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ORIGINAL ARTICLE

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Hormonal responses to three training protocols in rowing

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Abstract The aim of this study was to examine the acute responses of serum growth hormone, testosterone, and cortisol to three training protocols in rowing. Six young rowers, members of the national team, carried out three frequently used protocols in rowing, i.e., an endurance, a moderate interval, and a resistance protocol, on separate days in a counterbalanced design. Blood samples were collected before, immediately after, and 4 h after exercise for the determination of growth hormone, testosterone, cortisol, and creatine kinase. All three protocols caused marked increases in growth hormone, the most spectacular being that immediately after the endurance protocol. The change in testosterone concentration immediately after the endurance protocol was significantly higher than the changes after the other two protocols. Cortisol concentration was significantly higher immediately after the endurance protocol than after the other two protocols, but remained relatively low in all cases, suggesting that these protocols did not considerably promote catabolism in muscle tissue. Based on these data, endurance training caused greater responses of the three hormones studied compared to interval or resistance training. In fact, resistance training (at intensities above 85% of 1RM) did not cause any significant changes in the three hormones. We therefore propose that evaluation of training programmes designed for elite athletes should include measurements of hormonal changes in order to ascertain that the programmes do cause the expected adaptations.

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Introduction

Rowing is a sport placing high demands on both the anaerobic and aerobic energy systems, as muscle tissue is called to perform at high power output (350–400 W) during the 5.5–7 min (depending on the event) of a typical 2-km rowing competition (Hagerman 1984). Thus training programmes in rowing seek to find the right balance between developing muscle power and maximizing aerobic performance.

Hormonal concentrations in blood have been widely used to study the association of training programmes with performance or overtraining in a multitude of sports including rowing. The main hormones which have been studied in this sport are growth hormone, testosterone, and cortisol. Rowing performance in all-out 6-min or 2,000-m tests has been positively correlated with post-exercise serum growth hormone and cortisol concentration (Snegovskaya and Viru 1993a, 1993b), as well as resting testosterone concentration (Jürimäe and Jürimäe 2001). Steinacker et al. (1993, 2000), Urhausen et al. (1987), Urhausen and Kindermann (2002), as well as Vervoorn et al. (1992) examined the effect of training load during consecutive weeks on the ratio of testosterone to cortisol in rowers' serum. They found that the ratio decreased when training load increased, although they pointed out that this marker is not necessarily indicative of overtraining, since low testosterone to cortisol ratios were also observed in overreaching successful athletes (Steinacker et al. 2000).

The majority of the studies which have investigated the effect of rowing on hormonal levels have compared the values before and after a competitive effort or the resting values at different phases of a training season. Few studies have dealt with hormonal responses to different training programmes in rowing and even fewer

have monitored hormonal concentrations for sufficient time after a training stimulus to find out the duration of its effect. Therefore, the purpose of the present study was to evaluate three frequently used training protocols in rowing by monitoring the acute responses of serum growth hormone, testosterone, and cortisol.

Methods

Subjects

Six healthy male rowers participated in the study. All were members of the Seniors Greek National Team. Their age was 20.0 (1.6) years, body mass 74.7 kg (2.1 kg), and height 1.83 m (0.03 m) [all means (SD)]. Their 2,000-m record in rowing ergometer was 6 min 38 s (9 s). Each subject gave informed written consent to participate in the investigation, which was carried out according to the guidelines of the University of Thessaloniki Ethics Committee.

Design

The study took place during a week of the second month of the preparatory phase of the training cycle (November). On the first day the subjects performed an incremental protocol (Weltman 1995) in a rowing ergometer (Concept II, Morrisville, Vermont, USA) for the establishment of a velocity-blood lactate curve. The protocol consisted of 3-min constant velocity steps interspersed with 1-min intervals. Athletes were given specific 500-m times, starting with 2 min 15 s and decreasing by 5 s in each subsequent step, and kept a visual feedback through the monitor of the ergometer. The protocol was terminated when the rower could not maintain the desired pace. Capillary blood from an earlobe was taken during each interval and was mixed with 0.6 mol l^{-1} perchloric acid. Samples were centrifuged at 1,500 *g* for 10 min and lactate was determined in the supernatant as described below. Based on the lactate values and the corresponding rowing velocities, individual curves were constructed, which were used to determine the rowing velocities during the subsequent training protocols.

On the second day, which was a day of rest, each participant provided a blood sample from an antecubital vein in sitting position at 8 a.m., 9 a.m., and 1 p.m. to control for diurnal variation of hormones. The blood samples were left to coagulate, centrifuged at 1,500 *g* for 10 min, and the supernatant serum was stored at −20°C until used for the determination of growth hormone, testosterone, cortisol, and creatine kinase as described below. Blood samples were collected at the same time points and in the same way on the following 3 days, when the rowers performed the following training protocols proposed by the International Federation of Rowing Associations (FISA, 2003):

A. Sixty minutes of rowing in the above ergometer at a constant velocity corresponding to 3–4 mmol l^{-1} blood lactate concentration (endurance protocol).
B. Four sets of 5-min rowing bouts with 5-min intervals in the above ergometer at a constant velocity corresponding to 4–6 mmol l^{-1} blood lactate concentration (moderate interval protocol). Athletes warmed up for 15 min at the velocity of protocol A before these sets.
C. Resistance training consisting of the following exercises in order: bench pulls in prone position, leg press in sitting position (like rowing), and rowing from standing position (like clean in weightlifting). Each set consisted of three repetitions at 85% of 1RM, two repetitions at 90% of 1RM, and one repetition at 1RM. This set was performed six times for each exercise with a 2-min interval between sets.

Each rower carried out one of the above protocols on each day in a random counterbalanced design (Table 1). Subjects reported to the training site after a 12 h fast and provided a blood sample before the onset of each training session (at 8 a.m.). They provided a second sample immediately after the end of the training session (at 9 a.m.) and a third one 4 h later. During training sessions they consumed only water ad libitum. Immediately after providing the second blood sample they consumed a standardized light breakfast and nothing else, except water, until the time of the third blood sample. The meal provided 350 kcal derived from carbohydrate (73%), protein (19%), and fat (8%). The same diet had been implemented on the day of rest. Subjects were asked to abstain from any other physical activity and have normal sleep during the experimental period.

Table 1 Study design. A Endurance protocol; B interval protocol; *C* resistance protocol

Subject number	Day				
	1	2	3	4	5
1	Incremental protocol	Rest	A	B	C
2			A	C	B
3			B	A	C
4			B	C	A
5			C	A	B
6			C	B	A

Biochemical analyses

Blood lactate was assayed by an enzymic photometric method through the use of a reagent kit from Böhringer (Mannheim, Germany). Serum hormones were determined by enzyme immunoassays through the use of kits from Radim (Rome, Italy) for growth hormone, and DRG (Marburg, Germany) for testosterone and cortisol. Creatine kinase was measured by a photometric method through a kit from Randox (Crumlin, Co. Antrim, UK). Each parameter was measured in duplicate on a single day to eliminate inter-assay variability. The intra-assay coefficients of variation of the duplicate analyses were 8.0% for growth hormone, 9.4% for testosterone, 7.4% for cortisol, and 8.2% for creatine kinase.

Statistics

Data were analyzed using the SPSS 10.0 software (SPSS, Chicago, Ill., USA). Values are presented as means (SD). Significant differences among the three training protocols with respect to biochemical parameters were detected by analysis of variance (ANOVA) based on a counterbalanced Latin square design (Fellingham et al. 1978), which controls for possible carryover effects. Significant differences were followed-up with the Tukey test. Comparisons between each training protocol and the day of rest were performed with Student's one-tailed *t* test. The level of statistical significance was set at $\alpha = 0.05$.

Results

The serum concentrations of growth hormone during the day of rest and the days of the training protocols are presented in Fig. 1. All three protocols caused marked increases in growth hormone, the most spectacular being that after the endurance protocol. Values immediately after the endurance and interval protocols were significantly higher than those at the same time of the day of

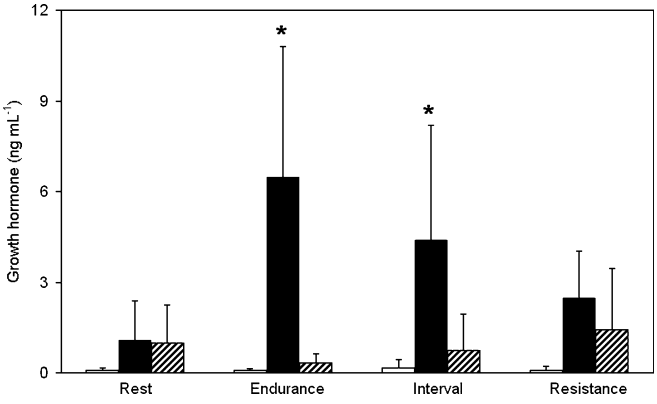

Fig. 1 Serum concentrations of growth hormone at 8 a.m. (*open bars*), 9 a.m. (*solid bars*), and 1 p.m. (*hatched bars*) of the day of rest and the days of the training protocols. *Error bars* indicate SD. *Significantly different from the corresponding value of the day of rest ($P \leq 0.05$)

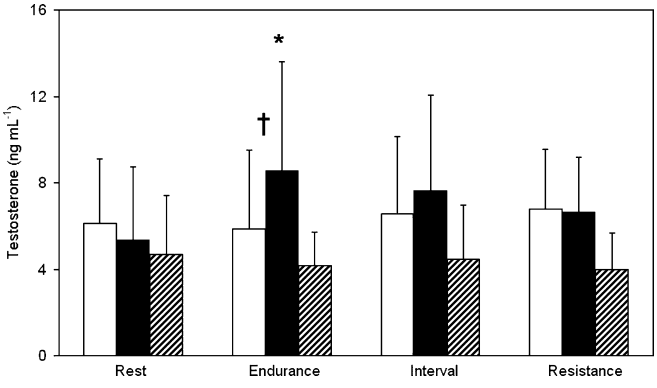

Fig. 2 Serum concentrations of testosterone at 8 a.m. (*open bars*), 9 a.m. (*solid bars*), and 1 p.m. (*hatched bars*) of the day of rest and the days of the training protocols. *Error bars* indicate SD. *Significantly different from the corresponding value of the day of rest; †Significantly different from the other training protocols with respect to change from pre-exercise to immediately post-exercise ($P \leq 0.05$)

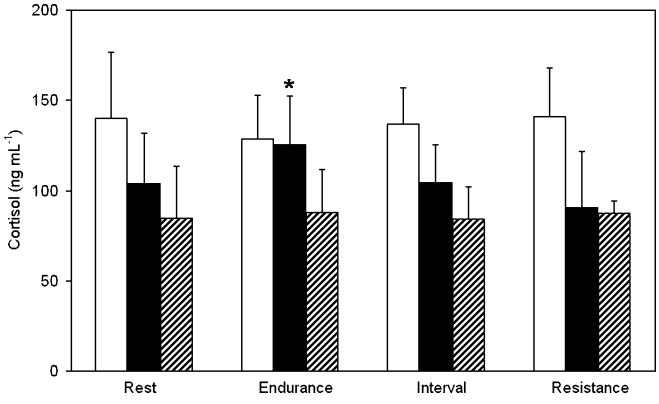

Fig. 3 Serum concentrations of cortisol at 8 a.m. (*open bars*), 9 a.m. (*solid bars*), and 1 p.m. (*hatched bars*) of the day of rest and the days of the training protocols. *Error bars* indicate SD. *Significantly different from the corresponding values of the other protocols ($P \leq 0.05$)

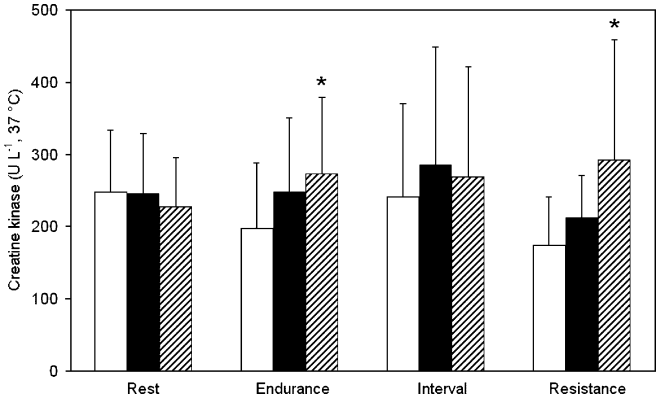

Fig. 4 Serum concentrations of creatine kinase at 8 a.m. (*open bars*), 9 a.m. (*solid bars*), and 1 p.m. (*hatched bars*) of the day of rest and the days of the training protocols. *Error bars indicate SD. **Significantly different from the corresponding value of the day of rest* ($P \leq 0.05$)

rest (by 504 and 309%, respectively). The value immediately after the resistance protocol did not differ significantly from that at the same time of the day of rest (although it was higher by 130%). The concentration of growth hormone 4 h after the end of all protocols did not differ significantly from the respective value on the day of rest. ANOVA did not show significant differences among the three protocols with respect to absolute values of growth hormone or changes from before exercise.

Testosterone concentrations are shown in Fig. 2. The concentration of the hormone immediately after the endurance protocol was significantly higher (by 60%) compared to the day of rest, while the corresponding changes after the interval and resistance protocols (by 42% and 24%, respectively) were not. Four hours after the end of all protocols the concentration of testosterone did not differ significantly from the respective value on the day of rest. ANOVA showed a significant difference among the three protocols with respect to changes from pre-exercise to immediately post-exercise. The change after the endurance protocol [an increase by 2.7 ng ml^{-1} (3.2)] was significantly higher than the changes after the other two protocols.

Cortisol concentrations (Fig. 3) exhibited a gradual decrease during the day of rest, characteristic of its diurnal variation (Wehr 1998). The endurance protocol curbed this decrease, while the interval and resistance protocols did not affect it. ANOVA showed a significant difference among the three protocols with respect to cortisol values immediately post-exercise. Again, the value corresponding to the endurance protocol was significantly higher than the values corresponding to the other two protocols.

The concentrations of creatine kinase are depicted in Fig. 4. Values 4 h after the endurance and resistance protocols were significantly higher than the respective value of the day of rest (by 20% and 29%, respectively). ANOVA did not show any significant differences among the three protocols.

Discussion

In the present study we investigated the effects of three different training protocols on the concentrations of two anabolic hormones (growth hormone and testosterone) and one catabolic hormone (cortisol), as well as on the activity of creatine kinase in the serum of high-level rowers. The changes of the three hormones were more pronounced after the endurance protocol. Based on the testosterone and growth hormone data, it appears that endurance training may promote anabolic processes. This does not necessarily mean muscle hypertrophy, but might mediate increased expression of aerobic enzymes or adaptations in other processes, such as erythropoiesis. It is noteworthy that the concentrations of growth hormone after the endurance and interval protocols were higher than its upper reference limit of 4 ng ml^{-1} at rest (Tietz 1995).

On the other hand, the concentration of cortisol after any of the three protocols did not exceed 125 ng ml^{-1} in terms of mean values or 162 ng ml^{-1} in terms of individual values. These values are lower than the upper reference limit of 230 ng ml^{-1} at rest (Tietz 1995). We might therefore assume that none of the protocols employed in the present study promoted catabolic processes in muscle tissue to a considerable degree.

Our findings are similar to those of Snegovskaya and Viru (1993b), who reported that cortisol and growth hormone responses to 40 min of rowing at the anaerobic threshold were more pronounced than to 7 min of rowing at supramaximal intensity. However, testosterone did not change significantly in contrast to the change we observed in the present study, probably because of the shorter duration of their endurance protocol. Concerning the resistance protocol, the lack of significant changes in any of the three hormones measured in the present study contrasts the significant increases reported by Kraemer et al. (1991, 1998a, 1998b) with resistance protocols of lower intensity. Interestingly, compared to our study, total work (which has been suggested to affect the changes of these hormones in a positive manner) was lower in the studies of Kraemer et al. (1998a, 1998b), which involved untrained subjects. Therefore, the above discrepancies may be explained by differences in intensity and training status. On the other hand, our data are in agreement with those of Häkkinen and Pakarinen (1993), who applied a resistance protocol of higher intensity than in the present study to top-level athletes. Consequently, the issue of hormonal responses of elite athletes to resistance training appears to warrant further investigation.

Serum creatine kinase is considered to be a marker of the mechanical-muscular strain of training (Urhausen 2002). The significant increases in this parameter 4 h after the endurance and resistance protocols suggest increased muscle fibre damage. However, all creatine kinase values were relatively low, suggesting that the muscular system of the athletes was well adapted to such training loads.

In conclusion, the results of the present investigation with high-level rowers indicate that endurance training caused greater responses of serum growth hormone, testosterone, and cortisol compared to interval or resistance training. In fact, resistance training at intensities above 85% of 1RM, which is prescribed as a means of inducing muscle hypertrophy in lightweight rowers (FISA, 2003), did not cause any significant changes in these hormones. We therefore propose that evaluation of training programmes designed for elite athletes should include measurements of hormonal changes in order to ascertain that these programmes do cause the expected adaptations.

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References

Fellingham GW, Bryce GR, Carter MW (1978) Latin square changeover design in physical education research. Res Q 49:125–134

FISA (2003) Training manuals. http://www.worldrowing.com/training/manuals.sps (accessed February 19, 2003)

Hagerman FC (1984) Applied physiology of rowing. Sports Med 1:303–326

Häkkinen K, Pakarinen A (1993) Acute hormonal responses to two different fatiguing heavy-resistance protocols in male athletes. J Appl Physiol 74:882–887

Jürimäe J, Jürimäe T (2001) Responses of blood hormones to the maximal rowing ergometer test in college rowers. J Sports Med Phys Fitness 41:73–77

Kraemer WJ, Gordon SE, Fleck SJ, Marchitelli LJ, Mello R, Dziados JE, Friedl K, Harman E, Maresh C, Fry AC (1991) Endogenous anabolic hormonal and growth factor responses to heavy resistance exercise in males and females. Int J Sports Med 12:228–235

Kraemer WJ, Häkkinen K, Newton RU, McCormick M, Nindl BC, Volek JS, Gotshalk LA, Fleck SJ, Campbell WW, Gordon SE, Farrell PA, Evans WJ (1998a) Acute hormonal responses to heavy resistance exercise in younger and older men. Eur J Appl Physiol 77: 206–211

Kraemer WJ, Staron RS, Hagerman FC, Hikida RS, Fry AC, Gordon SE, Nindl BC, Gothshalk LA, Volek JS, Marx JO, Newton RU, Häkkinen K (1998b) The effects of short-term resistance training on endocrine function in men and women. Eur J Appl Physiol 78: 69–76

Snegovskaya V, Viru A (1993a) Elevation of cortisol and growth hormone levels in the course of further improvement of performance capacity in trained rowers. Int J Sports Med 14:202–207

Snegovskaya V, Viru A (1993b) Steroid and pituitary hormone responses to rowing: relative significance of exercise intensity and duration and performance level. Eur J Appl Physiol 67:59–65

Steinacker JM, Laske R, Hetzel WD, Lormes W, Liu Y, Stauch M (1993) Metabolic and hormonal reactions during training in junior oarsmen. Int J Sports Med 14:24–28

Steinacker JM, Lormes W, Kellmann M, Liu Y, Reißnecker S, Opitz-Gress A, Baller B, Günther K, Petersen KG, Kallus KW, Lehmann M, Altenburg D (2000) Training of junior rowers before world championships. Effect on performance, mood

state and selected hormonal and metabolic responses. J Sports Med Phys Fitness 40:327–335
Tietz NW (1995) Clinical guide to laboratory tests. Saunders, Philadelphia
Urhausen A, Kindermann W (2002) Diagnosis of overtraining. What tools do we have? Sports Med 32:95–102
Urhausen A, Kullmer T, Kindermann W (1987) A 7-week follow-up study of the behaviour of testosterone and cortisol during the competition period in rowers. Eur J Appl Physiol 56:528–533
Vervoorn C, Vermulst LJM, Boelens-Quist AM, Koppeschaar HPF, Erich WBM, Thijssen JHH, de Vries WR (1992) Seasonal changes in performance and free testosterone:cortisol ratio of elite female rowers. Eur J Appl Physiol 64:14–21
Wehr TA (1998) Effect of seasonal changes in day length on human neuroendocrine function. Horm Res 49:118–124
Weltman A (1995) The blood lactate response to exercise. Human Kinetics, Champaign, p 85