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Effects of Training on the Exercise-Induced Changes in Serum Amino Acids and Hormones

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ABSTRACT

The purpose of this study was to examine power-type athletes to determine changes in amino acid and hormone concentrations in circulating blood following 2 different high-intensity exercise sessions before and after the 5-week training period. Eleven competitive male sprinters and jumpers performed 2 different running exercise sessions: a short run session (SRS) of 3 × 4 × 60 m (intensity of 91–95%) with recoveries of 120 and 360 seconds, and a long run session (LRS) with 20-second intervals (intensity of 56–100%) with recoveries of 100 seconds to exhaustion. The concentrations of serum amino acids, hormones, and lactate were determined from the blood samples drawn after an overnight fast and 10 minutes before and after both SRS and LRS. The average blood lactate concentrations were 12.7 ± 1.6 mmol·L^{-1} and 16.6 ± 1.4 mmol·L^{-1} ($p < 0.01$) following SRS and LRS, respectively. The average total running time was longer ($p < 0.001$) following LRS (164 ± 20 seconds) than following SRS (91 ± 8 seconds). The fasting levels of all amino acids decreased ($p = 0.024$; 19.4%) after the 5-week period, whereas an increase ($p = 0.007$; 24.5%) was observed in the fasting concentration of testosterone (TE). The exercise sessions induced no changes in the total sum of all amino acids, but significant increases or decreases were observed in single amino acids. When the range of the relative concentration changes before and after the training period was compared, significant decreases were found in valine ($p = 0.048$), asparagine ($p = 0.029$), and taurine ($p = 0.030$) following SRS. There were significant increases in the absolute hormonal concentration changes following LRS with TE ($p = 0.002$; 30.4%), cortisol (COR; $p = 0.006$; 12.0%), and in the TE/COR ratio ($p = 0.047$; 21.0%) but not in the concentration of growth hormone (GH). The results of the study indicate that the speed and strength training period strongly decreases the fasting concentrations of amino acids in the power-trained athletes in a good anabolic state with the daily protein intake of 1.26 g·kg^{-1} body weight. At the same time the intensive lactic exercise session induces strong decreases, especially in valine, asparagine, and taurine.

Key Words: proteins, metabolism, performance, nutrition, male, athletes

Reference Data: Pitkänen, H., A. Mero, S.S. Oja, P.V. Komi, H. Rusko, A. Nummela, P. Saransaari, and T. Takala. Effects of training on the exercise-induced changes in serum amino acids and hormones. *J. Strength Cond. Res. 16(3):390–398. 2002.*

Introduction

There has been a long-term interest in the interrelationships between physical exercise and the metabolism of amino acids. Muscle protein balance is determined by both muscle protein synthesis and muscle protein degradation. Influencing 1 or both of these factors results in a change in muscle protein balance and ultimately in changes in muscle structure and metabolism. The major part of amino acids exists in body proteins. Only 0.5–1.0% is free in the blood plasma or intracellular and extracellular spaces (free amino acid pool; 20). Free amino acids are derived from the diet, protein breakdown, or carbohydrate and fat intermediates via transamination reactions (17). They are in a state of equilibrium, which is altered by the daily protein intake and physical activity (26). The amino acid pool is renewed many times during each day (35), and since the pool is metabolically active more attention should be paid to how it is affected by training periods, single exercise sessions, and nutrition.

The available studies concerning training effects on the concentrations of serum amino acids are still sparse and the subjects have mostly been endurance-trained athletes. For example, Einspahr and Tharp (8) investigated 12 endurance runners (110 km·wk^{-1}) and 13 controls (<5 km·wk^{-1}) and found significantly higher plasma levels of leucine (41%), isoleucine (27%),

and tyrosine (23%) among the trained subjects at rest. The daily nutrition of the subjects was not reported by the authors. Mero et al. (22) concentrated on power-type athletes and examined serum fasting amino acid concentrations during the 5-week training period in sprinters and jumpers. They found considerable decreases in the branched chain amino acids (21%), isoleucine (21%), leucine (20%), and valine (18%) during the period when the daily protein intake was 1.3 $g \cdot kg^{-1}$ body weight.

Regarding exercise sessions, Bergström et al. (2) showed that during a 20-minute bout of exercise at 70% of maximal oxygen uptake, untrained men had increased plasma levels of alanine, glutamine, arginine, tyrosine, and phenylalanine, whereas levels of most of the other amino acids were decreased. For example, leucine decreased by 22%. The detailed description of the nutrition was not given in that particular study. Mero et al. (23) investigated sprinters and jumpers following a heavy strength exercise session lasting 90 minutes. They found with the daily protein intake of 1.2 $g \cdot kg^{-1}$ body weight a decrease of 24% in branched chain amino acids (BCAAs) and a decrease of 30% in both leucine and isoleucine, whereas a level of alanine increased by 4%.

Exercise training stress has been shown to activate the physiological mechanisms involved with the muscle adaptation and chronic adaptations to training (14), and according to the literature there exists a mechanism for an exercise-induced rapid or delayed hormonal activation (34). The exercise session–induced changes in hormonal status are shown to be increases in growth hormone (GH) and cortisol (COR) and a decrease or an increase in testosterone (TE; 6). In athletes who train effectively during macrocycles, both basal TE levels and COR levels slightly rise, but in overreached or overtrained athletes COR levels rise and TE levels decrease. The TE/COR ratio can thus be used to indicate the balance in anabolism/catabolism of the body (16).

Although the studies concerning amino acids and physical exercise are limited, they indicate that changes occur in the level of amino acids because of exercise training as well as following single exercise sessions. In the present study we concentrated on sprinters and jumpers and examined the influence of power-type training on serum amino acid concentrations following 2 various running exercise sessions. We hypothesized that the response might be different following a submaximal short run session (SRS) than following an exhaustive long run session (LRS) before and after the training period. Simultaneously we also examined changes in the hormonal status and tried to demonstrate a possible connection between hormonal and amino acid changes following both a training period and single training sessions. A hormonal mechanism is part of a complex integrated system that helps mediate and influence adaptations of the metabolic and cellular remodeling processes (e.g., protein synthesis) of muscles (11, 13). For the examination of the hormonal status we chose the anabolic hormones TE and GH, and we chose COR to demonstrate the possible catabolic state following the training period.

Table 1. The physical characteristics of the experimental group before and after the 5-week training period.†

Physical characteristics	Before	After	Before vs. after
Height (m)	1.84 ± 0.05	1.84 ± 0.05	
Mass (kg)	77.3 ± 6.2	77.0 ± 6.0	
Fat (%)	9.3 ± 1.6	9.1 ± 1.6	*
Sum of skinfolds (Σ 9, m)	0.054 ± 0.006	0.052 ± 0.006	*
Thigh girth (m)	0.55 ± 0.03	0.55 ± 0.03	
Shank girth (m)	0.39 ± 0.02	0.39 ± 0.02	
Countermovement jump (m)	0.53 ± 0.08	0.52 ± 0.06	

† Mean values ± *SEM.*
* $p < 0.05$.

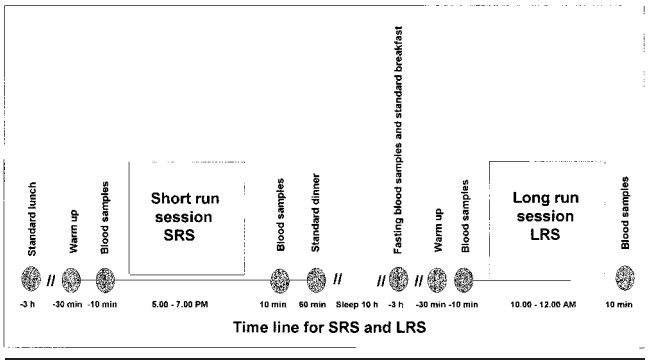

Figure 1. The study protocol that was carried out before and after the 5-week training period.

Methods

Subjects

Eleven competitive male sprinters and jumpers volunteered to participate in this study. Mean (±*SD*) age, training years, and record of the 100 m were 23.7 ± 4.4 years, 9.4 ± 3.8 years, and 11.26 ± 0.50 seconds, respectively. The physical characteristics of the group are shown in Table 1. All subjects gave written informed consent in accordance with the University's Ethical Board before participating in this study.

Experimental Design

Initially, each subject was familiarized with the training program during 2 months, which was planned by the coaches and the researchers. The laboratory visits and the measurements were compiled twice: before and after the 5-week training season (see Figure 1).

Table 2. Training volume during the 5-week training periods.*

	First 5-week period	Second 5-week period	*p*-value
Frequency	27 ± 6	28 ± 7	NS
Speed work (m)	1,539 ± 590	1,690 ± 905	NS
Speed endurance (m)	3,670 ± 1,980	3,752 ± 2,644	NS
Endurance work (m)	79,800 ± 78,900	85,200 ± 92,700	NS
Strength training (tons)			
Leg extensors	20 ± 11	18 ± 15	NS
Leg flexors	6 ± 6	6 ± 5	NS
Other	9 ± 7	8 ± 10	NS

* Mean values ± *SD*; NS = not significant.

The SRS consisted of 3 × 4 × 60 m on an indoor track with recovery periods of 2 minutes between repetitions and 6 minutes between series. The speed in the series gradually increased (91, 93, and 95% from the series maximum). The LRS consisted of numerous bouts to exhaustion (total fatigue), i.e., $n \times 20$ seconds on a treadmill with recoveries of 100 seconds between the runs. The initial treadmill speed (4.08 $m \cdot s^{-1}$ on a 4° slope) was increased by 0.38 $m \cdot s^{-1}$ for each consecutive run until exhaustion. The speed ranged from 56 to 100% from the speed of the last run.

Anthropometry

Girth measurements of the thigh and shank were bilaterally made with a tape measure applied around the relaxed muscles of a subject in a sitting position. The results from the right and left legs were averaged. Bilateral skinfold measurements were carried out with a John Bull skinfold caliper (British Indicators, LTD, London, England). Skinfold readings were taken from 4 skinfold points (m. subscapularis 2.5 cm lower than the nipple line at the axillary level; m. triceps brachii for maximal circumference [MC]; m. biceps brachii for MC; and crista iliaca 2.5 cm above the nipple line at axillary level) from the upper body and from 4 skinfold points (calf for MC; quadriceps for MC; hamstrings for MC; gluteus for maximal protrusion of the buttocks; and, anteriorly, the symphysis pubis) from the lower extremities. With the reading from a trunk skinfold point (abdomen), the averaged (right and left) 8 readings form the total sum of skinfolds (7). All anthropometric measurements were performed by the same researcher (Table 1).

Jumping Test

Immediately after the warm-up on both test occasions, the subjects performed a jumping test (3 maximal trials; the best jump was taken in the analysis) that evaluated the speed strength of leg extensor muscles using a counter movement jump (12) on a contact mat (Newtest Ltd., Oulu, Finland) connected by a cable to a digital timer (±0.001 second). The timer was triggered by the lift of feet from the mat and stopped at the touchdown. The flight time and rise of the center of gravity of the subject during the jump was recorded.

Training

The volume and intensity of the training program was planned together by the research group and the coaches according to the principles of Mero et al. (21). The training during the 5-week period and 5 weeks before the first test occasion was analyzed from the training diaries. Speed work included sprint running (short sprints of 30–60 m) at the intensity level of 95–100% from the personal best (PB). The speed endurance work consisted of sprint running at the intensity level of 90–94% from the PB using short and long sprints ranging from 60 to 400 m. The endurance work was both aerobic and anaerobic training, including running (distances from 100 to 1000 m) at the intensity level of 60–89% from the PB. The jumping training included both horizontal and vertical jumps with maximal effort (as fast as possible). The amount of jump training was calculated as takeoffs. Strength training consisted of power and maximum strength at the intensity level of 85–100% from the PB with free weights and with strength machines, focusing on leg extensor and flexor muscles with maximal intensity (as fast as possible).

Training volume (frequency, speed work, speed endurance, endurance work, and strength training) during the 5-week training period is presented in Table 2.

Nutrition

Subjects were advised to self-select their diet (normal home food) according to the principles of Nutrition Recommendations for Athletes in Finland (25). All subjects kept food diaries. A period of 10 days before both test occasions was included in the analysis of nutrition (Table 3). The nutritional analysis was performed using the Micro Nutrica software (version 1.0, Social Insurance Institution, Helsinki, Finland). During the test occasion subjects enjoyed a standard lunch 3 hours before the SRS (about 800 kcal consisting of 55% carbohydrates [CHO], 30% fat, and 15% protein) and a dinner 60 minutes after the SRS (about 800 kcal con-

Table 3. The percentage supply of daily energy intake from carbohydrate, fat, and protein during the 10 days before test occasions.*

Parameters	First 10-day period	Second 10-day period	*p*-value
Energy (MJ)	10.5 ± 1.49	10.5 ± 1.51	NS
Carbohydrate (%)	53.3 ± 4.2	53.1 ± 4.3	NS
Fat (%)	31.8 ± 3.6	31.5 ± 3.7	NS
Protein (%)	15.0 ± 2.1	15.5 ± 1.9	NS
Protein ($g \cdot kg^{-1}$ body weight)	1.26 ± 0.19	1.25 ± 0.18	NS

* Mean values ± *SD*; NS = not significant.

sisting of 60% CHO, 25% fat, and 15% protein). Then the subjects fasted overnight for a minimum of 10 hours prior to the beginning of the second test day. After the blood samples on the second day, the subjects enjoyed a standard breakfast 3 hours before the experiment (about 625 kcal consisting of 60% CHO, 25% fat, and 15% protein; see Figure 1).

Blood Collection and Analysis

A 5 ml blood sample was obtained 5 times during one test occasion: 10 minutes before and after both the SRS and LRS and an overnight fast sample before the LRS (see Fig. 1). All venous blood samples for amino acid and hormonal analysis were drawn from an antecubital vein and immediately frozen and stored at −20° C or below. The samples were deproteinized with 5% sulphosalicylic acid containing L-2,4-diamino butyric acid as an internal standard, mixed with lithium citrate buffer, and subjected to ion-exchange chromatography using an automatic Pharmacia LKB Alpha Plus amino acid analyzer with o-phthalaldehyde derivatization and fluorescence detection to analyze 21 amino acids.

Levels of TE, COR, and GH were determined in duplicate by radioimmunoassay (RIA). Serum samples for TE were determined with a solid phase ^{125}I RIA (Spectria Testosterone Coated Tube RIA Kit, Orion Diagnostica, Turku, Finland); serum concentrations of COR were determined with ^{125}I RIA (Cortisol RIA Kit, Orion Diagnostica); and serum concentration of GH was determined with an ^{125}I liquid-phase double-antibody procedure (Pharmacia hGH RIA, Pharmacia Diagnostigs AB, Uppsala, Sweden).

All of the samples from an individual subject were run in the same assay to avoid any changes in interassay variability. Intra-assay coefficients of variation were 2–5%, and interassay coefficients of variation were 4–10% for variables.

Blood samples for determining peak blood lactate concentration were drawn from the fingertip at the first, fourth, seventh, and tenth minute following the test runs.

Statistical Analyses

The set of the observations for 1 subject tended to be intercorrelated (i.e., the covariance between measurements within a subject tend to deviate from zero). These interdependencies were taken into account when modeling the data. The data were analyzed by the analysis of variance (ANOVA) according to the randomized complete block design with repeated measures. Subjects were considered as a random effect (block), whereas the season treatment (before or after the training period) as well as the exercise treatment (before or after exercise) were considered as fixed effects. Indeed the exercise was analyzed as the repeated-measures factor. If the interaction between the season and the exercises was found, the effects of exercise (the difference between before and after exercises) were determined separately in the beginning and at the end of the training season. All of these additional comparisons between means were performed by the t-type contrast examination. In addition, the differences were determined by the t-type 95% confidence intervals (CIs).

Before performing the ANOVA, the accordance of the data with the assumptions of equality of the group variances were checked. In addition, the normality assumption of errors was assessed by the graphic presentation, for example stem and leaf display and by the normal probability plot (24). Many violations were found in the assumptions on what basis some variables were transformed. Square root and logarithm transformations were used. In addition, outlier influences on the results were checked. In both cases the results based on the original data led to the same results, so only original results are presented (19, 27–29). All analyses were performed by means of the SAS statistical package when mixed (19), univariate (27), and GPLOT (28) procedures were used.

Results

Physical Characteristics

The percentage of the body fat decreased ($p < 0.05$) from 9.3 ± 1.6% to 9.1 ± 1.6%, and the sum of skinfolds decreased from 0.054 ± 0.006 m to 0.052 ± 0.006 m ($p < 0.05$) in the experimental group during the 5 weeks (Table 1).

Training and Nutrition

There were no differences in training or nutrition (Tables 2 and 3) between the periods before the test occasions.

Total Running Time and Peak Blood Lactate

There were no differences in running times and peak blood lactates when the performances were compared

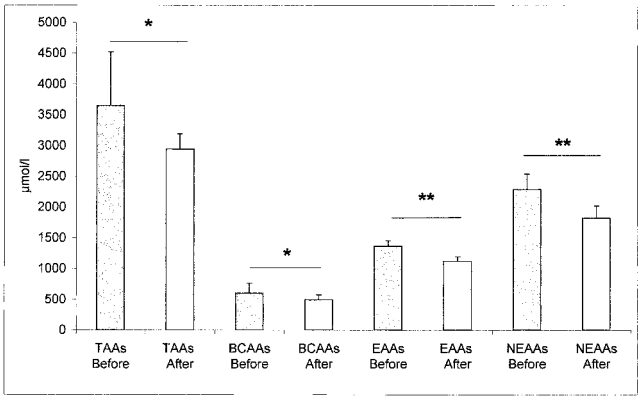

Figure 2. Decreases in the fasting concentrations of the amino acids during the 5-week training period (before-after comparison): * $p < 0.05$, ** $p < 0.01$.

before and after training. The total running time (average of the 2 test occasions) was longer ($p < 0.001$) following LRS (164 ± 20 seconds) than following SRS (91 ± 8 seconds), and the peak blood lactate concentration (average of the 2 test occasions) was higher ($p < 0.01$) following LRS (16.6 ± 1.4 mmol·L^{-1}) than following SRS (12.7 ± 1.6 mmol·L^{-1}).

Training and Fasting Amino Acid and Hormone Concentrations

Significant decreases in serum were observed in the fasting levels of the total sum of the amino acids (TAAs) from 3,648 ± 870 µmol·L^{-1} to 2,941 ± 249 µmol·L^{-1} ($p < 0.05$; 19.4%), BCAAs from 598 ± 162 µmol·L^{-1} to 491 ± 79.5 µmol·L^{-1} ($p < 0.05$; 17.9%), essential amino acids (EAAs) from 1,364 ± 86.7 µmol·L^{-1} to 1,121 ± 72.0 µmol·L^{-1} ($p < 0.01$; 17.8%) and nonessential amino acids (NEAAs) from 2,284 ± 254 µmol·L^{-1} to 1,820 ± 198 µmol·L^{-1} ($p < 0.01$; 20.3%), respectively, after the 5-week period (Figure 2). Table 4 shows the decreases in the fasting concentrations of the single amino acids: in 14 of 21 amino acids, the decrease was significant.

The fasting level of TE increased from 17.6 ± 3.5 nmol·L^{-1} to 23.3 ± 5.2 nmol·L^{-1} ($p < 0.01$; 24.5%) after the 5-week period. There were no significant changes in the fasting levels of COR, the TE/COR ratio, and GH.

Exercise Session–Induced Changes in Amino Acid Concentrations

There were significant changes in the concentration of NEAAs and in 5 of 21 single amino acids before the 5-week training period during SRS, whereas after the training period the concentration of BCAAs, EAAs, and 14 of 21 amino acids changed significantly (Table 5). Following LRS the significant changes were seen in NEAAs and in 11 single amino acids before the training period and in NEAAs and in 7 of 21 amino acids after the training period (Table 6).

Table 4. Fasting serum amino acid concentrations before and after the 5-week training period.†

Amino acids	Before	After	Before vs. after
Leucine	189 ± 45	151 ± 21	*
Valine	325 ± 86	268 ± 49	**
Isoleucine	90.8 ± 22.7	71.5 ± 14.2	*
Tryptophan	146 ± 34	122 ± 27	**
Threonine	168 ± 50	131 ± 18	*
Ornithine	96.1 ± 26.6	75.2 ± 7.4	**
Glutamine	874 ± 261	684 ± 83	*
Alanine	448 ± 90	354 ± 63	*
Glycine	303 ± 78	242 ± 24	*
Taurine	82.2 ± 33.8	70.1 ± 15.1	
Asparagine	77.7 ± 23.6	64.3 ± 11.9	
Tyrosine	79.6 ± 21.4	70.4 ± 11.4	
Serine	136 ± 51	109 ± 25	
Lysine	214 ± 47	184 ± 38	
Phenylalanine	77.9 ± 13.6	65.4 ± 7.9	
Metionine	31.4 ± 9.3	25.2 ± 2.8	*
Glutamate	66.7 ± 15.4	48.6 ± 9.0	***
Arginine	122.7 ± 32.4	99.7 ± 21.3	**
Citrulline	60.9 ± 19.9	47.9 ± 8.3	**
Histidine	122 ± 27	103 ± 14	**
Aspartate	32.8 ± 8.9	29.6 ± 5.3	

† Mean values (µmol·L^{-1}) ± *SEM*. Significance for before-after comparisons is shown following the after values.
* $p < 0.05$.
** $p < 0.01$.
*** $p < 0.001$.

The second comparison was made in order to find out differences in the range of exercise session–induced relative changes before and after the 5-week training period. Following SRS, significant decreases were found in valine from −7.60 ± 10.5 µmol·L^{-1} to −38.2 ± 10.6 µmol·L^{-1} ($p = 0.048$, 95% from −61.0 to −0.27 µmol/L); in asparagine from −1.48 ± 2.42 µmol·L^{-1} to −9.80 ± 2.43 µmol·L^{-1} ($p = 0.029$, 95% CI from −15.6 to −1.08 µmol·L^{-1}); and in taurine from 2.73 ± 6.62 µmol·L^{-1} to −16.6 ± 6.68 µmol·L^{-1} ($p = 0.030$, 95% CI from −36.17 to −2.40 µmol·L^{-1}; see relative changes in Figure 3). There were no significant changes in amino acids following LRS (see also Tables 5 and 6).

Exercise Session–Induced Changes in Hormone Concentration

The same study protocol as with the amino acids was carried out with the hormonal status. When analyzing the comparison during the first and second test occasion (mean values of the exercise session–induced changes), no significant changes were found in the hormonal status following SRS, but following LRS there were significant increases in the following: TE, 7.98 ± 1.86 nmol·L^{-1} ($p = 0.002$; 30.4%, 95% CI from

Table 5. Changes in concentrations of amino acids following a short run session (SRS) before and after the 5-week training.†

Amino acids	BI	AI	BI vs. AI	BII	AII	BII vs. AII
Total sum of amino acids	3418 ± 154	3588 ± 157		3247 ± 161	3127 ± 161	
Sum of branched chain amino acids	522 ± 30	499 ± 31		506 ± 32	426 ± 32	*
Sum of essential amino acids	1208 ± 59	1130 ± 59		1143 ± 62	990 ± 62	*
Sum of nonessential amino acids	2210 ± 101	2457 ± 104	**	2102 ± 106	2141 ± 106	
Leucine	155 ± 10	145 ± 10		153 ± 10	126 ± 10	*
Valine	286 ± 16	279 ± 16		276 ± 17	238 ± 17	*
Isoleucine	79 ± 5	74 ± 5		77 ± 6	63 ± 6	*
Tryptophan	128 ± 7	94 ± 8	*	124 ± 8	94 ± 8	*
Threonine	155 ± 8	147 ± 8		129 ± 8	116 ± 8	**
Ornithine	96 ± 4	82 ± 4	*	91 ± 4	70 ± 4	***
Glutamine	701 ± 28	744 ± 29		666 ± 29	654 ± 29	
Alanine	577 ± 52	822 ± 54	***	555 ± 55	718 ± 55	*
Glysine	261 ± 11	242 ± 11	**	228 ± 11	199 ± 11	*
Taurine	76 ± 7	79 ± 7		81 ± 7	64 ± 7	*
Asparagine	60 ± 4	59 ± 4		64 ± 4	55 ± 4	*
Tyrosine	73 ± 5	72 ± 6		81 ± 6	75 ± 6	
Serine	117 ± 8	109 ± 8		112 ± 8	96 ± 8	*
Lysine	197 ± 12	182 ± 12		184 ± 13	162 ± 13	*
Phenylalanine	68 ± 3	64 ± 3		68 ± 3	60 ± 3	*
Metionine	29 ± 2	29 ± 2		29 ± 2	27 ± 2	
Glutamate	60 ± 5	69 ± 5		59 ± 5	60 ± 5	
Arginine	110 ± 7	105 ± 7		91 ± 4	95 ± 7	
Citrulline	45 ± 3	44 ± 3		42 ± 3	40 ± 3	
Histidine	106 ± 6	114 ± 6	*	106 ± 6	106 ± 6	
Aspartate	30 ± 1	28 ± 1		29 ± 1	26 ± 1	*

† Mean values ($\mu mol \cdot L^{-1}$) ± *SEM*. BI = before SRS and before the 5-week training period; AI = after SRS and before the 5-week training period; BII = before SRS and after the 5-week training period, and AII = after SRS and after the 5-week training period). Significance for before-after comparisons is shown following the after values.

* $p < 0.01$.

** $p < 0.05$.

*** $p < 0.001$.

3.76 to 12.19 $nmol \cdot L^{-1}$); COR, 103 ± 28.6 $\mu mol \cdot L^{-1}$ ($p = 0.006$; 12.0%, 95% CI from 37.9 to 167 $\mu mol \cdot L^{-1}$); and TE/COR ratio, 0.006 ± 0.003 ($p = 0.047$; 21.0%, 95% CI from 0.000 to 0.013 $\mu mol \cdot L^{-1}$). No significant changes were observed in the concentration of GH following SRS or LRS during the 5-week training period.

No differences were detected in hormonal responses following SRS and LRS when the range of the relative changes was compared before and after the 5-week training period.

Discussion

In this study, we observed that the fasting concentration of all amino acids in serum decreased significantly during the 5-week period of speed and strength training in power-trained athletes with the protein intake of 1.26 $g \cdot kg^{-1} \cdot d^{-1}$, but at the same time the concentration of fasting serum TE increased. In addition, strong decreases were found in valine, asparagine, and taurine following SRS (3 × 4 × 60 m) at the end of the 5-week period.

The fasting concentration of all amino acids decreased after the 5-week training period, which shows that some changes occurred in the free amino acid pool. Amino acids enter the free pool by intake of protein and as a result of tissue degradation. In addition, some dispensable amino acids can be synthesized (18). The pool can be used for ''building materials'' in the synthesis of body tissue or for energy requirements through oxidation (6). In our study we assumed that the protein intake of 1.26 $g \cdot kg^{-1} \cdot d^{-1}$ has been regular (on an average 4 times the protein intake per day) throughout the period. According to this assumption it may be that during training the protein intake has not been sufficient for accelerated protein synthesis, which has led to decreases in fasting amino acid concentrations. This is supported by a good anabolic balance. The decrease in the free amino acid pool probably has not been compensated by tissue degradation during the 5-week period.

On the other hand, during the training period the pool may have been used for fuel supply through the glucose-alanine cycle (GAC), which consists of oxidation of BCAAs in the muscle (3) and alanine output by

Table 6. Changes in concentrations of amino acids following long run session (LRS) before and after the 5-week training.†

Amino acids	BI	AI	BI vs. AI	BII	AII	BII vs. AII
Total sum of amino acids	3362 ± 118	3578 ± 118		3195 ± 123	3344 ± 123	
Sum of branched-chain amino acids	508 ± 29	485 ± 29		485 ± 30	459 ± 30	
Sum of essential amino acids	1171 ± 54	1105 ± 54		1142 ± 56	1064 ± 56	
Sum of nonessential amino acids	2190 ± 73	2472 ± 73	*	2052 ± 75	2279 ± 75	*
Leucine	151 ± 10	150 ± 10		147 ± 10	141 ± 10	
Valine	285 ± 16	264 ± 16	**	268 ± 17	253 ±17	
Isoleucine	71 ± 5	70 ± 5		68 ± 5	64 ± 5	
Tryptophan	120 ± 8	79 ± 8	***	130 ± 9	101 ± 9	*
Threonine	143 ± 7	128 ± 7	**	135 ± 7	121 ± 7	**
Ornithine	93 ± 3	79 ± 3	*	75 ± 3	67 ± 3	
Glutamine	691 ± 26	720 ± 26		674 ± 27	699 ± 27	
Alanine	562 ± 38	788 ± 38	***	514 ± 39	748 ± 39	***
Glysine	267 ± 8	248 ± 8	*	252 ± 9	221 ± 9	*
Taurine	76 ± 8	94 ± 8	**	62 ± 8	78 ± 8	
Asparagine	66 ± 4	58 ± 4	**	65 ± 4	57 ± 4	**
Tyrosine	75 ± 5	73 ± 5		81 ± 5	76 ± 5	
Serine	114 ± 7	116 ± 7		109 ± 7	101 ± 7	
Lysine	196 ± 12	200 ± 12		192 ± 12	179 ± 12	
Phenylalanine	66 ± 3	67 ± 3		68 ± 3	65 ± 3	
Metionine	28 ± 2	28 ± 2		28 ± 2	27 ± 2	
Glutamate	58 ± 4	69 ± 4	*	44 ± 4	56 ± 4	***
Arginine	101 ± 12	139 ± 12	**	105 ± 13	99 ± 13	
Citrulline	54 ± 4	51 ± 4		46 ± 4	46 ± 4	
Histidine	107 ± 5	115 ± 5	**	104 ± 5	112 ± 5	**
Aspartate	29 ± 1	32 ± 1		28 ± 2	29 ± 2	

† Mean values ($\mu mol \cdot L^{-1}$) ± *SEM.* BI = before LRS and before the 5-week training period; AI = after LRS and before the 5-week training period; BII = before LRS and after the 5-week training period, and AII = after LRS and after the 5-week training period. Significance for before-after comparisons is shown following the after values.

* $p < 0.01$.

** $p < 0.05$.

*** $p < 0.001$.

the muscles. Alanine is further involved with gluconeogenesis (33). In our study GAC might have accelerated because of intensifying training, thus diminishing the amino acid pool during the 5-week period. This is supported by Babij et al. (1), who has demonstrated a near-linear increase in amino acid oxidation due to increases in exercise intensity. Thus the increased activity of GAC together with the increased protein synthesis might have led to decreased amino acid concentrations during the 5-week training period.

In our study we found a significant increase of 24.5% in the fasting concentration of TE, but the concentration of GH or COR was not changed during the training period. Training-induced adaptations of the endocrine system have previously been examined by Kraemer et al. (15) who found that strength-power training for 10 weeks increased free TE concentration, whereas Falkel et al. (9) observed an increase in the resting levels of serum TE and a decrease in COR after 6 weeks following heavy resistance training in men. These results are in line with our study regarding power-type training except for COR, which was not changed in our study.

Snegovskaya and Viru (31) investigated rowers within 20 months of a training period and stated that a further improvement of the performance capacity in previously trained sportsmen elevated GH and COR levels at least in supramaximal (7 minutes on a rowing apparatus) exercise. The difference in the response may be due to a different kind of training. Endurance-type training may have been of such intensity that GH was stimulated. On the other hand, the decrease of taurine that was seen following power-type training in our study may have inhibited the GH increase, because taurine has been shown to be an effective stimulator of GH secretion (6). Thus the decrease in taurine that was observed in our study may be related to the lack of change in the GH concentration.

The training effect was demonstrated by comparing the relative range of the concentration changes following the exercise bouts before and after the 5-week training period. Significant relative decreases were

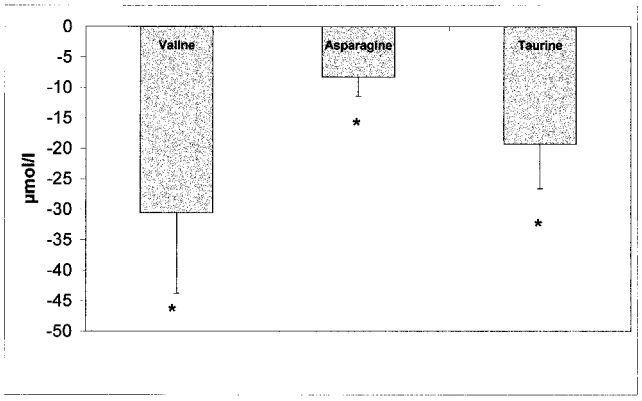

Figure 3. Significant differences in relative decreases in the before-after concentrations of single amino acids following short run session (SRS) during the 5-week training period: * $p < 0.05$.

found in valine, asparagine, and taurine following SRS. Valine is one of the BCAAs and has both anabolic and anticatabolic effects, and it has a role in energy production: therefore the decrease in its concentration in this study might have diminished the amino acid supply to GAC and thus might have affected energy production. Asparagine is an oxaloacetate precursor, and the lack of it may lead to a shorter time to exhaustion in exercise, which, however, was not seen in this study. Taurine is a conditionally essential nutrient, which has antioxidant and protective properties, and it may also have a role in the modulation of calcium levels and osmoregulation. The strong decrease in taurine concentration may lead to pathological changes and toxic damage in cells (6) which can only be speculated about in this study. Consequently it seems that the decreased amino acid concentration following the training period has diminishing effects on the exercise-induced levels of valine, asparagine, and taurine.

The changes in plasma volume were not measured in this study, but according to previous studies, for example running at approximately 75% $\dot{V}O_2$max, results in a 5–10% decrease in plasma volume (36). The loss of plasma from the blood results in a concentration of the constituents of the blood (36). Collins et al. (4, 5) investigated the changes of plasma volume among weightlifters and observed a plasma volume decrease of 7.7–14.3% during weightlifting. Thus without the effect of obvious plasma loss the decreases in amino acid concentrations might have been even greater in our study.

It was noticed that the exercise-induced decreases were great following SRS, and the decreases were even more marked after the training period when the basal amino acid concentrations were already reduced. According to Viru (33), the use of amino aids for adaptive synthesis is intensified during recovery following the end of the activity, but it may be possible that during short recoveries (2 and 6 minutes) in this study SRS protein synthesis is activated. Consequently, the concentrations of the serum amino aids decrease. On the other hand, the GAC may have been accelerated because of an intensifying exercise session (10), which is supported by the increase of the concentration of alanine. This activation might have decreased the concentration of BCAAs.

The significant hormonal increases in absolute values in our study were observed in TE (relatively 30.4%), COR (12.0%), and the TE/COR ratio (21.0%) between the first and the second test occasion following LRS, whereas following SRS we found nonsignificant increases. These findings are in line with the study of Skierska et al. (30), who also found the concomitant increase of anabolic hormones and COR following acute resistance exercise. The concentration of GH did not change following either SRS or LRS at the end of the training period. Following LRS, the increases in the hormonal concentrations were greater probably because the longer duration of the exercise bout diminished plasma volume. As discussed earlier, the average decreases of 5–14% in plasma volume after different exercise sessions show that hormonal increases (12–30%) in this study following LRS are in fact much smaller but probably true. The changes in the concentrations of both TE and COR may reflect the anabolic balance in the physiological loading during the training period, especially because the TE/COR ratio (fasting levels before the 5-week period were 2.5×10^{-2}, and after the 5-week period were 3.2×10^{-2}) was above the overstrain threshold of 0.35×10^{-3} (32), a value below which the performance capacity and recovery is depressed. This value is a critical point in the development of performance and the speed of recovery. In this study the TE/COR ratio points out that the training occurred at the level where muscle gains and performance improving are possible. Consequently the hormonal status of this study may reflect a successful adaptive response to training.

Practical Applications

Our purpose was to study the effects of a 5-week speed- and strength-training period on serum amino acid and hormonal concentrations among sprinters and jumpers following 2 different high-intensity exercise sessions. The results indicated that training induces strong decreases (19.4%) in the fasting amino acid concentrations on the protein intake of 1.26 $g \cdot kg^{-1}$ body weight per day, which may be insufficient for an optimal exercise performance in the power-trained athletes. However, according to the hormonal measurements the subjects were in an anabolic state during the 5-week period. At the same time, the intensive lactic anaerobic exercise session induced strong decreases, especially in valine, asparagine, and taurine, which must be taken into consideration in sport nu-

trition before, during, and after the session. From a practical point of view it seems necessary for power athletes to intake the suggested athletic amount of protein, 1.6–1.7 $g \cdot kg^{-1}$ body weight per day during heavy training (18).

References

1. Babij, P., S.M. Matthews, and M.J. Rennie. Changes in blood ammonia, lactate and amino acids in relation to workload during bicycle ergometer exercise in man. *Eur. J. Appl. Physiol.* 50: 405–411. 1983.
2. Bergström, J., P. Furst, and E. Hultman. Free amino aids in muscle tissue and plasma during exercise in man. *Clin. Physiol.* 5:155–160. 1985.
3. Buse, M.G., J.F. Biggers, K.H. Frederici, and J.E. Buse. Oxidation of branched chain amino acids by isolated hearts and diaphragm of the rat. *J. Biol. Chem.* 247:417–425. 1972.
4. Collins, M.A., K.J. Cuerton, D.W. Hill, and C.A. Ray. Relation of plasma volume change to intensity of weight lifting. *Med. Sci. Sports Exerc.* 21:178–185. 1989.
5. Collins, M.A., D.W. Hill, K.J. Cuerton, and J.J. DeMello. Plasma volume change during heavy-resistance weight lifting. *Eur. J. Appl. Physiol.* 55:44–48. 1986.
6. Di Pasquale, M. *Amino Acids and Proteins for the Athlete.* Boca Raton, FL: CRC Press, 1997. pp. 12–145.
7. Durnin, J.V.G.A., and M.M. Rahaman. The assessment of the amount of fat in the human body from the measurement of skinfold thickness. *Br. J. Nutr.* 21:681–688. 1967.
8. Einspar, K.J., and G. Tharp. Influence of endurance training on plasma amino acid concentrations in humans at rest and after intense exercise. *Int. J. Sports Med.* 10:233–236. 1989.
9. Falkel, J.E., F.C. Hagerman, and R.S. Hikida. Skeletal muscle adaptations during early phase of heavy-resistance training in men and women. *J. Appl. Physiol.* 76(3):1247–1255. 1994.
10. Felig, P., and P. Wahren. Protein turnover and amino acid metabolism in the regulation of gluconeogenesis. *Fed. Proc.* 33: 1029–37. 1974.
11. Florini, J.R. Hormonal control of muscle growth. *Muscle Nerve* 10:577–598. 1987.
12. Komi, P.V., and C. Bosco. Utilization of stored elastic energy in leg extensor muscles by men and women. *Med. Sci. Sports* 10:261–265. 1978.
13. Kraemer, W.J. Hormonal mechanism related to the expression of muscular strength and power. In: *Strength and Power in Sport.* P.V. Komi, ed. Oxford: Blackwell Scientific, 1992. pp. 64.
14. Kraemer, W.J. Endocrine responses and adaptations to strength training. In: *Strength and Power in Sport.* P.V. Komi, ed. Oxford: Blackwell Scientific, 1992. pp. 291.
15. Kraemer, W.J., K. Häkkinen, R.U. Newton, B.C. Nindl, J.S. Volek, M. McCormick, L.A. Gotshalk, S.E. Gordon, S.J. Fleck, W.W. Campell, M. Putukian, and W.J. Evans. Effects of heavy-resistance training on hormonal response patterns in younger vs. older men. *J. Appl. Physiol.* 87(3):982–992. 1999.
16. Kuoppasalmi, K., and H. Adlercreutz. Interaction between catabolic and anabolic steroid hormones in muscular exercise. In: *Exercise Endocrinology.* K. Fotherby, ed. Berlin: George Theime Verlag, 1985. pp. 65–98.
17. Lemon, P.W.R. Protein and amino acid needs of the strength athlete. *Int. J. Sport Nutr.* 1:127–145. 1991.
18. Lemon, P.W.R. Effects of exercise on dietary protein requirements. *Int. J. Sport Nutr.* 8:426–447. 1998.
19. Littell, R.C., G.A. Milliken, W.W. Stroup, and R.D. Wolfinger. *SAS System for Mixed Models.* Cary, NC: SAS Institute Inc., 1996. pp. 633.
20. Meister, A. *Biochemistry of Amino Acids.* New York: Academic Press, 1965. pp. 45–65.
21. Mero, A., E. Peltola, and J. Saarela. Speed and speed endurance training. Jyväskylä: Gummerus, 1987.
22. Mero, A., H. Pitkänen, S.S. Oja, P.V. Komi, P. Pöntinen, and T. Takala. Leucine supplementation and serum amino acids, testosterone, cortisol and growth hormone in male power athletes during training. *J. Sports Med. Phys. Fitness.* 37:137–145. 1997.
23. Mero, A.A., H.T. Pitkänen, P.J. Pöntinen, and S.S. Oja. Acute serum amino acid responses to one strength training session. *Med. Sci. Sports Exerc.* 30(5):S182. 1998.
24. Neter, J., M.H. Kutner, C.J. Nachtsheim, and W. Wasserman. *Applied Linear Statistical Models* (4th ed.). San Diego: Academic Press, 1996.
25. Nutrition Recommendations for Athletes in Finland. Helsinki: Printer Center, 1990.
26. Paul, G.L. Dietary protein requirements of physically active individuals. *Sports Med.* 8:164–176. 1991.
27. SAS Institute Inc. *SAS Procedures Guide, Version 6* (3rd ed.). Cary, NC: SAS Institute Inc., 1990. pp. 705.
28. SAS Institute Inc. *SAS System for Statistical Graphics* (1st ed.). Cary, NC: SAS Institute Inc., 1991. pp. 697.
29. SAS Institute Inc. *SAS/STAT Software: Changes and Enchancements Through Release 6.11.* Cary, NC: SAS Institute Inc., 1996. pp. 1104.
30. Skierska, E., J. Ustupska, B. Biczowa, and J. Lukaszewska. Effect of physical exercise on plasma cortisol, testosterone and growth hormone levels in weight lifters. *Endokrynologia Polska* 2:159–165. 1976.
31. Snegovskaya, V., and A. Viru. Elevation of cortisol and growth hormone levels in the course of further improvement of performance capacity in trained rowers. *Int. J. Sports Med.* 14:202–206. 1993.
32. Vervoorn, C., A.M. Quist, L.J. Vermulst, W.B. Erich, W.R. de Vries, and J.H. Thijssen. The behaviour of the plasma free testosterone/cortisol ratio during a season of elite rowing training. *Int. J. Sports Med.* 12(3):257–263. 1991.
33. Viru, A. Mobilisation of structural proteins during exercise. *Sports Med.* 4:95–128. 1987.
34. Viru, A. Plasma hormones and physical exercise. *Int. J. Sports Med.* 13(3):201–209. 1992.
35. Waterlow, J.C., P.J. Garlick, and D.J. Millward. *Protein Turnover in Mammalian Tissues and in the Whole Body.* New York: North Holland, 1978. pp. 22–49.
36. Wilmore, J.H., and D.L. Costill. *Physiology of Sport and Exercise.* Champaign, IL: Human Kinetics, 1994. pp. 139–141.

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