16, 0.20, 0.17 and 0.28. The conclusion was that the ranking at different distances are not exactly the same in Thoroughbred horses. The genetic correlations between racing distances ranged from 0.54 to 0.98.

5.6. Performance rates

Several authors reported the heritability estimate for performance rates (Foye et al., 1972; Kieffer, 1975; Watanabe, 1974; Williamson and Beilharz, 1996). Foye et al. (1972) reported that the heritability estimates of performance rates by fullsib and halfsib methods were 0.36 and 0.68 respectively. Watanabe (1974) obtained a heritability estimate of 0.64 under halfsib method for this trait. Kieffer (1975) stated that the heritability estimates for performance rates ranged between 0.39 and 1.45 for different sexes. Williamson and Beilharz (1996) estimated medium to high (0.36 to 0.83) heritability for this trait and the estimates were higher in dry tracks than in wet tracks (Table 11).

5.7. Tapered earnings and weight performance

Williamson and Beilharz (1996) obtained highest heritability estimates for both traits (Table 12) and concluded that these traits reflect most accurately the genetic variation in biologically meaningful aspects of performance. The heritability estimates based on females (dams) were higher than males (sires). In another study, Williamson and Beilharz (1998) used three measures i.e. performance rates, position rates and tapered earnings. By an appropriate linear adjustment of length of race, they derived speed rating and stamina rating for each horse and calculated heritabilities for all these measures. The resulting estimates (Table 13) were generally higher than those from other studies. Most estimates were above 0.5, with values for the stamina rating being consistently higher than those for speed and can be used as a selection criterion for genetic improvement of horses.

5.8. Earnings

The heritability estimates of earning traits are presented in Table 14. In many cases, heritability of earnings is moderate and is sufficient to facilitate selection and have been suggested as a logical measure of racing performance. Among the different earning measures, log of earnings or log of earnings/start may be used as a measure of racing performance in Thoroughbred horse racing. The repeatability of log of earning for Spanish Thoroughbred horses ranged between 0.23 and 0.25 (Chico, 1994). Langlois et al. (1996) reported that the repeatability of log of earnings of Thoroughbred horses of France at 2 and 3 years of age were 0.35 and 0.40 respectively. Langlois and Blouin (2004) observed that the breeding value estimation with the BLUP animal model calculated according to earnings in competitions in France appeared to be a very useful tool for breeders. However, they further recommended testing of new values of heritabilities for breeding value estimations for all racing activities. Svobodova et al. (2005) stated that the repeatability estimates for log of earning/race was ranged between 0.308 ± 0.014 and 0.399 ± 0.016. According to Ekiz et al. (2005) the repeatabilities of annual earnings, earnings per start, log of earnings and log earnings per start were 0.318, 0.447, 0.308 and 0.409 respectively for Thoroughbred horses of Turkey.

Langlois and Blouin (2007) analysed the racing careers of 2-, 3-, 4-, and 5-year-old Thoroughbreds 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 distributions of earnings corrected for year, age and sex were very skewed. Hence, log

Table 12
Heritability estimates of weight performance and tapered earnings

Characters	Method of estimation		
	Sire	Dam	Damsire
Weight performance			
Track			
Dry track	0.53 ± 0.02	0.78 ± 0.05	0.50 ± 0.03
Wet track	0.31 ± 0.02	0.47 ± 0.02	0.34 ± 0.04
Age (years)			
$2–2^{1/2}$	0.66 ± 0.06	–	0.49 ± 0.10
3	0.62 ± 0.04	–	0.48 ± 0.07
5	0.45 ± 0.03	0.77 ± 0.05	0.52 ± 0.04
Tapered earnings			
Track			
Dry track	0.64 ± 0.03	0.75 ± 0.05	0.60 ± 0.04
Wet track	0.47 ± 0.03	0.58 ± 0.08	0.48 ± 0.04
Age (years)			
$2–2^{1/2}$	0.71 ± 0.06	–	0.55 ± 0.11
3	0.70 ± 0.05	–	0.53 ± 0.07
4	0.54 ± 0.03	0.70 ± 0.10	0.56 ± 0.05
5	0.65 ± 0.02	0.79 ± 0.05	0.63 ± 0.03

Source: Williamson and Beilharz (1996).

Table 11
Heritability estimates of performance rates at different track conditions and age groups

Track/age group	Method of estimation		
	Sire	Dam	Damsire
Dry track	0.53 ± 0.02	0.83 ± 0.05	0.53 ± 0.03
Wet track	0.32 ± 0.02	0.52 ± 0.08	0.35 ± 0.04
$2–2^{1/2}$ years	0.83 ± 0.07	–	0.35 ± 0.04
3 years	0.72 ± 0.05	–	0.64 ± 0.08
4 years	0.46 ± 0.03	0.57 ± 0.10	0.54 ± 0.05

Source: Williamson and Beilharz (1996).

Table 13
Heritability estimates of speed and stamina ratings

Trait	Rating	Method of estimation		
		Sire	Dam	Damsire
Position rates	Speed	0.44 ± 0.02	0.56 ± 0.05	0.37 ± 0.03
	Stamina	0.65 ± 0.02	0.61 ± 0.05	0.69 ± 0.03
Performance rates	Speed	0.43 ± 0.02	0.72 ± 0.05	0.39 ± 0.03
	Stamina	0.57 ± 0.02	0.63 ± 0.05	0.60 ± 0.03
Tapered earnings	Speed	0.51 ± 0.02	0.61 ± 0.05	0.48 ± 0.03
	Stamina	0.71 ± 0.03	0.71 ± 0.05	0.78 ± 0.03

Source: Williamson and Beilharz (1998).

Table 14
Heritability estimates for different earning traits

Sex	Age (years)			Method of estimation	Reference
	$2–2^{1/2}$	3	Mixed		
Earnings/annual earnings					
Male	–	0.14	–	PHS	Pirri and Steele (1951)
–	–	0.04	–	OSR	Langlois (1975)
		0.07		ODR	
		0.04		OMR	
–	–	–	0.097 ± 0.014	REML	Bugislaus et al. (2004b)
–	–	–	0.194 ± 0.039	REML	Ekiz et al. (2005)
Log of earnings/log of annual earnings					
Male	–	0.60	–	PHS	Pirri and Steele (1952)
–	–	0.31	–	OSR	Langlois (1975)
–	–	0.28	–	ODR	
–	–	0.26	–	OMR	
–	–	0.44	–	PHS	
–	–	–	0.09	REML	Chico (1994)
			0.08		
–	0.22 to 0.28		–	REML	Langlois et al. (1996)
–	–	–	0.12	PHS	Sobczynska and Lukaszewicz (2004)
–	–	–	0.188 ± 0.036	REML	Ekiz et al. (2005)
–	–	–	0.144 ± 0.010 and 0.192 ± 0.008	General linear model	Svobodova et al. (2005)
–	0.147 ± 0.029	0.341 ± 0.033	0.319 ± 0.026		
–	–	–	0.155 ± 0.011	Model with two variables	Bokor et al. (2007)
–	–	–	0.155 ± 0.012	Model by a variable	
–	–	–	0.089 ± 0.009	Model with two variables	
–	–	–	0.086 ± 0.010	Model by a variable	
Average earnings/start					
–	–	–	0.30	–	Foye et al. (1972)
–	–	0.02	–	OSR	Langlois (1975)
		0.06		ODR	
		0.02		OMR	
–	–	–	0.291 ± 0.046	REML	Ekiz et al. (2005)
Estes average earnings per start					
Male	0.15	0.14	–	–	Galizzi-Vecchiotti and Pazzaglia (1976)
Female	0.04	0.12			
Male	0.32		–	–	Galizzi-Vecchiotti (1978)
Female	0.37				
Log of average earnings/start					
–	–	0.42	–	OSR	Langlois (1975)
		0.43		ODR	
		0.40		OMR	
		0.56		PHS	
–	–	–	0.341 ± 0.042	REML	Ekiz et al. (2005)
Log of Estes average earnings per start					
Male	0.12	0.29	–	–	Galizzi-Vecchiotti and Pazzaglia (1976)
Female	0.13	0.28			

ODR — offspring–dam regression, OMR — offspring–mid-parent regression, OSR — offspring–sire regression, PHS — paternal halfsib. Estes = average earning index.

transformation was used. Another problem of using annual or career earnings was that many horses did not win any money in France (41% of the Thoroughbreds) and hence it was difficult to correctly evaluate them. They found that the quadratic adjustment of the log of earnings by the log of the number of starts (sigmoid adjustment of the earning index) improved the adjustment for the Thoroughbred only and should be implemented for those horses.

5.9. Newer statistical methods and concepts

Bugislaus et al. (2004b) studied new performance traits independent from carried weight namely new rank at finish and new distance to first rank. The heritability values estimated for new rank at finish and new distance to first rank was 0.101 ± 0.017 and 0.142 ± 0.019 respectively and the genetic correlation between these two traits was one. The genetic and phenotypic correlations between the new distance to first rank and log of earning was 0.992 and 0.918 respectively. They concluded that the newly created traits showed better suitability for genetic estimation, due to high genetic correlation with other traits and showing highest genetic variances and recommended new distance to first placed horses for genetic estimation.

Langlois and Hernu (2003) made a study to create indicators to predict which horse had more chances to be placed in races than others. This study was limited to genealogical independent variables i.e., relative to the horse's family (sires, dams, paternal and maternal halfsibs). They considered the earning trait as the independent variable. Since it was bi-modal, a logistic regression was chosen as the appropriate statistical model. They concluded that it was not possible to predict the probability of being placed in France only from genealogical data; the most valuable information available to predict this probability was the previous performance of the horse itself. There was a great dissymmetry between the information given by the dam's performances and that given by the sire's performances.

Langlois and Blouin (2007) studied two earning indices viz. coefficient of success (defined as a horse's annual earnings divided by the mean earnings of the horses of the same age and sex in the same year) and earning index (defined as the logarithm of the preceding, standardised at a mean of 100 and a standard deviation of 20). They stated that the earning index was better manageable than rough earnings for breeding evaluation. Rough earnings are very inappropriate for estimating general statistics, especially in estimating breeding values. On the other hand, a logarithmic transformation of coefficient of success results in nearly normal distributions and thus was a better phenotypic estimation, without changing the ranking of the horses.

In Thoroughbreds and trotters there are changes of phenotypic performance with increasing in age. These changes in performance of individual animals with age could also be influenced by genetic factors (Atchley, 1998). One methodology to model the genetic change of performance of horses with increasing age is to treat racing performance depending on age as different traits. In comparison with multivariate model approach, random regression models result in smoother and less biased estimates of variances and covariances (Kirckpatrick et al., 1990). A further advantage is the possibility to calculate (co)variances between or at every age. Additionally, using random regression models, fewer parameters are needed to describe the same data in comparison with multivariate models. Random regression models are being rapidly adopted for the analysis in dairy cattle (Veerkamp et al., 2001; Banos et al., 2005). In horses, Bugislaus et al. (2006) studied the use of random regression model to account for change in racing speed of German Trotters with increasing age and observed that the heritabilities estimated using a random regression model for racing time ranged between 0.01 and 0.18. The genetic correlations among racing times per kilometre in six age classes were very high. Due to these high genetic correlations of racing time among six age classes, the breeding value of young trotter (2-year-olds) could be estimated accurately. When using random regression analysis almost no reranking of trotters over time took place. It was concluded that the random regression model improved the accuracy of selection of trotter over different age classes.

In the recent past, methods of deriving REML estimates are most commonly used (Meyer, 1998) but they have high computational demands. Hence, recently Bayesian procedures based on Gibbs sampling have been proposed as useful alternatives (Misztal et al., 2000; Meyer, 2002) because of their simplicity of implementation and efficient use of computer memory. In this method, the interpretation of the results are straight forward and the values were not dependent on the number of observations. Hence it was possible to compare values across different data sets (Legarra et al., 2005). In addition, Gibbs sampling may render random regression models suitable for the analysis of large data sets.

5.10. Selection criteria

Among the different traits, racing time in each race is the only direct measure of speed and is a suitable quantitative measure that can be used to evaluate the genetic racing performance of horses. However, the heritability estimates reported for racing time are low. Therefore most of the recent studies focussed on earnings or rank traits and the different transformations of these traits. The weighted and average estimates of heritability indicated that the performance rates, log of earnings and handicap weights are highly heritable, best handicap weights are moderately heritable, best times are slightly to moderately heritable and earnings are lowly heritable. The genetic improvement of racing performance can be achieved through selection based on the animal's own record, particularly if performance rates, log of earnings or handicap weights are available. The racing speed is not a useful criterion of selection because it is lowly heritable and on its own it is not a major determinant of success. Log of earnings showed consistently higher heritability estimates calculated by regression of offspring on dam than by regression of offspring on sire. This effect was attributable to non-genetic maternal contributions to the offspring as well as to the lower selection and therefore greater genetic variability in female parents (Hintz, 1980; Langlois, 1996).

However, Mota et al. (1998) pointed out that although time-related traits have heritability estimates lower than those related to rank and earnings, they are the only ones that can be submitted to selection for the population as a whole. For traits related to final rank in a race (number of percentage of victories, placement in the top three, placement in the top five) and money earnings it was not possible to change the mean for the entire population and only the mean of subpopulation can be changed. However, the animals that win races with better times than others do not receive monetary advantages because of this. Thus if there was a decrease in the racing time of the Thoroughbred races, an alternative would be to award prizes to the animals according to the time obtained on the track. Winning animals or animals obtaining placements that award prizes within shorter times than other would receive more prizes. Perhaps this would be a way to increase the interest of breeders in time-related racing performance traits. Ekiz et al. (2005) reported that the time traits have nearly normal distribution and are a better quantitative measure for statistical analysis than earning traits that differ greatly from a normal distribution.

In general, among the different performance criteria, contrary to a yearly or career performance criteria, a race performance criterion would be the advantage among others of avoiding the difficulties due to the variation in the number of starts. However, it should take into account the race level and the number of starting horses. Adopted criteria of using race ranks (Langlois, 1984) were still proposed and applied in practice for horses (Belhajyahia et al., 2003; Svobodova et al., 2005). Bugislaus et al. (2004a) and Sobczynska and

Lukaszewicz (2004) also proposed the use of the very simple, may be too simple, square root of the rank. These approaches on the race level when improved (Bugislaus et al., 2004b) will probably be the next future, but today racing organizations are still using annual or career criteria that need to be corrected for the number of starts. Another problem not modified by moving from annual or career criteria to criteria on the race level is how to evaluate the important proportion of horses born that never appeared in a race. Hence, it could be a new field of research in horse breeding (Langlois and Blouin, 2007). The final aim of any methodology in the prediction of breeding value is the genetic improvement of the population. Thus one should focus on the accuracy of those animals most likely to be selected. The random regression model and Bayesian procedures may offer valuable information for the evaluation and management of animal genetic resources.

6. Generation interval

The generation interval is the average age of the parents of foals or the average length of time between the birth of an animal and the birth of its replacement offspring. Horses have a long generation interval from 9 to 12 years compared with other domestic animals whose values are half of that or less. Often generation intervals of sires and dams are different (Bowling, 1996). Langlois (1976) reported a generation interval of 10.5 years in Thoroughbreds. The high value depends, on one hand, on the mean age at first mating of the males (6.9 years) and females (4.9 years) and on the other, the late culling of these animals: 16.3 years on an average in males and 14.3 years in the females. Gaffney and Cunningham (1988) reported a generation interval of 11.2±4.5 and 9.7±3.8 years for males and females respectively. Taveira et al. (2004) reckoned generation interval as {[(year of animal's birth−year of father's birth)+(year of animal's birth−year of mother's birth]/2} and reported the mean generation interval of Thoroughbred horses in Brazil as 10.93 with a range of 4 to 21 years. The generation intervals of males and females were 10.41 and 10.91 years. Burns et al. (2006) reported that the mating age of Thoroughbreds varied greatly and the average age of mating in males and females was 12 (range 4 to 18 years) and 9 years (range 4 to 15 years) respectively. The average age at culling was 18 and 15 years respectively for males and females. The higher generation intervals might be due to the fact that Thoroughbred animals begin their breeding only after completing their performance in races. Good animals might race for a longer time. They concluded that generally the genetic progress by selection was slow in Thoroughbred horses due to longer generation interval.

7. Longevity

It is defined as the length of productive racing life of an individual. It is of considerable economic importance in horses due to the greater amount of money and time invested. The heritability of longevity using the complete uncensored data was estimated to be 0.12±0.005 (Burns et al., 2006). Injury is the major cause of culling in Thoroughbred racehorses (Rossdale et al., 1985; Robinson and Gordon, 1988) and poor conformation may predispose a horse to injury (Stashak, 2002). Bourke (1995), citing the 1994 American Association of Equine Practitioners Report, stated that musculoskeletal injuries accounted for three times the wastage of all other medical problems. More than half of all 2-, 3- and 4-year-old racehorses became lame and 20% of all racehorses eventually suffered a career-ending injury. Bailey et al. (1997) observed that the incidence rate of musculoskeletal breakdown per start was 0.24%, while the incidence rate of fatalities for any reason among all starts was 0.04% (0.4/1000 starts) and rate due to musculoskeletal injury alone was 0.03% (0.3/1000 starts). Subsequently, Bailey et al. (1998) reported that the incidence of musculoskeletal injuries in flat, hurdle and steeple races in Thoroughbred horses were 0.29, 1.73 and 2.91% and the corresponding death rates were 0.06, 0.63 and 1.43% respectively. Numerous studies have examined factors that affect career longevity (Mason and Bourke, 1973; Rooney, 1983; Bailey et al., 1997; Williams et al., 2001; Pinchbeck et al., 2004a,b). The factors include conformation, training, environmental conditions, type of competition, age, and sex (Burns et al., 2006).

7.1. Training

Training has been found to have a significant impact on the risk of injury and thus on career longevity. Mason and Bourke (1973) found that trainers had a significant effect on the soundness of 2-year-old horses. Ainslie (1988) stated that the Thoroughbred racehorse reaches peak performance in the middle of its fourth year of age and maintains this peak through its seventh year. However, many careers are often prematurely shortened due to the stress and strain of early training on immature skeletons and due to insufficient recovery time following injuries.

7.2. Temporary environmental factors

Temporary environmental factors have been found to have effect on the risk of injury and on career longevity. Several studies have examined the relationship between track condition and risk of injury. Tracks with some moisture seem to reduce the risk of injury and falls, while dry tracks and very wet tracks both seem to increase the risk of injury. The increased speed associated with very dry tracks may contribute to the increased risk of injury (Rooney, 1983; Bailey et al., 1997; Williams et al., 2001). Bailey et al. (1997) concluded that the class of race, field size and barrier position had significant influence on injuries and in turn longevity.

Bailey et al. (1998) and Williams et al. (2001) observed that horse racing on fast good tracks had a greater risk of suffering musculoskeletal breakdown compared to those racing on heavy track surfaces i.e., harder, drier turf track surfaces were associated with greater risk than rain-affected softer tracks. This might be due to harder turf tracks had less cushion effect than softer turf track (as horses galloping on track with lower water content had greater forces exerted than those on tracks with higher water content). They concluded that to reduce the incidence of injuries, avoidance of excessively hard track surfaces through closer regulation of track moisture content was needed. Similarly Pinchbeck et al. (2004a) reported that the track surface and journey time to the racecourse were the risk factors for horse falls in the United Kingdom. In another study, Pinchbeck et al. (2004b) reported that the risk of injury was associated with distance and speed of the race and foot conformation.

7.3. Type of competition

The effect of type of competition on career longevity has been evaluated by different authors (Bailey et al., 1998; McKee, 1995; Pinchbeck et al., 2004a). The most important risk factor was the type of race. The fatality rates in National Hunt flat, hurdle and steeplechase races were 0.47, 0.49 and 0.70%, respectively. Horses in hurdle races were about four times as likely to suffer musculoskeletal breakdown, while horses in steeplechases had eight times more chance of suffering an injury, compared to horses racing on the flat (McKee, 1995; Bailey et al., 1998). Pinchbeck et al. (2004a) opined that the presence of barriers were likely to explain this. Falls at fences are significant contributors to equine fatalities during National Hunt racing. A horse's previous racing experience and history were also significantly associated with the risk of falling and horses participating in their first hurdle race were at almost five times greater risk of falling than that had hurdled before. A proportion of variation in the risk of falling could be attributed to horse and race. Trainer and jockey contributed very little to the variation in the risk of falling (Pinchbeck et al., 2002).

7.4. Age of start

Age at start of career has a significant impact on career longevity. High levels of loss occur in the first or second racing seasons (Mason and Bourke, 1973; Mohammed et al., 1991; Bourke, 1995); while lack of ability contributed to this loss, a significant proportion of horses may be retired due to injury or disease associated with training and racing. Several studies have found that the risk of injury increases with age (Robinson and Gordon, 1988; Mohammed et al., 1991; Bailey et al., 1997; Williams et al., 2001), but starting to compete at an older age has a negative impact on career duration (Bourke, 1995; Ricard and Fournet-Hanocq, 1997; Bailey et al., 1999). Bourke (1995) reported that the horses raced as 2-year-old had a greater number of starts during their racing careers and raced in more seasons than those that first raced as 3-year-olds. Ricard and Fournet-Hanocq (1997) reported that the stayability was greater for horses that started jumping competition earlier. The probability of still remaining after 5 years in competition was 59, 53, 45 and 41% respectively for starting ages of 4, 5, 6 and 7 years respectively in jumping horses. Similarly, Bailey et al. (1999) reported that the horses that first raced as 2-year-olds had significantly ($P<0.01$) greater number of race starts during period of study and raced significantly ($P<0.01$) more seasons than did horses that first raced as 3- or 4-year-olds. They further observed that this might be due to that the horses that first raced as 2-year-olds might have been raced earlier because of their superior ability or because they withstood the rigorous training. Consequently, these attributes may favour a longer racing career. Bailey et al. (1998) reported that the horses 4- or 5-year-old were 1.5 times more likely to suffer an injury compared to those, which had an age of 2 and 3 years. Whereas, horses that had an age of 6 years and older were over 2 times more likely to sustain injury. Langlois and Blouin (1997, 1998) reported that the horse's month of birth had significant influence of future sporting performance. This was mainly due to real age differences between horses from the same 'administrative' age class and also due to seasonal effect.

8. Molecular genetic approach in horse breeding

A new range of possibilities has been opened up by the development of molecular methods in the recent years. These offer new ways of studying population structure, measuring relationship between individuals and possibly making selection more effective (Cunningham, 2000a). The human gene sequences are very valuable for horse research because the organization of the horse genome has proven to be very similar to that of human genome. Indeed many horse genes show 90 to 95% conservation with human sequence, while the arrangements of genes also appears to be the same over large segments of the chromosomes. Therefore, scientists can use the human genome map to predict structure and organization of the equine genome. Construction of genetic maps allows traits of interest to be traced back through pedigrees. This enables the identification of chromosomal regions and often specific genes that have influence on the traits being studied. There are indications in human gene research that there are genes that affect muscular capacity and therefore stamina, a parallel gene in horse may well be identified shortly and that would provide benefit in selection of horses for breeding (Cunningham, 2000a). The development of the equine gene map will give horse breeders more accurate tools for selection for the most desirable characteristics. The most significant application so far has been for parentage testing. Efforts to identify disease genes providing tools for owners to breed healthy animals is anticipated. Cunningham (2005) opined that the coupling of genetic and historical data provides a powerful tool to identify and correct errors that may be present in contemporary Thoroughbred pedigrees. This is vital for Thoroughbred breeders who rely on the accuracy of stud books, as important breeding decisions are frequently made based on the integrity of the pedigrees. Also, such parallel analyses lend new perspective to the interpretation of the early history of the Thoroughbred and the contribution of the founder mares and stallions to the present day Thoroughbred gene pool.

Applications in practice of many of the molecular results are still limited. In part this reflects the diverse goals of breeders, the fragmented nature of the breeding industry, and the fact that the newer molecular techniques are not yet fully mature. However, the range of tools provided by research to-date offer a great possibility for breeders to breed healthy horses that will fulfill the particular performance goals for which they are bred (Bowling, 2000; Cunningham, 2000a,b; Ellis, 2001).

9. Inbreeding in Thoroughbred horse population and its effect

The Thoroughbred is one of the oldest breeds of domestic animals with pedigree records spanning three centuries. Because the population is closed, there is concern about the loss of its genetic variation. Steele (1944) reported an inbreeding coefficient of 0.014 for the Thoroughbreds in the U.S.A. Subsequently, Kieffer and Stewart (1979) also stated almost similar values of 0.011 and 0.0078 for the Thoroughbred horses in the same country. Kownacki and Jezierski (1979) observed an average inbreeding coefficient of 0.081 for the Thoroughbred stallions in Poland.

The reproductive efficiency of the Thoroughbred mare in Britain and Ireland is low and the Weatherby's General Stud Book shows an average annual foaling rate of 67%. Hence, Mahon and Cunningham (1982) studied the inbreeding in relation to fertility in Thoroughbred horse population in the two countries. The average level of inbreeding for the five most recent generations was found to be only 0.0096. Close inbreeding was also rare; there were only two sire–daughter matings and four halfsib matings. Pedigree analysis for the 21.5 recorded generations from the foundation of the breed in the 17th century to 1964 revealed an inbreeding coefficient of 0.125 with the overall rate of inbreeding coefficient per generation of 0.0058. They further observed that the recent inbreeding was not an important source of variation in fertility, since mating of close relatives was rare. It was concluded that over the recorded history of the breed it was probable that selection, both natural and artificial has counteracted any effect of inbreeding on fertility. Later, Cunningham (1991) observed that the pedigree analysis showed that the four top stallions have contributed a third of all the genes in the current population, and that 21 horses accounted for 80% of the makeup of the modern population. Comparison with the foaling rates of animals with different inbreeding levels showed that fertility declined by 7% for every 10% rise in inbreeding.

The inbreeding coefficient of the Thoroughbred horses in the present population (1987–1996) gave a value of 0.130 ± 0.014. Pedigree analysis revealed that 78% of alleles in current population were derived from 30 founders, 27 of these were males. Not all the founders contributed equally to subsequent generations. The most significant founders were the Godolphin Arabian (13.8%), the Darley Arabian (6.5%), the Curwen Bay Barb (4.2%), the Ruby Mare (4.2%) and the Byerley Turk (3.3%). Paternal and maternal lineages revealed that one founder stallion (Darley Arabian) was responsible for 95% of paternal lineages and 10 founder females accounted for 72% of maternal lineages in the modern population. The dominance of Darley Arabian on the sire line was not really a matter of great concern because it only affects the male to male contribution, which was a small part of the total genotype (10% or less) (Cunningham, 2000a; Cunningham et al., 2001).

Cunningham (2005) reported that the mitochondrial sequence data analysis revealed no difference in nucleotide diversity between Thoroughbred founder and contemporary horse populations and clarified the nature of domestication process in horses and showed a pattern different from that in other domesticated species. Study on level of allele sharing showed consistent level of sharing within and between Egyptian and Turkish and between them and Thoroughbred. This might be due to that many of the early individuals instrumental in the foundation of Thoroughbred were imported from Middle East. The regression of allele sharing with coefficient of co-ancestry gave an intercept of 0.309 and regression coefficient of 1.013. This combination of molecular and statistical measures of relationship provides a way of estimating genetic variability in founder groups.

Langlois (2005, 2006) opined that the estimators for pairwise relatedness or individual inbreeding coefficients need a lot of independent co-dominant marker loci where alleles are balanced in frequencies in order to reach a minimum accuracy in estimations. He proposed the realisation of an SNP kit. This kind of marker had the advantage of being easily revealed by DNA chips, being bi-allelic, co-dominant and null allele free. In addition it was thought that an SNP could be found in mammals every 500 to 1000 pairs of bases. Whereas, microsatellites were expected only 25 to 100 kilo-bases. Hence, the author concluded that the screening of the horse genome would be much more precise with SNP than with microsatellites.

In general, the inbreeding at the rate that is usually practised in Thoroughbred population does not enable much gene fixing. However, practice of close inbreeding may be avoided, even though it still fascinates breeders at subconscious level (Langlois, 1996).

10. Rate of genetic improvement

Anderson (1921) reported that new record times established in US Thoroughbred showed evidence of genetic progress. From 1872 to 1920, the time has been reduced from 1:42 3/4 to 1:35 1/2 min for a distance of 1 mile in Thoroughbred horses. Hamori and Halasz (1959) opined that there was some lowering of Thoroughbred racing times, because of prolonged selection for speed.

Cunningham (1975) showed that winning times in classic Thoroughbred races in England showed no improvements during the recent decades, despite the fact that heritability estimates of timeform rating are generally moderate in range. He analysed the data from 1850 to 1970 and reported that even though the selection was performance directed, elapsed time for the events had not decreased since 1900. This phenomenon, combining a high heritability with an apparent absence of response to selection was presented in Dublin in 1975 as “Cunningham Paradox” by Prof. Alan Robertson (Langlois, 1980). In an explanation to this paradox, Langlois (1980, 1996) suggested that this might be due to the possibility that Thoroughbreds had reached their highest level of genetic potential or over-estimation of heritability values. The over-estimation of heritability might be due to that the apparent variability has become greater than real variability because certain genetic effects are systematically associated owing to the generalized practice of assortative mating. The traditional methods of estimating heritability should, in fact, be corrected for this phenomenon. Thus genetic variability does not simply result from the variability of the genes at each locus, but also on covariances among the effects of these genes. The other source of over-estimation was correlation between genetic and environmental effects.

In a population, the age of males and females at first mating and at death or culling together with fertility, generation interval and mating structure determines the mean number of offspring per breeding animal. Study of these parameters in horse populations shows that their demographic structures are dominated by low reproductive performance. Indeed, the numerical productivity (number of weaned progeny/year/mare), ranged around 0.55. This is compensated by a long length of utilization of the animals and leads to a long generation interval, which cannot be reduced to less than 7 years even in rigorous breeding conditions. However, selection possibilities are offered by the number of offspring per breeding animal (about 5 per brood mare and 50 per stallion); they represent at the minimum a selection rate of 50% in the females and 5% in males. In the case of racehorse breeds, where almost all the animals are performance tested, this may lead to good selection intensities. The future production of highly specialized horses with a high added value should be based on modern techniques of reproduction and information management (data processing) using individual performance testing and according to national and international objectives (Langlois et al., 1983).

Initially, Hamori and Halasz (1959) and subsequently Gaffney and Cunningham (1988) predicted the rate of genetic gain in the British Thoroughbreds. This was based on generation intervals of 11.2 and 9.7 years and selection intensities of 6 and 52% in males and females respectively with a heritability value of 0.36; involving 516 stallions born in the years 1952–1977 and performance of their 11,328 progenies between 1961 and 1985. The estimated change of average was 0.94±0.13 timeform units/year. These values suggest that Thoroughbred population still contains genetic diversity with respect to racing ability and the reasons for lack of progress in winning times of the principal classic races will need to be sought elsewhere.

Eckhardt et al. (1988) was of the opinion that several factors might account for the lower apparent gain in response to selection among Thoroughbred horses, in comparison with other categories of livestock subjected to breeding regimens. The race performance in horses involves diverse components such as muscle mass, relative length of limb segments, joint strength, stability and aerobic capacity. Gain in some of these might even be antagonistic to progress in others. In case of domestic animals the characters considered are very different from those presumably favoured in wild populations. Under such circumstances the initial gains from artificial selections can be quite rapid. In contract, improvement in the running speed of horse extends a trend that goes back at least 50 million years to the Eocene; it was likely that current gains are occurring along the distant reaches of an asymptotic curve, where continued selection might be expected to produce relatively less net change.

James (1990) observed that it was well established that winning times in classic races for Thoroughbreds had improved little, if at all, during last century, despite continued selection for racing success and apparently moderate to high heritability of performance. Actual heritability was certainly lower than estimated values, and it was not certain that performance and time were closely correlated. A positive estimate of genetic trend in performance might not be justified. It was conceivable that limited effective population size and intense selection have led to a plateau in performance, and the apparent heritability of performance was illusory. Williamson and Beilharz (1998) opined that the reason for lack of progress has been due to misdirected selection.

Oki et al. (1995a) found the genetic trend of Thoroughbred horses in Japan as −0.0170 and −0.0084 s for turf and dirt tracks respectively. Mota et al. (2002) reported the genetic trend of −0.0045 s for the Brazilian Thoroughbred. To improve racing time it should be selected directly and not indirectly. Taveira et al. (2004) studied the genetic trend observed in Brazilian Thoroughbred horses and reported that the genetic trend of winning time calculated on the basis of mean breeding value against each year of birth and using predicted breeding value for each animal against the year of each animal's birth were −0.0027 and −0.0016 s/year and for race time were −0.0039 s and −0.0045 s/year. Mota et al. (2005) concluded that the genetic improvement of racing time was more pronounced at 1100 m, while gains tend to decrease with increasing distance. The genetic trends for racing time were approximately five times higher at 1000 and 1100 m than at distances of 1500 and 1600 m.

Langlois (1996) suggested that genetic management of Thoroughbred populations could be greatly improved by using methods that research has already virtually perfected. Unfortunately, horse breeding has a very old-fashioned history, convinced of the firm grounding of its archaic methods, and does not seem to be ready to adopt new proposals. The reason is doubtless that there are very few technical organizations responsible for coordinating horse breeding. Breeders regard their fellow breeders as competitors and can see no point in cooperation for genetic improvement. This restricts them to searching for the formula for some mythical, ideal mating that will give them the champion they hope one day to win and with that approach, obviously, dreams count for more than reality.

11. Conclusions

Thoroughbred performance has been stable for several decades. In other words, the winning time of horses has not shown any improvement. Yet most research on Thoroughbreds has found the existence of genetic variation sufficient for genetic progress higher than that the ones currently reported. Several authors have been discussing the reasons for the little genetic improvement of Thoroughbred performance in races (Cunningham, 1975; Langlois, 1980; Ricard et al., 2000). Some of the commonest reported reasons were opposing natural selection, environmental deterioration, exhausted additive genetic variation, racing speed and ability are not the same trait and possibility of existence of physiological limit to performance. However, Hill (1988) reported that there is no worsening of environment since, health, nutrition, training and condition has been improved much.

Several conceptual models have been proposed for the purpose of using racing performance in selection of breeding horses. Speed, money won and placing are certainly integral part of any method of evaluation. These traits are influenced by genetic factors to a greater or lesser degree depending upon the population. The overall picture emerging from these numerous studies is a reasonably consistent one. It shows that the heritability depends on the measure used. Time measure generally had a heritability in the range of 0.1 to 0.2 with the higher values for shorter races. For handicap and earning measures reported heritabilities were generally higher frequency in the range of 0.3 to 0.4 (Ricard et al., 2000), hence these may be considered in genetic evaluation of racing performance of Thoroughbred horses.

Different genetic factors are involved in performance in longer or shorter races and on different kinds of track. This could have serious implications for the evaluation of animals. In order to achieve improvement in Thoroughbreds, breeders need to target specific races or at least types or races when planning mating. It is unrealistic to expect to produce a horse that can win in all conditions, unless everyone else is striving to do the same. Surely by concentrating on particular areas of performance, improvement could be made.

It is well established that winning times in classic races for Thoroughbreds have improved little, if at all, during the last century, despite continued selection for racing success and apparently moderate to high heritability of performance. Actual heritability is certainly lower than estimated values, and it is not certain that performance and time are closely correlated. A positive estimate of genetic trend in performance may not be justified. It is conceivable that limited effective population size and intense selection have led to a plateau in performance, and the apparent heritability of performance is illusory (James, 1990). The net conclusion is to reinforce the old notion of 'horses for courses' (Ricard et al., 2000). The breeding of Thoroughbreds is accurately summed up by the old-timers "breed the best to best and hope for the best".

Racehorses have longer generation interval that limits the genetic progress per year. Fortunately racing performance may be evaluated in both males and females and repeated observations can be obtained on the same animal in relatively short periods. These factors coupled with the reasonable heritability of some measures of racing performance, suggest that mass selection based on a wide spread performance tests would be the selection procedure of choice. Information on racing performance of 2- and 3-year-old progeny and relatives could also be used, as becomes available, to increase the accuracy of sire and mare selection; but progeny testing only would unreasonably increase the generation interval and should be avoided. The inbreeding observed in Thoroughbred is generally within limits considering the small numbers of foundation horses. However practice of close inbreeding may be avoided, even though it still fascinates breeders at subconscious level.

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