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OXYGEN UPTAKE, HEART RATE, AND BODY TEMPERATURE DURING WORK IN MAN, DOG, AND SWINE

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Interim Report

NUTRITION BRANCH, FOOD DIVISION

March 1962

QUARTERMASTER FOOD AND CONTAINER INSTITUTE FOR THE ARMED FORCES
QUARTERMASTER RESEARCH AND ENGINEERING COMMAND, U.S. ARMY
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PROJECT:	*Attainment of nutritional reliability*
	7-84-15-092 A
TASK:	*Nutrition in relation to combat effectiveness*
PHASE:	*Correlation of performance in animals and man*

Oxygen uptake, heart rate, and body temperature during work in man, dog, and swine

by

D. R. Young and R. Price

Nutrition Branch, Food Division

Quartermaster Food and Container Institute for the Armed Forces

March 1962

ABSTRACT

This is the second of a series of reports dealing with comparative work physiology. Oxygen uptake, heart rate, and body temperature were examined in man, dog, and domestic swine during work of graded intensity on motor-drive treadmills. Differences in the body responses were noted, and ~~these are~~ discussed in relationship to species specificity.

OXYGEN UPTAKE, HEART RATE, AND BODY TEMPERATURE DURING WORK IN MAN, DOG, AND SWINE

Introduction

In an earlier study (1), we examined energy metabolism in man and dog at rest and during treadmill running. Results of these preliminary investigations suggested that gross energy expenditure and heart rate of the dog are considerably different from the responses measured with man during work. It appeared desirable therefore to reinvestigate the cardiovascular and respiratory responses, and tests were initiated to study these variables during conditions of identical physical work. In addition, as part of the over-all program of comparative work-physiology, a systematic study of heart rate and body temperature was undertaken with domestic swine to obtain basic information and to determine whether this species might be used for tests of physical endurance capacity.

Method

All work tests were conducted on motor-driven treadmills. Free air temperature varied between 69° and 75°F. Noise, lighting, and air movement were constant.

The data presented for human subjects were drawn from two sources. Thirty-nine subjects, representative of the healthy male personnel at this installation, were tested according to the procedure developed by Balke (2). Average age of the subjects was 28 years (23 to 45 years); average body weight was 75.4 kilograms (69.1 to 91.0 kg.).

Most of the treadmill tests were conducted in the morning several hours after consumption of a light breakfast. With all subjects the rate of progression was held constant at 2.72 m.p.h. and the grade increased one degree per minute until the onset of physical exhaustion; average walking time was 12 minutes. Heart rate was determined by palpation of the radial pulse. Data on human respiratory gas exchange were drawn from similar studies by Balke (2) with eight young aviation cadets whose body weights averaged 73.5 kilograms (61.0 to 84.2 kg.).

The dog data were obtained from studies with six well-conditioned male beagle dogs tested at a constant speed of 3.63 m.p.h. and at various grades ranging from 0^{o} to 22^{o} of incline. The dogs were 12 months of age and varied in weight from 8.4 to 12.3 kilograms. Most of the running trials were of 40 minutes duration. Heart rate was determined with a cardiotachometer; body temperature was determined with a thermistor probe inserted six inches into the rectum and indicating through a multichannel telethermometer. Oxygen uptake was determined by using special respiratory masks for collection in duplicate of samples of expired air; expired air samples were analyzed for oxygen and carbon dioxide content with a Beckman oxygen analyzer and Haldane apparatus, respectively. The procedure for measuring respiratory gas exchange in the dog has been set forth in detail elsewhere (3). Treadmill tests of work capacity in dogs are demonstrated in Figure 1.

Finally, tests were conducted with one male hog, "Cyril", obtained from a herd of registered Hampshire swine. The hog was castrated at nine weeks of age. One month was spent in technical training and physical conditioning of the animal in order to assure consistent responses.

At the time of testing, the hog was 17 weeks of age; body weight was held constant at 41 kilograms by controlled feeding. The treadmill tests were conducted at a constant speed of 1.5 m.p.h. and at grades varying from 1^{o} to 14^{o} of incline. Most of the tests were of one hour duration. Body temperature was determined with a thermistor probe inserted eight inches into the rectum. Heart rate was determined by auscultation with a stethoscope placed over the apex of the heart and fastened about the chest with an elastic strap. A treadmill test of work performance of the pig is shown in Figure 2.

With dogs and the domestic hog, the treadmill tests at the various grades of incline were administered in a random order to obviate any unusual bias referable to training effects. In all cases, physical work was determined from the vertical ascent and the body weight and expressed as kilogram-meters/minute.

Results

Oxygen uptake and workload. Average oxygen uptake in relationship to workload was examined in eight human subjects and six dogs. For both species, the oxygen uptake in cubic centimeters per minute is a linear function (r= .99) of workload. Equations of the linear form $y = mx + b$, were fitted to the data by the least squares method. The best fit curves along with the 95 percent probability limits are shown in Figure 3. It will be noted that for comparable workloads, the gross oxygen uptake of man is approximately twice as large as that observed with the dog. The oxygen uptake in man is described by the equation $y = 1.58x + 1047$, where y is the oxygen uptake in cubic centimeters

per minute, and x is the workload in Kg-m/min. In dogs, the relationship is described by the equation $y = 1.84x + 339$. Differences in the slopes of the lines are not significant.

Heart rate during work. Heart rate was studied in 39 human subjects, six dogs, and one swine during work of graded intensity. These data are shown in Figure 4. With the dog, the relationship between heart rate and physical work is described by the equation, $y = 0.216x + 196$; in man the relationship is $y = 0.0627x + 111$. The regression slopes are significantly ($p = .05$) different.

With the swine, the absolute level of the average heart rate lies midway between the values measured in man and dog. The rate of increase of heart rate with increased work parallels the changes observed with the dog. Since only one animal was tested, a detailed analysis of the data was not undertaken. Moreover at every grade tested, heart rate of the swine, in contrast to man and dog, showed a tendency to increase systematically with walking time. Accordingly, it is felt that additional tests should be undertaken in order to more fully evaluate the cardiovascular responses. A typical response of the swine during treadmill walking is shown in Table 1.

Effect of work on the body temperature. Body temperature was examined in the experimental animals. The relationship between rectal temperature and duration of work in treadmill tests of graded intensity is shown in Figure 5. With dogs, the average maximum rectal temperature attained was 108.3°F. At all work loads tested, the temperature of the dog increased more rapidly than did the temperature of the swine. The data set forth in Figure 5 suggest that for workloads in excess of

100 kg-m/min, body temperature of the dog rises as an exponential function of the duration of work. In contrast, the temperature of the swine appears to be a simple linear function of the duration of treadmill walking; the highest rectal temperature measured was 105.8°F.

Table 1

Increase of heart rate during treadmill walking (150 kg-m/min.) in the swine

Walking time in minutes	Heart rate per minute
4	160
8	168
12	168
16	164
20	164
24	164
28	172
32	172
36	176
40	176
44	176
48	176
52	176
56	176
60	172

Discussion

Over the general range of workloads (200 to 1150 kg-m/min.) examined, the oxygen uptake of man varied from 1360 to 2810 cubic centimeters per minute. With the dog, oxygen uptake varied between 460 and 1440 cubic centimeters per minute over the range of workloads (74 to 600 kg-m/min.). The increase in oxygen uptake as a function of work was similar in both species. Since the gross oxygen uptake is the sum of at least two components, i.e., the basal metabolism plus metabolism referable to the increased work of the muscles, preliminary computations were undertaken

to determine whether differences in the absolute levels of oxygen uptake measured might be associated with differences in basal metabolic rate. However, subtracting constants from the data did not materially alter the relationship between the two species, and the results continued to indicate that for comparable work, oxygen uptake of man is approximately twice as high as values observed with the dog.

The highest heart rates were observed with dogs; they ranged from 210 to 294 beats per minute. In man, heart rate varied from 123 to 189. Values of 180 to 190 per minute are commonly accepted as maximum rates in well-conditioned human subjects. Increase of heart rate in man during work of graded intensity is more gradual than that observed with dogs.

Comparisons were made of the effect of work on the body temperature of dogs and swine. Since both species are typically non-sweating mammals, it was assumed that the mechanisms associated with temperature regulation would be similar. However, characteristically at all workloads studied, the rectal temperature observed in the dog was consistently higher than the rectal temperature in the swine. Furthermore, increase in body temperature of the dog was more dramatic and appeared to be related exponentially to the duration of work. In contrast, the temperature of the swine appeared to be simply a linear function of the duration of work. Both species were observed to pant during the treadmill tests, and consequently it is presumed that a relatively large amount of heat was dissipated via the oral and respiratory tract. Nevertheless, the data set forth in Figure 5 suggest that the mechanisms of heat loss differ considerably in the two species tested, and moreover that temperature regulation of the swine is superior than that of the dog.

It is possible that the increase in heart rate observed in the swine at every workload increases the blood perfusion rate to the tongue and respiratory surfaces and results in more effective control of body temperature.

Conclusions

Several characteristic differences have been noted in the responses of man, dog, and swine to treadmill tests of work capacity. Somewhat surprisingly, the energy cost of physical work is much less for the dog than values reported for man. While it is well known that resting metabolism in many species increases as a function of the body weight, a similar relationship during work was unanticipated. Since the grades of incline were adjusted for differences in body weight in order to attain comparable workloads in dog and man, it is felt that the influence of body mass per se on the oxygen uptake was removed, and in consequence was not a factor contributing to the variability of the responses. Nevertheless, the dogs continued to show lower levels of metabolism and it is concluded that the data indicate a species specificity for oxygen uptake during work.

Similarly, heart rate during work appears to be specific for the species tested. Results of the present study indicate that heart rate is highest in the dog, intermediate in the swine, and lowest in man during comparable physical work.

A systematic study of body temperature in relationship to work was undertaken with two non-sweating species, dog and swine. The data show that, over the range of workloads tested, temperature regulation of the swine is superior to that of the dog.

The present results indicate the need for further studies in comparative work-physiology to elucidate the basic responses to physical work and to determine in detail the mechanisms whereby species may differ in their reactions to specific stress situations. Development of additional information eventually would permit construction of nomographs equating physiologic intensity to physical work in several species.

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2. Balke, B. Tech. Rpt. Nr. 1, April 1952. Air University School of Aviation Medicine, USAF, Randolph AFB, Texas.
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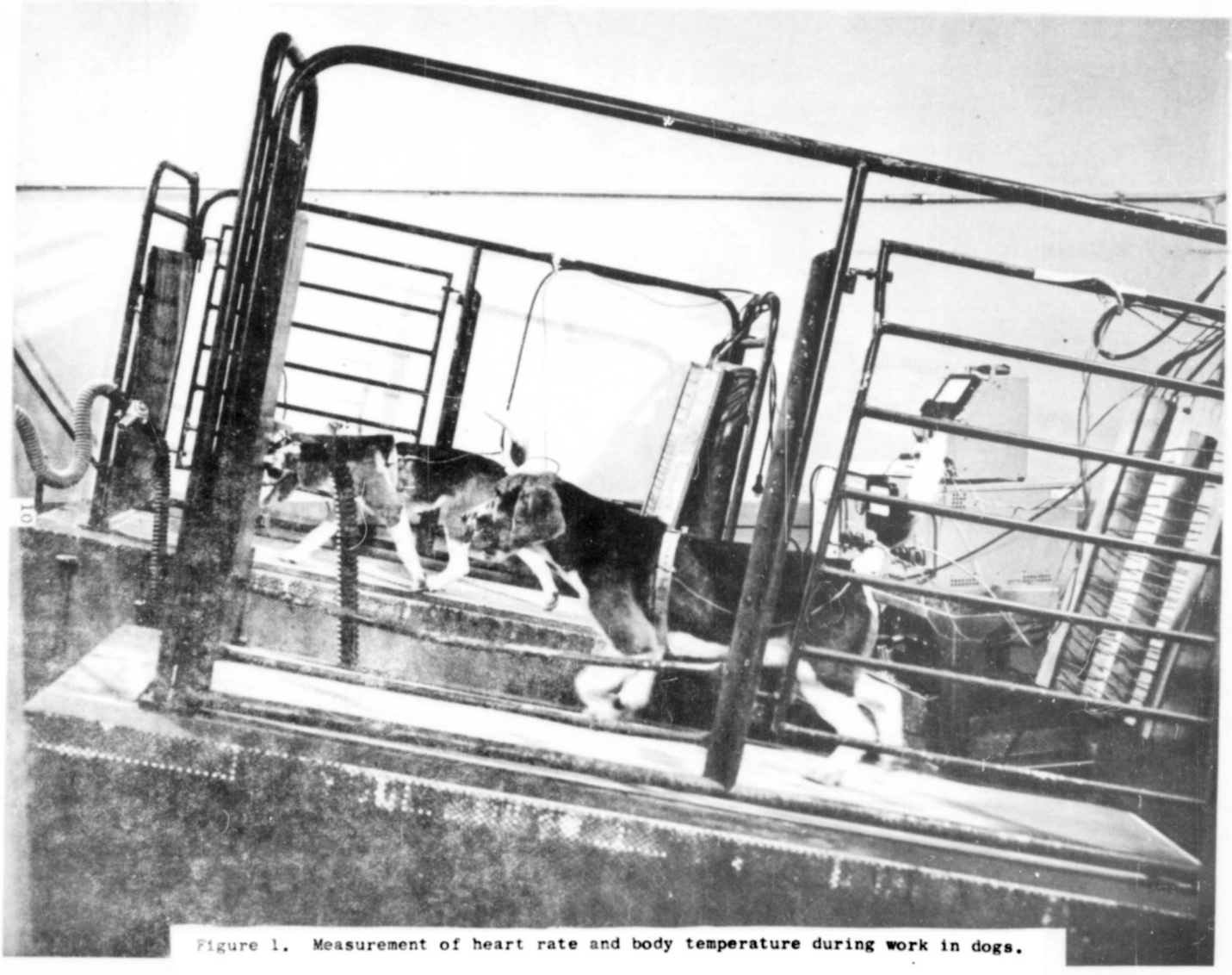

Figure 1. Measurement of heart rate and body temperature during work in dogs.

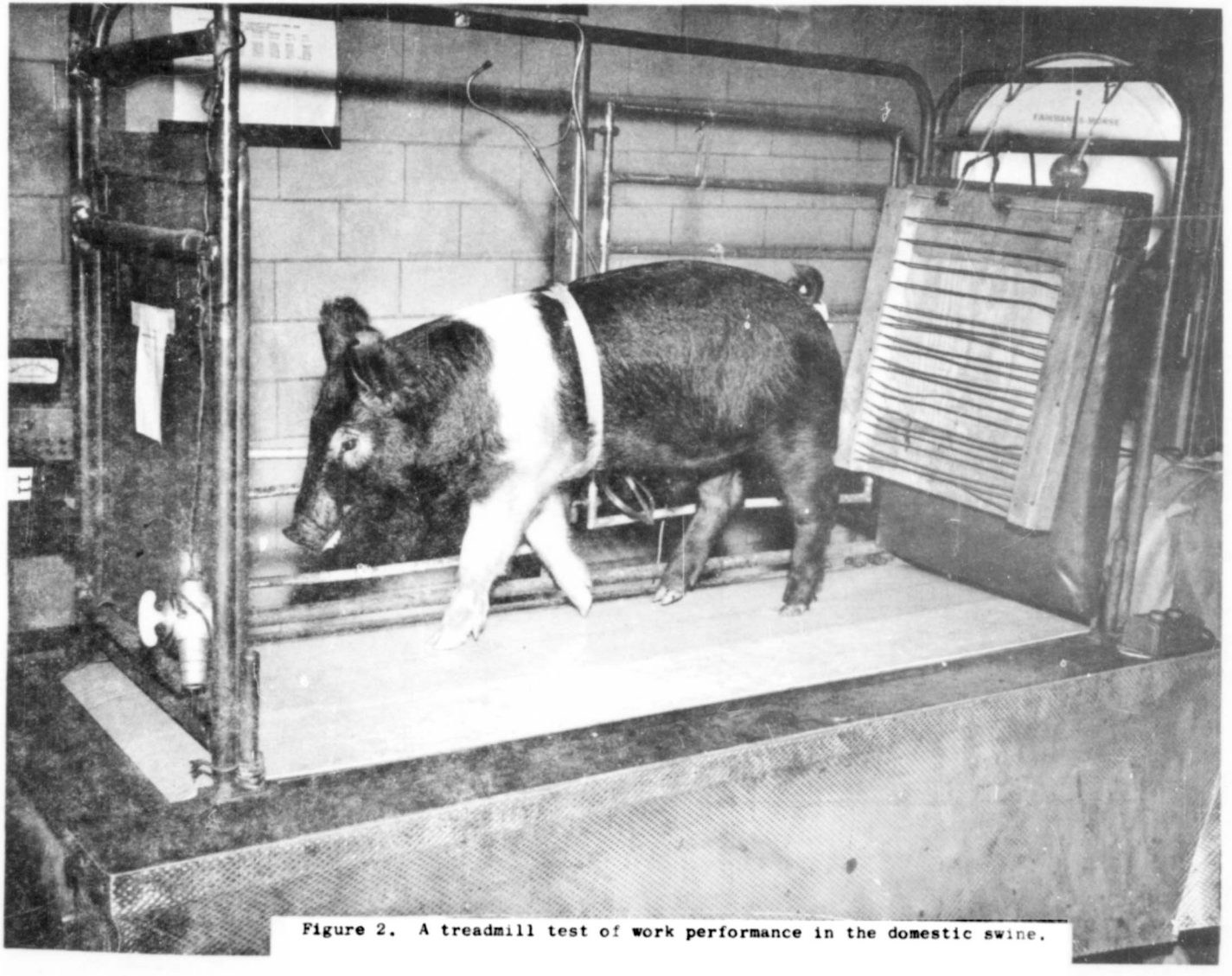

Figure 2. A treadmill test of work performance in the domestic swine.

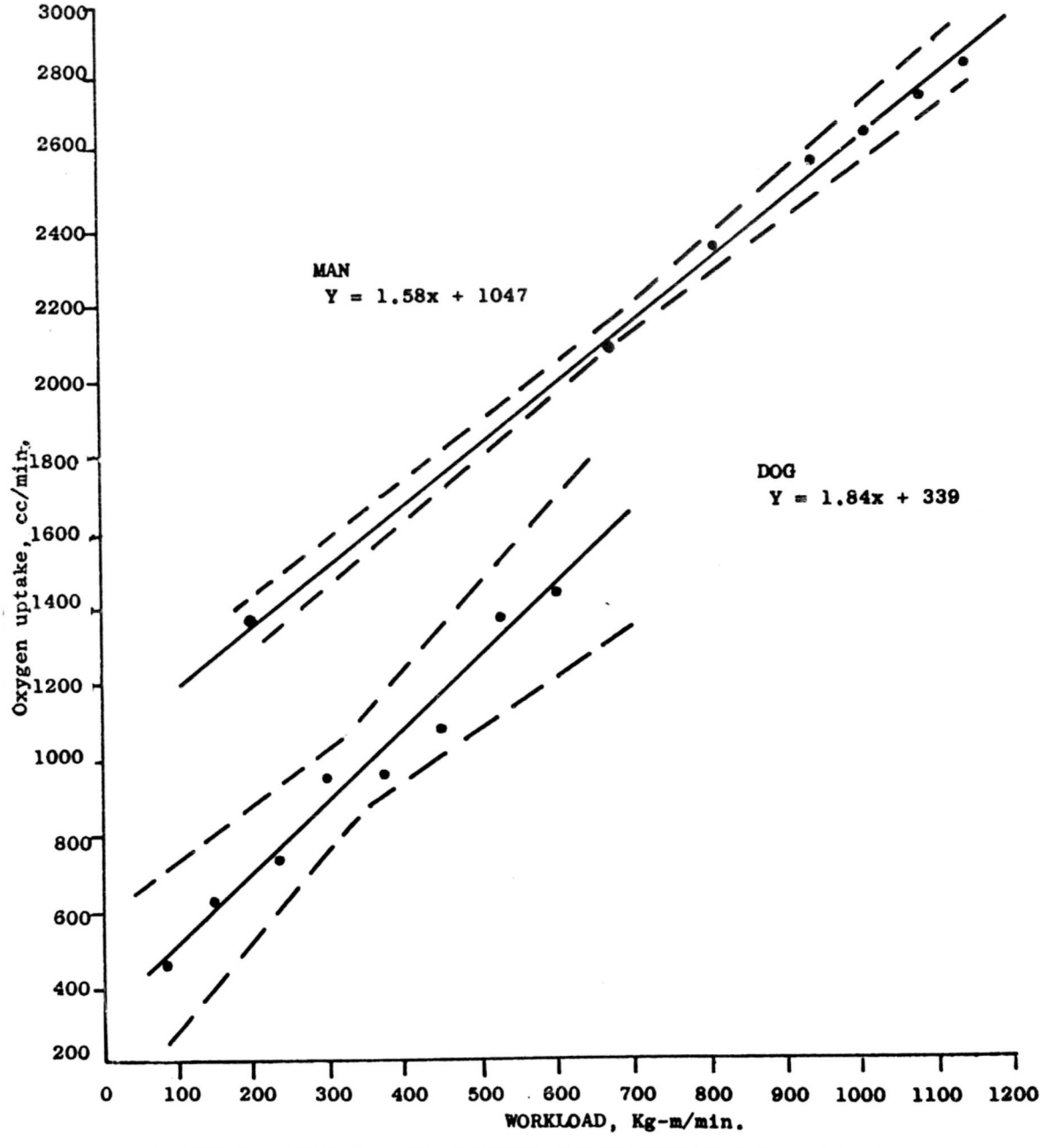

Figure 3. Relationship between oxygen uptake and workload in man and dog.

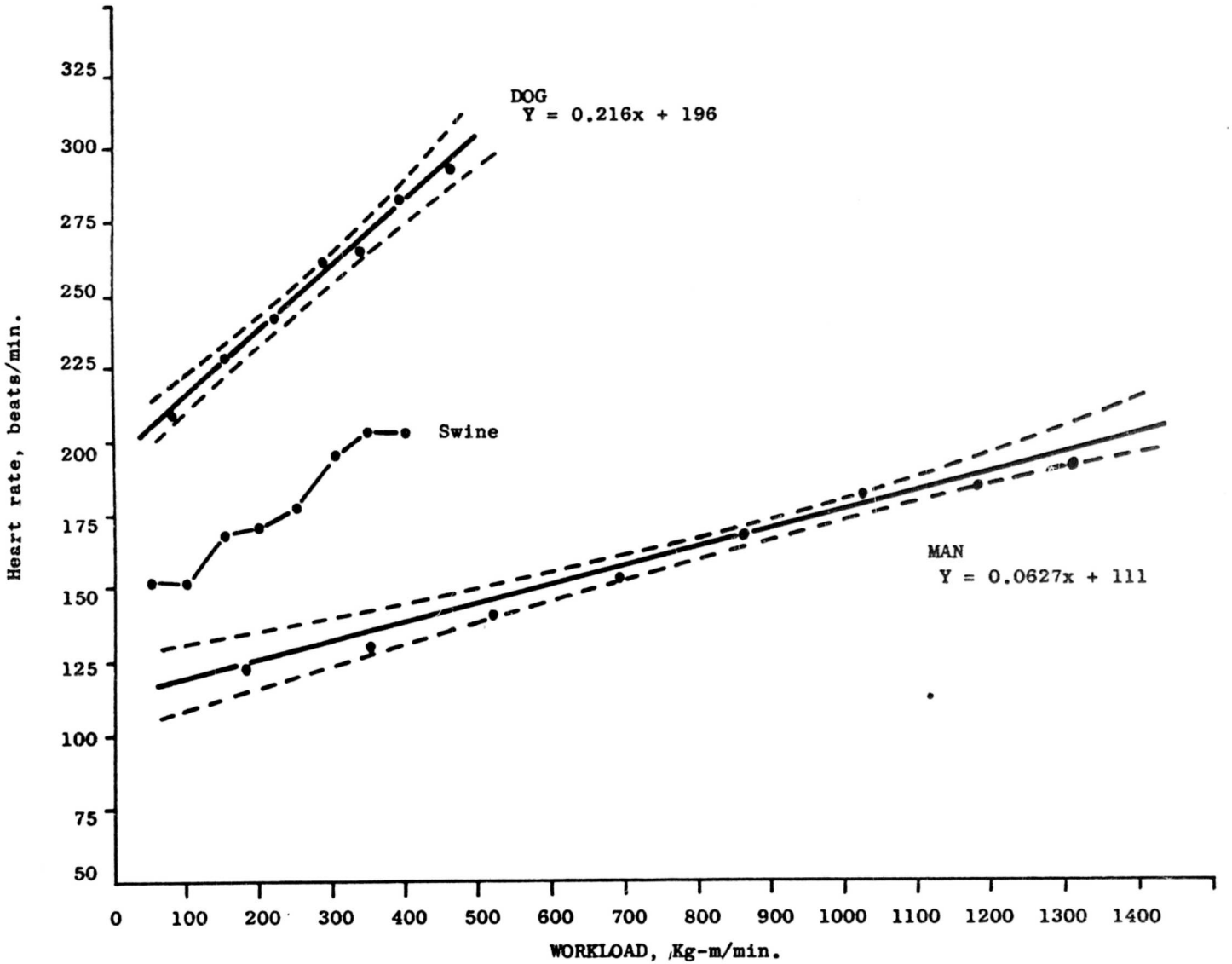

Figure 4. Relationship between heart rate and workload in man, dog, and swine.

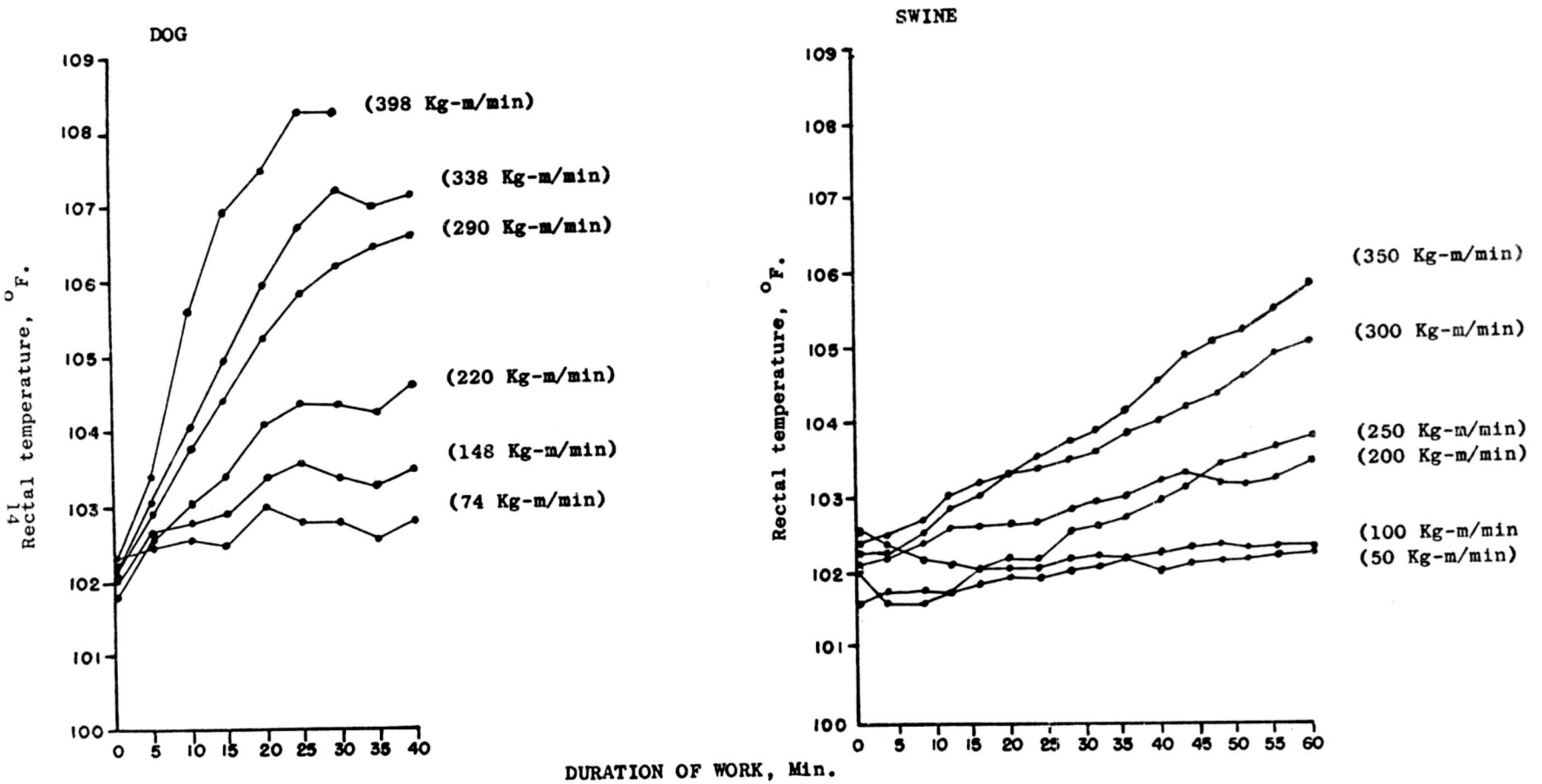

Figure 5. Relationship between rectal temperature and duration of work in treadmill tests of graded intensity with dogs and swine.

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