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Altered Hormonal Response to Short-term Bicycle Exercise in Young Men After Prolonged Physical Strain, Caloric Deficit, and Sleep Deprivation

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Summary. The hormonal response to a standardized bicycle exercise test was studied in 11 male cadets exposed to a course of 107 h of continuous activity with less than 2 h sleep. The subjects expended about 8,600–11,000 kcal/24 h whereas their daily food intake contained only about 1,500 kcal. The exercise test was performed once 12 days before the course (control experiment) and on day 3 and day 5 during the course, always between 0700–0900 h.

A two to six fold increase was seen in the resting levels of noradrenaline, adrenaline, dopamine, and growth hormone during the course whereas a decrease was observed for thyroxine, triiodothyronine, and prolactin. Cortisol increased on day 3 and then decreased to precourse levels on day 5.

The response to the exercise test during the course for all catecholamines was a further increase aboye and proportional to the raisted resting levels. Growth hormone increased by about 6–8 μg/l both before and during the course. During the exercise test, cortisol decreased before the course whereas it increased during the course. All plasma levels of cortisol were higher on day 3 than on day 5 and in the control experiment.

The post-exercise insulin increase was reduced during the course corresponding to a reduction in blood glucose levels. Prolactin decreased during and after exercise in the control experiment, whereas on day 5 the opposite response was seen. No changes in the disappearance rate of different hormones were observed during the course.

The present investigation has demonstrated that prolonged strain severely affects the resting plasma levels of different hormones as well as the endocrine response to a short-term physical exercise.

Key words: Hormones – Physical exercise – Sleep deprivation – Caloric deficit – Stress

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The endocrine response to short-term physical exercise has been widely investigated in rested subjects. Several investigators have shown gradual increases in noradrenaline and adrenaline during physical exercise (Vendsalu 1960; Christensen et al. 1979; Galbo et al. 1977). Above a certain work load, corticosteroids and growth hormone also tend to increase (Galbo et al. 1978). Cortisol is also increased by glucose deprivation (Brodows et al. 1973). Prolactin has been shown to increase during exercise (Sowers et al. 1978) and different forms of stress, such as sauna baths and surgery (Noel et al. 1976; Adlerkreutz et al. 1976; Cooper et al. 1962).

Each year the cadets of the Norwegian Military Academy participate in a 5-day ranger training course duration with heavy physical activities, sleep deprivation, and shortage of food. Previously, it has been shown that the strain of this course severely affects endocrine functions, with reduced serum levels of testosterone, triiodothyronine (T_3), thyroxine (T_4), and prolactin, and increased levels of cortisol and growth hormone (hGH) (Aakvaag et al. 1978 a, b).

In this paper the hormonal responses to a standardized exercise test performed before and on day 3 and day 5 of the course are considered.

Material and Methods

Subjects

Eleven cadets of the Norwegian Military Academy participating in a ranger training course as a part of their military training program, were the subjects of this investigation. The cadets had a mean age of 23.7 years (range 22–27). They had studied at the Academy for about 1 year and were in excellent mental and physical condition.

The Training Course

The course lasted from Monday, June 13, 1977 (day 1) at 0800 h until the following Friday afternoon at 1700 h (day 5) and took place in a mountainous forest area in the eastern part of Norway. The weather was fairly good during the course, warm during the days (25° C), and rather cool (5° C) at night.

The continuous simulated combat activities allowed the subjects to get only short periods of sleep, estimated to total about 1–2 h during the course. This fits well with conclusions drawn from continuous heart rate studies during previous courses (Waldum and Huser 1974; Aakvaag et al. 1978a). Continuous heart rate studies during two previous courses had also shown varying intensities of energy consumption from 8,600 kcal/24 h (Waldum and Huser 1979) to 10,940 kcal/24 h (Aakvaag et al. 1978a).

Diet

The daily food-intake for each cadet consisted of about 95 g of proteins, 65 g of fat, and 125 g of carbohydrate representing about 1,500 kcal.

Exercise Test

Before the course the maximal oxygen uptake ($\dot{V}O_2$) was estimated for each cadet by measuring heart rate during three different submaximal workloads. The cadets were then tested by ergometer bicycle exercise for 30 min at approximately 50% of maximal $\dot{V}O_2$ (workload between 600–1,150 kpm). The test was performed between 0700 and 0900 h, once 12 days before the course and again during the course on days 3 and 5. Precourse results were obtained in a laboratory at a room temperature of 21° C. During the course, on day 3, the subjects were tested outdoors in the training area at about 500 m altitude. The weather was sunny and warm (25° C). On day 5 the tests were performed indoors in a military camp with a room temperature of about 21° C. The workload had to be reduced for two of the cadets from 1,150 and 1,100 kpm before the course to 900 kpm on day 3 and for one of the cadets further to 750 kpm on day 5. Twenty minutes before the exercise a plastic catheter was inserted into the anticubital vein and blood samples for determination of hormones and metabolites were withdrawn just before the bicycle exercise, after 15 and 30 min of exercise and 5, 10, 20, and 40 min after completing the exercise with the subjects resting recumbent on the ground in sleeping bags.

Chemical Analysis

Heparinized blood for determination of catecholamines, thyroid stimulating hormone (TSH), thyroxine (T_4), triiodothyronine (T_3), insulin, growth hormone (hGH) and prolactin were centrifuged and the plasma was frozen immediately on dry ice and later kept frozen at −20° C until analyzed. Plasma for determination of catecholamines was stored at −80° C until assayed.

The catecholamines, dopamine, adrenaline, and noradrenaline were determined with a radio-enzymatic method based on 3-0-methylation of the amines by catechol-*o*-methyl-transferase and S-adenolsyl-L(methyl-^{3}H)methionine. The methylated amines were extracted with ether and sodium-tetraphenylborate, separated on TLC and lastly metanephrine and nor-metanephrine were oxidized by $NaJO_4$ (da Prada and Zürcher 1976). Radioimmunoassays were used for all other hormone assays, for hGH and insulin as described for Normann and Turter (1968) with the modifications introduced by Sand and Torjesen (1973), and PRL and TSH according to Rutlin et al. (1977) and Torjesen et al. (1973), respectively. T_3 and T_4 were analyzed as described by Haug et al. (1977) and Aakvaag et al. (1978b) and cortisol was assayed as described by Aakvaag et al. (1978a) after heat inactivation.

Statistics

The Wilcoxon signed rank test was used for statistical analysis (Lehmann 1975). Results are given as mean ± SEM. Correlation coefficient were calculated according to the method of least squares (Goldstein 1964).

The response to exercise was expressed as the area between the response curve and a horizontal line through the resting levels. For the catecholamines, plateau levels seemed to be obtained after 20 min of recovery and these values were therefore used as resting levels when the area of the response curve was calculated. For the other hormones the preexercise levels were used.

Results

The results obtained 12 days prior to the course are considered as controls. The resting plasma levels of catecholamines increased significantly ($p < 0.01$) during the course (Fig. 1, Table 1). Noradrenaline increased from 1.3 nmol/l before the course to 5 nmol/l on day 3 and 7.5 nmol/l on day 5. Similar values for adrenaline were 0.4, 0.8, and 0.9 nmol/l and for dopamine 0.2, 0.5, and 0.8 nmol/l.

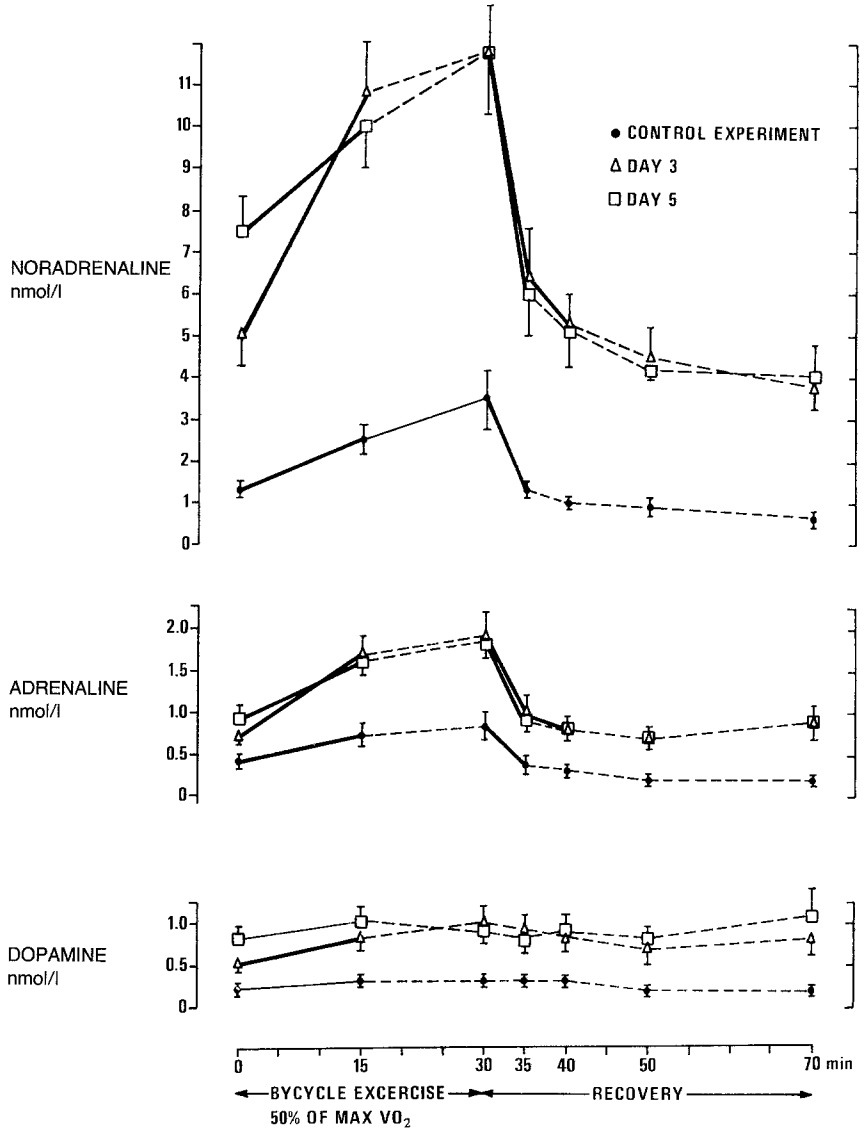

Fig. 1. The response to a standardized bicycle exercise test of 30 min with 50% of maximal $\dot{V}O_2$ for noradrenaline, adrenaline, and dopamine. Blood samples were withdrawn before the exercise while the subjects were sitting on the bicycle, after 15–30 min of exercise and after 5, 10, 20, and 40 min of supine recovery. The exercise test was performed between 0700 and 0900 h, once 12 days before the course (control experiment) and on day 3 and day 5 during the course. Variations significant at $p < 0.01$ are shown with a thick line, $p < 0.05$ with a thin line, and variations not significant with a dotted line. Abbreviations: Control experiment = C Day 3 = D3 and Day 5 = D5. For noradrenaline, adrenaline, and dopamine D3 and D5 > C; $p < 0.01$

Table 1

	Control experiment	Day 3	Day 5
TSH	0.32 ± 0.03 μg/l	0.36 ± 0.03 μg/l	0.36 ± 0.04 μg/l
T_3	2.11 ± 0.07 nmol/l	1.86 ± 0.05 nmol/l	1.80 ± 0.09 nmol/l
T_4	103 ± 4.4 nmol/l	97.6 ± 4.3 nmol/l	90.9 ± 5.1 nmol/l

Resting levels of thyroid stimulating hormone (TSH), triiodothyroninc (T_3), and thyroxine (T_4) before and during prolonged strain. The values are expressed as mean ± SEM. TSH: Precourse < Day; 3; $p < 0.02$, T_3 and T_4 precourse > day 3 > day 5; $p < 0.01$

Table 2

	Control experiment	Day 3	Day 5
Dopamine	2.3 ± 0.9	8.2 ± 3.0[a]	6.1 ± 2.7[a]
Adrenaline	15.0 ± 3.7	26.3 ± 5.4[a]	25.2 ± 3.8[a]
Noradrenaline	56 ± 11	151 ± 38[a]	178 ± 20[a]
Growth hormone	110 ± 30	167 ± 27[a]	144 ± 30[a]
Prolactin	− 30 ± 16	23 ± 40	26 ± 15[a]
Cortisol	−548 ± 500	3,840 ± 936[a]	2,828 ± 516[a]
Insulin	33 ± 15	10 ± 5[a]	19 ± 6

Hormonal response to a standardized exercise before and after prolonged strain expressed as the area between the response curve and a horizontal line through the resting levels
[a] Different from control experiment $p < 0.01$

Resting plasma levels of hGH increased ($p < 0.01$) from 2.1 μg/l before the course to 7.8 μg/l on day 3 and 6.1 μg/l on day 5 (Fig. 2), whereas prolactin decreased ($p < 0.01$) from 8.5 μg/l before the course to 5 μg/l on day 5 (Fig. 2). Cortisol showed an ($p < 0.01$) increase from 552 nmol/l before the course to 671 nmol/l on day 3, and a decrease ($p < 0.01$) to 465 nmol/l on day 5 (Fig. 2).

The resting plasma levels of insulin did not change significantly during the course (Fig. 2).

Plasma levels of TSH showed only a very small ($p < 0.05$) increase during the course whereas a decrease was found for T_3 and T_4 (Table 1). ($p < 0.01$).

For noradrenaline about a three-fold increase was seen as a response to exercise before as well as during the course (Fig. 1). In the control experiment performed 12 days before the course noradrenaline increased from 1.3−3.5 nmol/l and a plateau level of about 1 nmol/l was obtained during the recovery period. On day 3 of the course noradrenaline increased from 5−11.8 nmol/l, and on day 5 from 7.5−11.8 nmol/l. Stable levels of about 4 nmol/l were obtained during the recovery period. For noradrenaline the area of the response curve increased by about three- to four-fold during the course (Table 1). Adrenaline showed two- to three-fold increase during the exercise test before and during the

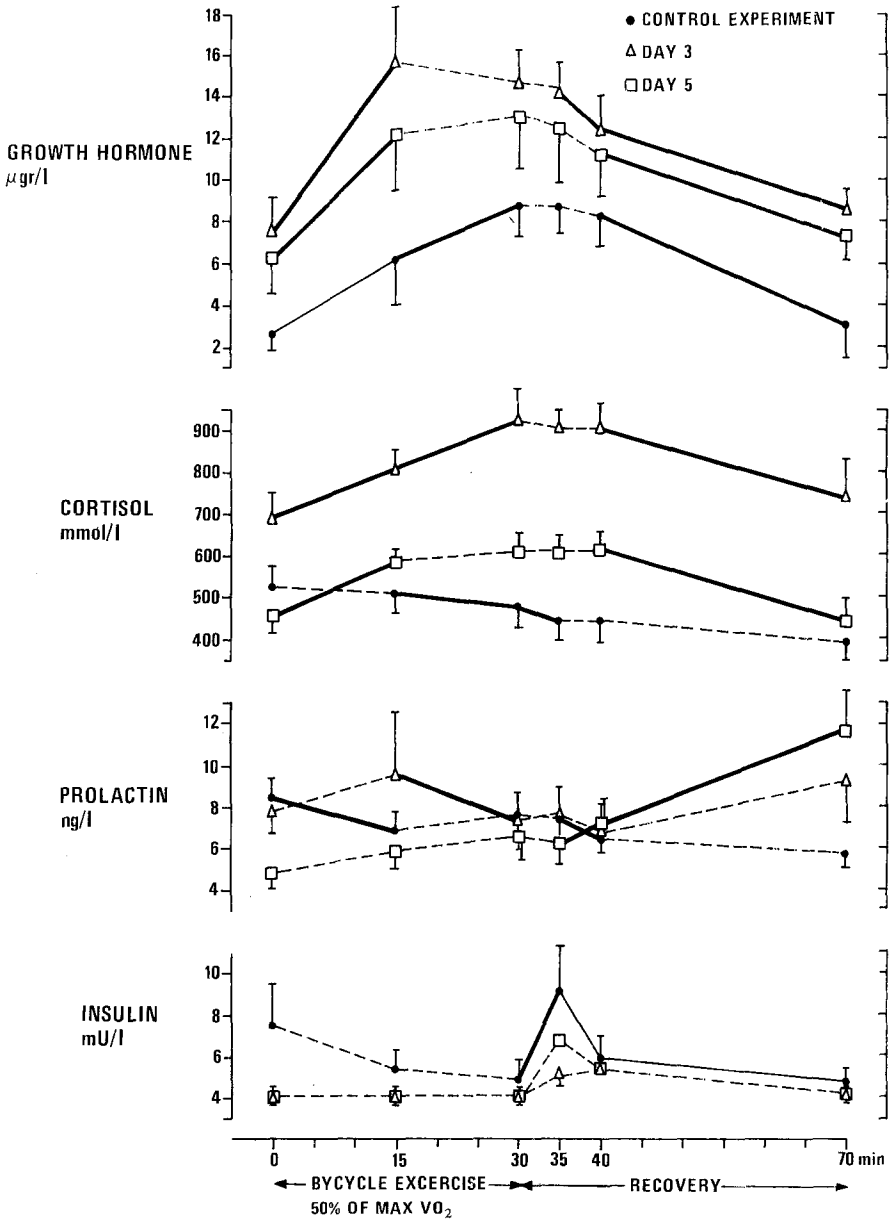

Fig. 2. Changes in growth hormone, cortisol, prolactine, and insulin to a standardized bicycle exercise before and after prolonged strain. For technical details see Fig. 1. Growth hormone: D3 and D5 > C; $p < 0.02$. Cortisol: D3 > D5 and C; $p < 0.01$; D5 > C at 30, 35, 40, and 70 min; $p < 0.04$. Prolactin: 70 min: C < D3 and D5; $p < 0.01$; 0 min: C > D5 $p < 0.02$. Insulin: 35 min C > D3

course (Fig. 1). In the control experiment adrenaline increased from 0.4 to 0.8 nmol/l, on day 3 from 0.7 to 1.9 nmol/l, and on day 5 from 0.9 to 1.8 nmol/l, whereas during the recovery period the level was stabilized at 0.3 before the course, and 0.8 nmol/l during the course. The area of the adrenaline response curve increased by about two-fold during the course (Table 1).

Dopamine showed only a small increase ($p < 0.03$) during exercise, from 0.2 to 0.3 nmol/l in the control experiment, from 0.5 to 1.0 nmol/l on day 3, and from 0.8 to 1.0 nmol/l on day 5. The area of the response curve also increased ($p < 0.01$) during the course (Table 1).

For dopamine no decrement was found during recovery periods, whereas for noradrenaline and adrenaline pre-exercise levels were attained within 5 min of rest both before and during the course. For noradrenaline a further significant ($p < 0.05$) fall was observed from 5 to 40 min of recovery. Except for the pre-exercise levels for noradrenaline and dopamine no significant difference was found between the day 3 and day 5 results for any of the catecholamines neither during exercise nor during recovery. This difference between the pre-exercise resting levels and the post-exercise recovery levels might be explained by different activities in the hours prior to the test, which then do not influence the levels during exercise or recovery. It might also be explained by differences in the sympathetic response to changes from supine to the sitting position, because the pre-exercise levels were obtained with the subjects sitting on the bicycles whereas the levels during the recovery period were obtained with the subjects in a recumbent position.

During exercise hGH increased by 6 to 8 μg/l before and during the course. In the control experiment hGH increased from 2.1 to 8.7 μg/l, on day 3 from 7.8 to 15.8 μg/l, and on day 5 from 5.0 to 13.1 μg/l (Fig. 2). However, a significant increase was seen during the course in hGH expressed as the area of the response curve (Table 1). A small decrease was seen after 10 min of recovery during the course, whereas preexercise levels were attained only after about 40 min. No significant difference was found between the day 3 and day 5 levels.

Prolactin decreased during and after exercise in the control experiment whereas an increase was seen during the course (Fig. 2). After 40 min of recovery a highly significant ($p < 0.002$) difference was found between the precourse results (5.7 μg/l) and the day 5 results (11.7 μg/l). Day 3 results took an intermediate position.

The plasma levels of cortisol decreased ($p < 0.01$) from 522 to 474 nmol/l during the ergometer test before the course and further to 391 nmol/l after 40 min of recovery (Fig. 2). On day 3 cortisol increased ($p < 0.01$) from 691 to 923 nmol/l, and on day 5 from 466 to 610 nmol/l. No significant decrease was found after 10 min of rest during the course whereas pre-exercise levels were attained after about 40 min of recovery. On day 3 all levels were significantly higher than the precourse and day 5 level. The area of the response curve increased significantly ($p < 0.01$) during the course (Table 1).

The plasma levels of insulin did not change significantly during the exercise test before or during the course. However, in the control experiment a significant increase from 4.9−9.7 mU/l was found after 5 min of recovery. On day 5, the post-exercise levels increased from 4.2−7.7 mU/l and on day 3 no

significant increase was seen. The area of the post-exercise insulin response curve was significantly ($p < 0.01$) reduced on day 3. The day 5 results were intermediate.

Correlation coefficient for the group means were significant ($p < 0.01$) for NA/A ($p < 0.09$) and hGH/A ($r = 0.7$). For hGH/cortisol a significant correlation ($r = 0.9$) was found only on day 3 and day 5 during the course.

Discussion

Physical strain, food deficit, and sleep deprivation were probably the major stress factors during the investigation. In addition, there were probably some influence from psychological stress and changes in environmental factors similar to previous courses (Waldum et al. 1974; Holmboe et al. 1975; Aakvaag et al. 1978a; Opstad and Aakvaag 1980; Lindemann et al. 1978; Opstad et al. 1980; Opstad et al. 1978; Bugge et al. 1979; Rognum et al. 1980). Although the courses have the same program from one year to another, the work load has been shown to change slightly mainly due to changes concerning the commanding officer and his staff.

The increased resting levels of noradrenaline, adrenaline, dopamine, and hGH were highly significant both in the pre-exercise levels and in the levels measured after 40 min of recumbency. The decreased levels of prolactin, T_3 and T_4, are in agreement with results obtained during previous courses (Aakvaag et al. 1978b). Cortisol was increased only on day 3 and then decreased toward the end of the course to precourse level.

During a previous course a decrease was seen for TSH whereas a very small increase was seen during the present course. This course, which was less stressing than previously (Aakvaag et al. 1978), showed less pronounced reduction in T_3 and T_4. This supports our previous assumption that an inhibiting mechanism is acting on the thyroid gland as well as on the hypophysis and/or hypothalamus. If the inhibiting mechanism only influenced the thyroid gland, an increase would have been expected in TSH. On the other hand, if the inhibiting mechanism only acted through the hypothalamus and/or the hypophysis, a fall would have been expected in TSH in both experiments. Catecholamines are thought to stimulate the secretion of T_3 and T_4 (Melander et al. 1972, 1974, 1975), but the strongly increased catecholamine levels during the course sould have given the opposite effect.

The noradrenaline increase during the ergometer test in the control experiments is in agreement with the results obtained by other investigators (von Euler 1974; Christensen et al. 1979). However, during the course, the noradrenaline response to the same work load increased by about three times when expressed in absolute values (nmol/l) whereas the percentage increase was unaltered. Similar results were obtaines for adrenaline. As the ergometer bicycle test was the same, the increased response of catecholamines must therefore be caused by the strain of the course. No difference was found between day 3 and

day 5 levels in spite of the intervening 48 h of exhausting activities. hGH increases during exercise if the work load is more than 40–50% of $\dot{V}O_2$ max and has a duration of more than 10 min (Sutton et al. 1969), and the increase is greater in untrained individuals. In the control experiments one of the individuals did not show any increase during exercise and some only after 30 min whereas during the course all had increased after 15 min. Normally, cortisol increases during exercise if the intensity of the exercise exceeds 60% of maximal $\dot{V}O_2$ after more than 1 h (Sundsfjord et al. 1975; Bloom et al. 1976; Davies et al. 1973). This was confirmed in our control experiment. However, on day 3 and day 5, in spite of only 30 min of exercise with 50% of $\dot{V}O_2$ max, an increase was found for cortisol. The increase in insulin secretion noticed 5 min after exercise in the control experiment, and not seen on day 3, fits well with the plasma glucose levels which were lowest on day 3 (Rognum et al. 1979). Insulin is also known to be suppressed by catecholamines (α-adrenergic agonists) which were strongly increased during the course (Gilman et al. 1975; Galbo et al. 1977).

During these training courses, glycogen stores are probably depleted during the first day of activity (Hultmann 1978; Howald et al. 1978; Newsholm 1978), and apart from the moderate amounts of carbohydrate in their food (about 600–800 kcal/24 h), glucose must be provided by gluconeogenesis. The increased levels of cortisol on day 3 together with the increase during exercise support this assumption. The fall in cortisol resting levels and the response to exercise on day 5 might indicate that gluconeogenesis has less importance toward the end of the course and that carbohydrates have largely been replaced by fat as the energy source. hGH and cortisol are most increased during the first 2 days of activity (Aakvaag et al. 1978a, b). hGH has a glucose sparing effect, increasing fat combustion, and has the ability to turn energy production from carbohydrate to fat. hGH may therefore contribute to this metabolic adaption. Fatty acid and ketone body uptake in the muscle cell are proportional to the plasma concentration and muscular blood flow (Hagenfeldt et al. 1971). The strongly increased plasma levels of FFA and BUT during the course were lower on day 5 than on day 3 (Rognum et al. 1980). This might be explained by the fall in thyroid hormones during the course and consequently a reduced need for fuels for thermogenesis (Steinberg et al. 1964). In dogs the thyroid hormones have been shown to potentiate the lipolytic and glycolytic effect of catecholamines (Brzinska et al. 1977). However, there seem to be large species differences, and conflicting results have been demonstrated in man (Svedmyr 1966b; Rosenquist 1972; Fain and Rosenthal 1971; Caldwell and Fain 1971). Rosenquist has shown that α-receptor stimulation inhibits lipolysis by inhibiting adenylate cyclase in the fat cells, and that α-receptors has increased sensitivity for noradrenaline in hypothyroid subjects. Prolactin has been shown to increase during different types of stress, such as physical exercise (Sowers et al. 1978), heat (Adlerkreutz et al. 1976), and surgery (Cooper et al. 1962; Noel et al. 1972). In contrast to Sowers et al. (1977), we found a decrease in PRL during and after exercise in the control experiment. Our subjects had higher pre-exercise levels possibly due to apprehension. Similar levels were obtained by Sowers et al. after 15 min of exercise. However, in both studies prolactin decreased to similar levels after

about 40 min of recovery. The high levels obtained on day 5 after 40 min of rest might be explained by anxiety regarding the activities to come.

A negative correlation was found between the serum levels of hGH and prolactin during a previous course (Aakvvag et al. 1978b). This was thought to reflect a common regulation pathway possibly via dopamine directly or indirectly since dopamine has been shown to influence and to have receptors on growth hormone and prolactin producing cells. The increased dopamine levels observed during the course support this hypothesis. No correlation was found, however, between hGH or prolactin and dopamine during the course. It is uncertain if hypothalamic dopamine secretion might give any measurable contribution to the plasma levels of dopamine or if the plasma levels of dopamine are able to influence the secretion of these hormones.

During the recovery period the disappearance rate of noradrenaline, adrenaline, hGH did not seem to be changed to any great extent by prolonged strain. This fits well with studies on liver function which is not affected during the course (unpubl. results).

Further investigation is needed to clarify the importance of the different stress factors, mainly the lack of sleep and food as well as possible underlying mechanisms.

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