Overtraining following intensified training with normal muscle glycogen

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ABSTRACT

SNYDER, A. C., H. KUIPERS, B. CHENG, R. SERVAIS, and E. FRANSEN. Overtraining following intensified training with normal muscle glycogen. Med. Sci. Sports Exerc., Vol. 27, No. 7, pp. 1063-1070, 1995. The purpose of this study was to determine if consumption of appropriate amounts of carbohydrate during a period of increased exercise training would protect the athletes from becoming overtrained. Eight male competitive cyclists were monitored and tested during three training periods: a) normal training (moderate intensity, long duration, 7 d, NORM); b) overtraining (high intensity training, 15 d, OVER); and c) recovery (minimal training, 6 d, REC). Throughout the training 160 g of liquid carbohydrate were consumed within the first 2 h after the daily exercise bout. Mean dietary intake (NORM = 13.7 ± 1.6, OVER = 14.1 ± 1.0 MJ d⁻¹) and carbohydrate percent (NORM = 64.0 ± 2.1, OVER = 67.4 ± 2.5%) were not different during the different training periods. Similarly, resting muscle glycogen levels were not different (NORM = 530.9 ± 42.5, OVER = 571.2 ± 27.5 μmol g⁻¹ dry weight). Five criteria were used to determine if overtraining occurred in a subject (decreased maximal workload, maximal heart rate, ratio of maximal lactate to rating of perceived exertion (HLa:RPE), and resting plasma cortisol levels, increased affirmative response to a daily questionnaire). All subjects met at least three of the five criteria and thus were classified as overtrained. Therefore, short-term overtraining may occur even when resting muscle glycogen levels are maintained.

EXERCISE PERFORMANCE, HEART RATE, CORTISOL

The obvious goal of athletic training is to enhance performance. However, the process of training too heavily (i.e., overtraining), as well as that of undertraining, will result in the opposite effect, that is, in a performance decrement. Chronic overtraining can result in the occurrence of the overtraining syndrome or statelessness (20). Many markers besides impaired performance have been suggested as antecedents of overtraining, including: delayed muscle glycogen resynthesis and thus reduced muscle glycogen levels, reduced caloric intake, reduced exercise heart rate but increased resting heart rate, reduced blood lactate levels, and muscle injury (1,5,12,19,20).

Low muscle glycogen levels can impair exercise performance at intensities primarily between 65 and 85% of maximal oxygen uptake, the exercise intensity at which most endurance athletes train (25). Few athletes, however, consume the recommended dietary intake of 70% carbohydrates (25) as athletes generally consume approximately 40-50% of their diet as carbohydrates (25). Costill et al. (5) recently demonstrated that heavily trained swimmers who had difficulty during 10 days of heavier than normal training had reduced muscle glycogen levels and had consumed a diet of only approximately 396 g d⁻¹ carbohydrates, while a group which had little difficulty during the heavier than normal training had normal glycogen levels and had consumed approximately 612 g d⁻¹ carbohydrates. Other investigations have also shown low muscle glycogen levels (10,20) and delayed muscle glycogen resynthesis (5) in athletes who were heavily training. Thus, overtraining could be initiated from insufficient dietary intake of carbohydrate coupled with increased exercise training and thus reduced muscle glycogen.

Therefore, the purpose of the present investigation was to determine if subjects who consumed sufficient amounts of carbohydrate during a period of increased exercise training could become overtrained. Specifically, male cyclists followed a protocol previously used in this laboratory to overtrain subjects (17); however, the subjects of the present study consumed carbohydrates in liquid form within the first 2 h post exercise to enhance muscle glycogen resynthesis (15,16) and retain normal glycogen levels throughout the period of increased exercise training. We hypothesized that even with normal muscle glycogen levels throughout the period of increased exercise training period that the subjects would still show signs of overtraining as indicated by reduced performance and decreased exercise heart rate. Since we had already used...
The study consisted of three time periods: a) normal (moderate) training (7 days, NORM), b) overtraining (15 days, OVER), and c) recovery training (6 days, REC). During the OVER period the cyclists rode 18 h-wk⁻¹ with the exercise consisting mainly of high intensity interval training (66% of time at >90% VO₂max) with some moderate intensity interval training (10% of time at 80% VO₂max) and some endurance training (24% of time at 70% VO₂max) as we have previously used (17). During the NORM and REC training periods, on the other hand, the cyclists rode about 12.5 and 7.5 h-wk⁻¹, respectively, which consisted mainly of moderate intensity (25% of time) and long duration endurance training (% of time) activity.

Throughout all training periods the daily protocols were different to avoid boredom, however the OVER protocols always had high intensity work. The NORM training was quite similar to what the cyclist had been training for the weeks prior to the start of the study, as verified by the subjects. Training was monitored and varied throughout the study through the use of heart rate (Sporttester, Finland) which was related to workload via the results of the maximal exercise test during the NORM period.

Exercise Testing

Twice during the NORM period (tests 1, for practice, and 2) and once at the end of the OVER (test 3) and REC (test 4) periods an incremental exercise test to fatigue (i.e., maximal performance test) was performed. The exercise test started at a power output of 100 W with the power output increased 50 W every 5 min until the subject reached a heart rate of 160 beats·min⁻¹. After this point the power output increased 50 W each 2.5 min until the subject reached volitional fatigue. If a plateau in oxygen uptake was not observed with an increase in power output, then two of the following three criteria had to be met to assure that a maximal effort occurred: 1) a plateau in maximal heart rate, 2) a respiratory exchange ratio above 1.10, and 3) a rating of perceived exertion of greater than 8.5 (on the 10 scale). The protocol developed for each subject during the first incremental exercise test was repeated for each subsequent exercise test, regardless of heart rate. The exercise tests were performed on a calibrated electrically braked bicycle ergometer (Lode, Curaçao, the Netherlands).
Groningen, the Netherlands) modified for competitive cyclists. Maximal work of each exercise test was obtained by multiplying the watts of the last workload by the percentage of time spent at that workload. Oxygen uptake was determined continuously during the exercise bout using a computerized on-line system (Oxyconbeta, Mijnhardt B.V., Bunnik, the Netherlands). The oxygen uptake system was calibrated using the manufacturers methods and a previously calibrated gas mixture before any testing each day. From this system the respiratory exchange ratio and ventilation were also obtained. Heart rate was determined continuously during the exercise test by a Stat Scope II (B-D Electrodyne, U.S.A.) integrated into the oxygen uptake computer program. Perceived exertion was obtained at the end of each workload using the category ratio scale developed by Borg et al. (3). The workload, time of each exercise stage, and all other variables measured were not visible to the subjects during the exercise testing. Of the 24 exercise tests performed, 14 were considered maximal efforts due to a plateauing of oxygen uptake, while the other 10 were verified as maximal efforts by the subjects obtaining at least two of the three established criteria.

Prior to each exercise test the subjects had their body height, weight, and percent fat determined. Prior to exercise tests 2, 3, and 4 a Teflon catheter was inserted into an antecubital vein of the subject so that blood samples could be obtained both at rest and during the last 30 s of each workload. The drawn blood was immediately centrifuged for 1.5 min at 14,000 r.min⁻¹ and the plasma stored at −80°C until analyzed for lactate or cortisol. Lactate concentration was determined by the lactate dehydrogenase method (11). Cortisol concentration was determined with a radioimmunoassay using a commercial kit (D.P.C. kit, Laboratory Service, the Netherlands). The analytical coefficients of variance for this assay as reported by the company are 8.2% at 120 nmol.l⁻¹ and 3.8% at 820 nmol.l⁻¹. Prior to exercise tests 2 and 3 the subjects had a needle biopsy of the vastus lateralis muscle (8). The tissue sample was immediately frozen in liquid nitrogen and stored at −80°C for later analysis of glycogen (24). While questions have been raised concerning the validity of using a single muscle biopsy to determine muscle fiber type due to the distribution of fibers throughout a muscle (2), we believe that obtaining a single muscle biopsy from a rested muscle to determine glycogen content is valid due to the fact that all of the fibers should have a similar content of glycogen in this condition (2).

The subjects performed a time trial (tt) twice during (at the middle and end) the NORM (tt1 and tt2) and OVER (tt3 and tt4) periods and once (at the end) during the REC (tt5) period. The time trial was performed on a 8.5-km circuit which had one climb at the beginning of the course of about 700 m (incline 6-7%). The time trial course had very little traffic to interfere with the cyclists. The subjects were assigned a starting time and were instructed to warm up as they wished prior to the start. The subjects were instructed to perform the time trial as fast as possible. The time, average heart rate (via Polar Sportstester), and peak heart rate were recorded for each time trial. The time trials took place 1-2 d after the incremental exercise test and before any exercise training occurred that day.

**Criteria for Overtraining**

The following criteria were analyzed to determine if a subject was overtrained:

1. A reduced performance ($W_{max}$) of greater than 10 W during the maximal test.
2. A reduced maximal heart rate of greater than 5 beats.min⁻¹.
3. A reduced plasma cortisol level of greater than 60 nmol.l⁻¹.
4. A reduced maximal lactate to rating of perceived exertion (HLa:RPE) ratio of greater than 20 points, previously described by us to be an indicator of overtraining (26).
5. At least a five-question affirmative increase in the daily questionnaire responses, previously shown by us to be an indicator of overtraining (17).

No single symptom or set of symptoms has been found to be associated with overtraining; however, these five criteria represent those symptoms most observed. Therefore, a subject in this study had to obtain three of the five criteria to be classified as overtrained.

**Statistical Analysis**

Most data (i.e., $W_{max}$, HLa:RPE ratio, heart rate, lactate, time trials) were analyzed using a one-way repeated measures analysis of variance technique comparing the results obtained following NORM, heavier than usual training (OVER), and REC. When significant differences occurred the location was detected with the use of Tukey’s post hoc analysis. With data collected only twice (i.e., diet records, muscle glycogen) a dependent t-test was used to analyze the data. During the last (REC) maximal exercise test of four of the subjects oxygen uptake was not determined due to technical difficulties, therefore dependent t-tests were used to compare the NORM and OVER oxygen uptake, RER, VE, TV, and RR values. The daily questionnaire responses were averaged for the different time periods (NORM, OVER, REC) with the heavy training period broken into the first 7-d (OVER1) and last 8-d periods (OVER2). Differences between the responses of the different time periods were then obtained through the use of a repeated measures analysis of variance with Tukey’s post hoc analysis performed if necessary. All data are presented as mean ± standard error ($\bar{X} \pm SE$).
RESULTS

Exercise Training

Heart rate data collected on all subjects for each training session verified that the subjects performed the exercise sessions as described. Ratings of perceived exertion during the exercise training sessions ranged from 5.8 to 9.1 with a mean of 7.3 ± 0.5. Consequently, all eight subjects had at least three of the five symptoms of overtraining at the conclusion of the heavier than normal training period (OVER) and therefore all eight subjects had at least three symptoms of overtraining. No one symptom had less than five subjects, i.e., the symptoms not obtained by the subjects were not the same symptoms.

Dietary Intake and Muscle Glycogen

While the subjects were given a liquid of 160 g of complex carbohydrates to consume within 2 h after their exercise training each day throughout the study, the subjects' carbohydrate consumption totaled 512 g (64.0 ± 5.5% of intake) during NORM and 548 g (64.0 ± 2.1% of intake) during OVER. The subjects also consumed similar total energy amounts during the two measured periods of the study (NORM = 13.7 ± 1.6 MJ; OVER = 14.1 ± 1.0 MJ).

Resting muscle glycogen was not significantly different when compared between the NORM (530.9 ± 42.5 μmol·g⁻¹ DW) and OVER (571.2 ± 27.5 μmol·g⁻¹ DW) time periods. Most subjects (N = 6) increased their resting muscle glycogen during the OVER time period, but there was no significant difference at similar workloads during the NORM and OVER training periods (Table 4). Similarly, the respiratory exchange ratio was not different at similar workloads during the NORM and OVER training periods except at the maximal workload (Table 4).

Heart rate during the maximal performance test was significantly higher at lower workloads during the OVER time period compared to that during the NORM (Fig. 1). Heart rate during the lower workloads (i.e., 100, 150, 200, 250, and 300 W) was significantly lower at all workloads during the OVER time period than during the NORM. Ventilation progressively increased throughout the maximal performance test, but was not different at similar workloads during the NORM and OVER training periods (Table 4). Similarly, the respiratory exchange ratio was not different at similar workloads during the NORM and OVER training periods except at the maximal workload (Table 4).

Resting Characteristics

The subject's body weight, percent body fat, and lean body mass did not change significantly during the course of the investigation (Table 3). Similarly, blood lactate levels were not different at rest over the three training periods (Table 3). Resting HR and hours slept per night were also not significantly different over the three training periods (Table 3).

Maximal Performance Test

Maximal work performed was not statistically significantly different (P = 0.08) between the three time periods even though seven of the eight subjects had an approximate 3% decrease in Wmax from NORM to OVER. Four of the subjects increased their Wmax from the OVER to the REC time period, but the means were not different from each other.

Oxygen uptake during the maximal performance test followed similar trends whether expressed in absolute (ml·min⁻¹) or relative (ml·min⁻¹·kg⁻¹) terms (Table 4). During the lower workloads (i.e., 100, 150, 200, 250, and 300 W) oxygen uptake was similar between the NORM and OVER time periods. However, during the 350 W and maximal workloads oxygen uptake was significantly lower during the OVER time period than during the NORM. Ventilation progressively increased throughout the maximal performance test, but was not different at similar workloads during the NORM and OVER training periods (Table 4). Similarly, the respiratory exchange ratio was not different at similar workloads throughout the maximal performance test when comparing the NORM and OVER training time periods except at the maximal workload (Table 4).

Heart rate during the maximal performance test was significantly lower at all workloads during the OVER time period compared to that during the NORM (Fig. 1). Heart rate during the lower workloads (i.e., 100, 150, 200, 250, and 300 W) was greater during the NORM time period than during the REC. However, during the 350 W and maximal workloads, heart rate during the NORM and REC time periods was similar, both significantly greater than that during the OVER time period.

Plasma lactate for the lower workloads (i.e., 100, 150, 200, 250, and 300 W) was greater during the NORM time period than during the OVER or REC time periods (Table 4). At the 350 W and maximal workloads, or workloads

<table>
<thead>
<tr>
<th>Subject</th>
<th>Wmax</th>
<th>HL/RPE</th>
<th>Heart Rate</th>
<th>Cortisol</th>
<th>Daily Questions</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>x</td>
<td>x</td>
<td>x</td>
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</tr>
<tr>
<td>2</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td></td>
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<tr>
<td>3</td>
<td>&gt;</td>
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<td>x</td>
<td>x</td>
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<td>8</td>
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</table>

Table 2. Symptoms of overtraining of each subject.

<table>
<thead>
<tr>
<th>Subject</th>
<th>Wmax</th>
<th>HL/RPE</th>
<th>Heart Rate</th>
<th>Cortisol</th>
<th>Daily Questions</th>
</tr>
</thead>
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<tr>
<td>NORM</td>
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<td>1.6</td>
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<td></td>
<td></td>
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<tr>
<td>OVER</td>
<td>14.1</td>
<td>1.0</td>
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</table>

Table 3. Resting characteristics of the subjects (X ± SE).
OVERTRAINING WITH NORMAL MUSCLE GLYCOGEN LEVELS

<table>
<thead>
<tr>
<th>Variable</th>
<th>Time</th>
<th>100</th>
<th>150</th>
<th>200</th>
<th>250</th>
<th>300</th>
<th>350</th>
<th>MAX</th>
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</thead>
<tbody>
<tr>
<td>VO&lt;sub&gt;2&lt;/sub&gt; (ml·min&lt;sup&gt;-1&lt;/sup&gt;)</td>
<td>NORM</td>
<td>23.0</td>
<td>30.0</td>
<td>38.1</td>
<td>47.1</td>
<td>54.8</td>
<td>66.6</td>
<td>4944</td>
</tr>
<tr>
<td></td>
<td>OVER</td>
<td>0.9</td>
<td>1.1</td>
<td>1.4</td>
<td>1.1</td>
<td>1.5</td>
<td>1.4</td>
<td>4651</td>
</tr>
<tr>
<td>VO&lt;sub&gt;2&lt;/sub&gt; (ml·min&lt;sup&gt;-1&lt;/sup&gt;·kg&lt;sup&gt;-1&lt;/sup&gt;)</td>
<td>NORM</td>
<td>42.4</td>
<td>52.6</td>
<td>65.5</td>
<td>83.9</td>
<td>109.9</td>
<td>172.7</td>
<td>8.4</td>
</tr>
<tr>
<td></td>
<td>OVER</td>
<td>1.1</td>
<td>1.3</td>
<td>2.4</td>
<td>2.2</td>
<td>5.1</td>
<td>8.4</td>
<td>1.3</td>
</tr>
<tr>
<td>Respiratory exchange ratio</td>
<td>NORM</td>
<td>0.86</td>
<td>0.88</td>
<td>0.89</td>
<td>0.93</td>
<td>0.99</td>
<td>1.11</td>
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<tr>
<td></td>
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<td>0.02</td>
<td>0.02</td>
<td>0.02</td>
<td>0.03</td>
<td>0.01</td>
<td>0.01</td>
</tr>
<tr>
<td>Lactate (mM)</td>
<td>NORM</td>
<td>1.4</td>
<td>1.4</td>
<td>1.6</td>
<td>2.5</td>
<td>4.1</td>
<td>13.1</td>
<td>0.01</td>
</tr>
<tr>
<td></td>
<td>OVER</td>
<td>1.2*</td>
<td>1.2*</td>
<td>1.3*</td>
<td>2.1*</td>
<td>3.5*</td>
<td>11.3</td>
<td>0.01</td>
</tr>
<tr>
<td></td>
<td>REC</td>
<td>0.9*</td>
<td>0.9*</td>
<td>1.2*</td>
<td>2.0*</td>
<td>3.4*</td>
<td>12.0</td>
<td>0.01</td>
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<tr>
<td>RPE</td>
<td>NORM</td>
<td>0.4</td>
<td>1.6</td>
<td>2.8</td>
<td>3.9</td>
<td>5.0</td>
<td>8.9</td>
<td>0.01</td>
</tr>
<tr>
<td></td>
<td>OVER</td>
<td>0.3</td>
<td>0.3</td>
<td>0.2</td>
<td>0.2</td>
<td>0.3</td>
<td>0.3</td>
<td>0.01</td>
</tr>
<tr>
<td></td>
<td>REC</td>
<td>0.7</td>
<td>1.6</td>
<td>2.9</td>
<td>4.1</td>
<td>5.4</td>
<td>9.5</td>
<td>0.01</td>
</tr>
</tbody>
</table>

* Significantly different from NORM.
† Significantly different from OVER.

Figure 1—Mean heart rate during maximal performance test during NORM, OVER, and REC training periods. Heart rate during OVER was significantly different from that during NORM at all workloads, and heart rate during REC was significantly different from NORM for all workloads except 350 W and maximal.

which elicited a lactate value of greater than 4 mM, plasma lactate was similar between the three training time periods.

The ratings of perceived exertion followed an expected trend for a maximal performance exercise and were not different at any workload for the three training time periods (Table 4). The ratio of maximal lactate to rating of perceived exertion (HLA:RPE) significantly decreased from the NORM (147.6 ± 7.1) to the OVER (119.3 ± 8.7) training time period. The ratio increased following a REC period (131.6 ± 16.5) and was not different from either the NORM or the OVER value.

Plasma cortisol concentration was significantly reduced during the OVER (381.8 ± 52.0 nmol·l<sup>-1</sup>) and REC (337.9 ± 31.2 nmol·l<sup>-1</sup>) training periods when compared to that during the NORM (514.8 ± 56.8 nmol·l<sup>-1</sup>). Six of the eight subjects demonstrated a reduced plasma cortisol concentration during the OVER training period.

**Time Trial Performance**

While the weather conditions for the first three time trials (tt1, tt2, and tt3) were similar to that of the last time trial (tt5), the weather during the fourth time trial (tt4) was quite different (heavy rain and wind), and thus comparison of the time trial times was inappropriate. However, comparison of mean and maximal heart rate during the time trials may give an indication of the abilities of the subjects during these exercise rides. The mean heart rate for tt4 (170 ± 5.2 beats·min<sup>-1</sup>) at the end of the heavy training period was significantly less than the mean heart rate for all other time trials (tt2 = 177.8 ± 4.6, tt3 = 176.6 ± 4.0, tt5 = 176.8 ± 4.0 beats·min<sup>-1</sup>). However, maximal heart rate was not different between the different time trials (tt2 = 187 ± 4.3, tt3 = 185.6 ± 4.2, tt4 = 185.2 ± 4.2, tt5 = 189.6 ± 4.0 beats·min<sup>-1</sup>).
Questionnaire Responses

During the NORM time period the subjects answered a mean of 2.5 ± 0.2 questions positively; however, during the two heavy training periods the number of positively answered questions increased to 4.7 ± 0.7 during OVER1 and 7.3 ± 0.6 during OVER2. During the REC time period the number of positively answered questions decreased to 3.8 ± 0.5. The number of positively answered questions was significantly greater during the OVER2 time period than during all other time periods, while those during the NORM time period were significantly less than during all other time periods.

The questions that were answered the most positively during the heavy training period were: Are you more quickly fatigued? Are your muscles more stiff or painful? Do you have the feeling of not being completely recovered? Is it harder for you to complete the training?

DISCUSSION

The main purpose of the present study was to determine if carbohydrate consumption by subjects undergoing a period of increased exercise training would reduce the occurrence of overtraining. The subjects in the present study consumed 160 g of carbohydrate in a liquid form immediately after their exercise training in addition to their normal caloric intake during a period of normal training, heavier than usual training, and recovery training. Following the period of heavier than usual training (OVER) the subjects had resting muscle glycogen levels comparable to that following the NORM period; however, all subjects indicated signs of overtraining.

Since no one indicator has been shown to correctly predict overtraining, in the present study five indicators of overtraining were used to classify the athletes, with a subject having to have three of the criteria to be classified as overtrained. As has been suggested by the literature (5,12,19,20,22,23) both physiological (W\text{max}, heart rate, plasma cortisol, HLa:RPE) and psychological (positive response to questionnaire) indicators were used in the criteria for an athlete being overtrained. Using these criteria all eight subjects of the present investigation were classified as overtrained, even though all had muscle glycogen levels that were not different from their levels during the NORM period.

In the present study the lower exercising heart rate would seem to be associated with the reduced oxygen uptake. At the high workloads (350 W, max) oxygen uptake was reduced during the OVER time period when compared to that of the NORM, however, at the low workloads (100, 150, 200, 250, 300 W) oxygen uptake was not affected by the performance of heavier than usual exercise training. More than likely, at the low workloads stroke volume was able to compensate for the lower heart rate and maintain oxygen uptake; however, at the high workloads stroke volume were not sufficient to maintain oxygen uptake. Kinderman (18) has previously reported a lower maximal oxygen uptake observed in overtrained athletes. Foster et al. (9) have also observed reduced maximal oxygen uptake values in athletes that were heavily trained, however, the statistical significance of the decrease was not determined. On the other hand, Costill et al. (5) and Verma et al. (28) observed no change in maximal oxygen uptake in athletes who had undergone a period of heavy exercise training. The ability of stroke volume to maintain oxygen uptake when heart rate is reduced by overtraining was not tested in the present investigation, but deserves further investigation. At the high workloads blood lactate levels were not different between the three training periods, but at workloads which elicited less than 4mM lactate, lactate values were reduced during the OVER and REC training time periods than during the NORM. Others (5,9,10,17,18,21) have observed lower submaximal and maximal lactate levels following periods of heavy training. While low muscle glycogen levels have been associated with reduced submaximal and maximal lactate levels (4,10), it is not the case in the present investigation. As the submaximal workload lactate values following a period of REC were still lower than that during the NORM period an improvement in lactate clearance and/or enhanced oxidative capacity of the muscles and therefore less lactate production can not be ruled out as causes of the reduced lactate values. However, as all of the subjects had been training for future competitions at the beginning of the study such adaptations would seem to be minimal. Another possible mechanism for the reduced submaximal lactate values would be decreased muscle glycogenolysis owing to the decreased sympathetic drive (21). However, post exercise muscle biopsies were not taken in the present study and therefore this hypothesis was not tested.
OVERTRAINING WITH NORMAL MUSCLE GLYCOGEN LEVELS

Plasma cortisol levels have been reported to decrease (29), not change (6,13,21,27) or increase (19) with heavier than usual training. Following a period of long lasting, intense exercise, Viru (29) observed lower plasma cortisol concentrations for several days when compared to those observed prior to the increased exercise training. Thus, lower plasma cortisol was expected during the OVER period of this study.

In agreement with that previously reported by Morgan and his colleagues (22,23), the psychological well being of the subjects in the present study decreased during the period of heavy training (OVER) as indicated by the increase in positive responses to the daily questionnaire. The questions with the largest increases in positive responses dealt with perceived fatigue and lack of recovery from the previous exercise bout. While the subjects recovered somewhat during the REC period, the REC period would appear to be too short to allow for full recovery. Morgan et al. (23) have previously reported that during the time period of a competitive season taper, mood disturbance is reduced to the beginning of the season level in collegiate swimmers. While the length of time of the taper was not given, most taper periods last from 10 to 21 d (14), while the recovery period in the present study was only 6 d long. Thus, even though the number of positive responses decreased during the REC period after 6 d, the number of responses was still significantly greater than that during NORM. Therefore, it would appear that somewhere between 6 and 10–21 d is required for most people to recover from the psychologically effects of overtraining.

The rating of perceived exertion (RPE), an indicator of psychophysical functioning (3), was not different for similar workloads across the three training time periods of the present investigation. As RPEs failed to detect overtraining in previous work (17) they are probably only appropriate for examining exertion during an activity and are not a sensitive enough measure by themselves to detect overtraining in an athlete. Previously we have shown the ratio of blood lactate to rating of perceived exertion (HLA:RPE) to be an indicator of overtraining (26), and that finding was corroborated by the results of the present investigation.

The resting values of the subjects (i.e., body weight, percent body fat, lean body weight, lactate, heart rate, and hours of sleep) were not different in the present study across the three training periods. Others have reported a decrease in body weight (18) or no change (6,21,28) in body weight, a decrease in resting lactate (19) or no change (21) in resting lactate, and an increase (6,28) or no change (19,21) in resting heart rate in athletes performing a period of heavier than usual exercise training. Probably the shortness of the heavier than usual exercise training period in the present study (15 d) lead to the nonsignificant difference in the resting values.

The single group design used in this study could present a problem when interpreting the results, as only one group of subjects was used and all subjects performed the control and treatment (i.e., overtraining) periods in the same order. A better research design would have been to have both control and treatment groups, but as suggested earlier, since we had used this protocol before and overtrained those subjects we felt that the use of a control group with the sole intent of them to become overtrained was inappropriate. We did have the subjects of this study perform a control period prior to the overtraining period, however the single group design we used necessarily limits the scope of the results obtained.

The purpose of the present study was to determine whether subjects with normal glycogen levels could increase their training intensity and still become overtrained. Eight cyclists overtrained for 15 days but maintained resting muscle glycogen levels by consuming 160 g of liquid carbohydrate within 2 h of their exercise bout (while also consuming a normal dietary intake of carbohydrates). Even though the subjects resting muscle glycogen levels were normal following the OVER period, the subjects showed other signs of overtraining, i.e., reduced maximal power, reduced maximal heart rate, reduced plasma cortisol levels, reduced ratio of HLA:RPE, and/or increased affirmative responses to a daily questionnaire. Thus, the occurrence of overtraining appears to occur even when resting muscle glycogen levels are normal, and other mechanisms of cause besides muscle glycogen levels should be investigated.

REFERENCES