

# The effect of a carbohydrate loading on running performance during a 25-km treadmill time trial by level of aerobic capacity in athletes

A. SULLO, M. MONDA, G. BRIZZI, V. MENINNO, A. PAPA,  
P. LOMBARDI, B. FABBRI\*

Dipartimento di Fisiologia Umana e Funzioni Biologiche Integrate "F. Bottazzi", Servizio di Fisiopatologia dello Sport, II University of Naples (Italy)

\*Centro di Medicina dello Sport Coni - FMSI di Padova (Italy)

**Abstract** – The aim of the present study was to examine the influence of a high carbohydrate diet and the level of aerobic capacity on running performance during a 25-km treadmill time trial. The study used a 2\*2 design with the factors being training and diet composition. We divided the athletes in 4 groups:

1. Trained athletes with carbohydrate loading (CHO<sub>1</sub>);
2. Trained athletes without carbohydrate loading (C<sub>1</sub>);
3. Untrained athletes with carbohydrate loading (CHO<sub>2</sub>);
4. Untrained athletes without carbohydrate loading (C<sub>2</sub>).

The carbohydrate loading was effected with confectionery. Performance time, running speed, blood glucose and blood lactate concentrations were evaluated during two 25-km treadmill time trial (trial 1 and trial 2) separated by 7 days in which two groups (CHO<sub>1</sub> and CHO<sub>2</sub>) had a carbohydrate loading. The results showed that the athletes with lower level of aerobic capacity had better performance time after carbohydrate loading. They ran faster and had a higher glucose and lactate concentrations in the last 5 km during trial 2. There were no significant differences in the other groups. In conclusion, we can assert that dietary carbohydrate loading can improve running performance and that confectionery can be used as an effective means of supplementing the normal carbohydrate intake in preparation for endurance competitions. But the improvement depends on some factors such as the distance and the level of aerobic capacity.

Key Words:

Diet, Carbohydrate loading, Endurance, Athlete, Training.

## Introduction

Christiansen and Hansen were the first to explore systematically the link between diet and exercise capacity<sup>1</sup>. Their study clearly showed the benefits of utilizing a high carbohydrate diet before prolonged exercise and was the first to establish the importance of carbohydrate content in diets of athletes preparing for competition.

A high carbohydrate diet increases the stores of liver and muscle glycogen<sup>2,3</sup>. The focus of these studies was the influence of dietary carbohydrate loading on endurance capacity rather than on endurance performance. Endurance capacity is defined as the time to fatigue at a fixed exercise intensity, whereas endurance performance is the time to complete a prescribed distance or work load. The importance of muscle glycogen during prolonged exercise was also confirmed in subsequent studies which showed that fatigue occurs when muscle glycogen concentrations are reduced to low values<sup>4,5</sup>.

The benefits of carbohydrate loading before prolonged submaximal exercise have been shown in both endurance cycling<sup>3,6,7</sup> and running<sup>5,8,9</sup> performance. One of the best examples of the influence of dietary manipulation on endurance performance was reported by Karlsson and Saltin. They reported that running times improved after carbohydrate loading, during a 30-km cross-country race<sup>5</sup>. In contrast, Sherman et al<sup>10</sup> found no improvement in running times of well-trained

runners over 20.9 km on a indoor 200-m track after carbohydrate loading.

A clear benefit from increasing the carbohydrate content of runners' diets is achieved with lower exercise intensity. Brewer et al<sup>9</sup> showed that endurance capacity during treadmill run to exhaustion at 70%  $\text{VO}_{2\text{max}}$  can be improved by supplementing normal mixed diets with either complex or simple carbohydrates. Williams et al<sup>11</sup> reported the effects of increasing carbohydrate content of a normal mixed diets on running performance during 30-km treadmill time simulated race in trained athletes. They found that the athletes ran faster during the last 5 km.

The improvements may further be influenced by training status since highly trained individuals have developed an enhanced capacity to use fat as energy source compared to less trained individuals. Thus, when working at the same absolute exercise intensity trained individuals may use less carbohydrates and more fat for muscle contraction.

The aim of this study was to examine the effects of increasing the carbohydrate content of trained and untrained runners' diet on running performance during 25-km treadmill time trial and then the relationship existing between the effects of carbohydrate loading and training status.

## Materials and Methods

The 24 male subjects who volunteered to take part in this study were professional long-distance athletes. The subjects were fully informed about the nature of the experiments and what was required of them before they volunteered to take part in this study. The subjects were divided into 2 groups on the basis of their aerobic capacity level related to free-fat weight (FFW): group I with  $\text{VO}_{2\text{max}} > 70 \text{ ml} \cdot \text{kg} \text{ FFW} \cdot \text{min}^{-1}$  and group II with  $\text{VO}_{2\text{max}} < 70 \text{ ml} \cdot \text{kg} \text{ FFW} \cdot \text{min}^{-1}$ .

### Anthropometric measurements and body composition analysis

The morning body weights of each subjects were measured daily with a Toledo Weight-Plate having a precision value of 0.1 kilo in the fasting state soon after evacuation. Naked

body weights were calculated as total body weight minus robe and hospital gown weight. Height of subjects were measured with bare feet to the nearest 0.1 cm with a wall-mounted stadiometer. Body mass index (BMI) was calculated as  $\text{wt}/\text{ht}^2$  ( $\text{kg}/\text{m}^2$ ).

Body composition was measured by using bioelectrical impedance analysis (BIA). BIA measurements were applied at the same time of the RMR measurements for the reproducibility of the study, under the following conditions: subjects after 12 hours of fasting, with empty bladder since 15 minutes and after drinking 250 ml of water. An analyser Xitron 4000 (Xitron Technologies, San Diego) was used. At supine position, the receiving electrodes were placed on the dorsal parts of the right wrist and right ankle, while the stimulating electrodes were placed to the dorsal surface of the right foot and right hand. The resistance (R) was measured three times and the mean of them was regarded as the result. The FFW values were calculated by using the predictive Lohman equation. The fatty weight (FW) was accepted as the difference between the total body weight (BW) and FFW. The percentage of body fat (BF%) was evaluated as  $(\text{BW}-\text{FFW}) \cdot \text{BW}^{-1}$  whereas total body water (TBW) was evaluated as  $\text{FFW} \cdot 0.73$ .

### Experimental design

All the subjects were required to complete two treadmill runs (trial 1 and trial 2) over a distance of 25 km, separated by a period of 7 days. After completing trial 1, the subjects of group I were randomly assigned to one of two dietary subgroups. For the 7 days after the first run, one subgroup (CHO<sub>1</sub> group) was prescribed a diet high in simple carbohydrates which was designed to increase their carbohydrate consumption by 70% during the first 3 days and by 35% during the remaining 4 days. This was achieved by supplementing their normal diets with simple carbohydrates in the form of confectionery. The subjects of the control group (C<sub>1</sub> group) maintained their normal carbohydrate intake during the 7-day period between the two trials but they consumed additional fat and protein to achieve energy intakes isocaloric in comparison to the diets of the CHO<sub>1</sub> group.

The subjects of group II were also assigned to one of the two dietary subgroups: CHO<sub>2</sub>

group and C<sub>2</sub> group. They had the same procedures of the group I (respectively CHO<sub>1</sub> and C<sub>1</sub> groups).

### Procedures

VO<sub>2max</sub> determinations were made by using an electrically treadmill and an open circuit gas analysis system (Radiometer Copenhagen). After a 10- to 15-min warm up period, the subjects started the test running horizontally at 15 km·h<sup>-1</sup>. Running speed was kept constant, and the slope was increased by 1° every min until exhaustion. During the test, heart rate was continuously monitored with a cardiofrequencymeter (Esaote).

After being on the 3 days of normal diets, the athletes were weighted in the morning after an overnight fast and monitored for heart rate. A capillary blood samples from the thumb of a prewarmed hand were collected. The subjects completed 5-min warm up on the treadmill at running speeds equivalent to 60% VO<sub>2max</sub>. At the end of the warm-up the treadmill speed was increased to 70% VO<sub>2max</sub> for the start of the 25-km run. This speed was an appropriate guideline for each subject and it was maintained for the first 5 km. Thereafter, the runners could change the speed at any time during the time trials.

Throughout the run, capillary blood samples from the thumb were collected at 5-km intervals. Heart rates were monitored and recorded every 30 sec. Water replacement was allowed ad libitum throughout the run, but after stopping the masses of the subjects were recorded before any other replacement.

Laboratory temperature and relative humidity was maintained constant over all the trials by an air conditioner.

### Nutritional status

From 2 to 3 weeks before trial 1 the subjects completed 7-day weighed food intake diaries. They were analysed to provide a quantitative description of each subject's normal daily food intake<sup>12</sup>. Using this information, the subjects were prescribed their normal daily food intake during the 3 days before trial 1. During the 3-day period immediately after trial 1, the subjects of CHO<sub>1</sub> and CHO<sub>2</sub> subgroups increased their carbohydrate intake by 70%. The consumption of this additional food increased overall energy intake by 50%. Over this same period, there was no change in the carbohydrate intake of the control groups (C<sub>1</sub> and C<sub>2</sub>), but they increase their energy intake by the same amount as the CHO<sub>1</sub> and the CHO<sub>2</sub> groups, which was largely the result of a 99% increase in fat consumption. During the following 4 days which preceded trial 2, the CHO<sub>1</sub> and the CHO<sub>2</sub> groups reduced their carbohydrate intake and energy intake to 35% and 25% respectively, above their normal values. Over the same 4-day period, the control groups (C<sub>1</sub> and C<sub>2</sub>) also reduced their energy intake to 25% above their normal intake, by reducing their intake of fat, but without changing their carbohydrate intake. The dietary patterns for all the groups are shown in Table II. There was no significant change in body masses of all the groups during the 7-day period between the 2 trials.

Table I. Physical characteristics of the 24 subjects classified on the basis of physical fitness level and assigned to the controls (C<sub>1</sub> and C<sub>2</sub>) and carbohydrate (CHO<sub>1</sub> and CHO<sub>2</sub>) groups; values are means ± SEM.

Variable	CHO <sub>1</sub>	C <sub>1</sub>	CHO <sub>2</sub>	C <sub>2</sub>
Age (years)	25.0 ± 2.6	26.0 ± 1.7	26.0 ± 2.2	27.0 ± 0.5
Height (cm)	170 ± 5	170 ± 2	170 ± 3	170 ± 1
Weight (kg)	74.0 ± 2.5	74.8 ± 2.2	73.5 ± 2.0	75.3 ± 1.2
Body Mass Index [Wt*(Ht <sup>2</sup> ) <sup>-1</sup> ]	25.0 ± 0.8	25.4 ± 0.9	25.3 ± 0.5	25.7 ± 0.7
Body fat (%)	25.2 ± 2.0	26.0 ± 1.8	26.3 ± 1.2	26.1 ± 0.9
Fat free weight (kg)	56.3 ± 3.3	55.4 ± 2.8	55.2 ± 2.1	54.9 ± 2.0
Resting heart rate (beat*min <sup>-1</sup> ) <sup>a</sup>	48.3 ± 1.6	49.3 ± 1.3	49.4 ± 2.6	50.1 ± 2.3
Maximal heart rate (beat*min <sup>-1</sup> )	189.1 ± 3.51	190.13 ± 4.0	192.4 ± 4.0	194.4 ± 3.36
VO <sub>2max</sub> (ml*min <sup>-1</sup> *Kg <sup>-1</sup> )	74.0 ± 4.0	73.0 ± 1.5	65.5 ± 2.3	64.8 ± 2.4
VO <sub>2max</sub> (ml* kg <sup>-1</sup> FFW*min <sup>-1</sup> )	81.8 ± 3.0	82.8 ± 1.4	78.2 ± 1.2	77.6 ± 1.7

**Table II.** Daily energy and macronutrient intakes of the four groups during the 3 days before trial 1 (pre-T1), during the consecutive 3 (1st-3 days) and 4 days (2nd-4 days) before trial 2; values are means  $\pm$  SEM.

Observation period	Energy (MJ)	Fat (g)	CHO (g)	Protein (g)
<b>CHO<sub>1</sub></b>				
Pre-T1	11.5 $\pm$ 0.5	110 $\pm$ 2	336 $\pm$ 13	107 $\pm$ 8
1st-3 days	17.0 $\pm$ 0.5	151 $\pm$ 7	572 $\pm$ 20	125 $\pm$ 12
2nd-4 days	14.5 $\pm$ 0.8	131 $\pm$ 9	463 $\pm$ 25	108 $\pm$ 7
<b>C<sub>1</sub></b>				
Pre-T1	12.3 $\pm$ 0.3	112 $\pm$ 2	325 $\pm$ 21	109 $\pm$ 2
1st-3 days	16.2 $\pm$ 0.6	249 $\pm$ 9	369 $\pm$ 26	179 $\pm$ 3
2nd-4 days	13.9 $\pm$ 0.5	190 $\pm$ 4	358 $\pm$ 24	144 $\pm$ 6
<b>CHO<sub>2</sub></b>				
Pre-T1	12.1 $\pm$ 0.8	112 $\pm$ 4	342 $\pm$ 15	108 $\pm$ 6
1st-3 days	17.8 $\pm$ 0.5	149 $\pm$ 7	586 $\pm$ 23	121 $\pm$ 13
2nd-4 days	15.2 $\pm$ 0.7	132 $\pm$ 4	471 $\pm$ 22	109 $\pm$ 9
<b>C<sub>2</sub></b>				
Pre-T1	11.9 $\pm$ 0.6	111 $\pm$ 6	333 $\pm$ 16	108 $\pm$ 8
1st-3 days	16.0 $\pm$ 0.3	248 $\pm$ 4	362 $\pm$ 12	177 $\pm$ 7
2nd-4 days	14.8 $\pm$ 0.7	191 $\pm$ 8	355 $\pm$ 16	149 $\pm$ 10

### Analysis

Capillary blood samples (25  $\mu$ l) were de-proteinised in 0.4 mol $\cdot$ l<sup>-1</sup> perchlorid acid, frozen at -20°C and later analyzed for lactate and glucose<sup>13</sup>.

### Statistical analysis

The values are presented as means  $\pm$  SE. Parametric t-test were used to examine differences between results which were distributed normally, whilst the non-parametric Wilcoxon matched pairs test was used to examine differences between sets which were not distributed normally. Pages L trend analyses was used to examine trends in data over a period of time<sup>14</sup>. In all analyses, the 95% level of confidence was taken to be indicative of statistical significance.

## Results

The performance time for C<sub>1</sub> group during trials 1 and 2 were 92.2  $\pm$  7.1 min and 93.5  $\pm$  5.7 min respectively (NS). The CHO<sub>1</sub> group covered the 25-km run in 93.4  $\pm$  4.3 min during trial 1 and 92.6  $\pm$  5.4 min during trial 2 (NS). The performance time for C<sub>2</sub> group during trials 1 and 2 were 99.8  $\pm$  6.7 min and 100.2  $\pm$  9.3 min respectively (NS). The CHO<sub>2</sub> group covered the 25-km run in 101.1  $\pm$  7.9 min during

trial 1 and 95.3  $\pm$  5.1 min during trial 2 (p < 0.05). The running speeds over each successive 5 km of trial 1 and trial 2 are shown for all groups in Figure 1. There were no differences for C<sub>1</sub>, CHO<sub>1</sub> and C<sub>2</sub> groups during the two trials. However, the running speed of CHO<sub>2</sub> group over the last 5 km during trial 2 was faster then the speed they achieved over the last 5 km during trial 1 (3.47  $\pm$  0.31 m  $\cdot$ s<sup>-1</sup> vs 3.95  $\pm$  0.33 m  $\cdot$ s<sup>-1</sup>; p < 0.001). Trend analysis significant decreases in running speed for all the groups during both trials 1 and 2.

Heart rates ranged between 48.3  $\pm$  2.2 and 50.4  $\pm$  1.3 beats  $\cdot$ min<sup>-1</sup> for all groups, during the two trials. No differences were found in the heart rate responses of all groups on trial 2 when compared to trial 1.

The blood glucose concentrations over each successive 5 km of trial 1 and trial 2 are shown for all groups in Figure 2. There were no differences in blood glucose concentrations for C<sub>1</sub>, CHO<sub>1</sub> and C<sub>2</sub> groups during the two trials. C<sub>2</sub> group did, however, decrease towards the end of the 25-km run on both occasions (p < 0.001). In contrast, the blood glucose concentrations of the CHO<sub>2</sub> group decreased during trial 1 (p < 0.05), but not during trial 2.

The blood lactate concentrations over each successive 5 km of trial 1 and trial 2 are shown for all groups in Figure 3. There were no differences in blood lactate concentrations for C<sub>1</sub>

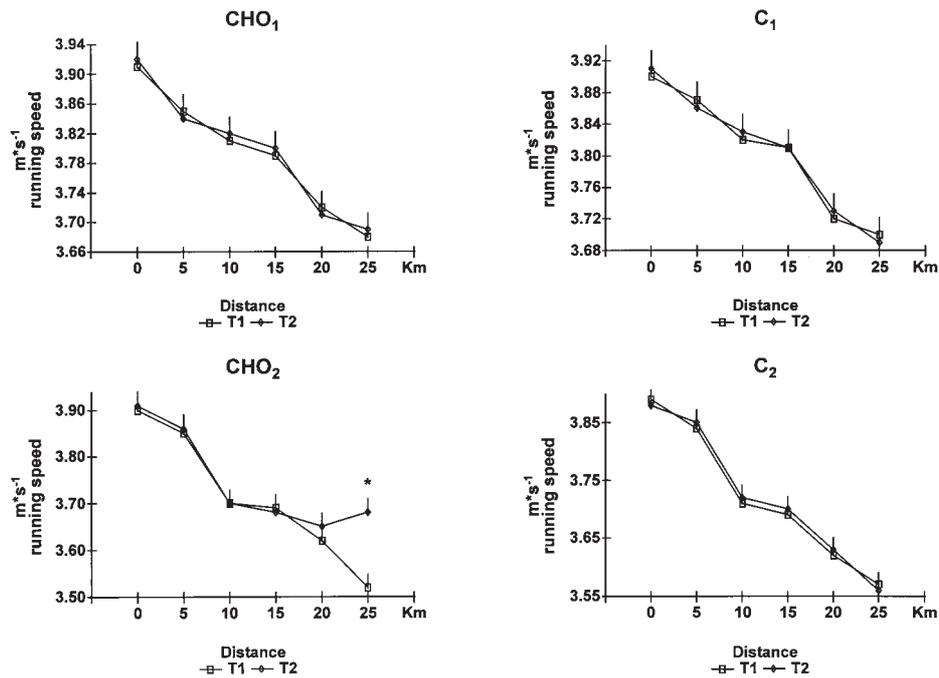


Figure 1. Mean  $\pm$  SEM running speeds during trial 1 (T1) and trial 2 (T2) for the carbohydrate group and the control group with higher level of aerobic capacity (CHO<sub>1</sub> and C<sub>1</sub>) and for the carbohydrate group and control group with lower level of aerobic capacity (CHO<sub>2</sub> and C<sub>2</sub>) during the two 25-km treadmill time trial. \*  $P < 0.001$ .

and CHO<sub>1</sub> groups during the two trials. Trend analysis revealed a decrease ( $p < 0.001$ ) in the values of C<sub>2</sub> group during trial 1. In contrast, the blood lactate concentrations of the CHO<sub>2</sub> group were higher after 25-km during trial 2, compared to the values obtained after the same distance during trial 1 ( $p < 0.05$ ).

Body masses of the runners in the C<sub>1</sub> group decreased by  $2.01 \pm 0.08$  kg during trial 1 and by  $2.08 \pm 0.1$  kg during trial 2. The runners in CHO<sub>1</sub> group had a decrease in body mass of  $1.99 \pm 0.11$  kg during trial 1 and  $2.03 \pm 0.12$  kg during trial 2. Body masses of the runners in the C<sub>2</sub> group decreased by  $2.02 \pm 0.08$  kg dur-

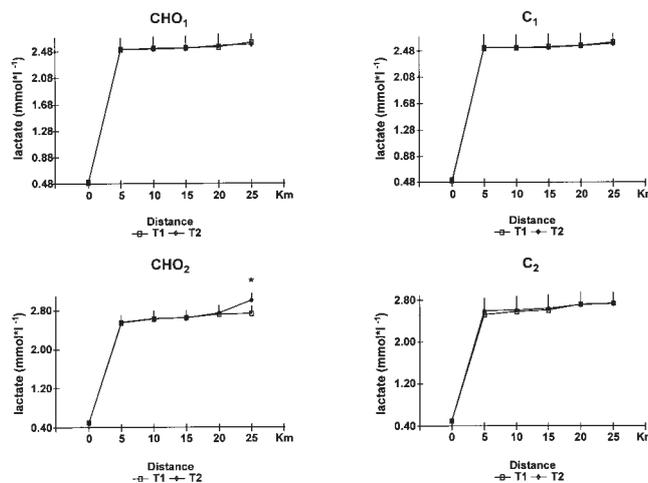


Figure 2. Mean  $\pm$  SEM blood glucose concentrations during trial 1 (T1) and trial 2 (T2) for the carbohydrate group and the control group with higher level of aerobic capacity (CHO<sub>1</sub> and C<sub>1</sub>) and for the carbohydrate group and control group with lower level of aerobic capacity (CHO<sub>2</sub> and C<sub>2</sub>) during the two 25-km treadmill time trial. \*  $P < 0.05$ .

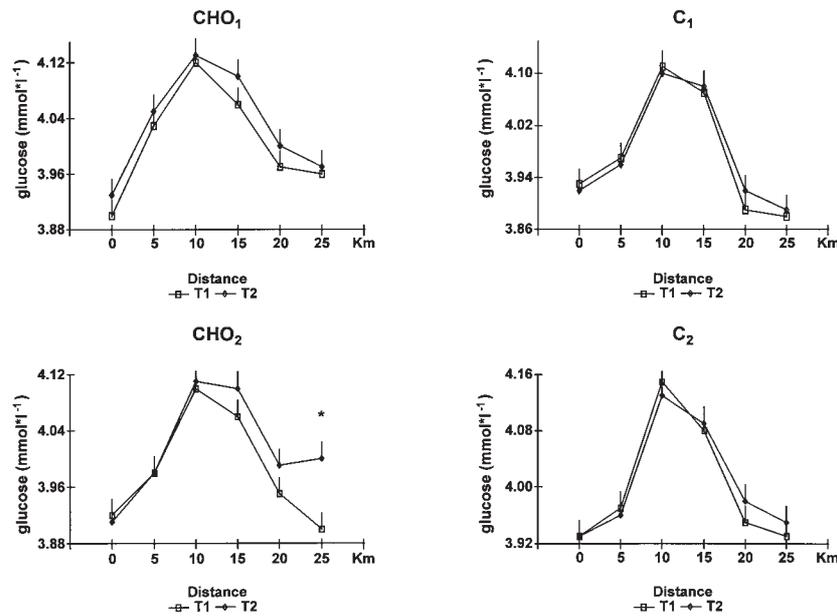


Figure 3. Mean  $\pm$  SEM blood lactate concentrations during trial 1 (T1) and trial 2 (T2) for the carbohydrate group and the control group with higher level of aerobic capacity ( $CHO_2$  and  $C_2$ ) and for the carbohydrate group and control group with lower level of aerobic capacity ( $CHO_1$  and  $C_1$ ) during the two 25-km treadmill time trial. \*  $P < 0.05$ .

ing trial 1 and by  $2.06 \pm 0.12$  kg during trial 2. The runners in  $CHO_2$  group had a decrease in body mass of  $2.05 \pm 0.1$  kg during trial 1 and  $2.09 \pm 0.07$  kg during trial 2. The fluid intake for  $C_1$  and  $CHO_1$  groups during trial 1 was  $370 \pm 55$  ml and  $364 \pm 65$  ml, respectively and during trial 2 the values were  $345 \pm 76$  ml and  $372 \pm 68$  ml, respectively. The fluid intake for  $C_2$  and  $CHO_2$  groups during trial 1 was  $348 \pm 43$  ml and  $356 \pm 67$  ml, respectively and during trial 2 the values were  $359 \pm 54$  ml and  $362 \pm 85$  ml, respectively. There were no significant differences between trials or among groups.

## Discussion

The main result of this study was that athletes with lower level of aerobic capacity had an improvement in performance time during a 25-km trial after 7 days on a high carbohydrate diet than they did after consuming their normal mixed diets. An other important result was that they ran faster during the last 5 km. Athletes with higher level of aerobic capacity showed no such improvement in performance time after 7 days on a high carbohydrate diet. The control groups ( $C_1$  and  $C_2$ )

also showed no improvement in performance time, even though their energy intake was the same of the other groups.

These improvements were not as great as those reported by Karlsson and Saltin<sup>5</sup> in their study on the influence of carbohydrate loading on running performance during cross-country races over 30 km. Their subjects improved their performance times by 5.4% after carbohydrate loading. Karlsson and Saltin had two groups of subjects who were of different ability. One group consisted of runners with high  $VO_{2max}$  and the other of students with modest  $VO_{2max}$  values. The reduction in running times were 3.2% and 7.6% for the experienced and less experienced runners respectively. We found no significant reduction in performance time of the athletes with higher  $VO_{2max}$  but a reduction of 4.2% for the subjects with lower  $VO_{2max}$ . The explanation for the differences in performances reported by the two studies is that the subjects in the earlier study ran over a 30-km undulating cross-country course, whereas the subjects of the present study completed 25-km on a level treadmill. There was probably a greater reduction in the muscle glycogen stores of the runners who completed the 30-km cross-country races than occurred in the runners who completed the 25-km treadmill time trials.

Our data are partially according to the results reported by Williams et al<sup>11</sup>. They studied the influence of carbohydrate loading on running performance during a simulated 30-km race conducted using a laboratory treadmill. One of the aim of this study was to determine at what point during the race runners began to show signs to fatigue and how this was modified by dietary manipulation. The runners were divided in two groups after the first 30-km treadmill time trial. One group increased their carbohydrate intake during the 7-day recovery period, whereas the other group consumed additional protein and fat in order to match the increased energy intakes of carbohydrate group. Although there was no improvement at all in performance times for the two groups, the carbohydrate group ran faster during the last 5 km of the simulated race. Some remarks would be made to explain the differences with our results. The subjects selected by Williams et al were men and women while in our study there were only men. An analysis of the results of Williams et al shows that only men had significantly better overall performance times during trial after carbohydrate loading. This result was confirmed by Tarnopolsky et al<sup>15</sup> who reported no improvement in performance time during an 85%  $VO_{2peak}$  trial after carbohydrate loading in trained female endurance athletes. The trials in the study by Williams et al were on 30-km, whereas the trials of the present study were on 25 km. This is compatible with the absence of improvement in performance time and in running speed of trained athletes although they had a carbohydrate loading. In fact, in earlier study there were no improvement in performance time and in running speed of the athletes with carbohydrate loading over 25 km. This is according to data reported by Sherman et al<sup>10</sup>. They reported no improvement in the running times of well-trained runners during a 20.9-km indoor course after carbohydrate loading. Their method of carbohydrate loading was different from traditional approach because it did not include 2 or 3 days on a low carbohydrate diet and their subject stopped the training and increased the carbohydrate intake during 4 days before the course. Williams et al explained the different results for the different approach of carbohydrate loading but we think that the decisive factors are the running distance and es-

pecially the training. In fact, we found improvement in performance time and in running speed during the last 5 km in untrained athletes but we found no improvement in trained athletes. Sherman et al found no differences in performance when a group of six well-trained endurance athletes completed three races over 20.9 km on a indoor 200-m track after carbohydrate loading. Three different dietary procedures were used to prepare for the races: a low carbohydrate diet followed by 3 to 4 days on a high carbohydrate diet (low/high); a normal mixed diet followed by the same period on a high carbohydrate diet (mixed/high); a normal mixed diet for the whole of the preparatory period before the race (mixed/mixed). The subjects who consumed their normal mixed diet throughout the week before the race showed increased muscle glycogen concentrations too, but not the same extent as in the carbohydrate-loading trials. The fastest time was recorded when the runners simply tapered their training and consumed their normal mixed diets. Under these conditions the runners had lower pre-race muscle glycogen concentrations and used less glycogen during the race. It is worth noting that the pre-race glycogen concentrations, even without carbohydrate loading, were high. Therefore the muscle glycogen concentrations of the subjects in the study reported by Sherman et al were more than enough to meet the demands imposed upon them by races over 20.9 km. It is clear from this study that well-trained runners need only taper their training in preparation for races over the half-marathon distance. They do not need to undertake any dietary manipulation in preparation for races over this or shorter distance.

In conclusion we can assert that dietary carbohydrate loading can improve running performance and that confectionery can be used as an effective means of supplementing the normal carbohydrate intake in preparation for endurance race. But the improvement depends by some factors such as the distance and the level of aerobic capacity.

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