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Heart weight and running ability

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INTRODUCTION

Traditionally, there has been a commonly held belief that superior physical work capacity in individuals is associated with their having a relatively large heart. More recently, attempts have been made to correlate heart size (as indicated by the duration of the QRS complex on an electrocardiograph of an individual) or heart score, with enhanced running capacity in differing types of horses (Steel, 1963; Nielsen & Vibe-Petersen, 1980; Illera & Illera, 1987) and dogs (Steel *et al.* 1976) and in man (Steel, Stewart & Toyne, 1970). However, these correlations have not found general acceptance (see Physick-Sheard & Hendren, 1983).

While the work potential of a normal heart is proportional to its bulk (Grande & Taylor, 1965) it is apparent that one of the major determinants of absolute heart size, as indicated by its weight and reflected by the QRS complex on an ECG, is the size of the individual to which the heart belongs. However, the relationship between heart size and body weight to total muscle mass, either in normal animals or individuals having superior running capacities, has not been considered previously.

This study investigates the relationships of heart weight with body weight and total muscle weight in growing and adult horses and dogs and compares these relationships in animals noted for high speed running – Thoroughbreds and Greyhounds – with those in other less well-endowed members of their species.

MATERIALS AND METHODS

The weight of the heart separated from the great vessels and pericardium was determined in 11 Thoroughbreds, 12 other horses, 18 Greyhounds and 9 other dogs. Details of individual horses and dogs are given in Tables 1 and 2 respectively. Although total muscle weight was determined in all of the dogs it was not possible to determine total muscle weight in one of the Thoroughbreds and seven of the other horses. The animals were of different sexes and were non-debilitated. Horses were obtained from the postmortem room or knackery sources, while the dogs were either given to the author to be put down or were obtained from the postmortem room. Pups were reared especially for this and other investigations. Horses of two years and older and dogs over 15 months of age were considered to be adults for the purpose of this study. Body weight was recorded before or immediately after death and total muscle weight was determined as described previously for horses (Gunn, 1987) and dogs (Gunn, 1978). Four of the adult Greyhounds had completed a period of one year out of training but with limited normal exercise prior to being put down while the remaining adult Greyhounds were in training for racing at the time of death.

The data from all the animals of each type were used to investigate the development of heart size. Allometric equations which compared the increase of heart weight with that of liveweight or of total muscle weight were calculated from these data. The

Table 1. *Heart weight (in g) and its percentage of liveweight and total muscle weight in horses*

Type of horse	Liveweight (g)	Age status	Total muscle weight (g)	Heart Weight (g)	Heart Live-weight (%)	Heart Total muscle (%)
Thoroughbred	691	Young	274·6	7·3	1·06	2·66
Thoroughbred	13429	Young	2806	178·2	1·33	6·00
Thoroughbred	23872	Young	8809	300·0	1·26	3·41
Thoroughbred	30965	Young	—	441·0	1·42	—
Thoroughbred	40500	Young	16257	425·0	1·05	2·57
Thoroughbred	42962	Young	16789	482·0	1·12	2·87
Thoroughbred	58664	Young	23679	625·0	1·07	2·64
Thoroughbred	432727	Young	191883	3689·0	0·85	1·92
Thoroughbred	379000	Adult	163200	2630·0	0·69	1·60
Thoroughbred	484000	Adult	270300	5000·0	1·03	1·80
Thoroughbred	490000	Adult	286300	4300·0	0·88	1·50
		Mean percentage of adults			0·86	1·63
		S.D.			0·17	0·15
		Mean of adults		3977	0·88	1·66
Welsh mountain pony	2977	Young	1272	29·97	1·01	2·36
Welsh mountain pony	109091	Young	37803	695·0	0·64	1·84
Welsh mountain pony	114546	Young	39051	590·0	0·52	1·51
Welsh mountain pony	153727	Young	—	695.0	0.45	—
Welsh mountain pony	178182	Adult	—	1200	0·67	—
Shetland	203636	Adult	85054	1471	0·72	1·73
Arab	305455	Adult	—	2170	0·71	—
Piebald	318182	Adult	—	2405	0·76	—
Thoroughbred ×	369091	Adult	—	3310	0·90	—
Exmoor ×	480000	Adult	—	3850	0·80	—
Clydesdale	496364	Adult	223997	3510	0·71	1·57
Cob	547273	Adult	—	4410	0·81	—
		Mean percentage of adults			0·76	1·65
		S.D.			0·07	0·11
		Mean of adults		2791	0·77	1·61

regression coefficient '*b*' of such equations is considered to be the differential growth ratio of heart weight relative to liveweight or to total muscle weight. Analyses were carried out on the significance of the difference between the value of '*b*' for heart weight in relation to liveweight or to total muscle weight and unity. If '*b*' was significantly greater or less than 1 then the growth of the weight of the heart was significantly greater or less, respectively, than that of liveweight or of total muscle weight. All data were plotted on double logarithmic graph paper and tests for significance of regression equations were carried out using an *F* test.

The data were tested for significant statistical differences between the two types of adult animal within each species using Student's *t* test. Comparisons of heart weight at nominal values of liveweight in the two groups of animals were carried out by comparing the 95 % confidence limits of heart weight of the two types of horse and dog at neonatal and adult liveweights – 50 and 500 kg for horses and 0·5 and 30 kg for dogs. These calculations were carried out using computer facilities and the statistical methods of Diem & Lentner (1970) and Dixon (1971).

Table 2. *Heart weight (in g) and its percentage of liveweight and total muscle weight in dogs*

Type of dog	Liveweight (g)	Age status	Total muscle weight (g)	Heart Weight (g)	Heart Live-weight (%)	Heart Total muscle (%)
Greyhound	377	Young	97·4	8·17	2·16	8·39
Greyhound	927	Young	206·4	12·2	1·32	4·69
Greyhound	1056	Young	327·5	9·86	0·93	3·01
Greyhound	1174	Young	296·3	16·5	1·41	5·57
Greyhound	1423	Young	300·4	20·3	1·43	6·76
Greyhound	2280	Young	606·7	24·0	1·05	3·96
Greyhound	5712	Young	2080	59·0	1·03	2·84
Greyhound	11000	Young	4338	89·0	0·81	2·05
Greyhound	15250	Young	7206	158·0	1·04	2·19
Greyhound	19750	Young	9563	185·0	0·94	1·93
Greyhound	23508	Young	12455	305·0	1·30	2·45
Greyhound	24150 D*	Adult	13297	334	1·38	2·51
Greyhound	25000	Adult	14088	419	1·68	2·97
Greyhound	25200	Adult	14692	365	1·45	2·48
Greyhound	25300 D*	Adult	14422	326	1·29	2·26
Greyhound	28500 D*	Adult	15742	422	1·48	2·68
Greyhound	29750	Adult	17983	460	1·55	2·56
Greyhound	30000 D*	Adult	17213	449	1·50	2·61
	Mean percentage of all adults				1·48*	2·58*
	S.D.				0·12	0·22
	Mean of all adults			396	1·48	2·58
	Mean percentage of (D*) detrained adult greyhounds				1·42*	2·52
	S.D.				0·90	0·18
Cairn Terrier	1256	Young	327·5	12	0·96	3·66
Boxer ×	6585	Young	2120	63	0·96	2·97
Boxer ×	8500	Young	3024	66	0·78	2·18
Boxer ×	9900	Young	4183	85	0·86	2·03
Collie ×	10400	Adult	4453	108	1·04	2·43
Afghan	25100	Adult	12639	258	1·03	2·04
Afghan	31900	Adult	14509	330	1·03	2·27
Labrador	33000	Adult	11250	272	0·82	2·42
Great Dane	46500	Adult	20875	414	0·89	1·98
	Mean percentage of adults				0·96*	2·23*
	S.D.				0·10	0·21
	Mean of adults			276	0·94	2·17

* Indicates values that are significantly different ($P \leqslant 0{\cdot}02$) between breeds.

RESULTS

The values for the weight of the heart and its percentage of liveweight and of total muscle weight in adults and young horses and dogs are shown in Tables 1 and 2. Details of the allometric equations calculated from these data, which describe the growth of the heart relative to liveweight and to total muscle weight are given in Table 3 for horses and in Table 4 for dogs. Predicted heart weights at 50 and 500 kg liveweight for horses and at 0·5 and 30 kg liveweight for dogs are shown in Tables 5 and 6 respectively. The percentage of liveweight comprised by heart weight as assessed by dissection and computation are shown in Table 7 for both horses and dogs.

Table 3. *Logarithmic regression equations comparing the growth of heart weight relative to liveweight in Thoroughbreds from* 0·7 *to* 490 *kg and other horses from* 3·0 *to* 550 *kg liveweight and the growth of heart weight relative to total muscle weight in Thoroughbreds from* 0·7 *to* 490 *kg and other horses from* 3·0 *to* 500 *kg liveweight*

Independent variable	Type of animal	Number of observations	Growth ratio *b**	S.E. *b*	Log *a*	*r*†
Liveweight	Thoroughbreds	11	0·941	0·029	−1·697	0·9959
	Other horses	12	0·968	0·021	−1·982	0·9876
Total muscle	Thoroughbreds	10	0·869‡	0·047	−1·022	0·9885
	Other horses	5	0·921‡	0·025	−1·392	0·9989

* Regression coefficient *b*, standard error S.E. *b*.
† Correlation coefficient.
‡ Values of *b* are significantly different ($P < 0{\cdot}025$ for Thoroughbreds and $P < 0{\cdot}05$ for other horses) from 1.

Table 4. *Logarithmic regression equations comparing the growth of heart weight relative to liveweight and total muscle weight in Greyhounds from birth to* 30 *kg and other dogs from birth to* 47 *kg liveweight*

Independent variable	Type of animal	Number of observations	Growth ratio *b**	S.E. *b*	Log *a*	*r*†
Liveweight	Greyhounds	18	0·987	0·040	−1·844	0·9873
	Other dogs	9	0·998	0·036	−2·027	0·9955
Total muscle	Greyhounds	18	0·808‡	0·030	−0·835	0·9891
	Other dogs	9	0·868‡	0·033	−1·134	0·9951

* Regression coefficient *b*, standard error S.E. *b*.
† Correlation coefficient.
‡ Indicates values of *b* that are significantly different ($P < 0{\cdot}05$) from 1.

Table 5. *Weight (in g) of the hearts of Thoroughbreds and other horses at* 50 *and* 500 *kg liveweight calculated from the allometric equations describing the growth of heart weight relative to liveweight in horses*

	Liveweight			
	50 kg		500 kg	
	Thoroughbreds	Other horses	Thoroughbreds	Other horses
Heart weight	529*	369*	4616	3427
95% limits	(468–599)	(302–451)	(3834–5559)	(2851–4120)

* Indicates values that are significantly different ($P < 0{\cdot}05$) between breeds.

Although the weight of the heart increases at a lesser rate than liveweight and total muscle weight in both types of horses and dogs, the relative growth rates are only significantly less ($P < 0{\cdot}05$) in the comparisons versus total muscle weight for both horses and dogs (Tables 3, 4). The rate of increase of heart weight relative to both liveweight and total muscle weight is less in athletic animals than in their fellows in both species. However, the differences are not significant (Tables 3, 4).

The calculated values for the weight of the heart at adult and neonatal liveweights (Tables 5, 6) demonstrate that young Thoroughbreds and adult Greyhounds have

Table 6. *Weight (in g) of the heart of Greyhounds and other dogs at* 0·5 *and* 30 *kg liveweight calculated from the allometric equations describing the growth of heart weight relative to liveweight in dogs*

	Liveweight			
	0·5 kg		30 kg	
	Greyhounds	Other dogs	Greyhounds	Other dogs
Heart weight	6·61	4·65	379*	277*
95% limits	(5·08–8·58)	(3·48–6·22)	(319–450)	(247–311)

* Values followed by this superscript are significantly different ($P < 0{\cdot}05$) between breeds.

Table 7. *Heart weight as a percentage of liveweight in dissected adult horses and in computed* 500 *kg liveweight horses, dissected adult dogs and in computed* 30 *kg liveweight dogs*

Type of animal	Percentage of liveweight in: Dissected adults	Computed adults
Thoroughbreds	0·86	0·92
Other horses	0·76	0·68
Greyhounds	1·48	1·26
Other dogs	0·96	0·92

Table 8. *Heart weight as a percentage of liveweight and total muscle weight in adult dogs*

Type of dog	Mean percentage of: Liveweight	(N)	Total muscle	(N)
Greyhound	1.48*	(7)	2·58*	(7)
Detrained greyhound	1·42*	(4)	2·52	(4)
Other dogs	0·96*	(5)	2·23*	(5)

* Indicates values that are significantly different ($P < 0{\cdot}02$) between breeds.

significantly greater heart sizes than their fellows. However, the values for adult Thoroughbreds and young Greyhounds are also greater (but not significantly so) than those of their fellows.

Both the calculated values for heart size and mean values measured on dissected adult animals were expressed as a percentage of liveweight in horses and in dogs (Table 7). These values indicate that adult fleet-running animals have larger hearts relative to their liveweights than their fellows.

Heart weight comprises a smaller percentage of both liveweight and total muscle weight in detrained Greyhounds than in trained dogs (Table 8). However, both values are greater than those of the other dogs.

Differences in the percentage of total muscle weight made up by heart weight are not significant between adult Thoroughbreds (1·63) and adult other horses (1·65) (Table 1).

DISCUSSION

The capacity of the heart to perfuse tissues depends on its pulse rate and stroke volume. While pulse rate varies with an individual's metabolic requirements, maximum stroke volume is considered to be proportional to the weight of the heart (Grande & Taylor, 1965). The heart may be considered as a sophisticated pump having its pumping rate (and volume) regulated by the central nervous system and by feedback mechanisms and its pumping capacity related to its weight.

The results of this investigation indicate that both between and within species, heart weight forms a progressively smaller proportion of liveweight with increasing body size. The proportion of their liveweight occupied by heart weight is greater in dogs than horses. Furthermore, pups and foals have a greater proportion of their liveweight occupied by heart weight than the adults of their species.

Grande & Taylor (1965) reviewed previous reports on measurements of heart weight and liveweight in adult mammals over a large range of body size and concluded that heart weight increases at a rate proportional to the 0·9 power of liveweight with increasing body size, in animals ranging in liveweight from the mouse to the whale. Furthermore, heart weight increases at a slower rate than increasing liveweight during growth in the rat ($b = 0{\cdot}71$; Beznák, 1954), beagle ($b = 0{\cdot}91$; Deavers, Huggins & Smith, 1972) and man ($b = 0{\cdot}93$ for males and $b = 0{\cdot}88$ for females; Müller, 1883). These results are in accord with findings for the horse and dog in the present investigation. This suggests that smaller individuals have a greater potential capacity for aerobic metabolism than larger individuals.

It is clear from the results of this investigation that heart size is influenced by factors other than body size. Clarke (1927) suggested that animals accustomed to continual intense muscular exercise (e.g. hares and foxes) had ratios of heart weight to liveweight of 0·6 or greater, while those animals not accustomed to continual exercise (e.g. the pig or domestic cat) had heart weight to liveweight ratios of less than 0·6. While the horses and dogs investigated in this study fall into the former category, the breeds within both species that have been selected for high speed running (though not necessarily of long duration) are favoured by having relatively larger hearts than their fellows.

These findings confirm those of Herrmann (1926, 1929) who found that adult Greyhounds and Thoroughbreds have relatively larger hearts than other horses and dogs and that Greyhounds have the highest ratio of heart weight to body weight of all mammals that have been investigated (see Grande & Taylor, 1965). Likewise, the ratios of heart weight to liveweight in adult horses recorded by Quiring & Baker (1953) in adult Thoroughbreds (0·82) and adult horses of other breeds (0·75) also demonstrate that adult Thoroughbreds have relatively larger hearts than their fellow specific members.

Breeds of bovines (Charlet & Poly, 1966) and porcines (Davies, 1974) which have been selected for meat production have a high proportion of muscle on their carcasses but have low heart weight to liveweight ratios. By contrast, Thoroughbreds and Greyhounds, which also have high muscle to liveweight ratios (Gunn 1978, 1987) have relatively larger hearts than other members of their species. This possibly emphasises the value of physical work capacity as a criterion of selection.

Results of dissection studies on selected populations of human athletes and non-athletes are not available. However, the results of measurements carried out by Zeek (1942) at autopsies of 933 individuals in which the hearts had been considered relatively normal, indicate that the hearts from individuals of "unusually powerful muscular development" were heavier than those from persons of "average muscular development". However, the 'lifestyle' of the better-endowed individuals is not recorded.

While chronic loads on the heart, whether they be physiological or pathological, are associated with its enlargement, it is generally accepted that physical activity alone may be associated with cardiac hypertrophy. The relationship between heart size and physical activity has been reviewed by Blomquist & Saltin (1983). The evidence that exercise is associated with cardiac hypertrophy in the rat, rabbit, guinea-pig and dog has been reviewed by Grande & Taylor (1965). Likewise, Kubo, Senta & Sugimoto (1974) have demonstrated that heart weight increases with training in the horse also. By using non-invasive techniques, Morganroth, Maron, Henry & Epstein (1975), Keul, Dickhuth, Simon & Lehmann (1981), Longhurst, Kelly, Gonyea & Mitchell (1981) and Graettinger (1984) also demonstrate an increase in heart size with endurance training in man.

It is unlikely that the larger hearts of the adult 'athletes' in this investigation were a response to the training stimuli to which they were exposed. Members of the non-athletic group were also very physically active prior to death. Perinatal 'athletes' had heavier hearts at similar liveweights than 'non-athletes' and although the rate of increase in heart weight with increasing liveweight is less in the athletes than in non-athletes, nevertheless the difference exists over the entire range of liveweights observed in this investigation.

Hort (1951) demonstrated that the heart weight of rats increases with exercise but reverts to pre-exercise values 5 to 6 weeks after training ceases. However, the Greyhounds in this study which were detrained for one year had relative heart sizes which were significantly larger than those of other dogs. The findings of this study therefore suggest that the greater heart size of adult Thoroughbreds and Greyhounds is not due to environmental stimuli alone.

It has been suggested that the value derived from measurements of the duration of the QRS complex of the electrocardiograph – the heart score – (which is taken to indicate the size of the heart) has been associated with running ability in the horse (Rose, Ilkiw & Hodgson, 1979; Nielsen & Vibe-Petersen, 1980; Stewart, 1981), in the dog (Steel *et al.* 1976) and in man (Steel *et al.* 1970) – large values being associated with enhanced running ability. While this relationship has been questioned (Leadon, Cunningham, Mahon & Todd, 1982; Physick-Sheard & Hendren, 1983) the factors that govern absolute heart size in normal individuals have not been determined previously, either in individuals noted for high speed running or in their fellows over a range of liveweights and different stages of maturity. The results of this study indicate that if measurements of heart size and their relationship to athletic ability in horses and dogs are to be meaningful, they should be related to liveweights or preferably total muscle weight – due to the close correlation of heart weight with liveweight and total muscle weight.

Measurements of heart size are remote from those of stride length and stride frequency – the dictators of running speed (Gunn, 1975, 1983). Nevertheless, an indication of potential blood pumping capacity may be useful in certain athletes if it is considered to be a limiting factor to the athletic performance of that individual.

SUMMARY

The weight of the heart as determined by dissection techniques was compared with liveweight and total muscle weight in different types of horses and dogs as adults and during growth.

With increasing body size both within and between species, heart weight forms a lesser proportion of liveweight and of total muscle weight.

Heart weight forms a greater proportion of liveweight in Thoroughbreds and Greyhounds (breeds noted for high speed running) than in other less fleet members of their species and Greyhounds have greater heart weights relative to total muscle weight than other dogs.

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