Biology of Sport, Vol. 23 N^{o}3, 2006

CHANGES IN TREMOR AND HORMONAL RESPONSES TO HIGH-INTENSITY EXERCISE ON KAYAK ERGOMETER

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Abstract. The aim of this study was to detect possible relationships between cortisol and testosterone concentrations and the exercise-induced changes in tremor. Twelve male kayakers, members of the National Team were subjected to routine physiological tests and tremor measurements. Specific kayak ergometer tests consisted of 3 submaximal bouts of increasing intensity lasting 4 min each followed by a 4-min maximal bout. Plasma levels of testosterone and cortisol were determined in capillary blood samples. Tremor was measured accelerometrically before the test and then 10 and 30 min after the last bout. It was demonstrated that the most significant post-exercise changes in tremor amplitude concerned mainly the 10-20 Hz frequency range. There were no signs of tremor recovery even 30 min after the exertion. A close relationship between cortisol and testosterone concentrations and changes in the high-frequency tremor amplitude was demonstrated. High testosterone concentrations were associated with higher changes in tremor amplitude, while high cortisol concentrations seemed to restrict this increase and to prolong simultaneously tremor recovery.

(Biol.Sport 23:237-253, 2006)

Key words: Human – Tremor – exercise – Testosterone – Cortisol - Kayak

Introduction

Physiological tremor is defined as a more or less regular, rhythmical, involuntary oscillation of the whole body or its part [10,25]. The origin and nature of this phenomenon remain obscure. Several factors attributed to the central and peripheral activities of the nervous system have been pointed as possibly involved in tremor generation [16,25]. The low-frequency forearm tremor (3–7 Hz) reflects

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mainly resonance properties of limbs and muscles [16]. However, some authors consider important role of the stretch reflex activity in this frequency range [11,19,24].

High-frequency tremor, observed as a well-pronounced peak at 8-12 Hz, is mainly considered to be the result of the central drive causing synchronisation of motor units firing [17,21,24,25]. Dengler *et al.* [2], Elek *et al.* [3] and Kakuda *et al.* [12] have suggested paired discharges of freshly recruited motor units as the reason of synchronisation.

It is well known that tremor amplitude can be enhanced in exercise-induced fatigue [1,4,9,30]. Tremor amplitude has been shown to decrease for a short time immediately after a strong, brief exertion [1] and then to increase considerably above the pre-fatigue level. Maximum tremor amplitude was observed 10-15 min post-recovery [8], and may remain elevated even 4 h later [4]. The fatigue-induced changes in tremor were suggested [9] to originate in the central nervous system (CNS). Nevertheless, increases in tremor amplitude appear locally, i.e. only for the limbs engaged in exercise [4,9,24].

The magnitude of tremor changes can be regarded as a measure of the response to fatigue [5,24,27], but this relationship has not been fully clarified. A comparison between variables describing tremor changes, and those known as biochemical correlates of fatigue, would seem the simplest way to clarify that relationship. In an earlier study, tremor changes proved independent from lactate concentrations [6].

Steroid hormones – cortisol and testosterone – are involved in the control of metabolic processes in working muscles. Cortisol mobilises energy substrates and induces protein degradation in muscle cells. Testosterone inhibits the degradation of proteins and enhances their resynthesis in muscles. Physical efforts, especially those of high intensity, were reported to bring about acute responses of cortisol and testosterone [20,28].

The aim of this study was to detect possible relationships between cortisol and testosterone concentrations and the exercise-induced changes in tremor.

Materials and Methods

Twelve male kayakers, members of the Polish National Team, subjected to routine physiological tests and tremor measurements at the Institute of Sport in Warsaw, participated in the study. Their age, body mass (bm) and height ranged from 19 to 29 years, 80.2-105.2 kg, and 1.78-1.91 m, respectively. Specific kayak ergometer tests [15], consisting of 3 submaximal bouts of graded exercise lasting 4 min each, were conducted in the morning, between 9:00 and 12:00. Exercise intensities were equal to 45, 55 and 65% of mean power output determined individually in previous maximal exercises. The subjects controlled paddling intensity by watching mean power of each stroke displayed on-line. Exercise bouts were spaced by one-minute breaks. After completing 3 submaximal bouts followed by 4-min recovery, each subject performed maximal bout lasting 4 min, during which individual maximal mean power (P_{max}) was measured.

Capillary blood samples were taken from earlobes at 7:30 in the morning (M), then directly before exercise (B), after the third submaximal bout (3) and 4 min after the maximal bout (4). Plasma levels of testosterone and cortisol were determined by specific ELISA assay kits (Orion Diagnostica). Lactate accumulation (LA) in 4th minute after the last bout was measured using the Boehringer-Mannheim assay kits. Heart rate (HR) was monitored on-line using Sport Tester (Polar Electro). Oxygen uptake (VO_2) was measured by a gas analyser (Ergo-oxyscreen, Erich Jaeger). The protocol of the routine test was approved by the local Ethics Committee.

Tremor was measured accelerometrically before (B) the test and then 10 and 30 min after the last bout Measurements were made in sitting position using an accelerometer (RFT, Germany) fixed to a cuff placed on subject's wrist. The subject flexed his forearm with a force of 30 N against a spring (stiffness equal to 270 $N \cdot m^{-1}$). The spring was fixed via a rigid chain and a force transducer to the floor. The chain length was individually adjusted – when the subject reached the desired force level, his forearm was aligned horizontally. During each single tremor measurement, an acceleration course lasting 32 s and sampled at 64 Hz frequency, was applied to every subject. The preamplified acceleration signals were band-pass filtered at the frequencies of 1 Hz (lower limit) and 32 Hz (upper limit). Based on the literature [14,29] 1-20 Hz frequency range was selected for further analysis. Power spectrum density (PSD) function was estimated using Fast Fourier Transform procedure for each acceleration course. Log-normal distribution of the tremor power [7,26] and correlation between pre- and post-exercise log-amplitudes [27] were main reasons for using logarithmic transformation. A logarithmic index of the tremor amplitude, λ [8], was utilised as a quantitative measure of high-frequency tremor. The index, calculated for each power spectrum, was defined as the average log-power in the range 10–20 Hz. Increases in λ-values in respect to pre-fatigue values ($\Delta\lambda_{10\text{-}B}=\lambda_{10}-\lambda_B$, $\Delta\lambda_{30\text{-}B}=\lambda_{30}-\lambda_B$ and $\Delta\lambda_{30\text{-}10}=\lambda_{30}-\lambda_{10}$) were used as measures of tremor response to exertion. The design of the experimental protocol is shown in Fig. 1.

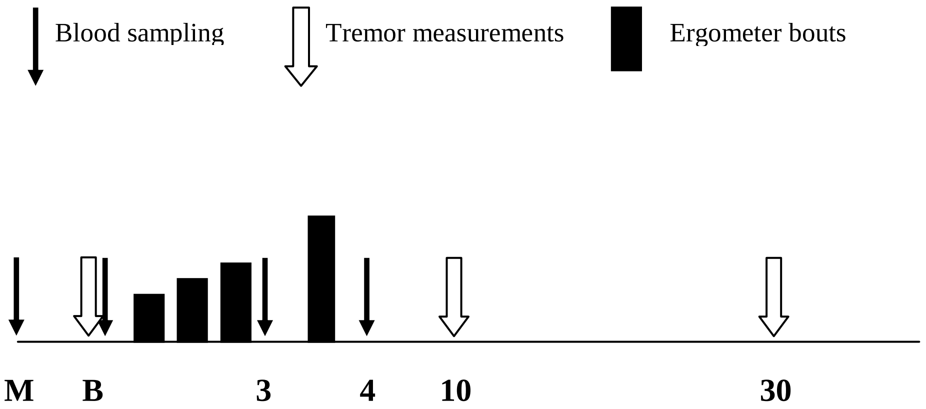


Fig. 1
Design of the experimental protocol; M – morning; B – before ergometer test; 3, 4 – after third, fourth bout; 10, 30 – after 10, 30 min post-exercise

The Shapiro-Wilk's test was used to assess the normality of distributions. Analysis of variance (ANOVA) followed by Newman-Keuls' test were employed to assess differences between means. Pearson's correlation coefficients were computed and then multiple regression procedure (stepwise, backward method) was used to construct models of relationships between variables. The significance level $\alpha=0.05$ was used for statistical analysis.

Results

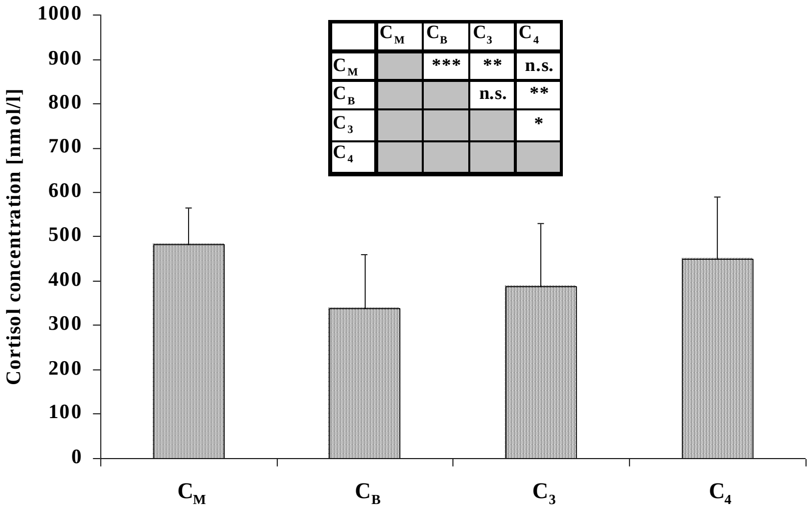
Mean values (±s) and ranges of variables studied, recorded during the maximal, 4-min bout, are presented in Table 1.

Table 1
Mean values (±s) and ranges of variables recorded in the maximal exercise bout

	P_{max} (W)	P_{max}/bm ($W \cdot kg^{-1}$)	HR ($beats \cdot min^{-1}$)	LA ($mmol \cdot l^{-1}$)	VO_{2max}/bm ($ml \cdot kg^{-1} \cdot min^{-1}$)
Mean ±s	305.3±29.9	3.44±0.31	191±6.5	13.33±2.41	56.0±3.87
Range	249–358	2.77–3.91	179–203	9.6–17.6	49.0–63.7

P_{max} - maximal mean power, bm – body mass, HR – heart rate, LA – lactate concentration, VO_{2max} – maximal oxygen uptake

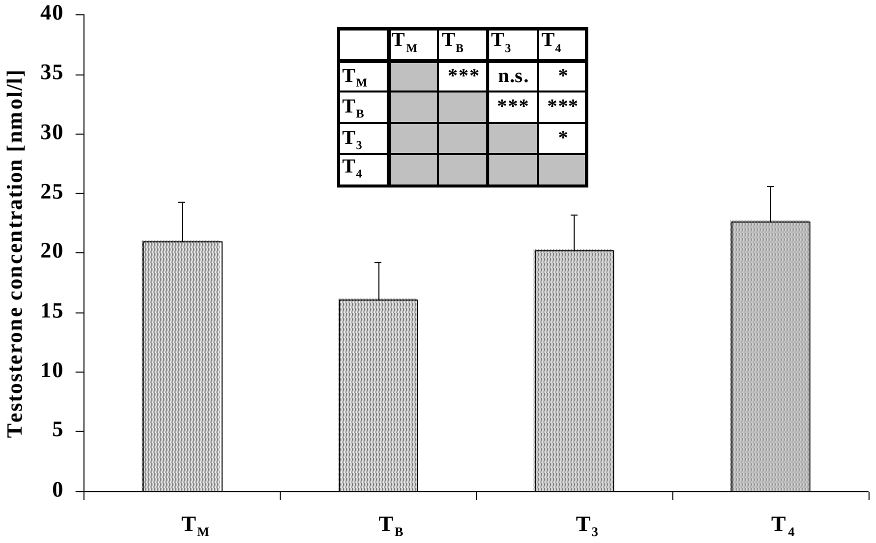
Cortisol concentrations and the results of post-hoc comparisons of means are presented in Fig.2. Subsequent means of cortisol concentration differed significantly from each other ($F_{3,33}$=10.24, $p<0.001$). The average level of cortisol increased post-exertion and returned to its morning value.



	C_M	C_B	C_3	C_4
C_M		***	**	n.s.
C_B			n.s.	**
C_3				*
C_4				

Fig. 2
Mean cortisol concentrations (±s) measured in the morning (C_M), before the test (C_B), after sub-maximal bouts (C_3) and after maximal bout (C_4); significance of differences (Newman-Keuls' post-hoc test): *$p<0.05$, **$p<0.01$, ***$p<0.001$

Mean testosterone concentrations and the results of post-hoc comparisons are shown in Fig. 3. The results of ANOVA for repeated measures revealed that the means differed significantly from each other ($F_{3,33}$=26.2, $p<0.001$). Testosterone concentrations, being lowest before the test, started to grow post-exercise, exceeding its morning level after the last bout. Distributions of cortisol and testosterone concentrations proved normal by Shapiro-Wilk's test ($p>0.20$).



	T_M	T_B	T_3	T_4
T_M		***	n.s.	*
T_B			***	***
T_3				*
T_4				

Fig. 3
Mean (±s) testosterone concentrations measured in the morning (T_M), before the test (T_B), after sub-maximal bouts (T_3) and after maximal bout (T_4). Significances of differences determined by Newman-Keuls' post-hoc test.

Correlation coefficients between the studied variables are shown in Table 2. Of interest are those between the concentrations of cortisol and lactate. Correlations within a set of the variables describing subjects' response to exertion are important for further analysis conducted in order to identify variables underlying the post-exercise changes in tremor.

Table 2
Coefficients of correlation between hormone concentrations and other variables studied (n=12)

	C_M	C_B	C_3	C_4	T_M	T_B	T_3	T_4	P_{max}/bm	VO_2/bm	HR
P_{max}/bm	0.562	0.541	0.688^{*}	0.735^{**}	-0.296	0.077	0.159	0.265			
VO_2/bm	0.423	0.578^{*}	0.651^{*}	0.478	-0.324	-0.060	-0.139	-0.237	0.568		
HR	0.347	0.596^{*}	0.537	0.417	-0.046	-0.193	0.005	-0.019	0.058	0.235	
LA	0.105	0.741^{**}	0.797^{**}	0.749^{**}	0.224	0.178	-0.041	0.181	0.643^{*}	0.412	0.319

Tremor power increased post-exertion along the entire frequency domain. Averaged log-power spectra recorded before the test and 10 and 30 minutes post-exercise are shown in Fig. 4.

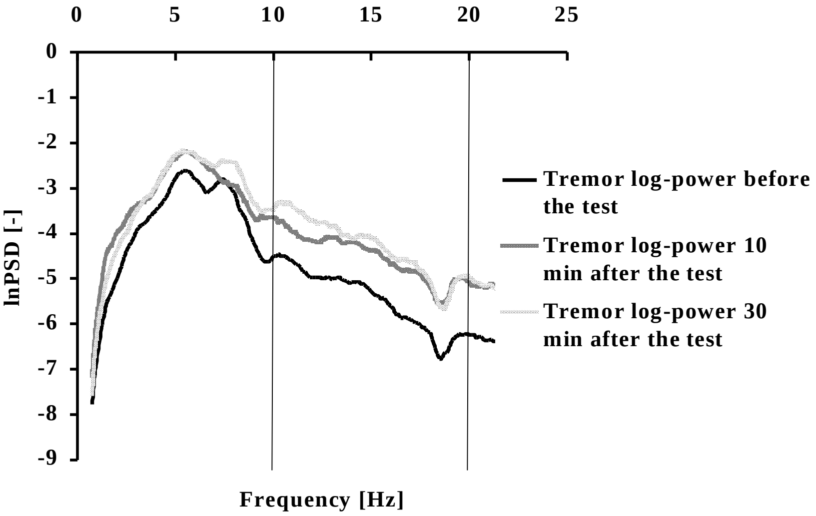


Fig. 4
Tremor log-power spectra averaged for twelve subjects, recorded before, 10 and 30 minutes after the test

Student's t-function was computed along the frequency domain in order to estimate the frequency range, in which changes in power were best pronounced. The t-function was defined as follows:

$$t(f) = \frac{\Delta \ln PSD(f)}{s_{\Delta}(f)} \sqrt{n-1}$$, where:

Δln PSD(f) – Average change in power (comparing to pre-exercise measurement) for frequency f,

S_{Δ} – Standard deviation of power changes for frequency f,

n – Number of subjects.

Values of t(f) greater than 2.23 indicate significant ($p<0.05$) changes in power. The course of t-function for power changes in the 10th minute after exertion, compared to the pre-fatigue level, is shown in Fig. 5. The same is shown in Fig. 6 for the 30th min. Post-exercise changes in amplitudes of high-frequency tremor were highly significant, especially those at 30th min post-exertion. Previous findings [8,27], indicating the range from 10 to 20 Hz as the most sensitive to fatigue, have been confirmed (see Fig. 6). So, $\Delta\lambda_{10\text{-}B}$ and $\Delta\lambda_{30\text{-}B}$ were used as measures of individual tremor responses to fatigue. The $\Delta\lambda_{30\text{-}10}$ determined the sign of tremor amplitude changes between the 10th and 30th min of recovery.

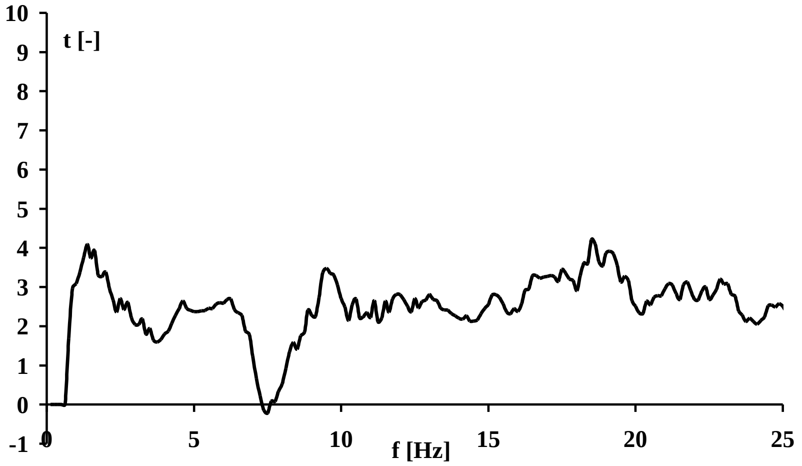


Fig. 5
t-Function computed for changes in power components along the frequency domain (10th minute of recovery related to the pre-fatigue state)

Mean values (±s) of $\Delta\lambda_{10\text{-}B}$ and $\Delta\lambda_{30\text{-}B}$ amounted to 0.948±0.941 and 1.173±0.615, respectively, and did not differ significantly from one another, individual values being uncorrelated. Mean value of $\Delta\lambda_{30\text{-}10}$ was 0.225±0.823, and its individual values negatively correlated with those of $\Delta\lambda_{10\text{-}B}$. This means that the higher was the initial change in tremor amplitude, the faster was its recovery. All changes in the log index of tremor amplitude correlated with hormone or LA concentrations, and with relative maximal power output (Table 3).

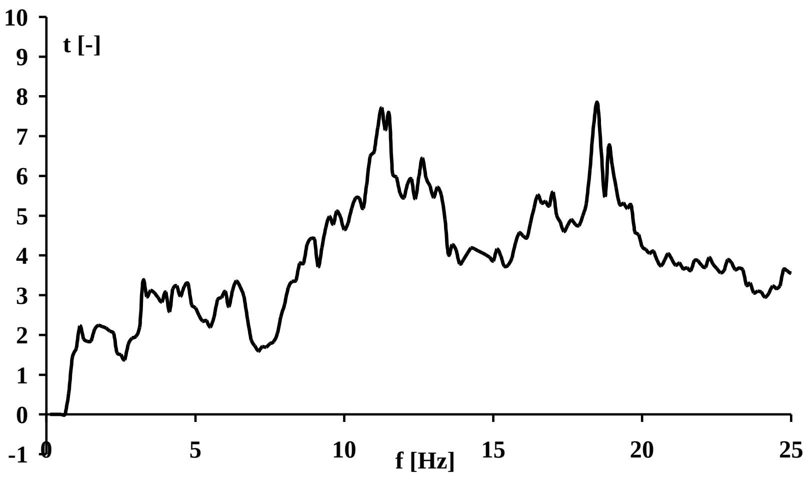


Fig. 6
t-Function computed for changes in power components along the frequency domain (30th minute of recovery related to the pre-fatigue state)

Table 3
Coefficients of correlation between changes in log index of tremor amplitude (Δλ) and other variables recorded

	C_M	C_B	C_3	C_4	T_M	T_B	T_3	T_4	P_{max}/kg	LA
$\Delta\lambda_{10-B}$	0.053	-0.626*	-0.739**	-0.746**	0.092	0.270	0.621*	0.403	-0.270	-0.618*
$\Delta\lambda_{30-B}$	0.429	0.156	0.066	0.044	0.413	0.619*	0.926***	0.765**	0.379	0.210
$\Delta\lambda_{30-10}$	0.260	0.832***	0.894***	0.886***	0.204	0.153	-0.020	0.110	0.592*	0.864***

Since these variables correlated with each other, a multiple regression procedure (step-backward) was employed in order to reveal variables undergoing changes in the high-frequency tremor amplitude. The set of dependent variables consisted of $\Delta\lambda_{10\text{-}B}$, $\Delta\lambda_{30\text{-}B}$ and $\Delta\lambda_{30\text{-}10}$. Because the subsequent hormone levels could not be considered independent, they were not included to the same set of predictor variables. Two sets of predictor variables were taken into consideration, each containing a pair of hormone concentrations (C_3,T_3 or C_4,T_4), LA concentration and

relative maximal power (P_{max}/bm). The stepwise backward procedure (STATISTICA^{TM} 7.0) automatically eliminated variables not contributing significantly to the criterion variable. In each case, only hormone concentrations passed into the models, other variables (LA,P_{max}/bm) being eliminated. The variable $\Delta\lambda_{10\text{-}B}$ proved related to both cortisol and testosterone concentrations. Best fits were obtained for zero-intercept models. Model I included C_3 and T_3:
$\Delta\lambda_{10\text{-}B}=-0.0048\cdot C_3+0.1389\cdot T_3$,
$F_{2,10}=54.12$; $R^2=0.899$ ($p<0.001$); error in regression =0.42.
Model II included C_4 and T_4:
$\Delta\lambda_{10}=-0.0055\cdot C_4+0.1507\cdot T_4$,
$F_{2,10}=45.94$, $R^2=0.882$, $p<0.001$, error in regression =0.45.
Observed $\Delta\lambda_{10\text{-}B}$ values and predicted from Model I are presented in Fig.7.
Changes in the high-frequency tremor amplitude 30 min post-exertion correlated only with testosterone concentrations and were described by the following equation (Fig. 8):
$\Delta\lambda_{30\text{-}B}=0.1925\cdot T_3-2.71$,
$F_{1,10}=59.88$, $R^2=0.857$, $p<0.001$, error in regression =0.24.

The same involving T_4 was:
$\Delta\lambda_{30\text{-}B}=0.1584\cdot T_4-2.41$,
$F_{1,10}=14.11$, $R^2=0.586$, $p<0.01$, error in regression =0.42.
The $\Delta\lambda_{30\text{-}10}$ coefficient, describing the sign and magnitude of changes in tremor amplitude between 10th and 20th minute of recovery, was highly correlated with cortisol concentrations. Again, two regression models were designed. The first model, involving C_3, was expressed by the following equation:
$\Delta\lambda_{30\text{-}10}=0.00514\cdot C_3\text{-}1.76$,
$F_{1,10}=39.73$, $R^2=0.799$, $p<0.001$, error in regression =0.39.
Model II, based on C_4:
$\Delta\lambda_{30\text{-}10}=0.00526\cdot C_4-2.14$,
$F_{1,10}=36.68$, $R^2=0.786$, $p<0.001$, error in regression =0.40.
Relationship between $\Delta\lambda_{30\text{-}10}$ and C_4 is presented in Fig. 9.

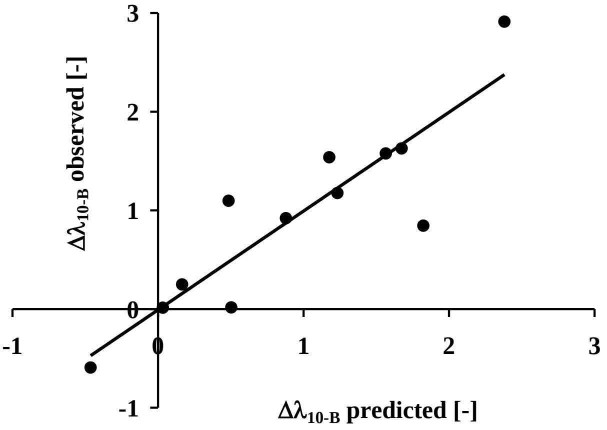


Fig. 7
Predicted vs. observed values of the change in tremor log-amplitude index ($\Delta\lambda_{10\text{-}B}$) calculated for 10th minute post-exertion, the regression model including C_3 and T_3

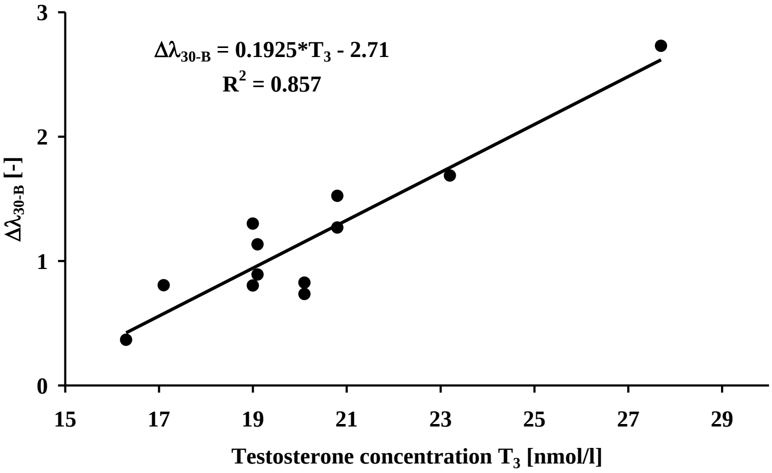


Fig. 8
Relationship between testosterone concentrations measured after submaximal exercise bouts (T_3) and changes in the tremor log-amplitude index calculated for 30^{th} min post-exertion ($\Delta\lambda_{30\text{-}B}$)

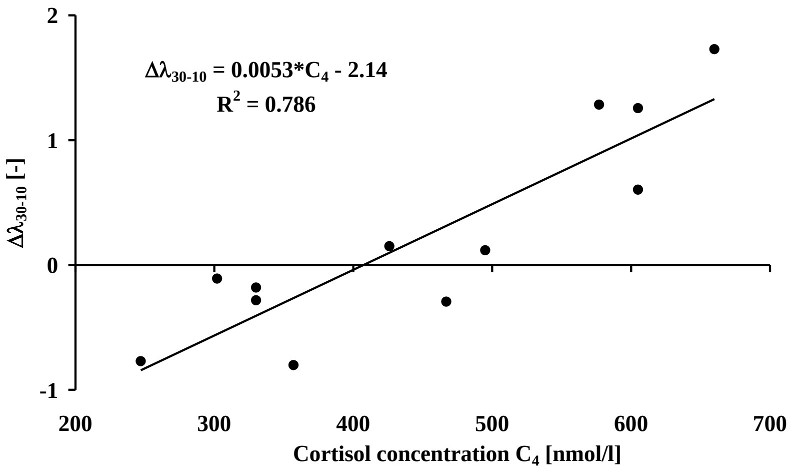


Fig. 9
Relationship between cortisol concentration C4 and $\Delta\lambda_{21}$ coefficient reflecting the direction and magnitude of tremor amplitude changes between 10th and 20th minute of recovery

Discussion

The exercise the subjects performed can be regarded as exhausting. Peak heart rate (191±6.5 beats·min^{-1}), lactate accumulation (13.33±2.41 mmol·l^{-1}) and oxygen uptake (56.0±3.87 ml·kg^{-1}·min^{-1}) reached considerably high levels. All subjects attained the anaerobic threshold during the third submaximal bout and it could be assumed that the subjects performed with maximum motivation. The observed increases in hormone levels during and immediately after exercise are in line with those reported by others [13,28] for high-intensity strength exercises. Changes in testosterone concentrations were more pronounced than those for cortisol and this seemed to depend on anaerobic and strength components of the exertion. Changes in tremor, measured 10 min post-exertion as the change in tremor log-amplitude index, were similar to those observed after strength exercises [8,27]. On the other hand, the recovery of tremor amplitude was delayed in the present study compared to previous studies. Gajewski *et al.* [8] observed maximal tremor amplitude 10 min after a strenuous isokinetic exercise session. A significant decrease in tremor amplitude occurred 25 min later. In the present study, there were no signs of tremor recovery even half an hour after the test. Such a prolonged delay in recovery from tremor was reported previously by Furness *et al.* [4] for hand muscles fatigued by an intense effort. The same authors concluded, that "the magnitude of the increase seemed to depend on the amount of 'effort' exerted by the subject rather than his actual performance in lifting the weight". This was demonstrated in the current study and previously [27], that the most significant post-exercise changes in tremor amplitude concerned mainly the so-called ‘high frequency tremor’ (10-20 Hz). This fact determined the way the quantitative estimation of changes in tremor was made. Since the interpersonal differences in tremor amplitudes are rather large [29], a relative measure ($\Delta\lambda$) was utilised.

The most interesting finding in this study was a close relationship between cortisol and testosterone concentrations and changes in the high-frequency tremor amplitude. High testosterone concentrations were associated with higher changes in tremor amplitude, while high cortisol concentrations seemed to restrict this increase and to simultaneously prolong recovery from tremor. Tremor changes are attributed to the local fatigue [24], whereas acute hormonal responses are rather characteristic of a global response to fatigue. In this study, local fatigue of upper extremities was limited by subjects’ aerobic and anaerobic capacities. The studied group was homogenous from this point of view – all subjects were top-level athletes. So, the final result of the test (reaching the subjective exhaustion), was probably dependent on motivation. It is suggested that the psycho-emotional state of subjects was reflected by hormonal concentrations before, during and after the test. A lack of correlation between morning hormonal levels with changes in tremor amplitude (effect of local fatigue) supports this view. It seems that there is no direct influence of hormonal levels on tremor changes (never reported before), so the observed relationship results rather from the magnitude of perceived exhaustion. The delay in tremor increase and recovery, which was shown to be associated with high cortisol levels, could be also explained by a higher lactate accumulation [18]. However, during stepwise regression procedure this variable (correlating with cortisol concentration) was eliminated from predictors set. It suggested that the magnitude of lactate concentration as well as tremor increase are both underlain rather by hormonal background.

Summing up, it can be stated that:

1. High-intensity kayak ergometer exercises evoked significant increases in cortisol and testosterone concentrations;
2. The most pronounced post-exercise increases in the forearm tremor power were observed in the 10 - 20 Hz frequency range;
3. There were no signs of recovery from tremor even 30 min after the exertion;
4. High concentrations of testosterone were associated with high post-exercise changes in tremor amplitude;

5. High concentrations of cortisol were associated with limited changes in tremor power and with a delayed recovery from tremor.

The presented results seem to suggest that steroid hormones were significantly and quantitatively associated with the effort performed and with a general response including changes in tremor spectrum. The mechanism underlying this relationship can be explained by the effects of hormones on muscle properties. Moreover, a relationship might exist between anticipatory hormone responses to the test and motivation [22]. Since the secretion of steroid hormones can be simultaneously considered as a part of the system response to effort [13], it is difficult to conclude that changes in tremor are determined directly by hormone levels. One could suppose both phenomena to be rather independently and proportionally fatigue-induced. However, degree of fatigue (see table 2) as well as tremor increases (table 3) were correlated also with pre-fatigue hormone levels. It is possible that anticipatory hormone responses moderated subjects' attitude toward the test and influenced subjective amount of exertion. Since the tested group of highly trained individuals was homogenous this phenomenon could effect on slight difference in performance and level of fatigue.

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Accepted for publication 10.07.2006

This study was partly supported by DS-71 AWF grant