

Studies on exercise physiology of the racehorse performed in Japan during the period from the 1930s to the 1970s: respiration and heart rate during exercise and the effect of exercise on blood characteristics

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After publication of the epic report on equine exercise physiology by Matsuba and Shimamura in 1933, papers on exercise physiology of the racehorse in Japan began appearing in scientific journals and increased in number. In 1944, respiration during exercise at a walk, trot, and canter was measured by recording expiratory sounds with a microphone attached near the nostril. Respiratory frequency during cantering was synchronized with stride frequency, and expiratory sounds were found to occur during the stance phase of the trailing forelimb. Development of a radiotelemetry system in 1964 for electrocardiogram recording enabled the first recording of an equine electrocardiogram during field exercise that included fast galloping and calculation of heart rate (HR) during exercise. During low intensity exercise including walking, trotting, cantering and extended cantering, HR increased from 45 beat/min during pre-exercise to 150 beat/min at an extended canter. HR increased to 200 beat/min or more in most horses during 100 m of high-intensity sprint galloping. When blood lactate was measured after 3 days of draft work in 12 warhorses in 1934, no increase in blood lactate was found. The erythrocyte sedimentation rate (ESR) was decreased by intense exercise and also decreased as training increased. It was suggested that measuring changes in ESR and body weight in relation to training might become useful as a screening index of training, condition, and fatigue. This evaluation method was named the “ESR-body weight method.”

Key words: equine exercise physiology, erythrocyte sedimentation rate, heart rate, respiration

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A research report entitled “Studies on exercise physiology and performance testing of the racehorse” was published in 1933 by Matsuba and Shimamura [31], and it was the most important study in the history of equine exercise physiology in Japan. After publication of the paper by Matsuba and Shimamura, the number of papers on exercise physiology of racehorses increased dramatically, and papers started to appear in journals such as the *Journal of the Central Society*

for Veterinary Medicine [71–74], *Nihon Juigaku Zasshi* (*The Japanese Journal of Veterinary Science: the current Journal of Veterinary Medical Science*) [56, 59], *Nihon Chikusan Gakkaiho* (published by the current Japanese Society of Animal Science) [69, 70], *Chosa Kenkyu Hokoku* (*Research Reports*) [40, 60–64, 75], and *Experimental Reports of Equine Health Laboratory* [38, 41, 42, 65–67, 76, 77]. In this article, we describe a series of studies on the exercise physiology of racehorse with particular reference to respiration and heart rate during exercise and on the effects of exercise on characteristics of the blood, especially the erythrocyte sedimentation rate, that were performed by successors of Matsuba.

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Respiration during Exercise

According to the studies of Matsuba and Shimamura in 1933 [31], respiratory frequency (RF) increased by 1.2 times (all values compared to with those at rest) when walking 200 m, by 1.5 times during a 200 m trot, and by 4–5-fold during a 5,000–6,400 m canter. However, these numbers were obtained by determining the RF just after exercise by counting the movements of the ribcage and upper flank with naked eye of an observer based on the assumption that the RF immediately after exercise is equivalent to the RF during exercise.

In 1944, Okabe and Sugiyama [56] measured RF continuously during exercise at a walk, trot, and canter by recording expiratory sounds with a microphone attached near the nostril that was connected to an amplifier and speaker pulled on a drafting vehicle. The RF and stride frequency (STF) during exercise were recorded for a total of 42 min consisting of a 30 min trot (170 m/min), 3 min canter (300–400 m/min), and 9 min walk (100 m/min) in 20 horses. As shown in Fig. 1, the STF during trotting was about 84 str/min (where str is strides) 1 min after starting the trot and remained almost constant throughout, and the average STF for a 30 min trot was 83.1 str/min. The RF during the first 1 min of trotting was 73 br/min (where br is breaths), then it increased to 100 br/min at 12 min and it increased to more than 110 br/min thereafter. The average RF for a 30 min trot was 99.9 br/min. The STF during cantering was 103 str/min 1 min after starting cantering and remained constant. The average STF during cantering was 105.3 str/min and the RF during cantering was synchronized with the STF, with expiratory sounds occurring during stance phase of the trailing forelimb. The STF during walking just after finishing cantering was 63 str/min, and then it remained at 57–59 str/min thereafter. The RF at the end of the canter was 108 br/min, it decreased to 97 br/min shortly after finishing cantering, and then it remained around at 110 br/min during walking. Immediately after the horse stopped walking, the RF decreased dramatically to 80 br/min. The authors concluded that the RF immediately after exercise while standing was completely different from the RF during exercise because of the very rapid decrease in RF that occurred after finishing exercise.

It was also noted that several different respiratory sounds, such as snorting and booming, were heard during exercise, and a booming sound was recorded during the stance phase of the trailing forelimb. It was also noted that the tone of the respiratory sounds changed during exercise. During trotting, the strength, pitch, and length of respiratory sounds tended to become irregular 16–20 min after starting trotting, but they became regular when the horse began cantering.

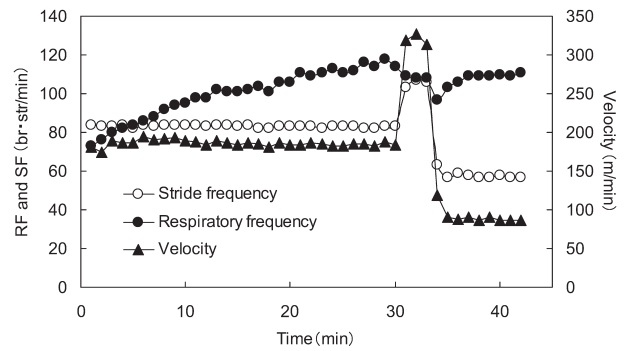


Fig. 1. Changes in respiratory frequency (RF), stride frequency (STF), and velocity during exercise. The authors generated this graph using data from a table in a study by Okabe and Sugiyama [56].

Sawazaki *et al.* [69] compared the RFs under 4 different workloads including plowing, cultivating (tilling with a cultivator), harrowing (crushing soil with a harrow), and free walking (as a control) using the same equipment as Okabe and Sugiyama [56]. According to their observations, the RF increased in a fluctuating manner and reached a steady state at each intensity of exercise. The average work resistance during plowing and harrowing (30–35 kg) was greater than that of cultivating (20–25 kg). Because horses have to walk on softer ground when harrowing compared with 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 in plowing than cultivating, it was suggested that RF tends to be higher at heavier workloads. Sawazaki *et al.* [70] reported the RF during trotting at a small riding ground (380 m/lap) with different exercise protocols: A, 300 m/min for 14 min (or 20 min), and B, 200 m/min for 30 min (or 45 min). The RF reached steady state in both protocols approximately 10 min after starting and remained constant thereafter. The RF in the steady state was higher during the 300 m/min trot (95–100 br/min) than the 200 m/min trot (75–80 br/min). The authors suggested that there was a relationship between STF and RF, because RF was sometimes synchronized with STF systematically in 1:1, 1:2, or 1:3 ratios when trotting in a straight line. These systematic relationships tended to disappear when horses ran around a curve.

In 1978, Attenburrow recorded both inspiratory and expiratory respiratory sounds with a radio-stethoscope during walking, trotting, cantering, and galloping [4]. He also recorded respiratory and limb cycles simultaneously and found that the respiratory cycle and limb cycle were synchronized only at a canter and gallop [5]. Later, Kai and Kubo [16] of the Equine Research Institute of the Japan Racing Association recorded respiratory and stride

frequency simultaneously during galloping just after a start dash from the starting gate and reported that a 4–6 sec apneic pause occurred just after starting, after which respiration restarted and synchronized with the stride frequency.

Heart Rate during Exercise

Pulse rate immediately after exercise was measured by auscultation in the study of Matsuba and Shimamura [31]. Because direct measurement of heart rate (HR) during exercise was impossible at that time (1933), pulse rate immediately after exercise was assumed to indicate HR during exercise. Later, Tatsumi *et al.* [80] showed that there is a close relationship between oxygen consumption of horses during exercise as measured by the Douglas bag method and the pulse rate immediately after exercise. Researchers then recognized the importance of HR measurements during exercise and began developing methods for measuring HR during exercise. It was difficult to obtain an ECG necessary for calculating HR during exercise, although it could be recorded at rest [30, 39, 83].

In 1960, Nomura and Tominaga [40] recorded ECGs from a horse walking on a specially constructed treadmill at a speed of 70 m/min while drafting 5 different weights. The ECGs were obtained by transmitting the signal to a receiver using a 20 MHz carrier wave and reproducing the signal with an electromagnetic oscillograph. Changes in HR during exercise and the recovery period were calculated by creating diagrams of R-R intervals from the ECG recording. Heart rate increased immediately when the horse started exercising and returned to a steady state within a short time when the workload was light. Even when the workload was heavy, the heart rate became to a steady state within 3 min, with a second increase in HR occurring about 10 min after the beginning of exercise. Although recording of ECGs from a horse exercising on a treadmill had become possible by using a transmitter set near the horse and a carrier wave, it was still very difficult to record the ECG of a horse exercising under field conditions.

A research project to record equine ECGs during exercise using radiotelemetry was performed as a collaborative study between Nomura of the University of Tokyo and the Equine Health Laboratory of the Japan Racing Association. For the research study, a custom-made radiotelemetry system that could record ECGs within 100 m was developed, and the performance of the system evaluated. During exercise at intensities ranging from walking to intense galloping, relatively clear ECGs that could be analyzed for changes in ECG waveform were obtained. The investigators concluded that ECGs obtained by this system were clear enough to calculate HR or R-R intervals during exercise. ECGs were recorded using the newly developed system during both low-intensity

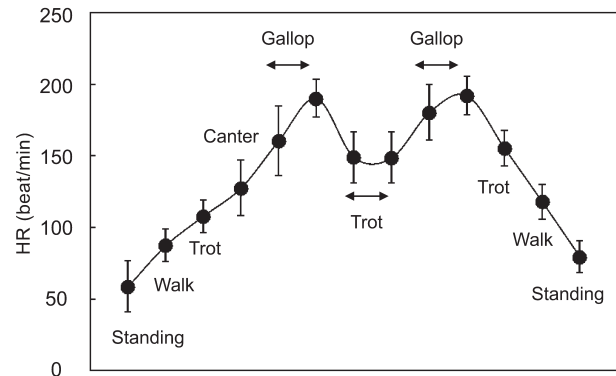


Fig. 2. Changes in heart rate (HR) during field exercise. The authors generated this graph using data from a table in a study by Nomura *et al.* [42].

exercise with a horse riding on the ground or jumping low hurdles and during high-intensity sprint-galloping on a track in order to calculate changes in HR during exercise. The major findings regarding changes in HR were as follows: 1) during low intensity exercise including the walk, trot, canter and extended canter, HR increased from 45 beat/min during pre-exercise to 150 beat/min at an extended canter, and; 2) HR increased to 200 beat/min or more in most horses during 100 m high-intensity sprint galloping (Fig. 2). The first report of ECGs measured during field exercise in the horse was from this study by Nomura *et al.* in 1964 [41, 42]. A similar report by Nomura was also published in 1966 in another journal [44]. Following Nomura's publications, Holms *et al.* in 1966 [15] and Banister *et al.* in 1968 [6] reported ECGs measured during field exercise in horses. In order to carry out a reliable recording of ECGs during exercise of a horse running on a large track, a high-power telemetric transmitter was constructed on special order and operated under a license from the Radio Regulatory Bureau [3]. Because the high transmitting power of 1 W enabled an effective transmission range of 5 km or more, it became possible to record ECGs for horses exercising in large areas, *e.g.*, on an oval track at a racecourse.

Although it had become possible to measure instantaneous changes in an ECG during exercise using radiotelemetry, this system had certain disadvantages, such as the fact that it could only be used for recording from a single horse and could only be used within the effective transmission area of the radio waves. Therefore, a portable electrocardiograph with a magnetic tape recording system for exercising horses was devised [2, 29]. Because the portable magnetic tape electrocardiograph allowed recording of ECGs from many horses exercising simultaneously, it became a useful tool for evaluating equine arrhythmias and HR during exercise tests performed at large race tracks. Currently,

digital Holter ECG systems are widely used for exercise electrocardiography in racehorses.

Nomura [43] also developed a beat meter to measure the HR of draft horses during heavy pulling work at slower speeds in the field. Although this device could not record a raw ECG, it enabled HR to be measured by counting the popping sounds per unit time that were created when the meter detected larger amplitude signals in the ECG, *e.g.*, the QRS complex. This device was useful when the running speed was slow.

Effect of Exercise on General Blood Characteristics

Matsuba and Shimamura evaluated the fitness of racehorses by analyzing 20 parameters they considered as being important for exercise physiology and that were possible to measure at that time (1933–1939) [31–37]. Among them, 5 blood parameters—fragility of erythrocytes, blood viscosity, erythrocyte sedimentation rate, freezing point depression, and pH—changed with time during training, so they recommended that these parameters would be useful indexes for future training studies [36].

In addition to the aforementioned parameters measured in their studies, other parameters such as the O₂ concentration, CO₂ concentration, and blood lactate concentration were also measured. In 1937, Shijo [72] reported that the O₂ concentrations in arterial and venous blood were 20.81% and 12.08%, respectively, and showed that plasma CO₂ concentrations in arterial and venous blood were 46.60% and 57.85%, respectively, using 26 horses. Shijo [73] measured venous O₂ and CO₂ concentrations weekly for about 3 months during a training period in 4 horses and showed that the average CO₂ concentration was 61.6% and almost the same in each horse. The O₂ concentration was 12.7%, and there was relatively high correlation between the O₂ concentration and erythrocyte count throughout the training period (Fig. 3). Shijo [74] also examined the effect of exercise on blood counts and showed that erythrocyte and leukocyte counts increased with intense exercise and numbers of neutrophils increased but that numbers of lymphocytes decreased.

Although the blood lactate concentration was not measured in studies by Matsuba *et al.* [31–37], the blood lactate concentration is considered to be one of the most important parameters in assessing performance in equine exercise physiology. In 1934, Yasuda [82] measured blood lactate concentrations during 3 days of draft work (total distance 111 km) in 12 warhorses. Because the exercise intensities were low, the blood lactate concentration did not increase (Fig. 4). This was the only study that had measured the blood lactate concentration up to that time. If blood

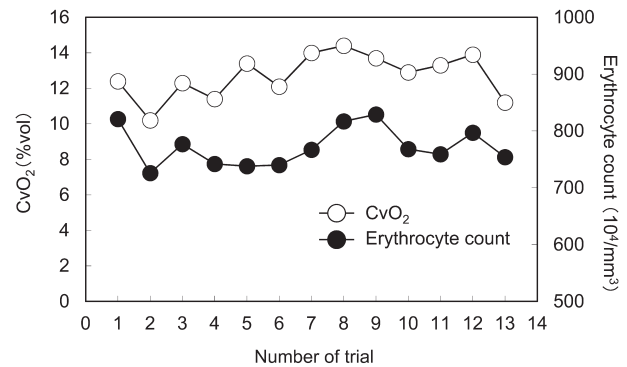


Fig. 3. Changes in oxygen concentration in venous blood (CvO₂) and erythrocyte count. The authors generated this graph using data from a table in a study by Shijo [73].

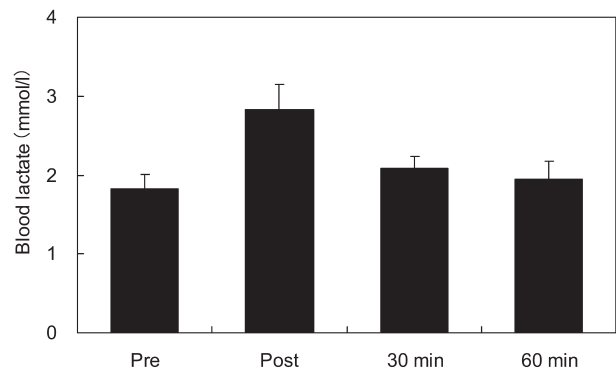


Fig. 4. Changes in blood lactate during exercise. The authors generated this graph using data from a table in a study by Yasuda [82]. (Pre, before exercise; Post, just after exercise; 30 min, 30 min after exercise; and 60 min, 60 min after exercise)

lactate had been measured in the studies of Matsuba *et al.*, it would likely have provided useful information.

In 1967, Sakurai *et al.* [67] compared the effects of exercise intensity (1,100 m at 6.7 m/s, 1,100 m at 11.1 m/s, and 1,600 m at 12.5 m/s) on changes in blood characteristics and reported that the red blood count, white blood cell count, hemoglobin concentration, hematocrit, erythrocyte resistance, and blood lactate concentration increased but that eosinophils, erythrocyte sedimentation rate, and blood water content decreased. In this report, the blood lactate concentration was 0.7 mmol/l after 1,100 m (at 6.7 m/s), 7.3 mmol/l after 1,100 m (at 11.1 m/s), and 12.1 mmol/l after 1,600 m (at 12.5 m/s). The glucose, pyruvate and lactate concentrations were also measured after 2 different kinds of exercise—relatively short distance cantering and long distance trotting—and the authors reported that both the lactate and pyruvate concentrations increased after cantering [76].

The question as to whether or not changes in the thyroid hormone concentration in plasma (T_3 and T_4) at rest might be useful as an indicator of physical fitness of a racehorse was investigated during the training period from September of the yearling year to May of the 2-year-old year [77]. The concentration of T_3 in plasma, which was used in that study as the T_3 binding capacity index, decreased clearly during the early period of training and remained constant during the latter half of the training period. The authors found that greater function of the thyroid gland during training correlated with changes in T_3 in the horses. Therefore, they speculated that changes in T_3 might be used to evaluate the physical fitness of active racehorses. The concentration of T_4 in plasma decreased clearly in the middle stage of training, but it increased markedly in the final stage. Because it was presumed that the horses were able to train more intensely in the final stage of their investigation, the authors considered that the elevation of T_4 was useful for evaluating the reserve of strength in the horse.

Relationships between changes of some blood enzymes and physiological conditions in exercising horses were investigated using 3 horses subjected to long distance running. They ran 22,000 m/day for 5 consecutive days mainly at an extended trot but partially at a slow canter [38]. Blood samples were collected before, in the middle, immediately after, and 1 and 5 hr after exercise every day during the exercise period and at 1, 2, 3, 5, and 7 days following the exercise period to document the recovery process. In this experiment, changes in the activities of creatine kinase, aspartate amino transferase, and fructose diphosphate aldolase were measured. Creatine kinase activity elevated maximally 5 hr after exercise and then decreased. The magnitude of the rate of increase became larger as the exercise intensity increased. Although aspartate amino transferase activity failed to increase markedly as the intensity of the exercise increased, it remained at a relatively high level and then increased gradually during the exercise period. Fructose diphosphate aldolase activity changed in an intermediate manner between the two enzymes mentioned above. These results suggest that creatine kinase might be utilized as the most useful index of the severity of exercise and that aspartate aminotransferase might be utilized as an index for overtraining. However, the significance of changes in fructose diphosphate aldolase activity with exercise is unclear.

Effect of Exercise on Erythrocyte Sedimentation Rate

The erythrocyte sedimentation rate (ESR) is the rate at which erythrocytes form a sediment during a fixed period of time, typically 1 hr; it considered to be a nonspecific parameter of inflammation. Although this parameter has

been used mainly as a nonspecific index of inflammation, it must be considered that it can be influenced by various factors. However, the relationship between the ESR and exercise was previously unknown, especially in horses. Yasuda and coworkers, who studied the exercise physiology of the warhorse, examined relationships between the ESR and exercise and fatigue in warhorses [14].

Hiroe *et al.* [14] examined the effects on the ESR of faster and slower speeds during exercise using 15 warhorses and 6 local horses. The faster exercise consisted of long distance riding for 3 days, and the total distance was 142.5 km. The slower exercise was draft exercise for 4 days, and the total distance was 116.5 km. The ESR was calculated as the median value from the sedimentation at 1 hr and 2 hr ($(1 \text{ hr} + 2 \text{ hr}/2)/2$). It was found that the ESR after faster exercise was 14.5 mm lower than the values before exercise. On the other hand, the ESR after slower exercise did not differ between before and after exercise, and the ESR tended to be low when the erythrocyte count was large. The authors suggested that measurement of the ESR might be a useful tool for evaluating fatigue, especially with faster riding exercise. Hiroe *et al.* [13] also reported the effects of similar exercise on blood viscosity in 25 warhorses. Blood viscosity was expressed as a relative value using distilled water as a reference (1.0). The average blood viscosity at rest was 4.89 and increased to 12.6 after faster exercise, and recovery took about 21 hr. On the other hand, blood viscosity was not changed after slower exercise compared with the pre-exercise value. The authors suggested that blood viscosity might be a useful index for evaluating fatigue during intense exercise in conjunction with the ESR.

In 1937, Shijo [71] examined relationships between both changes in ESR after exercise and changes in blood characteristics (blood O_2 concentration, plasma CO_2 concentration, erythrocyte count, hemoglobin concentration, and plasma volume), and clinical findings (pulse rate, respiratory frequency, and blood pressure). Measurements were performed using 9 different exercise protocols and 4 racehorses as follows: 1) walk, 200 m; 2) walk, 800 m; 3) walk, 1,600 m; 4) trot, 200 m; 5) trot, 800 m; 6) trot, 1,600 m; 7) canter, 200 m; 8) canter, 800 m; and 9) canter, 1,600 m. The ESR was calculated as a median value based on the values at 1 hr and 2 hr. The average ESR at rest was 92.2 mm (84–103 mm) and decreased after exercise. The quantitative decrease was greater with higher intensity exercise (Fig. 5). Because the ESR decreased when the erythrocyte count and O_2 concentration were increased, the authors suggested that there were close relationships between the ESR and erythrocyte count and O_2 concentration.

During the period from 1938 to 1941, Kikuchi published 4 papers on the ESR in horses: one on the ESR during normal status [17], one on the ESR during pregnancy and the

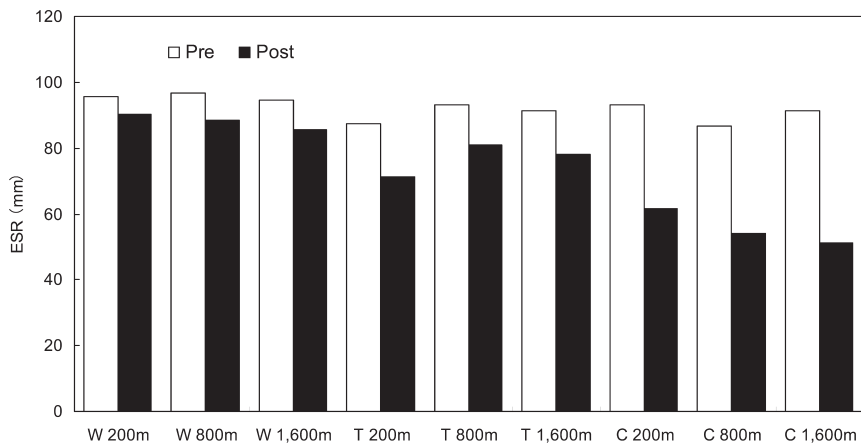


Fig. 5. Changes in erythrocyte sedimentation rate (ESR) after different intensities of exercise. The authors generated this graph using data from a table in a study by Shijo [71]. (W, walk; T, trot; and C, canter)

postnatal period [18], one on the ESR with various diseases [19], and one on factors influencing the ESR [20]. In the first paper [17], 54 female horses (2–20 years old), 22 male horses (2–19 years old), 13 geldings (5–19 years old), and 37 foals (2–170 days old) were investigated, and showed that the ESRs of each group were 66–100 mm, 71–100 mm, 71–100 mm, and 28–80 mm, respectively. The ESR of foals 6 days after birth was the lowest and it increased with growth. In the final paper [20], the author reported that the ESR decreased after exercise, as had been reported by Hiroe *et al.* [14] and Shijo [74], and also reported that differences between pre-exercise and post-exercise values were smaller in trained horses than in untrained horses. In the same paper, Kikuchi also investigated effects of various factors, such as temperature, congestion, concussion, feeding, and sodium citrate on the ESR of horses [20]. Kikuchi wrote interpretive articles on measurement of the ESR and its significance for clinical diagnosis [21–23]. In these articles, he described several methods of measuring the ESR, normal values of the ESR in the horse, cattle, dog, goat, sheep, and pig, factors influencing the ESR, the ESR in various diseases, and the mechanism of the ESR.

Ohi performed a series of experiments on species variation of the ESR in domestic animals using horses, pigs, dogs, cattle, sheep, and goats to evaluate variations of the erythrocyte sedimentation curve [45], shape of the erythrocyte sedimentation curve [46], correlation between the ESR and temperature of the laboratory [47], influence of measurement temperature on erythrocyte sedimentation [48], correlation between ESR and inclination of the tube [49], influence of tube inclination on erythrocyte sedimentation [50], correlation between the ESR and diameter of the tube [51], influence of tube diameter on erythrocyte

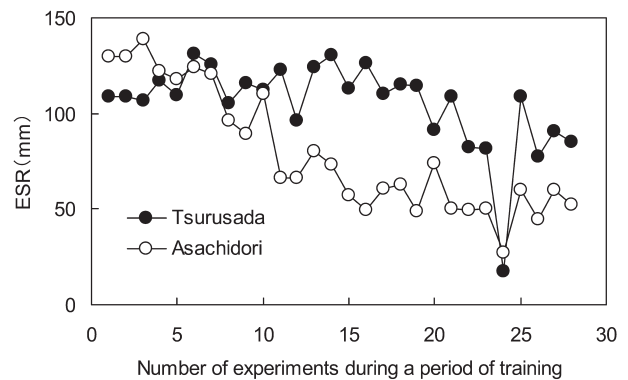


Fig. 6. Changes in erythrocyte sedimentation rate (ESR) in relation to training in 2 horses. ESR decreased as training advanced. The authors generated this graph using data from a table in a study by Matsuba *et al.* [36].

sedimentation [52], correlation between ESR and height of the blood column [53], and influence of the height of the blood column on erythrocyte sedimentation [54].

Matsuba *et al.* [36] showed in 2-year-old Thoroughbreds that the ESR decreased as training advanced (Fig. 6). After working on equine exercise physiology with Matsuba, Sakurai started working on exercise physiology of racehorses trained at racecourses, mainly studying blood characteristics, especially the ESR. Sakurai [59] examined the ESR in 100 horses, including 46 racehorses purchased at sales (referred to as “yobiUma” at that time), 31 racehorses purchased by an organization that held horse races (owners of these horses were determined by lottery; these horses were referred to as “chusenba” at that time), 10 trotters, and 13 riding horses. The chusenba lottery system was a

unique system in Japan. Because the yobiuma horses were purchased at sales by owners, the yobiuma horses were generally considered to be higher quality horses than those acquired in the chusenba system. Sakurai's measurements were carried out throughout the 26-day horse race meeting at Tokyo Racecourse in 1940. The ESRs of racehorses trained regularly were lower than those of detrained racehorses. The ESRs of the yobiuma were the lowest, and they were progressively higher in chusenba horses and trotters. The ESRs of riding horses were much higher. Sakurai concluded that the ESR of high-quality or high-performance horses tends to be lower.

Changes in ESR during the duration of a horse race meeting that included daily training and racing were investigated in 13 racehorses and compared to other parameters [75]. The ESR changed in relation to the state of the general condition of the horse, and it correlated highly with the erythrocyte count and hemoglobin concentration. This result was similar to the findings of Shijo [71] and Matsuba *et al.* [36]. Sakurai measured the ESR, plasma protein concentration, specific viscosity, and albumin content in 101 racehorses in order to examine relationships between the ESR and the other variables, and he found that total plasma protein correlated with specific viscosity [60]. The ESR in horses with good racing performance was low and albumin content in these horses was higher.

Sakurai then began a series of surveys on relationships between the ESR and training. Six horses were trained for about 1 month and able to perform a maximal speed run of 1,500 m at the end of the training period [61]. While the general physical condition of the horses improved, the ESR and body weight decreased. In contrast, when the condition of the horses by general inspection worsened, the ESR increased.

Sakurai *et al.* [62] performed intensive research throughout a long period of training from July to October using 110 racehorses trained at the Tokyo Racecourse. Changes in ESR, body weight, pulse rate, cardiac sounds, and nutritional status were observed, and the following results were reported: 1) the ESR decreased when a horse's condition by general inspection improved and increased when a horse's condition by general inspection worsened; 2) body weight decreased when the training intensity was higher and increased when the training intensity was reduced; and 3) pulse rate increased and cardiac sounds became weaker when the horse's condition worsened, while pulse rate decreased and cardiac sounds strengthened when the horse's condition improved. They concluded that measurement of these 4 parameters were useful for evaluation of a horse's condition. Sakurai [63] also performed similar experiments regarding the effects of training over intervals ranging from several months to 1 year on clinical

and blood parameters using 14 racehorses and concluded that changes in ESR and body weight would be good parameters for evaluation of the condition of a racehorse. From these results, Sakurai suggested that measurement of the ESR, body weight, pulse rate, and cardiac sounds was useful for evaluation of a horse's condition. Sakurai made similar observations on 18 riding horses trained for 2 months according to training regimens typically used for racehorses and reconfirmed that both the ESR and body weight decreased as training advanced [63].

In order to validate the usefulness of changes in ESR and body weight for evaluation of fatigue, Sakurai [64] observed changes in ESR and body weight once a week during a 6-week period of training using 2 horses. During the first 2 weeks of low-intensity training, the ESR decreased and body weight increased. During the next 2 weeks, the exercise intensity was increased gradually, and the ESR became much lower, and body weight decreased. During the final 2 weeks, higher-intensity training was carried out, and the horses showed signs of fatigue while ESR increased and body weight decreased further. These results suggested that changes in ESR and body weight were useful parameters for evaluation of fatigue or the condition of a racehorse. Sakurai named this method as the "ESR-body weight method" and concluded that it would be a useful index for screening tests of the effects of training on conditioning and fatigue.

Because previous research was conducted using adult horses trained at a racecourse or on retired racehorses, in 1961, Sakurai and Ogawa observed effects of training and growth on the ESR and body weight using 19 young racehorses trained at the Utsunomiya Yearling Training Farm of the Japan Racing Association [65]. Measurement of blood characteristics was performed at the beginning of June of the yearling year (1st), the end of September of the yearling year (2nd), the beginning of December of the yearling year (3rd), and the beginning of March of the 2-year-old year (4th). The ESR was measured as a 40 min value and converted to the value at 20°C. The average ESR for the 1st period was 74 mm, and it then decreased to 61 mm for the 2nd period, 40 mm for the 3rd period, and 39 mm for the 4th period. On the other hand, average body weight increased from 338 kg for the first period to 457 kg for the 4th period.

In 1964, Sakurai *et al.* [66] performed a more intense and longer study than in 1961 with 102 racehorses trained at the Utsunomiya Yearling Training Farm. Table 1 shows the training protocols. These horses were trained with a method referred as "oi-undo" (ponying, that is, running on a track without a rider, with 2 lead horses with riders) until the horses were broken. Breaking was carried out in December of the yearling year, and running exercise with a rider was started thereafter with the exercise intensity gradually increasing. The 1st study was conducted from

Table 1. Summary of training and testing (ponying, that is, running on courses without rider with 2 lead horses with riders)

Age	Training	Test
Yearling	Ponying (from September) and breaking (from December) at the Utsunomiya Yearling Training Farm.	1st: October to November (N=102)
2 years old	Training at a racecourse (from the end of March or the beginning of April). The training intensity was gradually increased. Most horses could join races until the end of December.	2nd: February to March (N=103) 3rd: June (N=49)
3 years old	Training at racecourses and participating in racing.	4th: March (N=39)

October and November of the yearling year. The 2nd study was conducted in February and March of the 2-year-old year. The horses were moved to racecourses in March to April and were then trained with high-intensity exercise in their trainer's stable. The 3rd study was performed in June of the 2-year-old year. From July onward, horses began to join racing meets, and most of the horses could race until December, except for those horses with musculoskeletal disorders. The 4th and final study was performed in March of the 3-year-old year. Although the number of horses examined was about 100 for the 1st and 2nd studies, the number decreased to 49 for the 3rd study and 39 for the 4th study.

The average ESR during the 1st study was 60 mm, and it decreased as training advanced to 11 mm by the 4th study (Fig. 7). Although individual variation was larger in the 1st survey, the variation became smaller and dispersion among horses decreased as training advanced, with 77% of the horses having values of 15 mm or less in the 4th study. The authors suggested that decrease of the ESR in relation to time during training might be a response to the stress of training. On the other hand, although body weight increased when the horses were trained at Utsunomiya Yearling Training Farm, where the training intensity was low, body weight decreased after moving to racecourses where the training intensity was high (Fig. 7).

In order to investigate relationships between the ESR, fibrinogen, and packed cell volume (PCV), 39 young horses were trained from September of the yearling year to May of the 2-year-old year, and changes in these parameters during the training period were measured [77]. The ESR during the early stage of training slowed, and fibrinogen decreased, as shown in Fig. 8; on the other hand, the PCV increased. All the three factors, however, were unchanged during the latter half of the training period. Additionally, there was a positive correlation between fibrinogen and the ESR at each experiment. When the coefficient of correlation was compared among changing values, the ESR appeared to be influenced mainly by the changes in fibrinogen, at least when the ESR was greatly decreased, or by the racehorse's condition progressing to good condition. However, the authors considered that the ESR might interact with the PCV and fibrinogen and result in the lack of observed changes.

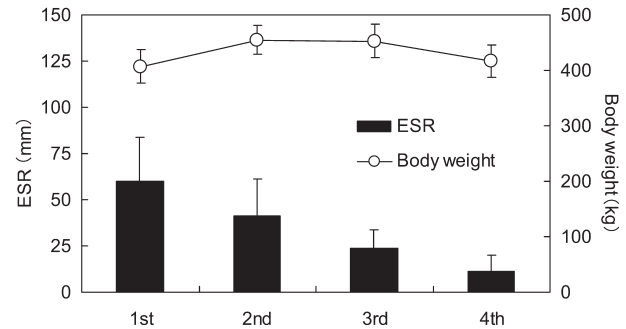


Fig. 7. Changes in erythrocyte sedimentation rate (ESR) and body weight during the training periods from October to November of the yearling year (1st), February to March of the 2-year-old year (2nd), June of the 2-year-old year (3rd), and March of the 3-year-old year (4th). The authors generated this graph using data from a table in a study by Sakurai *et al.* [66].

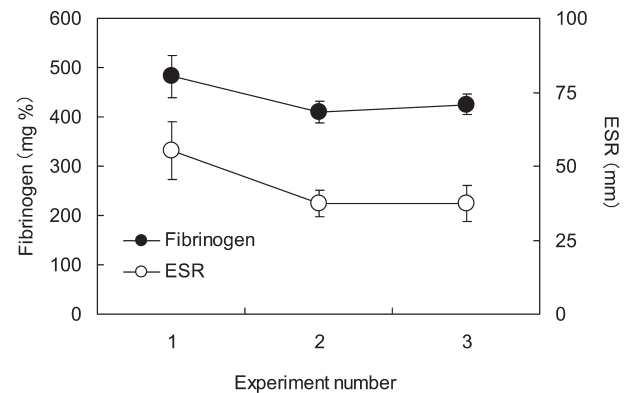


Fig. 8. Changes in fibrinogen concentration and erythrocyte sedimentation rate (ESR) during the training period. The authors generated this graph using data from a study by Takagi *et al.* [77].

Although the ESR was first measured in a warhorse, ESR recording in racehorses became popular following studies by Matsuba, Shijo, and Sakurai as mentioned above. A small number of studies were being performed in foreign countries on the relationship between the ESR and exercise in horses [7, 81]. Based on studies comparing the ESR in various

Table 2. Criteria for judgment of condition by using the erythrocyte sedimentation rate (ESR) and body weight

	ESR	Body weight	Judgment of condition
1	Fast	Heavy	Untrained
2	Became fast	Became heavy	So-called “horse is heavy”. Increase the training intensity.
3	Became slow	Became light	Good condition. Continue training carefully.
4	Became slow	Became slightly heavy	Enough surplus power. It is OK to increase the training intensity.
5	Became fast	Remarkably became light	Need to reduce training due to fatigue.
6	Remarkably became slow	Became light	Anorexia. Intensive training will worsen condition.

Cited from Sakurai [68].

species [22, 57], it was reported that the ESR of the horse was high and that the ESR in ruminants were low, although the reason was unknown. It was also reported that the ESR in active animals, such as pronghorn antelope, dog, and horse, was higher and that inactive animals, such as sheep and cattle, was lower [58]. Therefore, Sakurai’s finding that fit racehorses tend to have a low ESR is an interesting phenomenon that contradicts other studies. Several papers have evaluated factors influencing the ESR [1, 20, 70, 76].

Sakurai indicated in a review article [68] that the individual variation and dispersion of the ESR among horses became smaller as training advanced, suggesting that this index would be useful for evaluation of the condition of individual horses but it would be difficult to use as the basis for comparison of racing performance between different individual horses. He had evaluating conditions of large numbers of racehorses according to criteria for evaluated conditions associated with fatigue as shown in Table 2. Although there is no clear relationship between the ESR and a horse’s “condition”, there may be an association between the two.

Conclusions

The history of research on exercise physiology of the horse in Japan began in the 1920s during a time when the role of the warhorse was still most important, and then studies on racehorses started. Drs. Matsuba and Shimamura of the University of Tokyo played major roles in studies of racehorses performed during the 1930s. In particular, the first study they published in 1933 [31] was a seminal study, as mentioned above, and what is surprising is that they already had tried to evaluate performance of racehorses in the 1930s at the dawn of modern horse racing in Japan. It could be said that their study was ahead of its time.

Although it seems that they evaluated the fitness of racehorses using many blood parameters that were considered to be important in exercise physiology and were possible to measure at that time, it was difficult to evaluate the performance of a racehorse and the effects of training at that time. However, based on their studies, new approaches for

evaluating performance and conditioning of racehorses by using characteristics of the blood were developed by their successors [58–68, 71–74]. Additionally, techniques were developed for measuring cardiopulmonary variables such as respiration [56, 69, 70], heart rate [40–44], and oxygen consumption during exercise [78, 79], leading to additional understanding of equine exercise physiology.

In the present day, studies on cardiopulmonary function during exercise are mainly performed by measuring cardiopulmonary parameters such as oxygen uptake. Although the numbers of studies on blood characteristics is not large in Japan, studies on the fragility of erythrocytes were carried out intensively at the end of the 1990s. Hanazawa *et al.* reported the effects of exercise and splenectomy on the osmotic fragility of circulating erythrocytes [8–12]. In addition, studies of blood lactate changes during exercise have been carried out intensively. Anaerobic work capacity estimated by the lactate accumulation rate has added new ideas regarding energy expenditure during exercise [55]. Studies of lactate metabolism during high-intensity exercise and of the monocarboxylate transporter as it relates to lactate metabolism [24–28] are providing new perspectives and further insights into equine exercise physiology.

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