

HUMAN BLOOD LACTATE AND AMMONIA LEVELS AFTER SUPRAMAXIMAL UPHILL AND DOWNHILL RUNNING

HIROSHI ITOH¹, TETSUO OHKUWA¹,
YOSHIHIKO YAMAZAKI¹ and MIHARU MIYAMURA²

¹Department of Physical Education, Nagoya Institute of Technology, Nagoya 466, Japan
²Research Center of Health, Physical Fitness and Sports, Nagoya University, Nagoya 464-01, Japan

ABSTRACT

The purposes of this study were 1) to confirm whether there is a difference in the levels of blood lactate and ammonia after supramaximal uphill and downhill running for the same short duration and 2) to examine the relationship between peak blood lactate levels and work/lean body mass (LBM), as well as the relationship between peak blood ammonia levels and work/LBM following supramaximal uphill and downhill running. Eight healthy, untrained male subjects performed supramaximal uphill and downhill running on a motor-driven treadmill for about 70 sec. Though there was a significant difference ($p < 0.05$) in running speed and work/LBM between supramaximal uphill and downhill running, no significant difference was found in exhaustion time or heart rate. Both the peak blood lactate and ammonia concentrations were significantly lower after downhill running than after uphill running ($p < 0.05$). Although there was no significant relationship between peak blood ammonia levels and work/LBM following either uphill or downhill running, significant linear relationships between the peak blood lactate levels and work/LBM were observed following uphill running ($r = 0.74$, $p < 0.05$) and downhill running ($r = 0.72$, $p < 0.05$). These results suggest that the differences in the blood lactate and ammonia concentration between supramaximal downhill and uphill running of the same duration may be due to the total recruitable muscle mass during exercise, and that peak blood lactate can be used as an index of anaerobic work capacity for untrained subjects under these running conditions.

Key Words: Lactate, Ammonia, Uphill, Downhill, Supramaximal running

INTRODUCTION

Blood lactate concentration may give valuable information not only about changes in glycolysis, but also about the anaerobic work capacity in humans. Previous studies demonstrated that peak blood lactate, which was determined after 1 min of supramaximal exercise on a treadmill or 400-m sprinting, correlated with the running time of a 400-m sprint in untrained male and female subjects.¹⁻³ However, these results were obtained after exhaustive running exercise on a treadmill with a grade of 8.6% (uphill running) or on the en-tout-cas 400m track at a 0% gradient (level running). In other words, it is possible to assume that there may be some differences in peak blood lactate after supramaximal exhaustive exercise for short periods between uphill and downhill running, because Liefeldt et al.⁴ recently reported significantly lower blood lactate concentrations during maximal downhill running for 10–15 min than during level running,

Address for Correspondence: Hiroshi Itoh,
Department of Physical Education, Nagoya Institute of Technology, Nagoya 466, Japan
Telephone: (052) 735-5199
Fax: (052) 735-5201
E-mail: itoh@ks.kyy.nitech.ac.jp

despite the faster running speeds during downhill. To our knowledge, however, no one has investigated the differences in blood lactate concentration between supramaximal uphill and downhill running to the point of exhaustion for the same duration of about 1 min.

On the other hand, it is well known that the deamination of adenosine 5'-monophosphate (AMP) within muscle occurs during intensive exercise when the rate of ATP hydrolysis is high relative to the rate of oxidative phosphorylation.⁵⁾ AMP deamination leads to a stoichiometric production of ammonia, and ammonia leaves the active muscles and accounts for the increased concentration of blood ammonia.⁶⁾ Previous studies from our laboratory demonstrated that the blood ammonia concentration increased after supramaximal exercise,⁷⁾ and that the peak value of ammonia in the blood appeared in sprints within 15 sec.⁸⁾ In addition, we reported that the peak blood ammonia correlated with work/lean body mass (LBM) after supramaximal treadmill running with a grade of 5 or 3 for 60–70 sec before reaching exhaustion.⁹⁾ However, there is no available data for men detailing the differences in peak blood ammonia concentration between supramaximal uphill and downhill running for the same short periods.

The purposes of this study, therefore, were: 1) to clarify whether or not peak blood lactate and ammonia obtained after supramaximal uphill and downhill running of about 70 sec were about the same, and 2) to examine whether peak blood lactate and ammonia evaluated in the supramaximal downhill running can be used as an index of anaerobic work capacity.

METHODS

Eight male students (age 21.3 ± 2.8 years, height 170.3 ± 4.4 cm, mass 63.9 ± 4.7 kg, LBM 55.0 ± 4.1 kg) participated as the subjects in the present study. Though clinical checks were not made, all subjects were in good health. They had been performing recreational sports (swimming, tennis etc.) one or two days a week, and as far as possible maintained the same activity pattern during the experimental sessions. The protocol of this experiment and the possible risks were fully explained to each subject before they signed an informed consent document.

The subjects performed supramaximal uphill (grade 8.75%) and downhill (grade -5%) running on a motor-driven treadmill in a random test order. The test order of downhill and uphill running for each subject was separated by three months, because Byrnes *et al.*¹⁰⁾ reported that the influence of downhill running on serum creatine kinase, myoglobin and perceived muscle soreness disappeared after 9 weeks. All the subjects attended the laboratory on the day before the actual supramaximal running test so as to be able to familiarize themselves with running on a treadmill, and to gain confidence in running downhill, especially at very high speeds. The treadmill running speed was determined individually, and was set so as to elicit exhaustion within 60–70 secs. Both types of running were terminated as soon as it was obvious that the subject could not maintain the treadmill speed. Before supramaximal running, they first warmed up at a speed of 140 m/min with no incline for 5 min. Then they rested for 3 min, and warmed up a second time at a speed of about 90% of the individual's maximum speed, at each grade, for 30 sec. Thereafter, they rested for 3 min again, and performed supramaximal exercise.

To collect venous blood, a 21-gauge butterfly needle with a sampling vinyl tube was inserted into an antecubital vein at rest, immediately after the 2nd warming up, and during recovery. A series of 2-ml blood samples was obtained using disposable syringes, at rest, immediately after the 2nd warming up and at 2.5, 5, 7.5, 10, 12.5 and 15 min intervals during recovery. For blood ammonia analysis, each 1-ml blood sample was deproteinized in an iced 4-ml 10% sodium tungstate immediately, and centrifuged at 3,000 rpm for 10 min. Blood ammonia analysis was carried out with a commercial kit (Ammonia-Test, Wako Company, Osaka, Japan). Each

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0.5-ml of the remaining sample was immediately deproteinized in an iced 1.5-ml 5% metaphosphoric acid solution and the blood lactate concentration was measured by an enzymatic technique.

During the studies, the heart rate was measured continuously on an electrocardiograph using the Dynascope DS-502 system (Fukuda Denshi, Japan).

Total work as a function of energy expenditure was obtained using the method of Margaria et al.¹¹⁾ Subcutaneous skinfold thickness was measured in the tricep and subscapular areas, and LBM was estimated using the method of Brožek et al.¹²⁾

The differences were assessed by means of the Wilcoxon test for nonparametric paired data, and differences of $p < 0.05$ were considered significant.

RESULTS

Average values and standard deviations of the running speed, exhaustion time and total work/LBM were 288 ± 15 m/min, 70.0 ± 6.0 s and 0.56 ± 0.05 kcal/LBM for uphill running, and 409 ± 14 m/min, 71.5 ± 11.8 s and 0.42 ± 0.08 kcal/LBM for downhill running, respectively. There was a significant difference both in running speed and work/LBM between supramaximal uphill and downhill running ($p < 0.05$), but not in exhaustion time. Fig. 1 shows changes in heart rate at rest, during warming-up and following both types of running. Average values and standard deviations of the maximal heart rate were 191.0 ± 6.9 beats/min for uphill running and 187.2 ± 5.9 beats/min for downhill running. There was no significant difference in the heart rate between supramaximal uphill and downhill running.

Fig. 2 depicts the time course of the blood lactate concentration before and after uphill and downhill supramaximal running. During recovery, significantly higher ($p < 0.05$) blood lactate

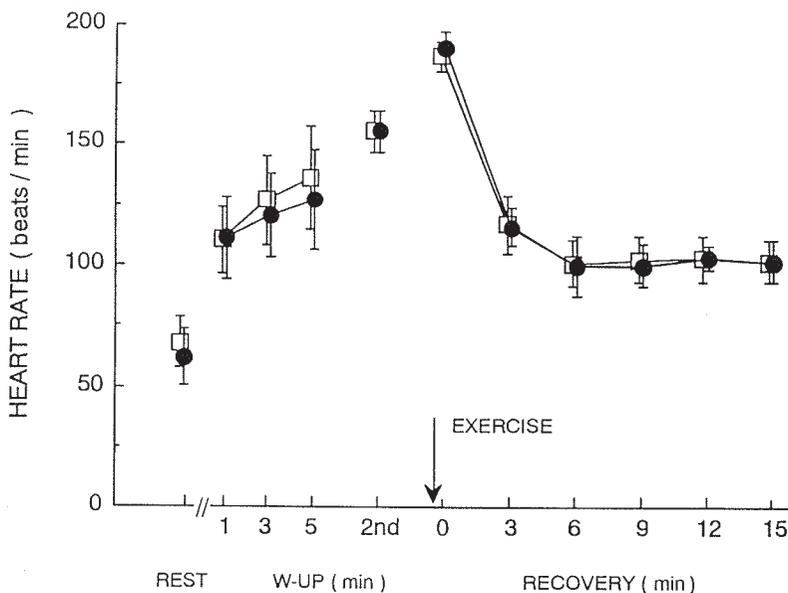


Fig. 1. Mean heart rate with standard deviations associated with supramaximal uphill (●) and downhill (□) running for the rest, warm up (W-UP) and recovery periods.

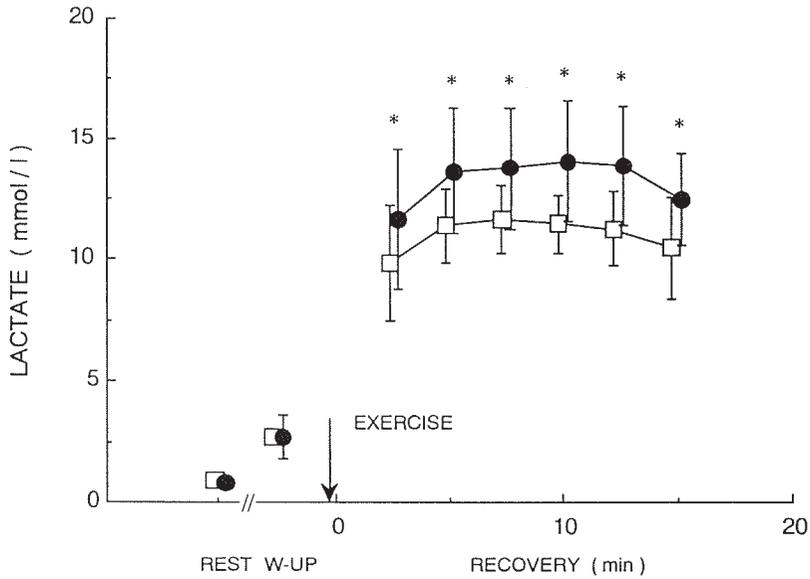


Fig. 2. Blood lactate concentrations associated with supramaximal uphill (●) and downhill (□) running for the following periods: at rest, immediately after warming up (W-UP) and during recovery. Values are means with standard deviations. * Statistically significant difference between uphill and downhill, $p < 0.05$.

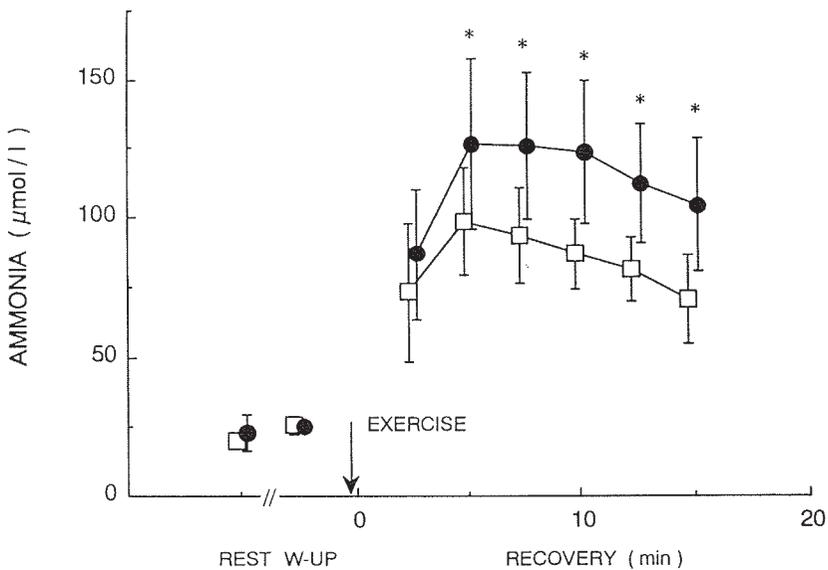


Fig. 3. Blood ammonia concentrations associated with supramaximal uphill (●) and downhill (□) running for the following periods: at rest, immediately after warming up (W-UP) and during recovery. Values are means with standard deviations. * Statistically significant difference between uphill and downhill, $p < 0.05$.

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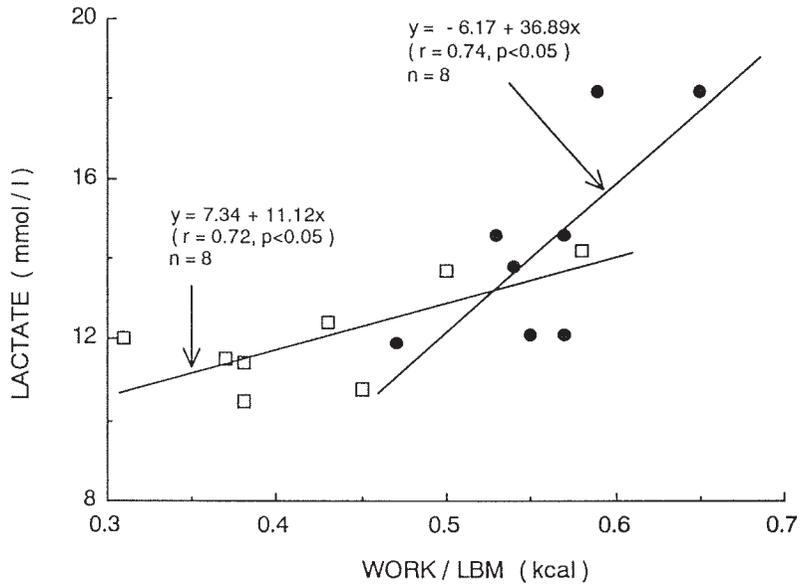


Fig. 4. Relationship between peak blood lactate and work/LBM following supramaximal uphill (●) and downhill (□) running.

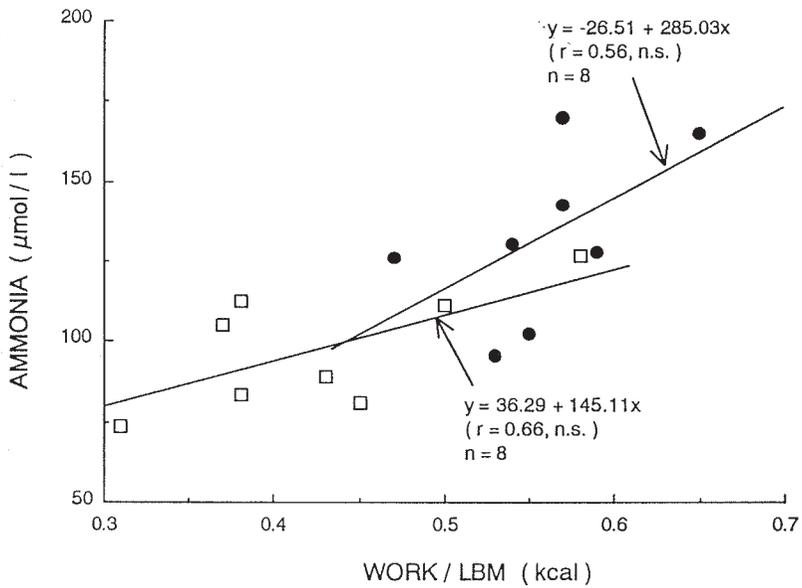


Fig. 5. Relationship between peak blood ammonia and work/LBM following supramaximal uphill (●) and downhill (□) running.

concentrations were observed after uphill running than after downhill running. The peak blood lactate concentration after uphill running (14.4 ± 2.6 mmol/l) was also significantly higher ($p < 0.05$) than after downhill running (12.1 ± 1.3 mmol/l).

The behavior of the blood ammonia concentrations is shown in Fig. 3. The peak blood ammonia concentration obtained during recovery was significantly ($p < 0.05$) higher in uphill running (132.7 ± 26.4 μ mol/l) than in downhill running (98.0 ± 18.6 μ mol/l).

Fig. 4 shows significant relationships between the peak blood lactate and work/LBM either following uphill ($r = 0.74$, $p < 0.05$) or downhill ($r = 0.72$, $p < 0.05$) running.

No significant correlation was found between the peak blood ammonia concentrations and work/LBM following either uphill ($r = 0.56$, ns) or downhill ($r = 0.66$, ns) running (Fig. 5).

DISCUSSION

In a previous paper, we demonstrated that the peak blood lactate, which was determined after 400-m sprinting, correlated with the running speed in untrained male and female subjects.¹⁻³ Furthermore, we found a significant correlation between peak blood ammonia and work/LBM after supramaximal treadmill running with a grade of 5 or 3 for 60–70 sec.⁹ These results suggest that the peak blood lactate and ammonia concentration obtained after supramaximal exercise for about 1 min is a useful index of anaerobic work capacity in human beings. However, these results were obtained after exhaustive running exercise on a treadmill with a grade (uphill running) or on the en-tour-cas 400m track at a 0% gradient (level running). In other words, it is possible to assume that there may be some difference in peak blood lactate and ammonia after supramaximal exhaustive exercise between uphill and downhill running for about 1 min, because Liefeldt *et al.*⁴ recently reported significantly lower blood lactate concentrations during maximal downhill running for 10–15 min than during level running. To our knowledge, however, no one has examined this assumption.

In this study, both blood lactate and ammonia concentrations were significantly lower during recovery from supramaximal downhill running than during recovery from uphill running (Fig. 2 and 3). At present, no definite explanation for this difference has been presented on physiological grounds. The difference in the peak concentrations of blood lactate and ammonia may be due to various factors, such as age, sex, muscle mass and training effects. Concerning muscle mass components, we have reported that the peak blood ammonia concentration was lower in females than in males after supramaximal running as the muscle mass involved during exercise was smaller in the former.⁹ Furthermore, a rearfoot striking pattern, grounding back toward the heel, during downhill running may have the effect of reducing the muscular involvement in load-bearing as compared with a more fore-foot striking pattern during uphill running.¹³ From these reasons, it is hypothesized that the differences in blood lactate and ammonia concentrations after supramaximal downhill and uphill running reflected the difference in the total amount of muscle involved during the respective runs.

Costill *et al.*¹⁴ demonstrated that prolonged downhill running on an inclined treadmill almost completely depleted the glycogen in the soleus muscle, which has a greater percentage of energy cost provided by aerobic metabolism, while level or uphill prolonged running resulted only in partial depletion. It has been reported that blood lactate and ammonia are mainly produced in the fast twitch muscle fiber (FT), but not in slow twitch muscle fiber (ST).¹⁵ We⁷ have already demonstrated that peak blood ammonia and lactate concentrations were higher after supramaximal exercise in sprinters than in long-distance runners. This phenomenon is related to the fact that sprinters have a greater LBM and/or a higher proportion of FT than long-distance runners,

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whereas long-distance runners have a higher proportion of ST fibers than sprinters. In addition, Dick and Cavanagh¹⁶⁾ suggested that there are greater effects of eccentric muscle contraction on motor unit recruitment during submaximal downhill running than during submaximal level running. Kuipers et al.¹⁷⁾ observed that little or no decline occurred in muscle (vastus lateralis) glycogen after eccentric cycling, when compared with concentric cycling at the same relative work load (80% $\dot{V}O_{2max}$). Thus, there is another possible explanation for the difference in the peak blood lactate and ammonia. The difference could be related to the muscle fiber recruitment pattern and also to the effect of eccentric and/or concentric muscle contraction during supramaximal downhill and uphill running. However, it is necessary to confirm this possibility.

We have observed that peak blood ammonia and lactate levels were positively related to work/LBM following supramaximal uphill running on a motor-driven treadmill.⁹⁾ As shown in Fig. 4, there were significant linear relationships between the peak blood lactate and work/LBM either after supramaximal downhill running ($r=0.72$, $p<0.05$) or uphill running ($r=0.74$, $p<0.05$). However, no significant relationship could be found between peak blood ammonia and work/LBM, either after downhill or uphill running, while a close relationship between peak blood ammonia and work/LBM in downhill ($r=0.66$) and in uphill ($r=0.56$) running did exist, as shown in Fig. 5. It is possible that a significant correlation was obtained if the number of subjects increased or if the exhaustion time was shortened to, say, within 15 sec.⁸⁾

In conclusion, we found significantly greater blood lactate and ammonia concentrations after supramaximal uphill running than after downhill running during the same duration of 60–70 secs. The peak blood lactate level related significantly to work/LBM either after downhill or uphill running, but the peak blood ammonia level did not. These results suggest that the difference in the lactate and ammonia concentrations between supramaximal downhill and uphill running may be due to total muscle mass involved during exercise. Thus, the peak blood lactate concentrations obtained after supramaximal downhill and uphill running on a treadmill for about 1 min can be used as an index of anaerobic work capacity in untrained subjects.

REFERENCES

- 1) Fujitsuka, N., Yamamoto, T., Ohkuwa, T., Saito, M. and Miyamura, M.: Peak blood lactate after short periods of maximal treadmill running. *Eur. J. Appl. Physiol.*, 48, 289–296 (1982).
- 2) Ohkuwa, T., Kato, Y., Katsumata, K., Nakao, T. and Miyamura, M.: Blood lactate and glycerol after 400-m and 3000-m runs in sprint and long distance runners. *Eur. J. Appl. Physiol.*, 53, 213–218 (1984).
- 3) Ohkuwa, T., Miyamura, M., Andou, Y. and Utsuno, T.: Sex differences in lactate and glycerol levels during maximal aerobic and anaerobic running. *Eur. J. Appl. Physiol.*, 57, 746–752 (1988).
- 4) Liefeldt, G., Noakes, T.D. and Dennis, S.C.: Oxygen delivery does not limit peak running speed during incremental downhill running to exhaustion. *Eur. J. Appl. Physiol.*, 64, 493–496 (1992).
- 5) Lowenstein, J.M.: Ammonia production in muscle and other tissues: the purine nucleotide cycle. *Physiol. Rev.*, 52, 382–414 (1972).
- 6) Dudley, G.A., Staron, R.S., Murray, T.F., Hagerman, F.C. and Luginbuhl, A.: Muscle fiber composition and blood ammonia levels after intense exercise in humans. *J. Appl. Physiol.*, 54, 582–586 (1983).
- 7) Itoh, H. and Ohkuwa, T.: Peak blood ammonia and lactate after submaximal, maximal and supramaximal exercise in sprinters and long-distance runners. *Eur. J. Appl. Physiol.*, 60, 271–276 (1990).
- 8) Itoh, H. and Ohkuwa, T.: Ammonia and lactate in the blood after short-term sprint exercise. *Eur. J. Appl. Physiol.*, 62, 22–25 (1991).
- 9) Itoh, H. and Ohkuwa, T.: Blood ammonia concentration after supramaximal treadmill running in males and females. *J. Sports Med. Phys. Fitness*, 33, 239–245 (1993).
- 10) Byrnes, W.C., Clarkson, P.M., White, J.S., Hsieh, S.S., Frykman, P.N. and Maughan, R.J.: Delayed onset muscle soreness following repeated bouts of downhill running. *J. Appl. Physiol.*, 59, 710–715 (1985).
- 11) Margaria, R., Cerretelli, P., Aghemo, P. and Sassi, G.: Energy cost of running. *J. Appl. Physiol.*, 18, 367–370 (1963).

- 12) Brožek, J., Grande, F., Anderson, J.T. and Keys, A.: Densitometric analysis of body composition: Revision of some quantitative assumptions. *Ann. N. Y. Acad. Sci.*, 110, 113–140 (1963).
- 13) Williams, K.R. and Cavanagh, P.R.: Relationship between distance running mechanics, running economy, and performance. *J. Appl. Physiol.*, 63, 1236–1245 (1987).
- 14) Costill, D.L., Jansson, E., Gollnick, P.D. and Saltin, B.: Glycogen utilization in leg muscles of men during level and uphill running. *Acta Physiol. Scand.*, 91, 475–481 (1974).
- 15) Komi, P.V., Rusko, H., Vos, J. and Vihko, V.: Anaerobic performance capacity in athletes. *Acta Physiol. Scand.*, 100, 107–114 (1977).
- 16) Dick, R.W. and Cavanagh, P.R.: An explanation of the upward drift in oxygen uptake during prolonged sub-maximal downhill running. *Med. Sci. Sports Exerc.*, 19, 310–317 (1987).
- 17) Kuipers, H., Keizer, H.A., Verstappen, F.T.J. and Costill, D.L.: Influence of a prostaglandin-inhibiting drug on muscle soreness after eccentric work. *Int. J. Sports Med.*, 6, 336–339 (1985).