Heart Rates and Blood Lactate Response in Thoroughbred Horses during a Race

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We measured the heart rate before, during and after a 1200-m race, and blood lactate concentration at 10 min after a race in 23 Thoroughbred horses. The heart rate increased when horses were walking through the underground passage and after the jockeys mounted them in the paddock, even though there was no increase in exercise intensity. During the canter from the exit of the underground passage to the starting stalls, the heart rate increased to a peak value of 194.0 ± 2.0 (mean $\pm$ SE) beat/min, which was equivalent to $91.1 \pm 0.8\%$ of the maximal racing heart rate. In the starting stalls immediately before the start of the race, the heart rate was 171.4 ± 5.3 beat/min. The peak value of the heart rate (HR_{peak}) during the race was 213.6 ± 1.7 beat/min, and the time taken to reach 95% of HR_{peak} was 12.4 ± 1.8 sec. The blood lactate concentration after the race was 22.5 ± 0.6 mmol/l. The mean speed of the horses was 15.9 ± 0.0 m/s, which was similar to those of 3-year-olds in maiden races. These data could be useful for planning training strategies for Thoroughbred horses.

Key words: exercise, heart rate, horse, lactate, race

J. Equine Sci.
Vol. 18, No. 4
pp. 153–160, 2007

It is important to understand the physiological condition of Thoroughbred horses during races and to construct training protocols to adapt them to these severe race events. However, there have been few studies of them [19] due to many limitations in measuring exercise physiological variables in Thoroughbreds during a race. More than 70% of the energy is supplied through the aerobic pathway during intense exercise lasting for 1 to 3 min in horses [6, 7]. In humans, maximal oxygen uptake ($\dot{V}O_{2max}$) has been most reliable in evaluating aerobic capacity and is considered the “gold standard” by which prolonged exercise can be judged. Many publications have shown that there is a correlation between athletic performance and $\dot{V}O_{2max}$ in humans [2, 4, 20]. Although there are many benefits in measuring $\dot{V}O_{2max}$, application of this measurement to racehorses has been difficult, because it requires the racehorses to run on a high-speed

treadmill in the laboratory, to acclimate to the treadmill, and to run until exhaustion. Trainers rarely accept these experimental conditions. In contrast, heart rate is well correlated with oxygen consumption during exercise [5], can easily be measured, and has been conventionally used as an index to evaluate cardiorespiratory functions in horses under field conditions [18, 25, 28]. Many researchers indicate that psychological conditions can influence athletic performance, putting forward the inverted-U-hypothesis as a useful working model of the relationship between arousal and performance [13, 17].

On the other hand, short-term supramaximal exercise results in intramuscular production of lactate in racehorses [21, 39]. The rate of lactate accumulation in skeletal muscles and its release into blood is exponentially related to an increase of $\dot{V}O_2$ accompanied with exercise intensity [15]. On the basis of this relationship, the lactate concentration in blood or plasma may provide valuable information about the working muscles and the rest of the body [12]. In

particular, data obtained after racing indicate the animal's response under conditions of actual competition and also of pre-race excitement. In addition, these data lead to an understanding of the demands of racing and aid in the planning of training schedules.

In this study, we have investigated heart rate throughout a race and the post-race blood lactate concentration in Thoroughbred horses to evaluate exercise intensity and psychological changes during the race.

Materials and Methods

Horses

Twenty-three Thoroughbred horses (8 males, 1 gelding, 14 female; 4.0 ± 0.2 yr, 451.9 ± 6.6 kg) in a racing condition were used in this study. Horses were trained for their race 6 days/week on a dirt track at The Horse Racing School of the Japan Racing Association (JRA). All horses were transported by horse vans on the day of the race, and were found to be clinically healthy with no lameness at the veterinary inspection before the race. Horses were weighed approximately 20 min after the race.

Race

The three simulated races of 1,200 m on a dirt surface, with eight, ten and five horses, respectively, were held at the Nakayama Racecourse of the JRA. The Nakayama Racecourse is one of the biggest racecourses in Japan and holds big races such as the international Nakayama Grand Jump, the Arima Kinen (Grand Prix race), the Satsuki Sho (Japanese 2000 Guineas) and Sprinters Stakes. The dirt course of the Nakayama Racecourse is 1,493 m and its home stretch is 308 m, and the racing direction is clockwise. Each horse was saddled up with a heart rate monitor (S810, Polar Electro Oy, Kempele, Finland) approximately 50 min before the start and was walked for 15 min around the stable. Then, the horses then passed through an underground passage and arrived at the paddock 30 min before the race. After 15-min of walking around the paddock, the horses were mounted by the jockeys and left for the course, passing through the underground passage again. On the course, they cantered for several hundred meters as a warm-up exercise before gathering to the starting stalls. Odd-

Fig. 1. The route of horses in the Nakayama Racecourse of JRA. (a) Walking around the stable. (b) Walking through the underground passage. (c) Walking in the paddock. (d) Walking through the underground passage with jockey mounted. (e) Galloping to the starting stalls. (f) In the starting stalls. (g) During the race.

numbered horses were loaded into the stalls first, followed by even-numbered horses (Fig. 1). After each race, each horse was unsaddled and walked for 10 min. Then blood samples from the jugular vein were collected using 18 gauge needles and vacuum-sealed tubes containing sodium fluoride and EDTA, and were retained on ice until analysis. Blood lactate concentrations were measured with an automatic lactate analyzer (YSI-2300 STAT Plus, Yellow Springs Instruments, Yellow Springs, USA). The race time was measured with an automatic timing device that utilizes infrared ray beams. The race was videotaped and the horses' speed was also measured by checking the videotape.

Heart rate

During the race, a Polar HR Monitor S810 was used to measure the average heart rate over 5-sec intervals. One of electrodes of the heart rate monitor was attached to the sponge set under the saddle, whereas the other electrode, the transmitter and the receiver of the heart rate monitor were attached to the elastic girth.

Statistical analysis

Data are means $\pm$ SE of horses across the three races. Data were analyzed for differences between the heart rates at various stages using repeated measures ANOVA, and pairwise comparisons were made using Tukey's test. Statistical significance was defined as $P < 0.05$. Statistical analyses were made using JMP v. 5.0.1a software.

Results

Heart rate (Fig. 2, Table 1. b)

The heart rate of 2 horses was not recorded from the onset of the experiment and the heart rate of another 2 horses was not recorded after the horses gathered at the starting point.

When horses were walking around the stable, the heart rate was 73.3 ± 2.9 beat/min. After entering the underground passage, the heart rate of horses increased significantly to 88.0 ± 4.2 beat/min. A heart rate of 71.1 ± 2.8 beat/min was recorded when the horses were being led by grooms around the paddock, but the heart rate increased to 97.3 ± 4.6 beat/min after

the jockeys mounted the horses. When the horses were walking to the course with the jockeys riding in the underground passage, the heart rate was 114.3 ± 5.4 beat/min, which was significantly higher than in the paddock with the jockeys mounted. During the canter from the exit of the underground passage to the starting stalls as a warm-up, the recorded heart rate increased to a peak value of 194.0 ± 2.0 beat/min. After gathering around the starting stalls, the horses were walking with a heart rate of 97.7 ± 3.5 beat/min. In the

Fig. 2. Typical pattern of heart rate from saddling-up to unsaddling. (a) Walking around the stable. (b) Walking through the underground passage. (c) Walking in the paddock. (d) Walking through the underground passage with jockey mounted. (e) Galloping to the starting stalls. (f) In the starting stalls. (g) During the race.

Table 1. Thoroughbred horse characteristics
(a)

	Units	Values
Run time	sec	75.6 ± 0.2
Running speed	m/s	15.9 ± 0.0
Body weight	kg	451.9 ± 6.6
Blood lactate concentration	mmol/l	22.5 ± 0.6
$t_{95\%}$	sec	12.4 ± 1.8

(b)

Heart rate	Units	Values
Around the stable	beat/min	73.3 ± 2.9^a
Underground passage	beat/min	88.0 ± 4.2^b
Paddock	beat/min	71.1 ± 2.8^a
Paddock with jockeys	beat/min	97.3 ± 4.6^b
Underground passage with jockeys	beat/min	114.3 ± 5.4^c
Around the starting stalls	beat/min	97.7 ± 3.5^b
In the starting stalls	beat/min	171.4 ± 5.3^d
Galloping to the starting stalls (peak values)	beat/min	194.0 ± 2.0
During a race (peak values)	beat/min	213.6 ± 1.7

Shown are (a) run time, running speed, body weight, blood lactate concentration 10 min after the race and the mean time taken to reach 95% of peak heart rate ($t_{95\%}$), and (b) the heart rate at various stages from saddling-up to unsaddling during a race. Values are means $\pm$ SE. Different letter superscripts indicate significant differences between values ($P < 0.05$).

Fig. 3a

Fig. 3c

Fig. 3b

Fig. 3. Three typical patterns of variation in heart rate during a race. (a) The heart rate remained stable throughout the race. (b) The heart rate was initially unchanged and increased in the last phase of the race. (c) The heart rate decreased gradually during the race.

starting stalls immediately before the start of the race, the heart rate increased to 171.4 ± 5.3 beat/min. The peak value of the heart rate (HR_{peak}) during the race was 213.6 ± 1.7 beat/min and the time taken to reach 95% of HR_{peak} was 12.4 ± 1.8 sec.

Three typical patterns of variation in the heart rate measured during the race are shown in Fig. 3a–3c. In Fig. 3a, once the heart rate had risen to the peak value, it remained stable throughout the race. In Fig. 3b, the heart rate was constant in the early stages and gradually increased in the latter periods. In Fig. 3c, after the heart rate reached its peak, it decreased gradually throughout the rest of the race.

Blood lactate concentration

The mean blood lactate concentration of the 23 horses 10 min after the race was 22.5 ± 0.6 mmol/l (Table 1. a).

Running speed

The mean race time and speed of all of the horses in the three 1,200-m races were 75.6 ± 0.2 sec and 15.9 ± 0.0 m/sec, respectively (Table 1. a).

Discussion

The mean run time of all horses in this study was similar to that of 3-year-olds in maiden races at the Nakayama Racecourse, and the mean speed of the horses was faster than that reported by Krzywanek *et al.* (15.4 m/sec) [19]. These results indicate that the horses used in this study were well-trained and that the races were of moderate quality to represent standard races.

The mean heart rate in the starting stalls just before the start of the race was 171.4 ± 5.3 beat/min. This increase in the heart rate indicated how excited the racehorses were before the start and may be the preparation for the following intensive bout of sprint exercise. The heart rate at the starting stalls in our study was higher than that reported by Krzywanek *et al.* [19] and this may result in an acceleration in the kinetics of oxygen consumption during subsequent intense exercise, given that a shorter time will be needed for the heart rate to reach maximal frequency as compared with the results of Krzywanek's study. Furthermore, Hada *et al.* [14] demonstrated that psychological stress before intense exercise reduced blood lactate accumulation and enhanced running performance in horses, suggesting that there is

increased contribution of aerobic metabolism to total energy production due to the increase in heart rate and haematocrit during intense exercise. On the other hand, it is also possible that over-excitement of horses may cause negative effects, such as getting off to a slow start or causing overrunning during the race. Krzywanek *et al.* also stated that the heart rate in the starting stall was recorded at a period of relative calm and this pre-start period was very variable depending on physical exertion and excitement. This variability may contribute to the difference between the results of Krzywanek and our study. In fact, in our study some horses tended to be excited just after entering the starting stalls, but gradually calmed down and showed a decrease in heart rate while waiting for the other horses to enter the stalls.

The peak heart rate during a warm-up exercise performed after entering the track was 194.0 ± 2.0 beat/min, which was equivalent to $91.1 \pm 0.8\%$ of the maximal racing rate (213.6 ± 1.7 beat/min). Some studies have referred to the effects of warm-up exercise in horses. However, the intensities of the warm-up exercise in those studies tended to be relatively low, that is, 30–50% $\dot{V}O_{2\max}$, and the durations of warm-up protocols were mostly over 5 min [11, 22, 23, 41]. From these results, the further research might be needed to investigate the effect of warm-up exercise under the conditions experienced by Thoroughbred races. Although the warm-up intensity in this study seems to be relatively high, both the warm-up duration (< 1 min) and the warm-up distance (< 600 m) were short, and the recovery time between the warm-up and the race was long (approximately 15 min). According to our unpublished data, the blood lactate concentration after the warm-up exercise in the present study is estimated to decrease to less than 2 mmol/l during the recovery time of 15 min; thus, this warm-up exercise is expected to have little effect on fatigue.

After jockeys mounted the horses in the paddock, the walking heart rate increased, and this effect was also reported by Krzywanek *et al.* [19]. A load of about 50 kg is physically applied when a jockey mounts a horse, and it is expected that the heart rate during a walk may increase owing to this load. However, Sloet van Oldruitenborgh-Oosterbaan *et al.* [36] undertook a study to investigate the influence of additional loading on heart rate in horses exercising submaximally on a treadmill and found that the heart rate during walking (1.7 m/sec), trotting (4.0 m/sec) and cantering (7.0 m/sec) did not differ significantly under three

conditions: unloaded, mounted by a rider of 90 kg and loaded with 90 kg of lead [36]. Thus, the increase in heart rate measured after the jockeys mounted may not be due simply to a physical load, but may be related to other factors, such as psychological factors.

In horses, the rate at which $\dot{V}O_2$ can increase with the onset of intense exercise is remarkable. Rose *et al.* [34] demonstrated in horses exercising at 120 percent of $\dot{V}O_{2\max}$ that the mean time taken to reach 50 and 95% of $\dot{V}O_{2\max}$ was 9.8 and 60 sec, respectively, and that $\dot{V}O_2$ reached a steady state by 75 sec. Even during a run at 125% $\dot{V}O_{2\max}$ that lasted for only a minute, 70 percent of the energy demand was supplied from aerobic pathway [7]. This intensity is equivalent to a sprint race of 1,000 m. In humans, by contrast, anaerobic capacity assumes a more substantial role, contributing approximately 50% of the energy supply in supramaximal exercise of 1 min duration [24]. Our study and Krzywanek's study showed that the heart rate may increase more rapidly to 95% of its peak value than to $\dot{V}O_2$, which required 60 sec to reach 95% of $\dot{V}O_{2\max}$.

Heart rate is highly correlated with work effort in running horses; however, the heart rate during exercise levels off towards a maximal heart rate level at very high intensities of exercise. Therefore, this should be considered when evaluating fitness based on the heart rate/work relationship. As the heart rate of many horses in the present study remained stable at the peak value during the race (Fig. 3a), the running speed of these horses may basically be stable throughout the race. There were also horses whose heart rate during the race gradually decreased (Fig. 3c); this may be explained by a few possibilities, including a decrease in running speed or an overshoot of heart rate. The heart rate rises rapidly at the outset of exercise, reaching a maximum in approximately 30 to 45 sec, and then often drops before reaching a plateau during steady-state work [21]. This overshoot of heart rate will vary depending on the level of exercise intensity, the temperament of the horse and the warm-up period [26, 27]. In several horses, the heart rate continued to increase gradually during the race in this study (Fig. 3b). The relative heart rate (as a percentage of the maximal heart rate) is highly correlated with relative oxygen consumption in horses during treadmill exercise [10]. It is known that during heavy exercise that causes significant lactic acidosis, oxygen uptake does not achieve an early steady state but continues to rise for several minutes until exercise is terminated or

exhaustion occurs [1, 30, 35]. The physiological mechanisms for this slow component of $\dot{V}O_2$ are not clearly understood. Several factors have been suggested to explain this component, including a change in blood lactate concentration, an increase in muscle temperature, an additional cost of ventilation caused by fatigue [3, 30]. Recently, it has been suggested that the percentage of type II fibers in the working muscles seems to be highly related to the amplitude of the slowly increasing $\dot{V}O_2$ component [29]. The percentage of type II fibers in the middle gluteal muscle in Thoroughbred horses is reported to exceed 80% [8, 9, 37, 38, 40, 42, 43]. A high ratio of type II fibers in Thoroughbred horses is consistent with the hypothesis that the $\dot{V}O_2$ slow component during high-intensity exercise is related to the energetics of contraction of type II fibers [29].

The high blood lactate concentration (22.5 ± 0.6 mmol/l) in this study strongly reflects a dependence on anaerobic metabolic pathways during the race. Lactate is produced in the working muscle by the glycolytic pathway during all types of exercise, and the blood lactate concentration increases because of diffusion and/or active transport of lactate via monocarboxylate transporters from the working skeletal muscle. High lactate concentrations do not occur, however, until higher intensities of exercise are reached. Although our lactate concentration seems to be lower than values measured with plasma in other studies [16, 39], it is considered to be of a magnitude similar to those previously reported because lactate concentrations in plasma are about 30% higher than those in blood [31–33]. It is known that horses with a high anaerobic capacity have highest peak plasma lactate concentrations after a maximal exercise test [7]; therefore, strengthening the glycolytic capacity and the ability to tolerate conditions of high lactate, and removing lactate from the muscle by transport through the blood may be important in racing.

In conclusion, we have demonstrated that 1) the heart rate of horses increases in the underground passage, after jockeys mount the horses in the paddock, and in the starting stalls just before the start of the race; 2) the intensity of warm-up exercise prior to a race is relatively high; 3) the exercise intensity during a race is intense enough to utilize both aerobic and anaerobic energy resources; 4) the time required to reach 95% of HR_{peak} is shorter than that taken to reach 95% of $\dot{V}O_{2max}$ [34]. Although further studies are required in larger populations of horses, the data

from this study could help both trainers and veterinarians to manage training strategies for Thoroughbred horses.

Acknowledgments

The authors wish to thank the staff of the Horse Racing School of the Japan Racing Association for expert technical assistance and husbandry throughout the study.

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