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Steroid and pituitary hormone responses to rowing: relative significance of exercise intensity and duration and performance level

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Summary. To analyse the relative significance of exercise intensity and duration as well as of performance capacity, hormone changes were recorded in 16 male rowers in two experiments separated by a year. The test exercises consisted of 7-min (at the supramaximal intensity) and 40-min rowing (at the level of the anaerobic threshold) on a rowing apparatus. In addition, somatotropin and cortisol responses were estimated in rowing for 8×2000 m in 14 rowers of national class. All three tests caused significant increases in somatotropin and cortisol concentrations in the blood. Follitropin concentrations were elevated in the 7-min exercise test in the second experiment and in the 40-min exercise test in both experiments. Lutropin and progesterone concentrations increased during the more prolonged exercise in the first experiment. No common change was found in testosterone concentrations. Cortisol and somatotropin responses to the 40-min rowing test at anaerobic threshold were more pronounced than to the 7-min exercise test at supramaximal intensity. When the rowers achieved a national class level of performance (the second experiment) the hormone responses to 7-min supramaximal exercise were increased. During the 8×2000-m rowing test cortisol but not somatotropin concentration increased to an extremely high level in the rowers of national class. It is concluded that in strenuous exercise cortisol and somatotropin responses were triggered by the exercise intensity threshold. The exact magnitude of the response would seem to have depended on additional stimuli caused by exercise duration and on possibility of mobilizing hormone reserves.

Key words: Cortisol – Exercise – Follitropin – Glucose – Lactate – Lutropin – Performance capacity – Progesterone – Rowing – Somatotropin – Testosterone

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Introduction

Endocrine responses to exercise have been shown to be determined by exercise intensity and duration as well as by the level of fitness of the person (Galbo 1983; Viru 1992). In sports activities the influences of these factors are usually combined and overlap. In track competitions and other cyclic events (rowing, swimming, cycling, skiing, etc.) the highest possible intensity of muscle activity has to be maintained to the finish. At the same time the duration of the exercise determines the intensity level that can be maintained. The increase in performance capacity in training allows, first of all the possibility of maintaining a higher exercise intensity to the finish. Thus, a special approach is necessary to differentiate between these factors and to evaluate the role of an increased functional capacity of endocrine systems in training. In an attempt to study this problem, steroid and pituitary hormone responses were recorded in athletes during three periods of strenuous exercise:

1. Exercise of a certain duration (7 min) performed at the supramaximal intensity
2. Prolonged exercise of a given intensity (corresponding to the anaerobic threshold)
3. Repetition of exercise performed at an intensity close to the highest possible rate.

In addition to studying the responses of various individual hormones, the adaptation to exercise was evaluated by the concentration ratios of hormones. These included the testosterone:cortisol concentration ratio (Adlercreutz et al. 1986; Häkkinen 1989; Urhausen and Kindermann 1992) for the assessment of anabolic/catabolic interrelations, the somatotropin:cortisol concentration ratio for specific metabolic interrelations and the progesterone:cortisol concentration ratio. In men progesterone is produced as a precursor of adrenocortical and testicular steroid hormones. Therefore, the ratio of progesterone:cortisol concentrations may be used as an indirect means of understanding the interrelations between the secretion of cortisol and the activity of the first stages of the biosynthetic process of the hormone.

Methods

Subjects. The subjects were 16 male rowers (aged 18–20, mean 19.6 years) selected by experienced coaches and according to medical examination as promising young sportsmen. The results of the medical examination showed they were all in a good state of health. Their height varied from 187 to 198 cm (mean 192 cm) and body mass from 81 to 100 kg (mean 90 kg). A 7-min test on the rowing apparatus, modelling the competition exercise, showed that the mean power output in the first experiment was 382 (SEM 7) W and after 1 year when these sportsmen had achieved the performance capacity required at national level it was 425 (SEM 16) W.

A group of 14 male rowers at national level (aged 20–23, mean 20.4 years) were studied when they performed 2000-m rowing sessions eight times. Of these subjects 9 of them also participated in experiments on the rowing apparatus.

Procedure. The rowing exercise tests used in the study were the following:
1. 7-min on the rowing apparatus performed at supra-maximal intensity
2. 40-min on the rowing apparatus at an intensity corresponding to the anaerobic threshold
3. 8 × 2000-m rowing sessions at 75%–85% of the competition velocity (rest intervals between the sessions were 4 min).

The rowing apparatus used (Monakhov and Tkachuk 1977) was supplied with a special device recording (a) work output per rowing cycle, (b) total work output, (c) mean power output, (d) rowing frequency, (e) time of each cycle.

The rowing intensity corresponding to the anaerobic threshold was determined by rowing on the apparatus using a stepwise increasing intensity. The initial power output of rowing was 250 W and this was increased in 25-W steps. Six steps each of 4-min duration were performed, with 5-min rest intervals between the sessions. The level of the anaerobic threshold was estimated from the increase in the blood lactate concentration to 4 $mmol \cdot l^{-1}$ (Mader et al. 1976; Heck et al. 1985).

The tests were performed on separate days. Blood samples were taken from an antecubital vein for hormone analysis and from the fingertips of lactate determination. Blood sampling took place before the activity, 3–4 min and 30 min after exercise.

Rowing for 8 × 2000 m was performed by coxless pairs. Blood samples were taken from fingertips only before the test, after the first two repetitions and after all eight repetitions.

The tests were designed to be performed between 10 a.m. and 12 noon, at least 2 h after the last meal. Due to unexpected changes in the daily routine of the athletes, in 5 cases the tests were performed between 1 p.m. and 3 p.m. The ANOVA showed that hormone concentrations and responses to exercise in these cases did not increase the variation and fitted well with the distribution of other results in the group. Therefore, these cases were not excluded.

Each individual warmed up before the tests. On the day of the study, as well as during the preceding day, no additional exercise, except the usual morning exercises, was performed. The initial blood samples were withdrawn before the warm-up. Immediately after sampling, the blood serum was separated by centrifugation. Samples taken from the fingertips for hormone determination (in rowing for 8 × 2000 m) were centrifuged in capillary tubes. The samples were cooled with the aid of liquid nitrogen and stored at −20° C.

Analytical methods. All analyses were carried out in duplicate; quality control was included in all sets of determinations. The coefficients of variation between duplicate analyses were within

Table 1. Mechanical characteristics of the exercise tests performed

Groups	*n*	7-min rowing at supramaximal intensity								40-min rowing at the anaerobic threshold									
		Mean power output (W)		Rowing frequency per min		Work output per cycle (J)		Total work output (kJ)		Mean power output (S)		Rowing frequency per min		Work output per cycle (J)		Total work output (kJ)		Duration (min)	
		mean	SEM	mean	SEM	mean	SEM	mean	SEM	mean	SEM	mean	SEM	mean	SEM	mean	SEM	mean	SEM
The first experiment	16	382	7	26.6	1.2	859	53	160	3	320	14	25.6	0.5	749	32	767	60	40	0
The second experiment (performance capacity at national level)	16	425	16*	29.2	1.0*	873	32	179	3*	326	8	23.8	0.6	827	20*	729	47	37	3

* Statistically significant difference ($P < 0.05$) between the two experiments

4%–7%. Pre- and postexercise determinations of a particular hormone were made at the same time to avoid inter-assay variations. Hormone concentrations were estimated by radio-immunoassays (Jaffe and Behrman 1979) using the commercial kits of Corning Medical (Medfield, USA) for cortisol, Compagnie Cris Industrie S.A. (Gif-sur-Yvette, France) for testosterone, lutropin and follitropin, Sorin Biomedica (Italy) for somatotropin, and Behringwerke AG (Germany) for progesterone. The within-assay as well as the between-assay variabilities were less than 8%. The accuracy test indicated the recovery of added standards was within the range 95% to 115%. All assays were highly specific.

To investigate the possibility of hormone estimation in very small samples of serum taken from the fingertips, blood samples were taken simultaneously from the antecubital vein and from the fingertips in 36 sportsmen in the resting state or after various tests. There were no systematic differences in cortisol concentrations between the samples of venous and capillary blood. The somatotropin concentration proved to be higher in the venous blood samples if the hormone concentration was less than 6 ng·ml^{-1}. The systematic differences disappeared at higher concentrations. Variations between venous and capillary values of somatotropin concentrations greater than 6 ng·ml^{-1} as well as of cortisol were within 5% to 9%.

Lactate and glucose concentrations were determined in the capillary blood by enzymatic methods. For determining lactate concentration a method proposed by Clausnitzer and Wendelin (1976) was used. Glucose concentration was estimation with the aid of the Beckman semi-automatic analyser.

Statistical analyses. The comparison of mean group values, as well as pre- and postexercise values within a group was performed with the aid of a Student's *t*-test after one-way analysis of variance (ANOVA). Correlation coefficients were computed between individual values.

Results

Exercise performance and metabolites

When the athletes achieved national level as judged by their performance capacity in competitions, their mean power output during the 7-min test on the rowing apparatus was significantly higher than the year before (Table 1). The increase was due mainly to rowing more frequently. The improved performance was associated with a significantly higher concentration of blood lactate (Table 2).

The exercise intensity for 40-min rowing was assessed individually by the lactate concentration increase up to 4 mmol·l^{-1}. During the year the anaerobic threshold intensity improved in only 11 rowers. There was no statistically significant difference between group values in the first and second experiment. Obviously, the improvement of rowing performance, indicated by the performance results and the 7-min rowing test, was founded mainly on an increase in the anaerobic exercise capacity. After the end of the 40-min test the lactate concentration in the first experiment was 4.7 (SEM 0.3) mmol·l^{-1} but in the second experiment significantly higher – 7.0 (SEM 0.6) mmol·l^{-1} (Table 2). In this experiment the work output per rowing cycle was higher (Table 1).

While mild hyperglycaemia followed the 7-min rowing tests, after 40-min of rowing the blood glucose concentration was insignificantly below the initial value (Table 2).

In 8×2000-m exercise the rowing velocity was calculated for each pair to correspond to 75%–85% of the competition velocity. The actual average time for 2000 m rowing varied among pairs from 8 min 20 s to 8 min 45 s. It was 4.4 (SEM 1.6) s better than that envisaged. From the first to the eight set the 2000-m rowing time increased by 17.7 (SEM 4.3) s.

Somatotropin and cortisol

All three exercise tests caused significant increases in somatotropin and cortisol concentrations in blood (Fig. 1). The responses to the 40-min rowing at the anaerobic threshold level were more pronounced than to the 7-min exercise at a supramaximal intensity of rowing ($P<0.05$). When 2000-m rowing was repeated for eight times, the cortisol concentration increased to an extremely high level. However, the somatotropin response to this exercise was less pronounced than to continuous rowing over approximately the same time. A comparison of the results obtained in the two experiments showed that the improved performance capacity was associated with significantly higher somato-

Table 2. Lactate and glucose concentration changes during and after rowing exercise

	7-min test				40-min exercise at the anaerobic threshold			
	First experiment		Second experiment		First experiment		Second experiment	
Lactate concentration (mmol·l^{-1})	mean	SEM	mean	SEM	mean	SEM	mean	SEM
Before exercise	2.2	0.2	2.1	0.2	1.7	0.4	1.8	0.1
Just after	13.4	0.5[a]	15.1	0.5[a,b]	4.7	0.3[a]	7.0	0.6[a,b]
30 min after	5.9	0.3[a]	8.3	1.0[a,b]	2.9	0.3[a]	2.2	0.1[a]
Glucose concentration (mmol·l^{-1})								
Before exercise	6.0	0.4			5.1	0.4		
Just after	8.6	0.7[a]			4.6	0.2		
30 min after	6.2	0.1			4.7	0.4		

[a] Denotes statistically significant difference ($P<0.05$) from the initial values
[b] Denotes statistically significant difference ($P<0.05$) between the values of two experiments

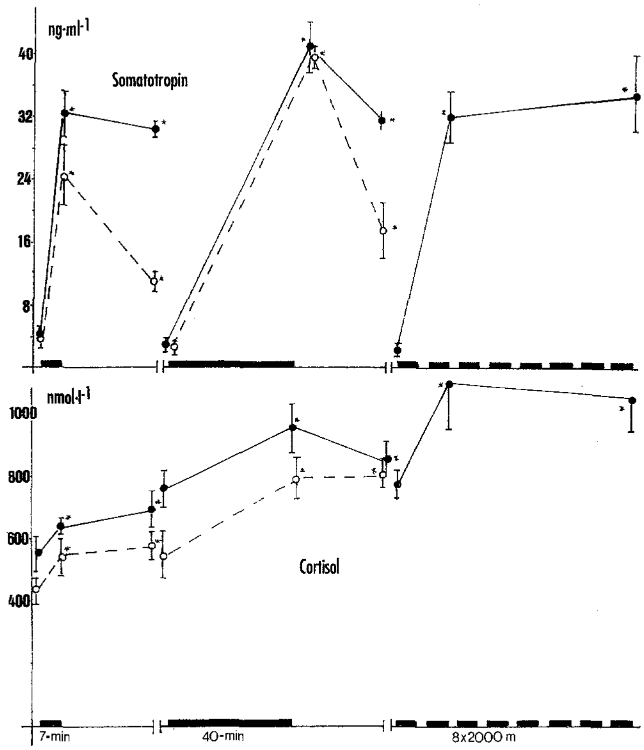

Fig. 1. Somatotropin and cortisol concentrations before, immediately and 30 min after three rowing exercise tests: 7-min exercise on a rowing apparatus, performed at supramaximal intensity, 40-min exercise on a rowing apparatus performed at the intensity of the anaerobic threshold, 8×2000 m rowing at 75%–85% of the competition velocity (4-min rests between exercise periods). Mean and SEM are indicated. *Open circles, interrupted lines*, first experiment; *closed circles, solid lines*, a year later, when the rowers had reached a performance level at national class. *Asterisks* denote significant difference ($P<0.05$) from the initial values of the group

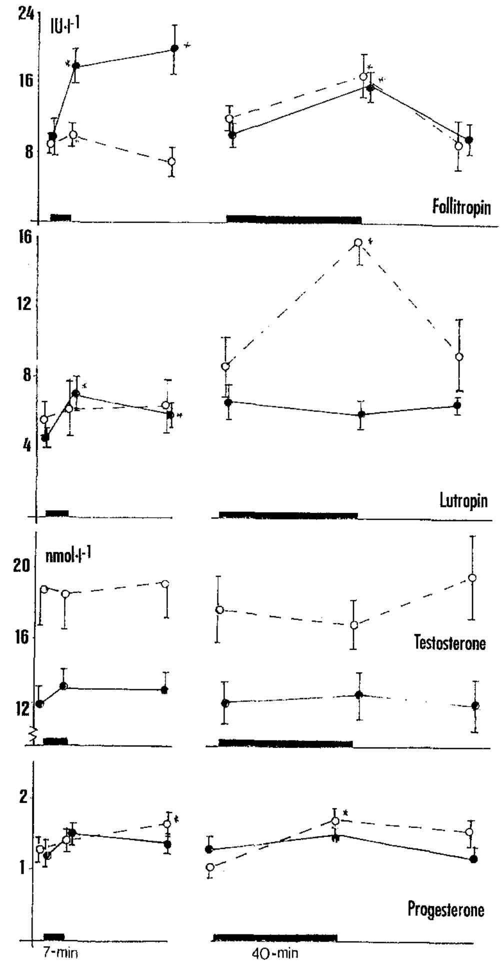

Fig. 2. Follitropin, lutropin, testosterone and progesterone concentrations before, immediately and 30 min after 7-min and 40-min exercise on a rowing apparatus. For further explanations see Fig. 1

tropin and cortisol concentrations after 7-min rowing. After 40-min rowing this difference in the somatotropin concentrations was insignificant. The cortisol concentrations of the rowers at national level were significantly higher ($P<0.05$) than those of the rowers of lower performance capacity, despite the lack of differences in performance during the 40-min test. The increase in performance capacity would seem to have been associated with a significant elevation in the cortisol resting concentration (Fig. 1).

Follitropin, lutropin, testosterone, progesterone

In lutropin and follitropin concentrations significant increases were caused by the 7-min test only in the rowers at the national level (Fig. 2). More prolonged but less intense exercise led to increased follitropin concentrations in both experiments and lutropin concentration in the first experiment. No significant changes were found in testosterone concentrations. In both tests progesterone concentrations were elevated in the rowers of lower performance capacity, but not in the rowers at the national level.

Hormone ratios

All tests caused an increase in the somatotropin:cortisol concentration ratio and decreases in the testosterone:cortisol concentration ratio (Table 3). The 40-min test at the anaerobic threshold resulted in lower concentration ratios of testosterone:cortisol and progesterone:cortisol than the 7-min test. In the rowers of national class the somatotropin:cortisol concentration ratio was higher after the 7-min test but lower after all-out exercise in comparison with the rowers of lower performance capacity.

Individual analysis

Individual data on the power output during the 7-min test distinguished the subjects with higher and lower performance levels. Among the persons with higher performance levels, there was a subgroup which exhibited highly pronounced somatotropin and cortisol responses. The somatotropin:cortisol concentration ratio was high and the progesterone:cortisol concentration ratio low in those subjects. In the rest of the subjects

Table 3. Hormone concentration ratios before and after various exercise tests

Exercise tests and groups	Time of sampling	Somatotropin:cortisol	Testosterone:cortisol	Progesterone:cortisol
		$\frac{ng \cdot ml^{-1}}{mmol \cdot l^{-1}} \times 100$	$mmol \cdot l^{-1} \times 100$	$mmol \cdot l^{-1} \times 100$
7-min Rowing		mean	mean	mean
First experiment	before	4.88	4.40	2.93
	just after	43.57	3.30	2.55
	30 min after	19.31	3.29	2.83
Second experiment	before	4.55	2.24	2.05
	just after	51.75	2.10	2.40
	30 min after	44.34	1.91	1.90
40-min Rowing				
First experiment	before	4.00	3.22	1.98
	just after	50.00	2.11	2.09
	30 min after	20.48	2.41	1.94
Second experiment	before	4.08	1.61	1.71
	just after	40.32	1.34	1.47
	30 min after	37.50	1.49	1.25
8 x 2000 m Rowing				
Rowers at national level	before	2.46	1.62	
	after 2 sets	25.65	1.34	
	after 8 sets	28.23	1.49	

with higher performance capacity, hormone responses were moderate, the somatotropin:cortisol concentration ratio low and the progesterone:cortisol concentration ratio high. Among the subjects with lower exercise capacity two subgroups also became apparent:
1. Subjects with moderate power output in association with high postexercise concentrations of somatotropin but not cortisol, high somatotropin:cortisol and medium progesterone:cortisol concentration ratio
2. Subjects with comparatively low power output in association with moderately pronounced somatotropin and cortisol responses, low somatotropin:cortisol concentration and medium progesterone:cortisol concentration ratios.

Correlation analyses of data from individuals indicated the dependence of the responses of lactate ($r=0.495$), somatotropin ($r=0.613$), cortisol ($r=0.401$), follitropin ($r=0.588$) and progesterone ($r=0.425$) concentrations on power output in the 7-min rowing test. Significant correlation was established between concentrations of glucose and steroid hormones ($r=0.757$ for cortisol, $r=0.710$ for testosterone, $r=0.527$ for progesterone). In the 40-min exercise the dependence of concentrations of lactate ($r=0.709$), somatotropin ($r=0.908$) and progesterone ($r=0.796$) but not of other hormones on power output was found. Glucose concentrations were in negative correlation with power output ($r=-0.791$), somatotropin ($r=-0.854$) and progesterone ($r=-0.791$) concentration responses.

Discussion

To evaluate the relative importance of exercise intensity and duration in hormone responses, the effects of two types of strenuous exercise were compared. The performance of both tests needed the mobilization of functional capacities up to the maximum. One of them (the 7-min test) was based on a high degree of mobilization of the anaerobic glycolysis [lactate concentrations increased up to 13.4 (SEM 0.5) and 15.1 (SEM 0.5) $mmol \cdot l^{-1}$ in respect of the two experiments] and, obviously, also on maximal mobilization of the aerobic capacity. Since the duration of exercise was previously determined, the performance capacity determined the highest possible level of power output and thereby the exercise effects on metabolic and functional levels. In the second exercise tests the intensity was limited by individual levels at a lactate concentration of $4\ mmol \cdot l^{-1}$ which was considered to be the level of the anaerobic threshold (Mader et al. 1976; Heck et al. 1985). In these cases the performance capacity determined the possibility of the subject continuing the exercise for a 40-min period. The results indicated that with exercise duration an additional stimulus for cortisol and somatotropin responses arose, resulting in increases in the concentrations of these hormones to higher levels than those in short-term very intense exercise. In agreement with this, in several studies it has been found that the hormone responses are more pronounced in more prolonged but less intense exercise (Kuoppasalmi et al. 1981; Weicker et al. 1981; Kindermann et al. 1982). Only when there are great differences in exercise intensities does the situation change (Kuoppasalmi et al. 1981; Näveri et al. 1985).

Sympatho-adrenal and pituitary-adrenocortical responses, as well as the responses of some other endocrine systems, are triggered by a certain exercise intensity called the intensity threshold (for review see Viru 1992). For the pituitary-adrenocortical system at least the existence of a duration threshold has also been demonstrated (Viru et al. 1990; Viru 1992). As the intensity threshold would appear to be closely related to the anaerobic threshold (Lehmann et al. 1981; Rahkila et al. 1988; Viru et al. 1990), the exercise performed at the anaerobic threshold would have to reach the level of the intensity threshold. Obviously, an accumulation of various changes constituting the background for the duration threshold would add an additional stimulus, thereby increasing the cortisol and somatotropin responses. Lactate accumulation as well as the accompanying reduction of pH have been suggested to stimulate somatotropin (Sutton et al. 1976; Karagiorgos et al. 1979; Vanhelder et al. 1984, 1987) and pituitary-adrenocortical responses (Few et al. 1980). When plotting somatotropin and cortisol postexercise concentrations against lactate concentration responses in these two exercises, an inverse relationship appeared. This result would indicate that the additional stimulus for hormone responses arose during the 40-min exercise causing overcompensation for this exercise by producing different blood lactate concentrations.

When the 2000-m rowing test was repeated at 75%–85% of the competition velocity, cortisol but not somatotropin concentrations increased to a very high level. The exaggerated cortisol response would agree with the suggestion of the additive effects of intensity and duration. The difference between cortisol and somatotropin responses might be related to peculiarities in the postexercise kinetics of these two hormones, determining the hormone concentration changes (a decrease or a further increase) during the rests between the exercise periods. In previous studies the comparison of the effects of aerobic continuous exercise and of repeated intensive anaerobic exercise periods have shown more pronounced increases of somatotropic concentration during intermittent exercise (Karagiorgos et al. 1979; Vanhelder et al. 1984, 1985). From the results obtained 40-min exercise at the anaerobic threshold exerted a stronger influence than the effect of the repetition of short-term intense exercise. However, one must take into account that the subjects performing these two tests were not always the same.

In the rowers studied the improvement in performance seemed to be based on increased anaerobic capacity, as indicated by the increased lactate concentration response to the 7-min rowing test. In the 40-min rowing test despite the choice of exercise intensity at a blood lactate concentration of $4\,\mathrm{mmol \cdot l^{-1}}$ in incremental exercise, the lactate concentration increased to 7.0 (SEM 0.6) $\mathrm{mmol \cdot l^{-1}}$. Obviously, the increase in anaerobic capacity was associated with a change in the individual's anaerobic threshold and as a result the lactate concentration was not maintained at $4\,\mathrm{mmol \cdot l^{-1}}$.

The increased performance capacity was associated with increases of somatotropin and cortisol concentrations to higher levels in the 7-min test and of cortisol in the 40-min exercise. The magnitude of the cortisol concentration response did not increase. However, in the responses which play a great part in triggering hormone secretion, it is meaningful to consider the postaction level in hormone concentration. The increase of cortisol concentration to a higher level might be related either to a more pronounced lactate concentration response after an improvement in the performance capacity or to the increased functional capacities of the pituitary and adrenal cortex. In any case, the results obtained demonstrated that after a high level of performance capacity (athletes at national level) was achieved, the endocrine glands mentioned were able to respond to exercise of higher power output by more pronounced increases in hormone concentrations in the blood. Thus, training would appear to increase the capacity to secrete hormones resulting from such strong influences as supramaximal exercise (Farrell et al. 1987; Barreca et al. 1988; Kjaer 1989). Evidence has also been published that training-induced adrenal hypertrophy is associated with an augmented potential for hormone biosynthesis (Viru and Seene 1985). The question remains as to whether the more pronounced responses to supramaximal exercises reflect the maximal capacity to secrete hormones or the improved possibility of mobilizing the resources for hormone secretion in sportsmen of high performance capacity. Two of the facts obtained would point to the second possibility. In the 40-min test, already in the first experiment, the magnitude of the somatotropin response was the same as a year later in both supramaximal 7-min and submaximal 40-min exercise. Furthermore, in the second experiment the cortisol concentration response was elevated in both tests, despite the lack of increased performance in the 40-min test. The functional capacity of the pituitary-adrenocortical system was, it would seem, capable of increasing the cortisol level to a very high level in rowers of national class when they repeated rowing for 2000 m.

All exercises induced reduced testosterone:cortisol concentration ratios. These changes probably reflect the general trend in the regulation of anabolic and catabolic processes. However, it is necessary to assess whether these hormone changes have a significance in metabolic control during exercise that lasts for 7 or 40 min. In the 7-min tests the progesterone:cortisol concentration ratio decreased in the first experiment but increased in the second. One could therefore suggest that the more pronounced cortisol concentration response in a state of high performance capacity is associated with a rapid activation of biosynthetic mechanisms, including its first stages. In the 40-min test the situation was different. In the first test no substantial changes were observed, in the second experiment the ratio decreased.

In conclusion, in strenuous exercise cortisol and somatotropin concentration responses were determined by an integration of exercise intensity and duration, as well as of the performance capacity of the subject. Responses were triggered if the exercise intensity was higher than the intensity threshold, an additional stimulus arising from exercise duration. The exact magnitude of the response would seem to depend on the functional capacities of the endocrine systems and in the main on the potential to mobilize hormone secretion in strenuous exercise.

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