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# The Effects of Amino Acid Supplementation on Muscular Performance During Resistance Training Overreaching

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**ABSTRACT**

The purpose of this study was to examine the effects of amino acid supplementation on muscular strength, power, and high-intensity endurance during short-term resistance training overreaching. Seventeen resistance-trained men were randomly assigned to either an amino acid (AA) or placebo (P) group and underwent 4 weeks of total-body resistance training consisting of two 2-week phases of overreaching (phase 1: 3 × 8–12 repetitions maximum [RM], 8 exercises; phase 2: 5 × 3–5RM, 5 exercises). Muscle strength, power, and high-intensity endurance were determined before (T1) and at the end of each training week (T2–T5). One repetition maximum squat and bench press decreased at T2 in P (5.2 and 3.4 kg, respectively) but not in AA, and significant increases in 1RM squat and bench press were observed at T3–T5 in both groups. A decrease in the ballistic bench press peak power was observed at T3 in P but not AA. The fatigue index during the 20-repetition jump squat assessment did not change in the P group at T3 and T5 (fatigue index = 18.6 and 18.3%, respectively) whereas a trend for reduction was observed in the AA group ($p = 0.06$) at T3 (12.8%) but not T5 (15.2%; $p = 0.12$). These results indicate that the initial impact of high-volume resistance training overreaching reduces muscle strength and power, and it appears that these reductions are attenuated with amino acid supplementation. In addition, an initial high-volume, moderate-intensity phase of overreaching followed by a higher intensity, moderate-volume phase appears to be very effective for enhancing muscle strength in resistance-trained men.

***Key Words:*** muscle strength, power, fatigue, high-intensity endurance

***Reference Data:*** Ratamess, N.A., W.J. Kraemer, J.S. Volek, M.R. Rubin, A.L. Gómez, D.N. French, M.J. Sharman, M.M. McGuigan, T. Scheett, K. Häkkinen, R. U. Newton, and F. Dioguardi. The effects of amino acid supplementation on muscular performance during resistance training overreaching. *J. Strength Cond. Res. 17(2):250–258. 2003.*

## Introduction

Overreaching is a short-term training phase in which the volume and/or the intensity of resistance exercise is increased beyond normal. The rationale is to overwork (in order to suppress performance and build up tolerance) and then taper to produce a subsequent ‘‘rebound’’ in performance (8, 10, 23). Overreaching for an extended period of time may lead to overtraining in which significant declines in performance are observed. However, the overwork associated with overreaching is typically mild and recovery may occur relatively quickly following normal or reduced training (23). Thus the practice of acute overreaching may enhance performance only if it is followed by normal training. In particular, athletes who may not have the opportunity to reduce training volume and/or intensity during acute overreaching may experience reductions in muscle strength and power, which could have a negative impact on performance during a competitive season and possibly result in overtraining. Therefore, nutritional interventions that enhance recovery may be necessary to optimize performance in these individuals.

Amino acid supplementation has been reported to augment recovery during endurance and resistance exercise by mechanisms that are unclear but appear to involve increasing protein synthesis and/or reducing protein degradation and reducing muscle damage (5, 7, 17). Although most of the literature has focused on amino acid supplementation during endurance training, it appears that the overall volume and intensity of exercise are critical factors for determining macronutrient needs. However, less is known concerning the effects of amino acid supplementation during short-term resistance training overreaching for periods longer than 1 week (9). Considering that athletes need to perform under stressful conditions and many times show signs of overwork, amino acid supplementation may be beneficial if it enables the athlete to maintain performance when adequate recovery between workouts, competitions, practices, etc., is not feasible. Therefore, the purpose of the present study was to investigate the effects of amino acid supplementation during short-term resistance training overreaching. It was our hypothesis that amino acid supplementation, by enhancing recovery between workouts, would maintain muscle strength and power during the initial unaccustomed stress of resistance training overreaching. In addition, a secondary purpose was to examine the rapidity of the ''rebound'' effect associated with overreaching, which would serve as an indicator of the efficacy of the overreaching program used in the present study.

## Methods

### *Experimental Approach to the Problem*

In order to examine the primary hypothesis of this investigation, a double-blind randomized study was employed using 2 experimental groups (amino acid or placebo supplementation) who underwent 4 weeks of resistance training overreaching followed by a 2-week reduced volume/frequency phase. The training program consisted of 2 weeks of moderate-intensity, high-volume resistance training and 2 weeks of high-intensity and a lower volume of resistance training. Acute overreaching was produced by training the whole body on consecutive days, thereby minimizing recovery between workouts. Muscular strength, power, and high-intensity endurance were assessed every 2 weeks. This experimental design enabled us to investigate potential ergogenic effects (e.g., recovery enhancement) of amino acid supplementation during resistance training overreaching in resistance-trained men.

### *Subjects*

Seventeen resistance-trained men were matched for body mass, age, and muscle strength and were randomly assigned to 1 of 2 supplementation treatments, an amino acid (AA; $N = 9$, age $= 19.7 \pm 1.4$ years, height $= 183.6 \pm 6.9$ cm, body mass $= 89.1 \pm 19.8$ kg, and training experience $= 4.4 \pm 2.2$ years) or a placebo (P; $N = 8$, age $= 21.3 \pm 3.0$ years, height $= 179.4 \pm 6.4$ cm, body mass $= 88.9 \pm 11.1$ kg, and training experience $= 5.1 \pm 3.0$ years) group. Each of the subjects were informed of the benefits and risks of the investigation and subsequently signed an approved consent form in accordance with the guidelines of the university Institutional Review Board for use of human subjects. No participant had any medical or orthopedic problems that would compromise his participation and performance in the study. In addition, none of the subjects was taking any medications, nutrition supplements, or anabolic drugs that would confound the results of this study.

**Table 1.** Composition of the amino acid supplement.

| Amino acid | mg/Tablet | g/100 g |
|---|---|---|
| L-leucine | 250 | 27.2 |
| L-lysine | 130 | 14.1 |
| L-isoleucine | 125 | 13.6 |
| L-valine | 125 | 13.6 |
| L-threonine | 70 | 7.6 |
| L-cysteine | 30 | 3.3 |
| L-histidine | 30 | 3.3 |
| L-phenylalanine | 20 | 2.2 |
| L-methionine | 10 | 1.1 |
| L-tyrosine | 6 | 0.7 |
| L-tryptophan | 4 | 0.4 |

Subjects assigned to the AA group ingested a total of 0.4 g/kg body weight of an amino acid supplement per day divided into 3 daily doses (Big One; Professional Dietetics, Milan, Italy). In addition, each participant was instructed to ingest the supplement separate from meals, 1 hour before a meal, and 2 hours following a meal. The composition of the amino acid supplement is presented in Table 1. Subjects in the P group received the same instructions and ingested the same number of capsules as the AA group. All supplement doses were administered by a registered dietitian who calculated each serving size and distributed the supplements in clearly marked plastic bags. All subjects recorded the times of supplementation in accordance with the investigators' instructions.

### *Strength Testing*

One-repetition maximum (1RM) strength was determined for the free-weight squat and bench press exercises according to methods previously described by Kraemer and Fry (16). A warm-up set of 5–10 repetitions was performed using 40–60% of the perceived maximum 1RM. After a 1-minute rest period, a set of 2–3 repetitions was performed at 60–80% of the perceived maximum 1RM. Subsequently, 3–4 maximal trials (1-repetition sets) were performed to determine the 1RM. Rest periods between trials were 2–3 minutes. A complete range of motion and proper technique were required for each successful 1RM trial. For the squat exercise, each participant was instructed to descend until the upper thighs were parallel to the ground. A research assistant was located lateral to the subject and gave a verbal ''up'' signal to initiate the concentric action of the exercise. For the bench press, each participant lowered the bar until it came in contact with the chest musculature. ''Bouncing'' the weight off of the chest and excessive arching of the back were not permitted. Strength testing was performed prior to initiation of the 4-week overreaching period (T1), and after the completion of each training week (T2, T3, T4, and T5). In addition, 1RM testing was performed after a 2-week reduced volume and frequency period (RED). Strength testing was performed at the same time each session and approximately 24 hours following the last training session. All subjects refrained from activity not related to the present investigation for at least 24 hours prior to testing. Test-retest reliability for both the squat and bench press was $R = 0.99$.

### *Power Testing*

Upper and lower body power was measured using the ballistic bench press and jump squat exercises, respectively, with the Plyometric Power System (PPS; Norsearch Limited, Lismore, Australia). The PPS enables ballistic movement and has been described in detail elsewhere (15). For the jump squat, each participant descended to a position in which the thigh musculature was parallel to the ground. In a ballistic manner, each participant ascended as rapidly as possible and proceeded to jump as high as possible while minimizing any contributions from the arms. The weight was released upon jumping and bar displacement was calculated. For the ballistic bench press, each participant lowered the weight from the fully extended elbow position until it came in contact with the chest musculature. The concentric action of the exercise was performed as rapidly as possible, and the weight was released upon completion. The PPS incorporates a unidirectional electromagnetic braking system that immediately prevented descending bar movement once engaged. Thus the bar was safely released. A rotary encoder attached to the PPS and interfaced with a computer-enabled measurement of bar movement with an accuracy of 0.001 m, and peak power was calculated.

The jump squat and ballistic bench press were performed with a load corresponding to 30% of the squat and bench press 1RM, respectively, attained during the pretraining testing period. Testing order was randomized such that half of the subjects began with the squat jump and half began with the ballistic bench press. Each participant was given 3–5 maximal trials with 2 minutes of rest between trials, and the best trial was recorded for analysis. Power testing was performed prior to initiation of the training program (T1), after the 2-week higher volume phase (T3), after the 2-week lower volume phase (T5), and following the 2-week reduced volume/frequency phase (RED).

Following peak power testing, each participant performed a 20-repetition jump squat protocol used to measure high-intensity local muscle endurance. Loading for this assessment consisted of 30% of each participant's pretraining 1RM squat. Subjects were instructed to jump as high as possible for each repetition while maintaining proper exercise technique and range of motion. The fatigue index (percentage decline in power) was calculated by using the following equation: $[(\text{peak power} - \text{lowest power}) / \text{peak power}] \times 100$. Test-retest reliabilities for all power tests ranged from 0.97 to 0.99.

### *Anthropometry and Body Composition*

Circumference measurements were obtained using standardized procedures (22) before and following the overreaching period (T1 and T5). The sites for circumference measurements were the right thigh, upper arm, chest, and waist. The same individual performed all circumference measurements. Percent body fat and bone mineral density were obtained with dual energy X-ray absorptiometry (DEXA) at T1 and T5 with a total-body scanner (Prodigy, Lunar Corporation, Madison, WI) that uses a constant potential X-ray source of 76 kVp and a cerium filter that produces dual-energy peaks of 38 and 62 keV. All analyses were performed by the same technician using computer algorithms (software version 2.17.008). Quality assurance was assessed by analyzing a phantom spine provided by the company, and daily calibrations were performed prior to all scans using a calibration block provided by the manufacturer. Intraclass correlation coefficients ($R \geq 0.98$) were obtained for bone mineral content, lean body mass, and fat mass from repeated scans on a group of men and women in our laboratory.

### *Nutrition Assessment*

In order to control for possible confounding effects of alterations in dietary intake over the training period and to isolate the independent effects of the supplementation treatments, an attempt was made to standardize dietary nutrient intake at an isocaloric level for each individual. Prior to beginning the study, subjects were weighed before and after a 7-day period during which time they recorded all food/beverages consumed according to instructions provided by the same registered dietitian. If body weight fluctuated $>1$ kg during the 7-day period, subjects were provided with nutritional counseling to either increase or decrease food intake in order to maintain body weight. The 7-day food records were subsequently photocopied and returned to subjects. All subjects reproduced this 7-day diet during each week of the training and supplementation period. Prior to beginning the study, each group consumed similar relative proportions of car-

**Table 2.** Resistance training program.

| Week | Monday, Wednesday | Tuesday, Thursday | Friday |
|---|---|---|---|
| 1 | Back squat, 3 × 10–12* | Leg press, 3 × 10–12* | 1RM squat |
| | Bench press, 3 × 10–12* | Incline bench press, 3 × 10–12* | 1RM bench press |
| | Lat pulldown, 3 × 10–12† | Bent-over row, 3 × 10–12† | |
| | Lunge, 3 × 10–12† | Stiff-leg deadlift, 3 × 10–12† | |
| | Seated shoulder press, 3 × 10–12† | Upright row, 3 × 10–12† | |
| | Dumbbell curl, 3 × 10–12† | Barbell curl, 3 × 10–12† | |
| | Lying triceps extension, 3 × 10–12† | Dips, 3 × 10–12† | |
| | Leg raise, 3 × 20‡ | Sit-ups, 3 × 20‡ | |
| 2 | Back squat, 3 × 8–10* | Leg press, 3 × 8–10* | 1RM squat |
| | Bench press, 3 × 8–10* | Incline bench press, 3 × 8–10* | 1RM bench press |
| | Lat pulldown, 3 × 8–10† | Bent-over row, 3 × 8–10† | Jump squats |
| | Lunge, 3 × 8–10† | Stiff-leg deadlift, 3 × 8–10† | Ballistic bench press |
| | Seated shoulder press, 3 × 8–10† | Upright row, 3 × 8–10† | |
| | Dumbbell curl, 3 × 8–10† | Barbell curl, 3 × 8–10† | |
| | Lying triceps extension, 3 × 8–10† | Dips, 3 × 8–10† | |
| | Leg raise, 3 × 20‡ | Sit-ups, 3 × 20‡ | |
| 3 | Back squat, 5 × 5* | Leg press, 5 × 5* | 1RM squat |
| | Bench press, 5 × 5* | Incline bench press, 5 × 5* | 1RM bench press |
| | Deadlift, 5 × 5† | High pull, 5 × 5† | |
| | Lat pulldown, 5 × 5† | Bent-over row, 5 × 5† | |
| | Seated shoulder press, 5 × 5† | Close-grip bench press, 5 × 5† | |
| 4 | Back squat, 5 × 3* | Leg press, 5 × 3* | 1RM squat |
| | Bench press, 5 × 3* | Incline bench press, 5 × 3* | 1RM bench press |
| | Deadlift, 5 × 3† | High pull, 5 × 3† | Jump squats |
| | Lat pulldown, 5 × 3† | Bent-over row, 5 × 3† | Ballistic bench press |
| | Seated shoulder press, 5 × 3† | Close-grip bench press, 5 × 3† | |

* Three minutes of rest between sets.
† Two minutes of rest between sets.
‡ One minute of rest between sets.

bohydrates, fats, and protein. However, during the study the AA group consumed an additional 25–55 g protein per day via amino acid supplementation.

### *Resistance Training*

Prior to initiation of the 4-week overreaching program, each participant underwent 4 weeks of base resistance training. This ensured that each subject began the study in a trained state. Base training consisted of 5 exercises per workout (squat, bench press, lat pulldown, leg press, and shoulder press) for 3 sets of 8–10 repetitions with 1–3 minutes of rest between sets performed 2 days per week.

Multiple-set, periodized resistance training was performed on 4 consecutive days using a total-body program (see Table 2). Due to time limitation constraints with the subjects, the overreaching program trained each muscle group on consecutive days, thereby limiting recovery. That way a program lasting approximately 1.5 hours would suffice. The first 2 weeks consisted of a higher volume, moderate-intensity resistance exercise, whereas the last 2 weeks consisted of high intensity with a lower volume of resistance exercise. All sets were performed with RM loads such that all sets were either performed to or near muscular exhaustion. When each subject was able to complete the desired number of repetitions with the current load, weight was added to subsequent sets or during the next workout. All workouts were supervised by a certified strength and conditioning specialist who also monitored the training loads (20).

Following the 4-week experimental period, each participant underwent a 2-week RED resistance training phase. The program used during this phase was identical to the base resistance training program used prior to initiation of the 4-week overreaching protocol (i.e., 5 exercises per workout, 8–10 repetitions, 2 days per week). Only 1RM squat, bench press, peak power attained during the ballistic bench press, and jump squat were assessed following this training 2-week phase.

### *Statistical Analyses*

Statistical evaluation of all performance data was accomplished using an analysis of variance (ANOVA) with repeated measures. Subsequent pairwise differences were determined using a Tukey post-hoc test when appropriate. For the 20-repetition jump squat as-

**Table 3.** Changes in anthropometry and body composition.*

| | T1 | T2 | T3 | T4 | T5 |
|---|---|---|---|---|---|
| Body mass (kg) | | | | | |
| AA | 89.1 ± 19.8 | 90.4 ± 19.8 | 90.4 ± 20.1 | 90.9 ± 20.1 | 90.9 ± 20.0 |
| P | 88.9 ± 11.1 | 90.1 ± 11.1 | 89.7 ± 10.7 | 89.9 ± 10.8 | 89.8 ± 10.5 |
| Bone mineral density ($g \cdot cm^2$) | | | | | |
| AA | 1.32 ± 0.09 | | | | 1.32 ± 0.09 |
| P | 1.34 ± 0.06 | | | | 1.31 ± 0.05 |
| Chest cir. (cm) | | | | | |
| AA | 105.9 ± 11.8 | | | | 105.7 ± 11.5 |
| P | 107.4 ± 7.9 | | | | 107.1 ± 6.3 |
| Thigh cir. (cm) | | | | | |
| AA | 60.3 ± 6.3 | | | | 61.2 ± 6.3 |
| P | 60.0 ± 4.8 | | | | 60.0 ± 2.5 |
| Upper arm cir. (cm) | | | | | |
| AA | 34.7 ± 3.6 | | | | 35.5 ± 3.4 |
| P | 35.7 ± 2.3 | | | | 36.0 ± 2.0 |
| Waist cir. (cm) | | | | | |
| AA | 86.4 ± 11.8 | | | | 85.9 ± 11.1 |
| P | 90.8 ± 9.0 | | | | 89.4 ± 8.6 |
| Body fat (%) | | | | | |
| AA | 18.1 ± 9.6 | | | | 18.1 ± 9.2 |
| P | 20.3 ± 8.8 | | | | 19.3 ± 8.6 |

* T1 indicates before training; T2–T5, training weeks 1–4; AA, amino acid group; P, placebo group; cir., circumference.

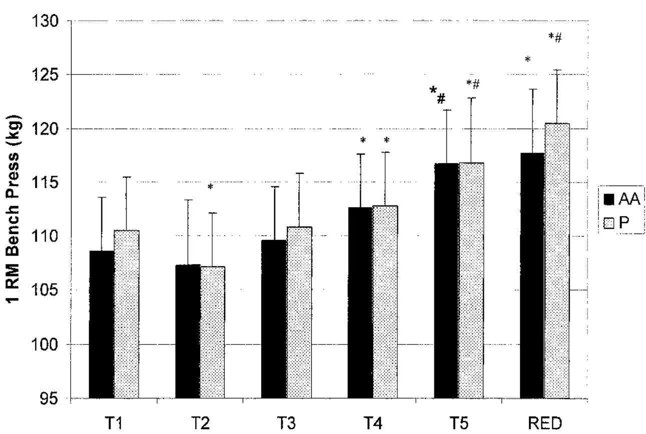


**Figure 1.** Changes in 1 repetition maximum (1RM) bench press during 4 weeks of resistance training overreaching and 2 weeks of reduced volume/frequency training. AA indicates amino acid group; P, placebo group. T1, baseline; T2, after week 1 of protocol; T3, after week 2 of protocol; T4, after week 3 of protocol; T5, after week 4 of protocol; RED, after reduced volume/frequency 2-week period. Asterisk indicates $p < 0.05$ from corresponding point T1; number sign (#), $p < 0.05$ from previous time point. Data presented are means ± *SE*.

sessment, the delta change in the fatigue index between T1–T3 and T3–T5 was used for the ANOVA. Using the nQuery Advisor software (Statistical Solutions, Saugus, MA), the statistical power for the *n* size used ranged from 0.80 to 0.92. Significance was set at $p \leq 0.05$.

## Results

Changes in anthropometry, body composition, muscle strength, and power are presented in Table 3 and Figures 1–4. One repetition maximum squat and bench press decreased significantly at T2 in P, whereas no change was observed in AA. At T3, 1RM squat and bench press reached baseline T1 values in P, whereas a significant increase in 1RM squat was observed in AA. Both 1RM squat and bench press increased significantly at T4 and T5 with no differences observed between groups. Following RED training period, 1RM bench press did not change significantly (117.7 ± 18.9 kg) in the AA group ($p = 0.17$) but increased significantly (120.5 ± 15.5 kg) in the P group. For the 1RM squat, both groups increased significantly following RED (AA = 145.0 ± 35.0 kg; $P$ = 150.0 ± 23.4 kg). No differences were observed between groups in either the 1RM bench press or squat at RED.

Peak power during the ballistic bench press decreased significantly in the P group at T3, whereas no

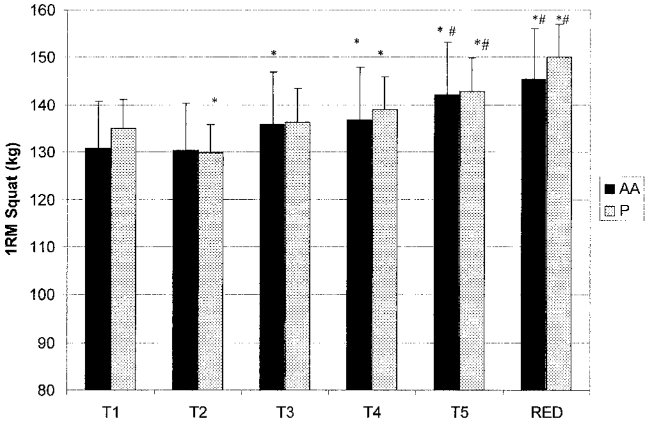


**Figure 2.** Changes in 1 repetition maximum (1RM) squat during 4 weeks of resistance training overreaching and 2 weeks of reduced volume/frequency training. AA indicates amino acid group; P, placebo group. T1, baseline; T2, after week 1 of protocol; T3, after week 2 of protocol; T4, after week 3 of protocol; T5, after week 4 of protocol; RED, after reduced volume/frequency 2-week period. Asterisk indicates $p < 0.05$ from corresponding point T1; number sign (#), $p < 0.05$ from previous time point. Data presented are means ± *SE.*

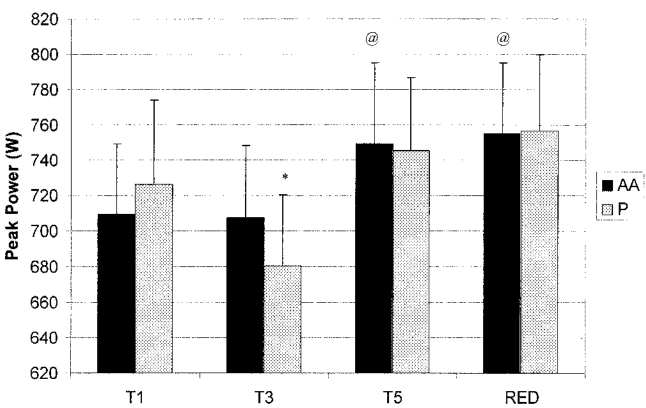


**Figure 3.** Changes in ballistic bench press peak power at T1, T3, T5, and following 2 weeks of reduced volume/frequency training. AA indicates amino acid group; P, placebo group. T1, baseline; T3, after week 2 of protocol; T5, after week 4 of protocol; RED, after reduced volume/frequency 2-week period. Asterisk (*) indicates $p < 0.05$ from corresponding point T1; at sign (@), $p = 0.08$ from corresponding point T1. Data presented are means ± *SE.*

difference was observed in the AA group. At T5, peak power during the ballistic bench press returned to baseline (T1) values in the P group, but a trend ($p = 0.08$) for improvement was observed in the AA group. In the RED period, peak power during the ballistic bench press did not change significantly in either group (AA = 755.1 ± 124.8 W; P = 756.4 ± 136.5 W). Peak power during the jump squat did not significantly change at T3 in either group. At T5, peak power during the jump squat increased significantly in the AA group only as the small increase observed in the

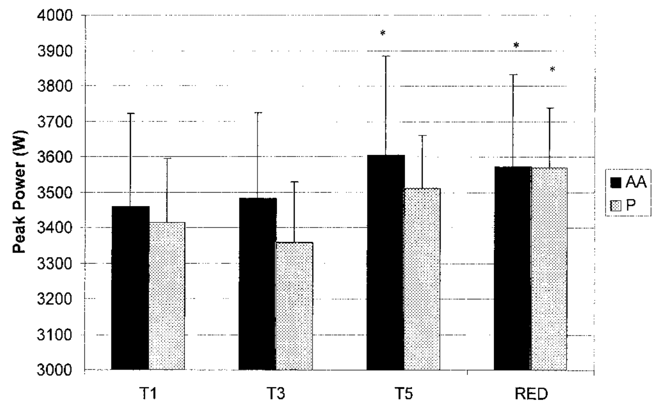


**Figure 4.** Changes in jump squat peak power at T1, T3, T5, and following 2 weeks of reduced volume/frequency training. T1, baseline; T3, after week 2 of protocol; T5, after week 4 of protocol; RED, after reduced volume/frequency 2-week period. Asterisk (*) indicates $p < 0.05$ from corresponding point T1. Data presented are means ± *SE.*

P group was not significant ($p = 0.12$). In the RED period, peak power during the jump squat did not change significantly from T5 in either group (AA = 3572.1 ± 811.1 W; P = 3569.7 ± 510.2 W). However, the increase observed in the P group was significant in comparison to T1. No significant changes in body mass density, circumferences, or percent body fat were observed in either group.

The fatigue index during the 20-repetition jump squat assessment was calculated at T1, T3, and T5 in both groups. At T1 there was no significant difference between groups (21.4 vs. 19.3% in the AA and P groups, respectively). In the P group there were no differences in the fatigue index at T3 and T5 (fatigue index = 18.6 and 18.3%, respectively). In the AA group a trend ($p = 0.06$) for a reduction in the fatigue index was observed at T3 (12.8%) but not T5 (15.2%; $p = 0.12$). In addition, a trend for a lower fatigue index was observed in the AA group compared with the P group at T3 ($p = 0.09$). It appeared that this trend between groups took place during the last 5 repetitions of the protocol, although ANOVA revealed no significant differences in the power attained between groups in any of the repetitions ($p = 0.19$–$0.43$).

## Discussion

The major findings of this study are (a) the initial stress of acute resistance training overreaching reduces muscle strength and power, and this phenomenon is attenuated by amino acid supplementation; (b) a trend for a reduction in the fatigue index during the 20-repetition jump squat assessment was observed during the first phase of the overreaching period in the AA group; and (c) the overreaching program used in the present study was very effective for enhancing muscular strength in resistance-trained men.

Amino acid supplementation has been shown to enhance recovery from exercise by increasing protein synthesis and/or reducing degradation (2, 25); by enhancing glycogen resynthesis when ingested with glucose; and by reducing muscle damage (2, 7). Efficient recovery of protein metabolism is critical to maintaining and promoting the anabolic processes involved in maintenance and development of skeletal muscle mass (2). Recovery from consecutive total-body workouts is critical to performance, especially when overreaching is performed with the goal of enhancing performance due to a rebound effect (8, 23). Dietary intake strategies to help mediate optimal repair and recovery of skeletal muscle have prompted the suggestion that high-volume and/or high-intensity resistance training increases protein needs (18, 21). In the present study, muscle strength and upper-body power were significantly reduced only during the initial phase of overreaching in the P group. A reduction was not observed in the AA group, thus showing the importance of greater amino acid intake during this initial phase of overreaching. Conversely, with the increase in the intensity and partial reduction in volume of the overreaching protocol, no performance reduction was observed during weeks 3 and 4. This demonstrated that the ability of resistance-trained men to rapidly adapt to a new training stimulus helped mediate a successful overreaching endpoint of higher performance values. The rapidity of adaptation to a resistance exercise stress may underlie the effectiveness of the overreaching protocol and be aided by the early amino acid intake in those unaccustomed to the initial training stress. This was shown by Fry et al. (9), who reported no reductions in performance (and consequently no effects of amino acid supplementation) during 1 week of high-volume overreaching in elite junior weightlifters accustomed to this type of training stress. In addition, it has been shown previously that adaptation to the initial stress of eccentric training may take place in as few as 13 days (19). Our data present a similar time course of adaptation. The body's ability to rapidly adapt to the stresses of an overreaching protocol (i.e., changes in protein kinetics, neural activation, etc.) in resistance training clearly demonstrates the need for variation in program design.

The results of the present study indicate that amino acid supplementation does not provide an ergogenic effect for strength improvement during the rebound phase of a short-term overreaching period. This finding supports previous research in men and women during traditional resistance training. Williams et al. (26) reported that postresistance exercise glucose/amino acid supplementation (0.2 g/kg body mass) did not significantly enhance muscle strength after 10 weeks of training. Antonio et al. (3) reported no significant additional improvements in muscle strength with amino acid supplementation in previously untrained women. Therefore, our results support these data from other laboratories, as no advantage in strength enhancement was observed during amino acid supplementation after the subjects adapted to the initial phase of the overreaching protocol.

Amino acid supplementation appeared to provide a small advantage for peak power performance throughout the course of the present study. The AA group maintained both jump squat and ballistic bench press peak power performance at T3, whereas a significant reduction in the ballistic bench press was observed in the P group. In addition, only the AA group showed a significant increase at T5 in the jump squat (146 vs. 98 W, respectively, in AA and P) and a trend ($p = 0.08$) for increase at T5 in the ballistic bench press (40 vs. 20 W, respectively, for AA and P). The lack of a significant increase in peak power in the P group at T5 (in comparison with strength improvements) was not surprising. The subjects in this study had significant training experience and the program used was traditional in the sense that ballistic exercises (i.e., those most effective exercises for improving power) were not included. Several studies have shown improved power performance following a traditional resistance training program in moderately trained individuals (1, 4). However, the effectiveness of traditional resistance training methods used solely for developing maximal power has been questioned in trained individuals because this type of training tends to only increase maximal strength at slow movement velocities, rather than improving the other components contributing to maximal power production (12). In fact, heavy resistance training may actually decrease power output unless accompanied by explosive movements (6). Our data demonstrate that improvements in power capacity do occur with traditional resistance training overreaching and that the rate of improvement appears to be augmented with amino acid supplementation.

It appeared that the initial stress of the overreaching protocol reduced power to a longer extent than muscle strength in the P group, as peak power was still reduced 2 weeks into the protocol (as opposed to 1 week for the strength measurements). These data indicate that power production may be more susceptible than strength to reductions during the initial stress of overreaching. This finding is of particular importance to athletes who frequently train using high volumes of exercise. Considering that muscle power is a better indicator of sports performance than muscle strength per se, any reductions in power could potentially affect sports performance. Maintenance of power during these high-volume periods would be advantageous, and therefore our data demonstrate a potential benefit of amino acid supplementation during these high-volume training phases.

High-intensity local muscle endurance, as measured using the 20-repetition jump squat protocol, tended to improve only in the AA group at T3 ($p = 0.06$). The fatigue index decreased from 21.4% (T1) to 12.8% (T3) in the AA group, whereas no difference was observed in the P group (19.3–18.6%) during this higher volume phase of overreaching. Amino acid supplementation, especially branched-chain amino acids, has been suggested to improve endurance during aerobic events. However, less is known concerning high-intensity local muscle endurance performance. Amino acid supplementation did not provide an advantage for increasing 12RM loads compared with placebo following 6 weeks of resistance training in previously untrained women (3). In the present study, the small advantage gained with amino acid supplementation appeared to take place during the last 5 repetitions of the protocol (e.g., repetitions 16–20), as peak powers were similar between groups initially during the first several repetitions, and yet the fatigue index was lower in the AA group, indicating less of a drop-off in power during the last few repetitions. Therefore, our data indicate that amino acid supplementation may be advantageous for augmenting high-intensity local muscular endurance during resistance training overreaching when a sufficient duration is used (i.e., at least 15 repetitions for power testing). To our knowledge this is the first study showing high-intensity local muscle endurance enhancement with amino acid supplementation during resistance training overreaching.

An interesting finding in the present study was the effectiveness of the overreaching protocol for improving muscular strength and power. It has been suggested that acute increases in volume and/or intensity of resistance exercise resulting in a greater volume load may enhance performance when followed by normal or reduced training (23). A possible decrement in performance may be observed due to the initial stress, but the adaptation then provides greater tolerance for increasing intensity during subsequent training phases (24). This period of reduced volume/frequency, or ''tapering,'' has been shown to enhance performance over an 8-day period, providing adequate intensity is maintained (11). The first 2-week phase used in the present study was of high volume in comparison with the second 2-week phase. We expected an initial decrement in performance, as the subjects were accustomed to a 3–4 d/wk resistance training split routine program (thereby having at least 48 hours of recovery before the muscles are trained subsequently) and not a program stressing all major muscle groups intensely on consecutive days. Our data demonstrate that an initial high-volume overreaching phase may reduce performance as previously suggested (23), although this reduction was attenuated by amino acid supplementation. Interestingly, when the frequency remained constant, the intensity significantly increased, and the volume was somewhat reduced during the second phase there were significant weekly strength increases in both groups at T4 and T5. Most remarkably, the improvements at T4 and T5 were greater than those observed during our 2-week RED period where subjects returned to the base resistance training program. These data demonstrate the importance of high-intensity resistance training following high-volume training to optimize the benefits of overreaching. It appeared that the high-volume phase prepared the subjects physiologically by increasing tolerance for the high-intensity phase. Although the tapering did produce significant increases in strength and power, the impact was less dramatic than that observed during the high-intensity phase.

No differences were observed in circumferences, bone mineral density, or body composition. The duration of the experimental protocol may not have been long enough to significantly increase muscle mass in resistance-trained men. The protocol used in the present study limited recovery between workouts. Considering the importance of recovery for muscle hypertrophy, it appears that the lack of change observed in the present study may have been partially caused by the high initial stress of the training program. In addition, the lack of hypertrophy and significant increases in strength may reflect the importance of neural factors for increasing strength in resistance-trained men, especially when the intensity is high (e.g., 3–5RM loading phase used in the present study). Increases in lifting performance with minimal hypertrophy have been shown in elite weightlifters over long-term training periods (12–14). Our findings suggest that an interplay may exist between neural and hypertrophic factors for strength improvements in resistance-trained men.

In summary, amino acid supplementation was effective for attenuating the reductions in muscle strength and power observed during the high initial stress of resistance training overreaching. In addition, the overreaching program used in the present study was effective for increasing muscular strength and power in resistance-trained men. These findings demonstrate a potential benefit of amino acid supplementation during high-volume resistance training.

## Practical Applications

In the quest for optimal performance, nutritional supplementation has been a topic of interest in the strength and conditioning field for many years. Amino acid supplementation has been studied mostly in endurance training, and the few resistance training studies that have investigated the subject have shown potential benefits for increasing protein synthesis, reducing protein degradation, and reducing muscle damage without providing an ergogenic effect for overall strength and power enhancement. The results of the present study show a beneficial role of amino acids in enhancing recovery and maintaining performance during the initial phase of high-volume resistance training overreaching. These findings have direct impact on nutritional strategies for optimizing performance during high-volume resistance training overreaching.

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