

Studies on the exercise physiology of draft horses performed in Japan during the 1950s and 1960s

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Although the total number of horses raised in Japan dramatically decreased after World War II, because draft horses were still used for farm work in paddy fields and on farms during the period of the 1950s and 1960s, a performance test for selecting better draft horses was needed. In order to determine the most suitable size of draft horses for Japanese farm conditions, the working power of horses weighing from 185 to 622 kg was evaluated by performing an endurance test, several kinds of working power tests, and maximum pulling power tests. Oxygen consumption during draft exercise was measured by the Douglas bag method in order to evaluate effects of draft workload under the conditions of different types of work (14- and 18-cm plow depths, cultivator, and tillage), traction methods (shoulder traction, shoulder-trunk traction, and chest-trunk traction), walking speeds (40, 60, 80, 100, and 120 m/min), and depths of water (0, 18, 36, and 54 cm) on energy expenditure. The relationship between energy consumption and pulse rate during exercise was also evaluated. A study of a performance test for draft horses was conducted to establish a new approach for evaluating draft horse performance using heart rate as an index. For this study, a beat meter for measuring heart rate was developed, and experimental protocols were used to evaluate the relationship between heart rate and workload. Although the research results obtained from these studies do not have particular relevance in the current day, these studies are valuable for understanding the history of equine exercise physiology in Japan.

Key words: body size, draft horse, exercise physiology, heart rate, oxygen consumption

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During the period from the 1930s to the beginning of the 1940s, research on draft work of horses was mainly performed using warhorses [12, 13, 46] because warhorses were important at that time. In 1942, Ogura of the Taipei Imperial University (now defunct) published a 100-page research report entitled “Performance testing of the horse” [35], which reported about research conducted using warhorses. In this report, many physiological variables, such as body temperature, respiratory frequency, blood viscosity, hemoglobin concentration, blood pH, and other parameters were measured during running, carriage, and draft tests, and

the original index to evaluate performance of the warhorse was calculated. This research was carried out with reference to the epoch-making studies of racehorses by Matsuba and Shimamura in the 1930s [11, 24, 25].

The total number of horses raised in Japan in the period just after World War II was about 1.5 million, and this number dramatically decreased during the early postwar period. The reasons for the rapid decrease were not simple, and it is thought that several factors might have influenced the decline in numbers. However, it is generally considered that the large shift in usage from warhorses to draft horses that occurred in the early stages of the postwar period was a major reason for the rapid and large decrease in numbers. The trend toward decreasing numbers continued during the 1950s and 1960s, and the total number of horses had decreased to fewer than 400,000 by 1964. On the other hand, because draft horses were still used for working in paddy fields and on farms at that time (Fig. 1), a performance test for selecting better draft horses was needed. Farm work

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Fig. 1. Plowing on farm during the 1950s in Hokkaido. This photo was used through the courtesy of the Horse Museum at Obihiro Racecourse.

performed by draft horses was roughly classified into two categories: carrying loads and draft work such as pulling a plow, cultivator, or harrow. In the case of draft work, the draft workload might be different depending on the pulling method, machinery or equipment used, and/or the weight pulled. Even if the draft workload were the same, differences in the pulling method or size of the horse might affect the workload imposed on the horse. With this as the background, studies on the exercise physiology of draft horses were performed during the period of the 1950s and 1960s.

Studies on the Relationship between Body Size and Work Power

According to a paper by Ishizaki *et al.* of the Nasu Branch of the Zootechnical Experiment Station in 1949 [15], although the purpose of selective breeding of horses to develop specific traits had been demonstrated by the army during the period prior to the end of World War II, a new perspective on selective breeding of draft horses in the postwar era was required. This was especially true in terms of body size, with the need for draft horses that were of smaller size but with sufficient power for doing farm work in Japan and with economic efficiency for feeding. Therefore, Ishizaki performed a series of experiments on the relationship between body size and working power in draft horses. Although there were several foreign reports on the relationship between body size and work power in heavy draft horses and it had been suggested that body weight

(BW) is an important factor determining pulling power, there were few reports on smaller draft horses such as those in Japan.

In order to determine the most suitable size of draft horses that are fit for Japanese farm conditions, the work power of horses weighing from 200 to 500 kg was investigated. In a series of experiments, endurance, several kinds of working power, and maximum pulling power were all measured. Endurance tests were conducted by having horses draw carts over 3 successive days. Working power was evaluated by having horses plow, draw a cart, pack, or be ridden for 4 hr. Maximal pulling power was evaluated by having horses draw carts and wagons with heavy loads for a distance of 600 m.

In the first experiment, three Korean ponies (avg. BW 190 kg) were used as a model of 200 kg horses [15]. The previously described endurance, working power, and maximal pulling power tests were performed.

The major findings of the endurance test were as follows: 1) Korean ponies could draw carts (147 kg cart weight and 210 kg load) 24 km per day for 3 successive days. For this test, the mean draft workload was 20 kg (1/9 of the pony's BW), and the working time per day was about 7 hr including 2 hr of rest. 2) When drawing carts (147 kg cart weight and 480–520 kg load) with a mean draft workload of 40 kg, ponies could draw the cart 8 km per day over a working time of about 3 hr including 1 hr of rest.

Major findings obtained from the working power tests were as follows: 1) Regarding plowing, Korean ponies

could plow a 720 m² paddy field in about 3.5 hr. The plowing depth was 11 cm, and the mean draft workload was 42–45 kg. 2) Regarding drawing carts, Korean ponies could pull carts with a mean draft workload of 20 kg about 13 km in 4 hr including 1 hr of rest. 3) Regarding packing, Korean ponies could carry an 80 kg load and walk 16 km in about 4 hr including 30 min of rest. 4) Regarding riding: In riding (proportion of 10 min walking and 5 min trotting), Korean ponies could go 18 km in about 4 hr including 1 hr of rest. The mean speed was 74 m/min when walking and 162 m/min when trotting.

Major findings from the maximum pulling power test were as follows: 1) When pulling carts (147 kg cart weight), Korean ponies could pull a load of about 1,000 kg. In this case, the mean draft workload was 58–64 kg. 2) When drawing wagons (300 kg wagon weight), ponies could pull a load of 675–850 kg with a mean draft workload of 56–66 kg.

From these results, it appeared that there are some suitable types of farm work for these ponies on small Japanese farms. Because the horses used in this study were not in good condition because of a shortage of feed and the fact that they had never been trained until the experiments, it was concluded that these horses might have reasonable potential for use in farm work if they were fed and trained appropriately. Similar experiments were performed on Hokkaido ponies weighing about 300 kg [16], as well as crossbred horses weighing about 500 kg [17].

Relationships between work power of draft horses and their BW were evaluated [18] using data from 185 to 622 kg obtained during several power tests and maximal pulling power tests mentioned above [15–17]. When the horses were made to work pulling carts or wagons with a mean draft workload of about 1/10 of their BW, there was no significant correlation between walking speed and BW. When they plowed a paddy field with a Japanese plow, the two factors became significantly correlated, i.e., the lighter the BW, the slower the speed. However, it was not indicated if the draft workload of the plow was the same percentage of BW for different-sized horses. In a riding test with repeated bouts of walking for 10 min followed by trotting for 5 min, 190 kg Korean ponies moved markedly slower than heavier horses.

Speed was influenced by both stride length and stride frequency. When horses walked freely during the tests, the stride frequency of heavier horses was lower, while their stride length was greater than that of lighter horses (Fig. 2). These relationships between body size, stride length, and stride frequency are typical of nearly all mammalian quadrupeds. Small mammals cannot move their legs fast enough to make up for their short stride length, whereas, large mammals must keep their legs more vertically beneath

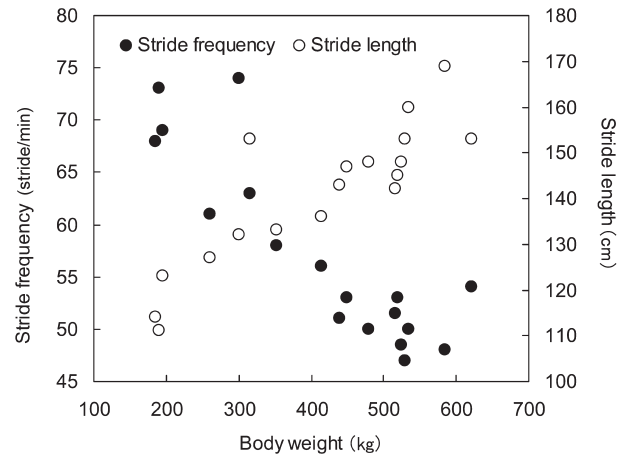


Fig. 2. Stride frequency and stride length in relation to body weight. The authors generated this graph using data in a report by Ishizaki *et al.* [18].

them to minimize the risk of breaking a leg when extending a stride so far that the bone cannot withstand the shearing force. As a result, the fastest mammals (cheetah, pronghorn antelope, Indian blackbuck) are all about 50 kg in BW.

The plowing of paddy fields with a Japanese plow was work too heavy for Korean ponies that only weighed about 200 kg. The 300 kg Hokkaido pony appeared to be the smallest horse that could easily pull a Japanese plow in a paddy field. The correlation coefficient between the area plowed and the BW of the horse was $r=0.92$. Heavier horses showed a tendency to plow more deeply than lighter horses.

The maximum weight load that could be carried as well as the load that could be pulled by horses were correlated with body weight, with correlation coefficients of $r=0.91$ and $r=0.98$, respectively. Although the maximal pulling power of horses was almost proportional to their BW, their maximal packing ability was not proportional. Lighter horses could pack heavier loads disproportionately to their BW. It was suggested that pulling power was different from packing ability in terms of BW. The regression coefficient of the percentage of area surrounded by the four hoofs of the horse was quite similar to that of the maximal load that could be packed in relation to BW. From these results, it could be concluded that the area surrounded by the four hoofs had a certain relationship to packing ability.

The question as to the size required for deeper plowing, i.e., to a depth of 18–20 cm, was investigated using 13 horses weighing from 306 to 652 kg [19]. The results suggested that horses weighing 498 kg or more could perform deeper plowing for 4 hr, and in terms of body conformation, those horses would be at least 148 cm in height, 177 cm in chest circumference, 19.9 cm in cannon circumference, and 156

cm in body length [14].

Relationships between body size and pulling power were also evaluated by another research group at the Tohoku Agricultural Experiment Station using 3 Percherons (avg. 650 kg BW), 3 crossbred horses (500–600 kg BW), 3 trotters (340–440 kg BW), and 3 Hokkaido ponies (avg. 300 kg BW). Endurance and pulling power tests (80 kg, 1/6 of BW, and 1/4 of BW) were performed. The results revealed that pulling power per kg BW was highest in the trotters, then the Percherons, Hokkaido ponies, and crossbred horses, in that order [23]. Data obtained from a plowing power test that used 2 Percherons (avg. 691 kg BW), 2 crossbred horses (avg. 544 kg BW), 2 trotters (avg. 406 kg BW), and 2 Hokkaido ponies (avg. 292 kg BW) revealed that working capacity was highest in the trotters. Furthermore, the trotters and Hokkaido ponies had higher working efficiencies per unit BW [4].

Results obtained from research by Ishizaki *et al.* [14–19] and others [4, 23] showed that smaller horses raised in Japan could perform farm work without being excessively stressed by the workload. However, because a BW effect was observed in some of the power tests, careful attention had to be paid when selecting horses for certain types of work.

Studies on Energy Expenditure during Exercise

In order to evaluate workload during exercise, it is necessary to measure energy expenditure. Because energy expenditure can be estimated from oxygen consumption (VO_2), measurement of VO_2 during exercise is essential for calculation of energy expenditure. Although the Douglas bag method was a standard method for measuring VO_2 of animals, the experiments required that a newly devised face mask and other equipment had to be improved for application in animals exercising in field conditions. There was no study on this topic for horses in Japan until Tatsumi *et al.* of the National Institute of Agricultural Sciences tried making measurements as described later in this chapter.

To study respiration during draft exercise, Sawazaki *et al.* [47] of The University of Tokyo compared respiratory frequency (RF) during 3 different types of draft work: plowing, cultivating, and harrowing using the same equipment Okabe and Sugiyama had used [10, 38]. According to their observations, RF increased in a fluctuating manner and reached a given steady state for each exercise. The average draft workloads for plowing and harrowing (30–35 kg) were greater than that for cultivating (20–25 kg). Because horses had to walk on softer ground when harrowing than when plowing, it is generally considered that harrowing is heavier work than plowing. Because the rate of increase in

RF tended to be higher when harrowing than plowing and higher when plowing than cultivating, they suggested that RF is higher when performing heavier work.

Oxygen consumption of horses exercising in various forms of draft work during field exercise was measured using the Douglas bag method by Tatsumi *et al.* In the first experiment, energy expenditure during paddy field plowing of 2 crossbred horses weighing about 540 kg with the draft workload set at 50 kg (about 1/10 of the horse's BWs) was measured [49]. Plowing distance, plowing depth, and speed were 368 m, 10 cm, and 60–80 m/min, respectively. In the morning, expired gas was collected for 6 min and analyzed to determine resting values before any food had been ingested before the measurement. Expired gas was also collected and analyzed throughout 5 min of the main exercise and during recovery for 6 min. The results showed that the net exercise caloric cost per 100 m² was 200 calories. Gross efficiency, net efficiency, and relative metabolic rate were 18%, 26.5%, and 4.7, respectively. Because this workload was considered to be equivalent to draft work on a flat surface, it was concluded that this work would not be excessive for well-trained draft horses.

A second study was done to measure energy metabolism during 4 different kinds of pulling when working crops, including 14-cm-deep plowing (55 kg draft workload), 18-cm-deep plowing (112 kg draft workload), soil crushing with a square harrow (42 kg draft workload), and intertillage using a cultivator (48 kg draft workload), and the results were compared using 3 crossbred horses [50]. Expired gases were collected throughout walking for 360 m and during 10 min of recovery to calculate VO_2 . Relative metabolic rate was calculated from energy expenditure during exercise by subtracting basal metabolic energy expenditure. Since basal metabolic energy expenditure had not yet been measured in horses at that time, resting metabolic energy expenditure measured in early morning was used instead of basal metabolic energy expenditure for the calculation of relative metabolic rate. Tatsumi named this variable the "relative metabolic rate of animal". According to the results in Table 1, it was presumed that 18-cm-deep plowing was a heavy draft workload but efficient work, while soil crushing was a low draft workload but inefficient work.

Energy metabolism of 3 different pulling methods including shoulder-trunk traction, chest-trunk traction, and shoulder traction was evaluated by using a sleigh that was weighted to offer a draft workload that was 1/10–1/9 of the horse's BW during a 400 m unstrained walk [53]. Although draft workload, work rate, and net efficiency were almost equal among the 3 methods, the calories used for the work and relative metabolic rate tended to be higher for shoulder traction. From these results, it was concluded that the preferred method for each horse must be chosen by

Table 1. Energy expenditure during various types of draft work in paddy fields and on farms

	Paddy field plowing	14-cm-deep plowing	18-cm-deep plowing	Crushing soil	Intertillage
Draft workload (kg)	54.7	55.3	112	42	48
Velocity (m/min)	71.8	50.8	46.3	56	55.9
Breadth of plowing (m)	2.0	0.11	0.1	1.2	0.67
Depth of plowing (cm)	10.0	13.7	18.0	3.7	9.3
Work (cal)	44.6	46.8	94.6	35.5	40.5
Energy expenditure (cal)	248	313	359	299	292
Net efficiency (%)	26.6	21.7	36.1	17	21.2
Relative metabolic rate	4.7	5.4	6.3	5.8	5.2

Crushing soil and intertillage were performed with a square harrow and cultivator, respectively. The authors generated this table using data in reports by Tatsumi *et al.* [49, 50, 54].

considering its body size, pulling weight, and the pulling condition, because it was assumed that the point of support or point of action of the lever where force was applied might be different among the 3 pulling methods.

Although the relative metabolic rate calculated from energy expenditure is a useful index for evaluation of workload, several special pieces of equipment, e.g., a Douglas bag or gas analyzer, were needed for the measurements, and the measurement procedure was somewhat complicated. Therefore, the relationship between VO_2 and pulse rate, which was easier to measure in field conditions than VO_2 , was examined in order to use pulse rate as an index of VO_2 for exercise tests in field conditions [52]. Resting pulse rate was obtained by auscultation and averaged for 2 min, and the pulse rate immediately after exercise was counted from 10 to 40 sec after exercise and converted to beat/minute. Seven crossbred horses (450–550 kg BW) were used for this study. In the first experiment, 5 horses walked freely 3 times at speeds of 40, 60, 80, 100, and 120 m/min, respectively. In the second experiment, 3 horses walked 5 times while pulling a draft workload equal to 1/7 of the horse's BWs in a sleigh at speeds of 60, 80, 100, and 120 m/min, respectively. VO_2 and pulse rate were correlated ($r=0.83$), as were relative metabolic rate and pulse rate ($r=0.78$). These results indicated that pulse rate measured immediately after exercise could be a useful index of workload. Although Tatsumi's recommendation that pulse rate should be counted immediately after exercise, e.g., from 5 to 20 sec afterward, and converted to beat/min was more reasonable than calculating it from 10 to 40 sec after exercise, needless to say, direct measurement of heart rate (HR) during exercise is much more preferable. Following these studies, a new system for recording an electrocardiogram (ECG) during exercise using radiotelemetry was developed by Nomura *et al.* of The University of Tokyo in order to obtain HR during exercise [9, 30, 31], and a new simplified device for measurement of HR during draft exercise was also developed [32].

Effects of differences in walking speed on energy metabolism were evaluated using 6 crossbred horses (400–500 kg BW) [52, 54]. As shown in the lower panels in Fig. 3, relative metabolic rate and energy consumption per minute increased linearly with increasing speed. On the other hand, the upper panels show that total energy consumption at 80 m/min was lowest and that the values for total energy consumption at speeds of 60 and 100 m/min were lower than those of 40 and 120 m/min. Similarly, the values for energy consumption expressed per kg BW and per m at 80 m/min were the lowest. These results indicate that the cost of transport at the speed of 80 m/min was the minimum and that walking faster or slower is less efficient, perhaps because less elastic energy is stored in muscles and tendons that can be recovered during the stride to reduce metabolic energy expenditure. When horses walked freely, total energy consumption and energy calculated per kg BW and distance traveled showed similar low values as in the experiment, suggesting that free walking is the most efficient gait and speed.

Energy metabolism while walking in water of different depths was evaluated using 2 crossbred horses (482 and 542 kg BW) [51]. Horses walked in a circular pool with a 12 m diameter for a total distance of 320 m with 4 different water depths (0, 18, 36, and 54 cm) at a speed of 60 m/min. Total energy expenditure and net energy expenditure increased linearly with increasing water depth, and net energy expenditure at a depth of 54 cm was nearly twice that at a depth of 18 cm (Fig. 4). The relative metabolic rate increased to 3 times the resting metabolic rate at a depth of 54 cm; this was almost the same as when walking on the flat ground with a speed of 100 m/min for a horse carrying no load.

Studies on Performance Tests Using Heart Rate as a New Index

A research project by Nomura of The University of Tokyo was conducted in order to develop a new perspective on

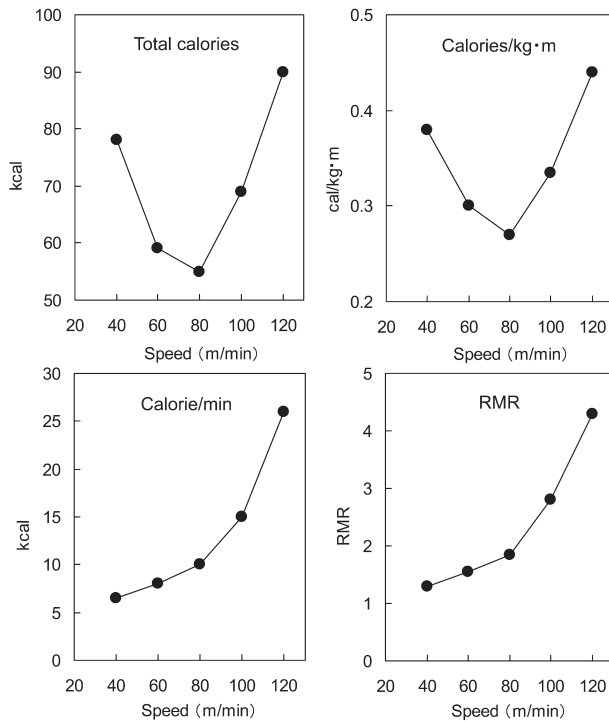


Fig. 3. Effects of walking speed on energy expenditure. RMR is the relative metabolic rate compared with at rest. The authors generated this graph using data in reports by Tatsumi *et al.* [52, 54].

performance testing for selecting better draft horses using heart rate as an index [32]. In 1960, Nomura and Tominaga [29] recorded ECG from a draft horse walking on a specially constructed treadmill while drafting 5 different weights: 1/15, 1/10, 1/8, 1/6.5, and 1/5 of the horse's BW. Then, in 1964, Nomura had succeeded in recording ECG during field exercise, including sprint galloping, using a newly constructed radiotelemetry system [9, 30, 31, 34]. However, this system was large in scale and very expensive, and only one other similar system was available in a research facility at that time in Japan. Accordingly, Nomura developed a beat meter to measure HR of draft horses during heavy draft work [32]. Although this device could not record raw ECG, it enabled HR to be measured by counting the number of popping sounds per unit time that were created when the meter detected larger amplitude signals in the ECG, e.g., the QRS complex.

Preliminary experiments to establish experimental protocols were conducted using 3 horses raised at the Stock Farm of The University of Tokyo. Heart rate was measured using a beat meter during exercise with the horses pulling a sleigh with 4 different weights: 40, 75, 100, and 125 kg. Figure 5 shows changes in HR observed in a horse during this experiment. Heart rate during exercise increased with

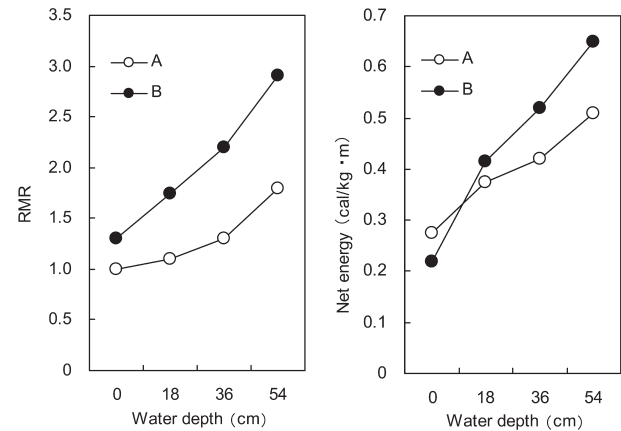


Fig. 4. Effects of water depth on energy expenditure when walking in a circular pool. RMR is the relative metabolic rate compared with at rest. Letters indicate data collected from an individual horse. The authors generated this graph using data in a report by Tatsumi *et al.* [51].

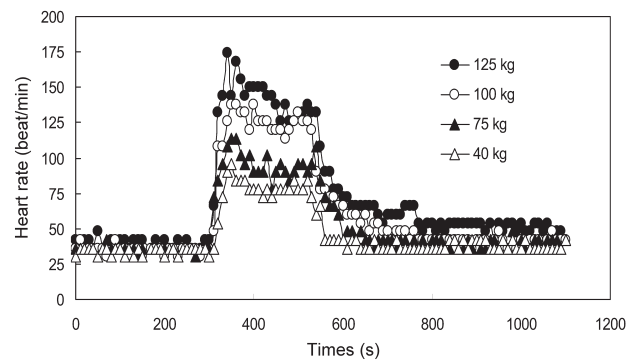


Fig. 5. Effects of differences in carriage weight (indicated by different symbols) on heart rate (HR). The authors generated this graph using data in a report by Nomura [32].

increasing pulling weight (draft workload was measured with a dynamometer), and there was a tendency for the recovery of HR to be delayed when the weight pulled increased. After another similar experiment, the following basic experimental protocol was proposed: 1) The reference draft weight would be set to about 1/4 of the horse's BW, and at least 3 different weights, including upper and lower reference weights, would be used. 2) A 300 m straight course would be used to obtain a steady state. 3) The walking speed would be set at 70 m/min. 4) Resting HR would be measured for 3 min. Heart rate during exercise was measured every 15 sec just after passing the 50, 150, and 250 m marks after the start of walking, at about 30–45 sec, 90–105 sec, and 150–165 sec, respectively. Heart rate after exercise was measured every 30 sec during the following time intervals

30–60 sec, 90–120 sec, and 150–180 sec. 5) Workload was calculated as : $[(\text{draft workload} \times \text{distance}) \div (\text{BW} \times \text{time})]$ and given as an absolute number without units when graphs were drawn. Draft workload was measured several times with a dynamometer. 6) Performance was evaluated using a correlation diagram between workload and total HR during exercise. By drawing 2 straight lines at the upper and lower limits of the SD of the regression line, performance evaluation was assigned to 3 categories: A, the area above the upper limit line; B, the area between the upper and lower limit lines; and C, the area below the lower limit line. A was classified as passing, B was classified as good, and C was classified as excellent.

A total of 22 horses raised at the Oh-u National Livestock Breeding Station with daily training (trained) and horses without training (untrained) were tested using the above-mentioned protocols. When total HR during exercise and recovery was plotted on a graph, the relationship between total HR and workload was linear (Fig. 6), and the total HRs of trained horses were lower than those of untrained horses. To determine whether a linear relationship between workload and total HR existed in individual horses, the same test was performed several times using 6 horses. As shown in Fig. 7, total HR increased linearly in each horse. Among these horses, horse A was considered to be an excellent horse, and horses E and F were untrained horses.

Whether or not the relationship between workload and total HR would remain linear when the workload became too heavy or light was investigated. The effect of a heavier draft workload was investigated at the Tokachi National Livestock Breeding Station using 3 different draft workloads (142–156 kg, 197–213 kg, and 243–255 kg) and 22 horses with BWs between 649 and 750 kg. The results yielded a graph in which the slope between the workload and total HR became steeper when the workload exceeded 450. Similar experiments were performed using 15 horses of lighter weight than in the previous experiment (530–650 kg BW) by setting different draft workloads (about 100, 150, and 200 kg). The results were portrayed in a similar graph showing that the slope became steeper when workload exceeded 450 (Fig. 8). Although Nomura did not evaluate his data statistically, according to our statistical analysis, there were significant differences between the slopes of the two regression lines. Because the workload exceeded the critical value of 450 when 1/3 or more of a horse's BW was added the workload, Nomura concluded that 1/3 of a horse's BW must be the upper limit for the performance test. In another experiment, the effects of lighter draft workloads (90, 130, and 170 kg) were investigated at the Tohoku Agricultural Experiment Station and Iwate National Livestock Breeding Station using 24 horses weighing between 530–725 kg. This experiment resulted in a graph showing

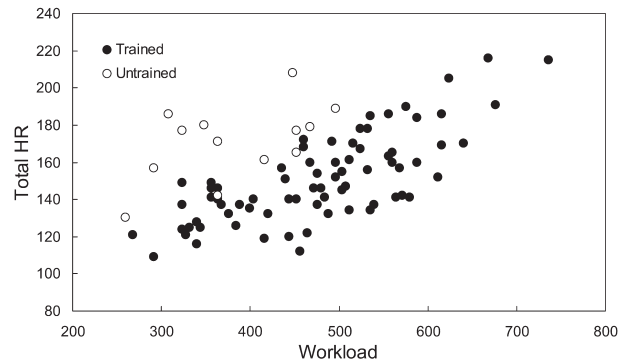


Fig. 6. Relationship between total HR (heart rate during exercise and recovery) and workload. The authors generated this graph using data in a report by Nomura [32].

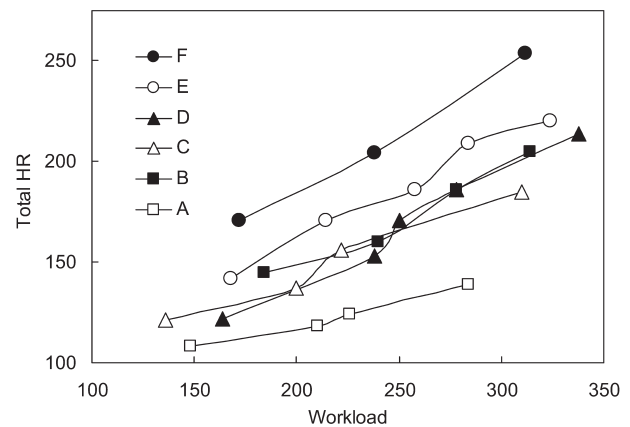


Fig. 7. Relationship between total HR (heart rate during exercise and recovery) and workload. Letters indicate data collected from an individual horse. The authors generated this graph using data in a report by Nomura [32].

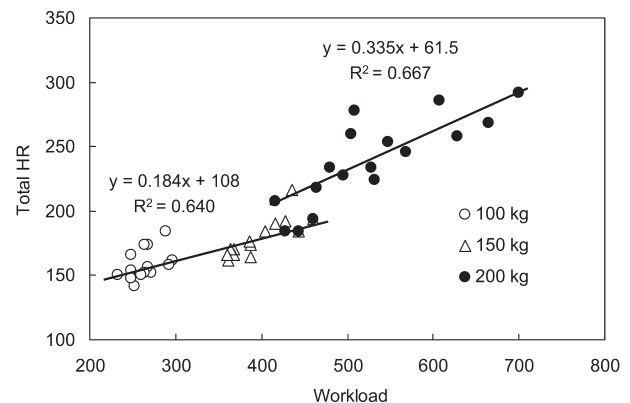


Fig. 8. Relationship between total HR (heart rate during exercise and recovery) and workload with a heavier draft workload. The authors generated this graph using data in a report by Nomura [32].

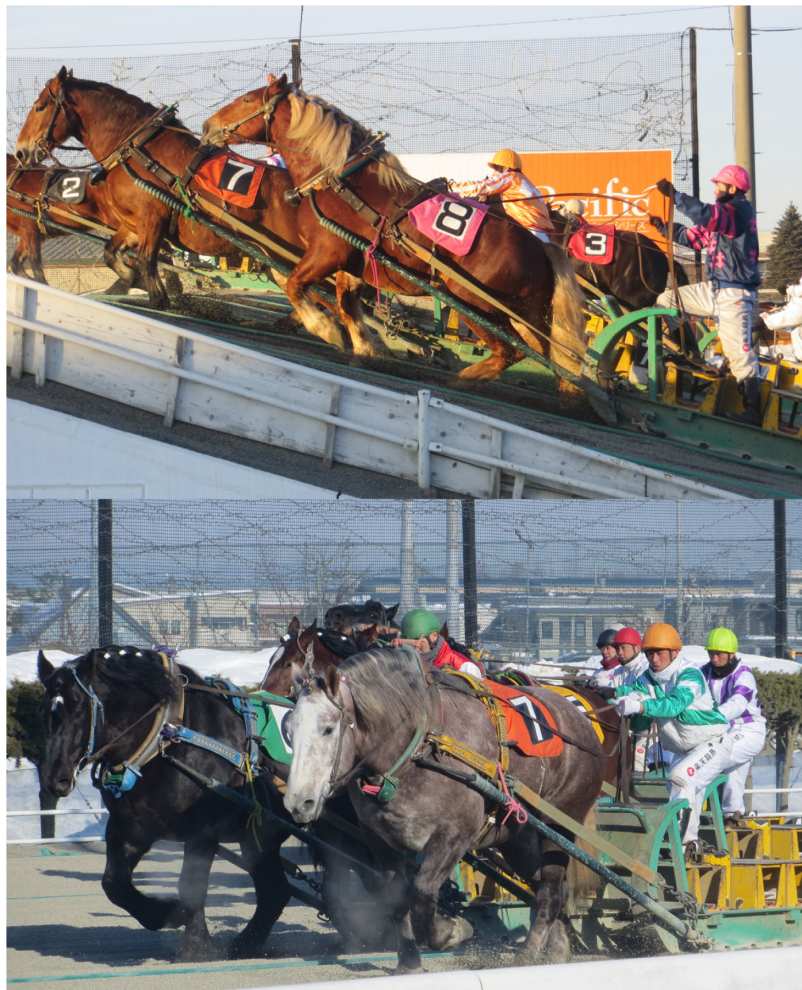


Fig. 9. Ban-ei horse racing at Obihiro racecourse in Hokkaido.

that the slope became steeper when the workload was 250 or less, and Nomura suggested that less than 1/5 of a horse's BW (a draft workload of about 100 kg) could not be used for the performance test. Based on these experiments, Nomura suggested that the draft workload to be used for the performance test should be between about 1/5 and 1/4 of the horse's BW. Using the principles that Nomura had shown in his experiments, performance tests were performed at the Oh-u National Livestock Breeding Station during the period from August 1963 to April 1964, and the research results were reported in 1965 [33].

In Hokkaido, the northern large island of Japan, there is a unique form of horse racing called "Ban-ei" (Fig. 9). The horses that race are crossbred Percherons, Bretons, and Belgians. The horses race along a 200-m straight sand course that has two hills (the first is 1-m in height and the second is 1.6–1.7-m in height) while pulling a sled with 460–1,000 kg of weight. Recently, exercise physiological

data during draft work in heavy draft horses used in Ban-ei were investigated at the National Livestock Breeding Center Tokachi Station [1, 2]. In one of these studies [2], four Percherons and 3 Bretons were exercised by pulling weights of 350, 450, 550, 650, and 750 kg on a 300 m flat sand course. In Thoroughbred racehorses, V200 (running velocity at a HR of 200 beat/min) is frequently measured and utilized as an index of fitness [7, 8, 36, 37]. The draft horses were exercised for 300 m [(100 m at a walk) + (100 m at a trot) + (100 m at a maximal run)] in order to calculate V200. Running velocity and HR during each exercise were recorded, and V200 was calculated for each weight. As shown in Fig. 10, V200 decreased as weight increased. Although the draft workload was not measured and, therefore, workload as shown in Nomura's experiment was not calculated, it seemed that reasonable data were obtained. In these experiments, the blood lactate concentration, which Nomura did not measure, was also reported for the draft

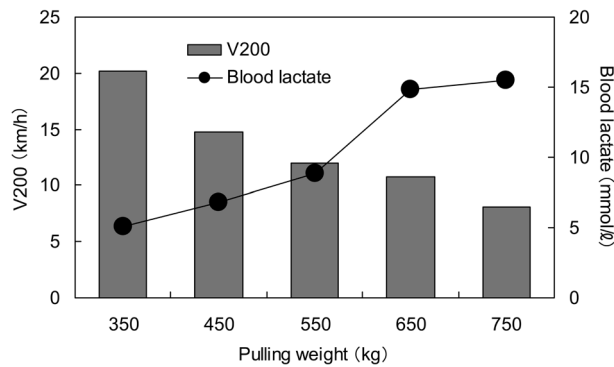


Fig. 10. V200 (running velocity at a heart rate of 200 beat/min) and blood lactate concentration measured 3 min after exercise in heavy draft horses. The authors generated this graph using data in a report by Arakawa [2].

horses. The results showed that blood lactate concentration 3 min after exercise increased as pulling weight increased, with the values for 650 and 750 kg being 14.8 and 15.5 mmol/l, respectively (Fig. 10). These results suggest that the workload of a draft horse running 300 m while pulling a weight of 650–750 kg is similar to that of a Thoroughbred flat racing [3, 26, 48].

Studies on Biomechanics of Draft Horses and Exercise Physiology of Other Animals

In addition to the exercise physiological studies mentioned in this article, studies on the biomechanics of draft work were performed during the same period by Okabe *et al.* of The University of Tokyo. In these studies, changes in vertical movements of several parts of the body of the horse [39, 41] and alterations of the joint angles [40, 42] were analyzed using serial photography at 1/25 sec intervals photographed from a vehicle moving at the same speed as the horse, and the effects of different draft weights on stride frequency and stride length were also evaluated [43].

Studies on exercise physiology of other animals, e.g., cattle and goats, were conducted during the same period. Although research results obtained from these studies did not have practical significance as much as those on horses, the authors briefly summarize the results of several of those studies. Uesaka of Kyoto University, who recorded the first ECG of cattle in Japan in 1943 [56], observed the effects of draft work on body temperature, respiration, pulse rate, blood variables, and ECG in cattle during 4,000 m of draft exercise with a draft workload of 25 or 50 kg [55, 57]. In order to understand gas metabolism during draft work, Habu *et al.* of Kyoto University collected gas samples in cattle at

rest and during exercise using a Douglas bag and reported that resting VO_2 was 0.149 l/kg·hr and RQ was about 0.72 and that VO_2 increased 4–6 times compared with at rest by 4,000 m when doing draft work with a draft workload of 60–65 kg [5, 6]. The steady states of many physiological variables were investigated using cattle for various pulling times (10, 30, 60, and 120 min) and a draft workload of 12% of their BWs [44, 45]. The effects of exercise on pulse rate in goats were also investigated [58, 59].

The effects of draft exercise on physiological variables in goats [20, 21] and cattle [22] were investigated using a treadmill. In the first study on goats [20], changes in VO_2 , carbon dioxide production, heat produced, respiratory quotient, pulse rate, oxygen pulse, respiration rate, pulmonary ventilation rate, tidal air, oxygen decrement, and oxygen debt were measured, and it was concluded that oxygen pulse per kg BW might be used as an index for the level of fatigue. The effects of air temperature, training, work, and metabolic disturbance caused by thyroidectomy in goats were also investigated [21]. The effects of preceding work on resting oxygen pulse immediately before test work and the shape of the pulse rate curve at an early stage of the test work in cattle were also investigated [22]. Cattle were exercised on a horizontal treadmill while drafting a draft workload of 15% of their BWs for 40 min (A) without or (B) with preceding work (the same work as the test work). The test work was performed 1 hr after the preceding work. The results showed that the resting oxygen pulse decreased from 0.051 ml/kg (A) to 0.047 ml/kg (B) and that the pulse rate in the early stage of the test work was higher in B than A. From these findings, the authors suggested that the oxygen pulse per kg BW and the shape of the pulse rate curve at the early stage of the test work could be used as indices of fatigue and work capacity of cattle as well as goats. Some of these findings were similar to those of warm-up studies in Thoroughbred racehorses [27, 28].

Conclusions

After World War II, the number of horses raised in Japan decreased dramatically, mainly due to the big shift in usage of the horse from the role of a warhorse to the role of a draft horse. Additionally, the number of draft horses decreased thereafter due to the development and spread of farm machinery after the 1950s. In the present day, the total number of horses raised in Japan is about 80,000, and among them, only about 7,000 draft horses are raised, less than 10% of the total. In the time period when the studies described in this article were performed, about 400,000 horses were still raised in Japan. Although Nomura of The University of Tokyo pessimistically described in his report in 1964 [32] that due to social conditions only 200,000 draft

horses would be required for breeding in the future, the present situation is far beyond his expectation. In the present day, with there being only a few cases in which draft horses actually work in the field, the research results obtained from the series of studies mentioned in this article do not have realistic applicable meaning, although it is certainly useful to consider these studies in the context of them being valuable for understanding their place in the history of equine exercise physiology in Japan.

In conclusion, this article traced the rich history of exercise physiological studies of draft horses in Japan. Furthermore, it also briefly discussed studies conducted on cattle and goats as well as comparisons for some of the results from the draft horse studies. Although draft horses are not as important in our modern society as they were in past years, nevertheless, they played an important role in Japan's equine heritage and can be appreciated for their former importance to agriculture and society.

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