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Multivariate analysis of morphometry effect on race performance in Thoroughbred horses

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ABSTRACT - The objective of this study was to determine the effects of morphometric measurements on race performance (m/sec) of Thoroughbred horses. Data of morphometric measurements (withers height, rump height, chest girth, chest width, front chest width, chest depth, neck length, shoulder length, length of withers to rump, rump length, body length, head width, head length, and cannon circumference) were taken from 244 Thoroughbred horses chosen at random. A total of 2888 racing records were considered for race performance. The effects of environmental factors on morphometric measurements (stallion, gender, age, and mother age) and race performance (gender, age, mother age, year, hippodrome, race distance, racetrack, and race type) were analyzed using the least squares method. Principal component analysis (PCA) was performed for morphometric measurements, and then the factor loadings were rotated by Varimax method. Multiple linear regression analysis was applied for the significance of the obtained factors on race performance. Significant effects for stallion on all morphometric measurements, except head length and width, and for gender on withers height, cannon circumference, and head width were determined. Race performance was significantly influenced by stallion, gender, age, year, hippodrome, race distance, racetrack, and race type. After PCA, four factors with eigenvalues >1 were attained. The effects of factors on race performance were not significant, according to the results of multiple linear regression analysis. Therefore, the effects of the morphometric measurements examined on the race performance were not significant in Thoroughbred horses.

Keywords: environmental factors, morphometric measurements, PCA, flat racing

Introduction

It is widely accepted that the horse was domesticated in the years 3000 BC, after dogs, sheep, goats, and cattle. After domestication, horses started to be used for various purposes, which have changed throughout history. Nowadays, horse breeding is mostly undertaken for sport and recreation purposes (Taylor and Field, 2014). Horses have been also used for transportation and farming in some countries (McManus et al., 2013; Tennah et al., 2014).

The Thoroughbred horse breed is mainly known for running, especially flat racing, but is also used in a variety of sports such as jumping, hunting, three-day eventing, dressage, and polo. Flat racing with Thoroughbred horses has a very important place in equestrian sports around the world. This breed has been improved for speed at middle - distances (1400-2400 m) (Evans et al., 1994; Taylor and Field, 2014).

Horse performance during the race is measured in various forms. In flat racing, speed (m/sec) is a measure largely used in assessing race performance. Many factors influencing race performance of Thoroughbred horses (e.g., husbandry, nutrition, exercise, race distance, racetrack, gender, handicap weight, age, mother age, and hippodrome) have been addressed in some studies (Oki et al., 1994; Barron, 1995; Ekiz and Kocak, 2007; Buxadera and Mota, 2008; Bakhtiari and Heshmat, 2009; Paksoy and Ünal, 2010; Park et al., 2011; Takahashi, 2015).

Morphometric measurements of horses are considered a criterion in determining breed characteristics and body conformation. In addition, they are important in monitoring development during the growth period and in determining the suitability for breed standards in the post-growth period. Thoroughbred horses are required to conform to the breed characteristics in various body measurements. Many studies involving morphometric measurements in different horse breeds have been carried out (Anderson and McIlwraith, 2004; Staniar et al., 2004; Gücüyener Hacan and Akçapınar, 2011; Yılmaz and Ertuğrul, 2012; Padilha et al., 2017). On the other hand, no research has been found on the impact of morphometric measurements of Thoroughbred horses on their race performance (m/sec). Only one study (Smith et al., 2006) reported that withers height, rump height, body length, and heart girth of yearling Thoroughbred foals were positively correlated with lifetime earnings and win percentage.

Principal component analysis (PCA) is the simplest of the true eigenvector-based multivariate analyses. It is most commonly used to intensify the information included in a large number of variables, strongly correlated, into a smaller set of new composite dimensions, without much loss of information. It does so by composing new uncorrelated factors that successively maximize variance (Sadek et al., 2006; Park et al., 2011; Alpar, 2013).

The purpose of this study was to evaluate the impact of morphometric measurements on race performance of Thoroughbred horses using multivariate analysis.

Material and Methods

The animal material consisted of 244 Thoroughbred horses of different ages that run in races in Hippodromes organized by the Jockey Club of Turkey. The animals were randomly selected from horses housed in Adana Yeşiloba Hippodrome, in Adana city, Turkey (37°0' N and 35°19' E), in 2013. Pedigree (stallion, birth date, age, gender, and mother age) and racing (running year, hippodrome, race distance, race duration, racetrack, and race type) information of the horses was obtained from the records of the Board of High Stewards, Ministry of Food Agriculture and Livestock of Turkey, and the Jockey Club of Turkey.

All morphometric measurements (Table 1) were taken from the right side with the horse standing in a normal position inside a fixed crush.

Of the 244 investigated animals, 159 horses that had at least three paternal half-sibs and three official racing records were selected for the statistical analysis of race performance and effects of morphometric measurements on race performance. Race performance (m/sec) was calculated based on duration and distance for each race.

The least squares mixed models including fixed effects of factors was used, as shown below:

$$y_{ijklm} = \mu + \alpha_i + \beta_j + \gamma_k + \delta_l + e_{ijklm} \text{ (for morphometric measurements)},$$

in which y_{ijklm} = dependent variable, μ = overall mean, α_i = fixed effect of stallion, β_j = the fixed effect of gender, γ_k = fixed effect of age, δ_l = fixed effect of mother age, and e_{ijklm} = random error.

$$y_{ijklmnoprs} = \mu + \alpha_i + \beta_j + \gamma_k + \delta_l + \eta_m + \kappa_n + \sigma_o + \tau_p + \omega_r + e_{ijklmnoprs} \text{ (for race performance)},$$

in which $y_{ijklmnoprs}$ = dependent variable, μ = overall mean, α_i = fixed effect of stallion, β_j = fixed effect of gender, γ_k = fixed effect of age, δ_l = fixed effect of mother age, η_m = fixed effect of year, κ_n = fixed effect of hippodrome, σ_o = fixed effect of race distance, τ_p = fixed effect of racetrack, ω_r = fixed effect of race type, and $e_{ijklmnoprs}$ = random error.

The meanings of the factors used in the mix models given above are explained below:

Stallion: father of horses investigated.
Gender: male and female horses investigated.
Age: ages of horses investigated = 2, 3, 4, 5, and 6+ years old.
Mother age: mother ages of horses investigated = 2-5, 6, 7, 8, 9, 10, 11, 12, 13-15, and 16-19 years old.
Year: the years of horse racing; 2001-2004, 2005, 2006, 2007, 2008, 2009, 2010, 2011, 2012, and 2013.
Hippodrome: cities of hippodrome where horse races took place = Adana, Bursa, İstanbul, Ankara, İzmir, Diyarbakır, Şanlıurfa, and Elazığ.
Race distance: between 800 and 2400 m, and run by the horses investigated from start to end points = 800-1000, 1100, 1200, 1300, 1400, 1500, 1600, 1700, 1800, 1900, 2000, 2100, 2200, and 2400 m.
Racetrack: ground composition of racetrack = dirt and turf.
Race type: flat racing categories organized according to various characteristics. Maiden race: racing joined by horses that have never won. Handicap race: racing in which different weights are loaded on the horses, and these weights are determined by scores of official handicappers to equalize their chances of winning; handicap 13 (horses with a score between 1-50); handicap 14 (horses with a score between 1-65); handicap 15 (horses with a score between 1-75); handicap 16 (horses with a score between 30 and 85); and handicap 17 (horses with a score between 40 and 100). Condition race: racing where horses participated according to the total amount of lifetime earnings, and additional weights are loaded on horses according to the total amount of lifetime earnings. The more the number of condition race increases, the more total amount of lifetime earnings are needed to participate. Open class: racing with high-performance horses carrying the same weight.

Statistical significances among the subgroups were determined by Tukey's test at 5% significance level. Pearson's correlation coefficients were calculated among morphometric measurements.

Table 1 - Descriptions of morphometric measurements examined in the research

Morphometric measurement	Definition
WH - withers height	Vertical distance from the highest point of the withers to the ground
RH - rump height	Vertical distance between the highest point of the sacrum and the ground
CG - chest girth	Circumference around the chest from behind the scapula
CW - chest width	Distance in the front side between the outer sides of the right and left articulatio humeri
FCW - front chest width	Distance in the front side between the inner sides of the right and left articulatio humeri
CD - chest depth	Vertical distance between the highest point of the withers and the sternum
NL - neck length	Distance from the angulus mandibula to the scapula
SL - shoulder length	Distance from the highest point of the withers to the caput humeri
LWR - length of withers to rump	Straight distance between the end of the withers and the beginning of the rump
RL - rump length	Distance from the tuber coxae to the tuber ischia
BL - body length	Horizontal distance from the caput humeri to the tuber ischia
HW - head width	Distance between the right and left processus lacrimalis rostralis
HL - head length	Distance from the crista occipitalis to the os incisivum
CC - cannon circumference	Circumference at the middle of the metacarpal bone

The Kolmogorov-Simirnov normality test for normal distribution fitness, the Kaiser-Meyer-Olkin test for sample size adequacy, and Bartlett's sphericity test were applied in the morphometric measurement data. Principal component analysis for morphometric measurements were performed, and then the factor loadings were rotated by the Varimax method. The significance of the rotated factor loadings was determined using the value of 0.45, which is the limit for n = 159. Factor eigenvalues greater than 1 were accepted (Alpar, 2013; Tabachnick and Fidell, 2014). For factor analysis, the basic factor analysis equation was used, as follows:

$$Z_{p\times 1} = \lambda_{p\times m} F_{m\times 1} + e_{p\times 1},$$

in which Z = p×1 vector of variables, λ = p×m matrix of factor loadings, F = m×1 vector of factors, and e = p×1 vector of error factors.

Multiple Linear Regression Analysis, using the model below, determined the importance of the effects of the obtained factors on race performance (RP):

$$RP = a + b_1FS_1 + b_2FS_2 + b_3FS_3 + b_4FS_4 + e,$$

in which a = regression constant value; FS = factor scores; b_1, b_2, b_3, and b_4 = regression coefficients of factor scores; and e = error term.

The t test was used for significance of the regression coefficients. The autocorrelation assumption was determined by the Durbin-Watson test. Statistical procedures were carried out using SPSS software (Statistical Package in Social Sciences for Windows, version 14.01).

Results

Least squares means (Table 2) were 169.34±0.52 cm for withers height, 187.66±1.12 cm for chest girth, and 168.52±0.75 cm for body length.

Table 2 - Descriptive statistics and P-values for the morphometric measurements of the horse

Morphometric measurement	Descriptive statistics of all horses (n = 244)				P-value of the selected horses for race performance (n = 159)				
	X±Sx (cm)	Min (cm)	Max (cm)	CV (%)	X±Sx (cm)	Stallion	Gender	Age	Mother age
WH	169.15±0.23	157	178	2.11	169.34±0.52	<0.001	0.021	0.355	0.312
RH	167.46±0.23	155	177	2.16	167.65±0.54	<0.001	0.169	0.386	0.267
CG	187.22±0.46	162	204	3.86	187.66±1.12	0.032	0.390	0.555	0.852
CW	42.33±0.16	34	47	5.86	42.24±0.38	<0.001	0.469	0.227	0.356
FCW	20.34±0.10	16	24	8.01	20.10±0.25	0.038	0.606	0.552	0.769
CD	84.88±0.27	70	93	5.03	84.88±0.64	<0.001	0.302	0.282	0.524
NL	57.83±0.29	44	68	7.80	58.43±0.70	<0.001	0.158	0.600	0.671
SL	72.10±0.20	63	79	4.29	72.38±0.44	<0.001	0.211	0.171	0.741
LWR	62.50±0.26	54	72	6.45	62.43±0.56	<0.001	0.599	0.542	0.731
RL	37.57±0.17	31	43	7.13	37.22±0.36	<0.001	0.185	0.530	0.393
BL	168.17±0.33	154	178	3.04	168.52±0.75	<0.001	0.459	0.646	0.303
HW	23.88±0.05	21	25	3.02	24.00±0.13	0.116	0.029	0.381	0.552
HL	52.95±0.13	48	59	3.44	52.93±0.28	0.192	0.102	0.146	0.338
CC	20.46±0.05	19	22	3.52	20.48±0.11	0.040	0.038	0.326	0.453

WH - withers height; RH - rump height; CG - chest girth; CW - chest width; FCW - front chest width; CD - chest depth; NL - neck length; SL - shoulder length; LWR - length of withers to rump; RL - rump length; BL - body length; HW - head width; HL - head length; CC - cannon circumference; CV - coefficient of variation.
Tukey's test (P>0.05).

Age and mother age had no significant effects (P>0.05) on any of the investigated morphometric measurements, while gender was pronounced on withers height, cannon circumference, and head width (P<0.05). On the other hand, for stallion, a significant effect (P<0.05; P<0.001) occurred on all morphometric measurements except head length and width.

Least squares means for race performance were 15.29±0.06 m/sec (Table 3). Race performance was significantly influenced by stallion (P<0.01), gender (P<0.01), age (P<0.05), year (P<0.05), hippodrome (P<0.001), race distance (P<0.001), racetrack (P<0.001), and race type (P<0.001), while mother age had no marked effect on this trait.

In general, high and significant (P<0.05; P<0.01; P<0.001) correlation coefficients among morphometric measurements in positive direction were calculated, varying from 0.117 to 0.679 (Table 4). The 14 morphometric measurements examined showed fitness to normal distribution by the Kolmogorov-Smirnov test (P>0.05). Sample size adequacy by the Kaiser-Meyer-Olkin test was 0.849. The significance level of Bartlett's sphericity test was P<0.001.

Four factors (FI, FII, FIII, and FIV) with eigenvalues >1 were attained as a result of the analysis with PCA. The factors of FI (general size), FII (body thickness), FIII, and FIV explained 52.46, 15.50, 8.01, and 7.21% of the total variation of 83.19%, respectively. Ten loads in FI, five in FII, two in FIII, and two in FIV were statistically significant (Table 5).

The regression coefficients obtained for the factors were not significant (P>0.05) (Table 6). The Durbin-Watson test for autocorrelation yielded a value of 1.377. Correlation coefficients between race performance and regression coefficients of FI, FII, FIII, and FIV were calculated as –0.012, –0.079, 0.022, and 0.050 (P>0.05), respectively.

Discussion

Size and morphometry are extremely important traits in nearly all horse breeds including Thoroughbred, and numerous breed registries select horses on functional criteria and support the breeding of horses with body types most convenient for those particular functions. Using many body measurements from the head, neck, trunk, and limbs in a great number of horse breeds such as Thoroughbred, Shire, and Friesian in USA showed that there was a high body size variation among the horse breeds (Brooks et al., 2010).

Coefficients of morphometric measurements covered in this study were low and less than 10%, which shows that the uniformity of morphological characteristics of the breed were rather high. These findings agreed with the report by Brooks et al. (2010) in which the lowest variation for body measurements among 65 horse breeds was observed in Thoroughbred horse breed.

In terms of morphometric measurements examined, males showed higher values than females. However, the effect of gender on morphometric measurements was generally not very clear, given that gender effects were only important for withers height, cannon circumference, and head width.

There was usually a slight increase in morphometric measurements as the animals grew older, but none of these increases was statistically significant. This shows that Thoroughbred horses generally complete their growth and development at the age of two, agreeing with the statement that Thoroughbred horses are early-maturing. In fact, Thoroughbred horses start their racing life one year earlier (two years old) than Arabian horses, the other breed used in flat racing in many countries. A research by Anderson and McIlwraith (2004) found that the various body measurements of Thoroughbred horses were similar at two and three years old, despite significant increase from one to two years old. Similarity of body measurements between two- and three-year-old Thoroughbred

Table 3 - Effects of gender, age, mother age, year, hippodrome, race distance, racetrack, and race type on race performance of horses

Item	n	X±Sx (m/sec)	Item	n	X±Sx (m/sec)	Item	n	X±Sx (m/sec)	Item	n	X±Sx (m/sec)	P-value	
Gender			Year			Race distance (m)			Race type			Gender	0.006
												Age	0.026
Male	1499	15.331±0.061	2001-2004	66	15.086±0.108a	800-1000	27	15.667±0.141a	M	563	15.100±0.062b	Mother age	0.245
Female	1389	15.244±0.057	2005	83	15.306±0.101bc	1100	36	15.618±0.126a	HC13	42	15.125±0.113b	Year	0.033
Age			2006	74	15.216±0.09ab	1200	493	15.723±0.061a	HC14	210	15.280±0.071ab	Hippodrome	<0.001
			2007	148	15.299±0.081d	1300	242	15.665±0.071a	HC15	295	15.329±0.068ab	Race distance	<0.001
2	462	15.184±0.053a	2008	190	15.257±0.076c	1400	505	15.584±0.062a	HC16	254	15.349±0.069ab	Racetrack	<0.001
3	1341	15.256±0.043b	2009	229	15.341±0.067d	1500	371	15.578±0.068ab	HC17	122	15.371±0.079a	Race type	<0.001
4	644	15.280±0.049b	2010	205	15.272±0.070cd	1600	179	15.402±0.073b	C1	103	15.074±0.089b		
5	260	15.347±0.062c	2011	465	15.379±0.060de	1700	97	15.149±0.086c	C2	98	15.184±0.084b		
6+	181	15.374±0.072c	2012	856	15.395±0.056e	1800	67	14.800±0.096d	C3	207	15.233±0.071b		
Mother age			2013	572	15.328±0.059d	1900	405	15.053±0.065e	C4	257	15.276±0.067ab		
			Hippodrome			2000	195	15.087±0.072e	C5	194	15.286±0.071ab		
2-5	230	15.325±0.071				2100	143	14.936±0.078e	C6	129	15.358±0.080a		
6	481	15.321±0.066	Adana	1136	15.194±0.055e	2200	78	14.970±0.093e	C7	129	15.350±0.078a		
7	368	15.297±0.072	Bursa	250	15.487±0.068b	2400	50	14.798±0.106d	C8	100	15.445±0.086a		
8	271	15.289±0.082	İstanbul	542	15.727±0.057a	Racetrack			C21-22	54	15.269±0.104ab		
9	412	15.280±0.070	Ankara	602	15.410±0.057d				OC	41	15.584±0.115a		
10	255	15.328±0.078	İzmir	162	15.429±0.074c	Dirt	1964	15.018±0.057	Total	2888	15.288±0.057		
11	135	15.211±0.087	Diyarbakır	39	15.038±0.121e	Turf	924	15.558±0.061					
12	151	15.253±0.087	Şanlıurfa	50	15.047±0.110e								
13-15	291	15.241±0.074	Elazığ	107	14.973±0.08e								
16-19	294	15.332±0.074											

Averages in the columns followed by different letters differed in Tukey's test (P<0.05).
n - race number; M - maiden; HC - handicap; HC13 - horses with a score between 1-50; HC14 - horses with a score between 1-65; HC15 - horses with a score between 1-75; HC16 - horses with a score between 30 and 85; HC17 - horses with a score between 40 and 100; C - conditions (C1, C2, C3, C4, C5, C6, C7, C8, C21-22) - horses that participate in these races according to the total amount of lifetime earnings. The more the number of condition race increases, the more total amount of lifetime earnings are needed to participate; OC - open class.

horses (Anderson and McIlwraith, 2004) was close to the findings of the present research. On the other hand, mother age did not significantly influence morphometric measurements, which suggests that the effect of mother age remained unchanged before the age of two years.

The average withers height, one of the most important measurements, detected in this study (169.34 cm) was close to the upper limit of the range (165-170 cm) for that breed (Arpacık, 1999), but was higher than the 164.1 and 163.0 cm reported in studies conducted in Turkey (Yılmaz and Ertuğrul, 2012) and Iran (Bakhtiari and Heshmat, 2009), respectively. Withers height of the two-year-old horses in this study (168.75 cm), however, corresponded to 98.6% of this value in horses of 6+ -years old (171.12 cm), which is in line with reports describing that two-year-old horses should reach 95% of the adult value in terms of withers height (Kocher and Staniar, 2013). The average withers height of the two-year-old foals in this study was very similar to the 168.9 cm predicted for Thoroughbred foals at same age in 34 regions of England, Ireland, and the USA (Kocher and Staniar, 2013), but higher than 154.7 cm reported for the same age of Thoroughbred foals in a private enterprise in USA (Anderson and McIlwraith, 2004).

Table 4 - Correlation coefficients among morphometric measurements of race horses

Morphometric measurement	RH	CG	CW	FCW	CD	NL	SL	LWR	RL	BL	HW	HL	CC
WH	0.679	0.610	0.391	0.117	0.536	0.398	0.442	0.464	0.153	0.677	0.384	0.330	0.115
P-value	<0.001	<0.001	<0.001	0.045	<0.001	<0.001	<0.001	<0.001	0.041	<0.001	0.001	0.001	0.031
RH		0.384	0.430	0.142	0.454	0.307	0.402	0.320	0.128	0.532	0.303	0.414	0.126
P-value		<0.001	<0.001	0.042	<0.001	<0.001	<0.001	<0.001	0.039	<0.001	0.008	0.003	0.039
CG			0.484	0.355	0.698	0.453	0.443	0.481	0.123	0.571	0.304	0.335	0.089
P-value			<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.048	<0.001	0.006	<0.001	0.340
CW				0.344	0.617	0.334	0.323	0.342	−0.026	0.443	0.509	0.360	0.060
P-value				<0.001	<0.001	<0.001	<0.001	<0.001	0.523	<0.001	<0.001	<0.001	0.552
FCW					0.430	0.346	0.327	0.063	0.046	0.433	−0.065	0.111	0.048
P-value					<0.001	<0.001	<0.001	0.545	0.523	<0.001	0.475	0.039	0.593
CD						0.490	0.455	0.541	0.125	0.593	0.388	0.314	0.049
P-value						<0.001	<0.001	<0.001	0.040	<0.001	<0.001	<0.001	0.560
NL							0.379	0.421	0.025	0.587	0.142	0.150	0.103
P-value							<0.001	<0.001	0.645	<0.001	0.047	0.038	0.145
SL								0.338	0.074	0.327	0.182	0.140	0.109
P-value								0.001	0.320	<0.001	0.036	0.045	0.140
LWR									0.085	0.453	0.302	0.469	0.026
P-value									0.325	<0.001	0.006	<0.001	0.612
RL										0.167	0.059	0.018	−0.018
P-value										0.038	0.589	0.696	0.690
BL											0.334	0.440	0.155
P-value											0.001	<0.001	0.032
HW												0.367	−0.036
P-value												<0.001	0.602
HL													0.074
P-value													0.312

WH - withers height; RH - rump height; CG - chest girth; CW - chest width; FCW - front chest width; CD - chest depth; NL - neck length; SL - shoulder length; LWR - length of withers to rump; RL - rump length; BL - body length; HW - head width; HL - head length; CC - cannon circumference.
Test - Pearson's correlation method.

In this research, race performance was evaluated as the speed of horses (m/sec) during the activity. The general evaluation of the effects of various factors on race performance revealed that the effects of all factors were important, except for mother age. Male horses had a better race performance than females (0.087 m/sec), corroborating results of studies conducted on the same breed (Ekiz et al., 2005; Mota et al., 2005; Buxadera and Mota, 2008; Park et al., 2011). On the other hand, Oki et al. (1994) noticed that mares were faster than stallions on turf at all race distances, while on dirt, Japanese Thoroughbred stallions were faster than mares, except at 1200 m.

In the present study, race performance improved steadily with age, from the lowest, two years old, to the highest, 6+ years old. The effect of age on race performance was significant and was consistent

Table 5 - Loadings and rotated loadings of four factors with eigenvalues >1 for the morphometric measurements of race horses

Morphometric measurement	Factor loading				Rotated factor loading				Common variance
	FI	FII	FIII	FIV	FI	FII	FIII	FIV	
WH	0.925	−0.236	−0.106	−0.239	0.928[1]	0.316	−0.106	−0.062	0.976
RH	0.875	−0.35	0.112	−0.404	0.896[1]	−0.025	−0.079	0.119	0.824
CG	0.926	0.251	0.104	0.081	0.875[1]	0.477[1]	0.019	0.005	0.994
CW	0.925	0.275	−0.089	−0.222	0.825[1]	0.251	−0.001	−0.093	0.752
FCW	0.468	0.684	0.407	−0.240	0.435	0.151	0.743[1]	0.088	0.772
CD	0.978	0.195	0.072	0.100	0.859[1]	0.495[1]	0.002	0.005	0.983
NL	0.894	0.359	−0.006	0.219	0.777[1]	0.594[1]	0.195	0.002	0.994
SL	0.749	0.371	0.104	−0.207	0.430	0.290	0.247	0.006	0.330
LWR	0.686	0.142	−0.045	0.580	0.780[1]	0.625[1]	−0.008	0.011	0.988
RL	0.295	−0.243	0.716	0.403	0.391	0.291	0.113	0.807[1]	0.902
BL	0.919	0.233	−0.112	0.025	0.926[1]	0.307	−0.011	−0.054	0.955
HW	0.569	−0.646	−0.169	0.085	0.565[1]	0.183	−0.562[1]	0.108	0.680
HL	0.579	0.189	−0.270	0.173	0.736[1]	0.392	−0.222	−0.126	0.761
CC	0.289	0.678	−0.449	0.207	0.199	0.563[1]	0.273	−0.542[1]	0.725
Eigenvalue	8.015	2.136	1.054	1.014	7.345	2.170	1.122	1.010	11.647
Variation (%)	57.250	15.257	7.529	7.243	52.464	15.500	8.014	7.214	83.193
Cumulative variance (%)	57.250	72.507	80.036	87.279	52.464	67.964	75.978	83.193	83.193

WH - withers height; RH - rump height; CG - chest girth; CW - chest width; FCW - front chest width; CD - chest depth; NL - neck length; SL - shoulder length; LWR - length of withers to rump; RL - rump length; BL - body length; HW - head width; HL - head length; CC - cannon circumference; FI - factor I; FII - factor II; FIII - factor III; FIV - factor IV.
Test - Principal Component Analysis and Varimax method.
[1] Rotated factor considered important.

Table 6 - Results for multiple linear regression analysis of the factors with eigenvalues >1 for the morphometric measurements of race horses

Factor	Coefficient	Standard error	t*	P-value
FI	−0.005	0.034	−0.150	0.345
FII	0.034	0.034	0.979	0.875
FIII	0.010	0.034	0.278	0.310
FIV	0.021	0.034	−0.620	0.596
R: 0.097; R^2: 0.009; Corrected R^2: 0.017				

FI - factor I; FII - factor II; FIII - factor III; FIV - factor IV.
* P>0.05.
Test - multiple linear regression analysis.

with the findings of investigations on the same breed (Ekiz et al., 2005; Buxadera and Mota, 2008; Park et al., 2011; Takahashi, 2015). The increase in race performance with age may be related to a gradual adaptation of horses to race conditions. Young horses can exhibit behaviors that may adversely affect race performance before and during the race. Horses with poor race performance might be separated from race life at an earlier age. As a matter of fact, in a study conducted in Japan (Takahashi, 2015), it was determined that the race performance of Thoroughbred horses increased to four years old and continued high after this age. Four-year-old Brazilian Thoroughbreds were significantly faster than horses of other ages for all race distances, except for 1100 m. However, the horses older than five years showed a significantly lower performance than the other ages for all race distances, excluding the 1100 m (Mota et al., 2005). Gramm and Marksteiner (2010) observed that peak age was 4.45 years and the lowest age was two for race performance in Thoroughbred in USA. On the other hand, race performance was not significantly affected by mother age. This finding differs from those reported in a study with Thoroughbred horses in England (Barron, 1995), in which race performance was higher for horses from younger mares and reduced for horses from older mares. Furthermore, similar results of unimportant mother effects on race performance were reported in a study with Arabian horses (Köseman and Özbeyaz, 2009).

In this research, significant differences in race performance were determined among the hippodromes. This may be because high-performance horses participate more in the races in Istanbul, Ankara, Izmir, and Bursa compared with the other hippodromes. In fact, highly awarded races are organized more often in these cities.

The fact that the differences in horse race performance between the 800 and 1500 m distance were not significant indicated that races up to 1500 m did not negatively impact performance. After 1500 m, the increase in race distance affected race performance negatively. It is possible that the number of turns on the racetrack had an influence on race performance, because races up to 1500 m include a single turn, while racetracks from 1600 to 2400 m include two turns. A research conducted on Thoroughbred horses in Japan reported that the number of turns was changeable (one or two) according to race distance, and turns induced a decrease in race performance regardless of the composition of the racetrack (Takahashi, 2015).

Horses running in turf racetrack performed better than those running in dirt racetrack, with 0.54 m/sec, and this result was consistent with literature reports (Arpacık, 1999; Buxadera and Mota, 2008; Park et al., 2011; Takahashi, 2015).

Race type also affected race performance, and the lowest was obtained in the Maiden and Condition 1 racings. Horses that have never been ranked first participated in maiden racing, while horses competing for the first time were involved in Condition 1 racing. Therefore, race performance was expected to be low in these races. On the other hand, the highest race performance was achieved in open-class racing. High-performance horses are known to have participated in open-class racing and being highly awarded.

Withers height, rump height, and chest girth were positively and significantly correlated with the other measurements. These results are in agreement with previous reports on Thoroughbred horses (Brooks et al., 2010), Brazilian Sport horses (Padilha et al., 2017), and Arabian horses (Sadek et al., 2006).

All measurements loaded in a positive direction for FI, indicating a positive correlation among all 14 measurements, and therefore head, neck, trunk, and limbs increase or decrease in size coordinately. Factor I was represented by significantly positive high loadings on withers height, body length, chest girth, chest width, chest depth, rump height, neck length, length of withers to rump, head length, and head width. Factor I explained more than half of the variation. Therefore, this factor seemed to represent general size. For FII, all measurements, except rump height, loaded in a positive direction. Factor II was highly loaded for chest girth, cannon circumference, chest depth, neck length, and length of withers to rump, and this factor seemed to represent body thickness. While half of the measurements in FIII were loaded in negative direction, this factor included significantly positive high loadings for cannon circumference and head width. The top contributors to FIV included cannon circumference (negative direction) and rump length (positive direction). Both FIII and FIV had only two significant loadings. It has been reported that two factors were obtained using the data collected from the head, neck, trunk, and limbs in 65 horse breeds including Thoroughbred using 35 body measurements (Brooks et al., 2010). Miserani et al. (2002) described only two factors for 15 linear measurements in Pantaneiro horses, while Sadek et al. (2006) reported that three extracted factors for each gender (mares and stallions) were determined in Arabian horses using 13 body measurements. These may be due to the differences among breeds or the type of investigated measurements.

Lower common variance for shoulder length and head width might indicate that these measurements were less effective to the variation compared with the other measurements in Thoroughbred horses.

According to the results of multiple regression analysis, the effects of the four factors on race performance obtained in this study were not significant, and only a very small portion of the variation of race performance can be explained by the examined morphometric measurements.

Conclusions

The effects of the examined morphometric measurements on race performance are not significant in Thoroughbred horses.

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