Iron Status of Young Males and Females Performing Weight-Training Exercise

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ABSTRACT

DERUISSEAU, K. C., L. M. ROBERTS, M. R. KUSHNICK, A. M. EVANS, K. AUSTIN, and E. M. HAYMES. Iron Status of Young Males and Females Performing Weight-Training Exercise. *Med. Sci. Sports Exerc.*, Vol. 36, No. 2, pp. 241–248, 2004. **Purpose:** To determine the effect of weight training on measures of iron status in young males and females. **Methods:** Forty (27 female, 13 male) non-weight-trained college age subjects participated in a 12-wk weight-training program conducted 3 $d \cdot wk^{-1}$. Blood samples and food diaries were obtained pretraining and at 4-wk intervals. Blood was analyzed for hemoglobin, hematocrit, serum iron (SI), total iron binding capacity (TIBC), transferrin saturation (TS), serum ferritin (SF), soluble transferrin receptor (sTfR), and creatine kinase (CK). Subjects were grouped by SF level (FL, females $\leq$ 20 $\mu g \cdot L^{-1}$; FN, females $>$ 20 $\mu g \cdot L^{-1}$; ML, males $\leq$ 45 $\mu g \cdot L^{-1}$; MN, males $\geq$ 50 $\mu g \cdot L^{-1}$) to determine the impact of initial iron status on measured responses. **Results:** Weight training increased strength and fat-free mass and decreased levels of percent body fat. Hemoglobin concentration declined after 12 wk of training (13.7 $\pm$ 1.6 vs 13.2 $\pm$ 1.7 $g \cdot dL^{-1}$), independent of gender or initial iron status. Only the MN group experienced a decline in SF level after 8 wk of training (129.7 $\pm$ 77.9 vs 102.0 $\pm$ 57.8 $\mu g \cdot L^{-1}$). No significant changes were observed for hematocrit, SI, TIBC, TS, sTfR, or CK measures. Total iron intake, but not heme or bioavailable iron intakes, declined at the 12th week of training compared with baseline (13.4 $\pm$ 6.5 vs 10.7 $\pm$ 4.8 $mg \cdot d^{-1}$) and was not significantly correlated with hematological or iron status measures. **Conclusions:** Hemoglobin concentration declines without alterations in SI, TIBC, TS, or sTfR after 12 wk of weight training. The SF level of males with adequate iron status is lowered with weight training but not among females or males with low iron status. **Key Words:** HEMOGLOBIN, FERRITIN, TRANSFERRIN RECEPTOR, STRENGTH

Traditionally, studies examining the effect of exercise on measures of iron status have focused on endurance athletes. However, weight training has become an important part of exercise programs among both competitive and recreational athletes. This form of training may adversely affect measures of iron status. Damage to red blood cells incurred as a result of mechanical and oxidative stresses may lead to increased intravascular hemolysis and iron turnover (15,22). An increased level of fat-free mass (FFM) may increase tissue iron demand and result in elevated soluble transferrin receptor (sTfR) levels (19). Additionally, exercise-induced muscle damage may be associated with an acute phase inflammatory response. Indices of iron status including serum iron (SI), serum ferritin (SF), total iron binding capacity (TIBC), and transferrin saturation (TS) are affected by inflammation (11).

Limited data suggest that an alteration in iron status can occur among young individuals participating in weight-training exercise. Young males have experienced impaired measures of iron transport and storage (13,22) and lower hemoglobin levels (22) after 6–8 wk of weight training. A preliminary investigation involving young females has reported an improved iron status following twelve weeks of aerobic-resistance exercise (14). Therefore, the main purpose of this investigation was to further examine the relationship between weight-training exercise and measures of iron status during a program of progressive weight training involving young males and females. In addition, a second purpose was to assess the effect of exercise induced muscle damage on SF levels.

Individuals with initially low iron status were hypothesized to experience a decline in the levels of hemoglobin, SI, TS, and elevations in sTfR as a result of the weight-training program. Individuals with initially adequate iron stores were expected to experience decreased SF levels with no change in hemoglobin or measures of iron transport.

MATERIALS AND METHODS

Subjects. Subjects were 13 male and 27 female undergraduate and graduate students at Florida State University. Characteristics of the subjects are reported in Table 1. A written informed consent document approved by the Florida State University Institutional Review Board was completed by all of the participants. Exclusion criteria for this investigation included: 1) mild infection or fever within 1 month before enrollment; 2) history of diabetes, heart disease, or

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TABLE 1. Subject characteristics.

Characteristics	Pretraining	Posttraining
Age (yr)		
Female	22 ± 4.0	—
Male	23 ± 3.0	—
Height (cm)		
Female	165.3 ± 6.0[a]	—
Male	178.5 ± 8.5	—
Weight (kg)		
Female	62.9 ± 12.5[a]	63.4 ± 12.5[a]
Male	78.8 ± 16.1	79.2 ± 15.7
Body fat (%)		
Female	25.4 ± 5.1[a,b]	24.5 ± 4.9[a]
Male	20.1 ± 6.7[b]	18.9 ± 7.3
FFM (kg)		
Female	43.8 ± 6.1[a,b]	44.7 ± 6.0[a]
Male	63.1 ± 9.0[b]	64.5 ± 8.6

Values are mean ± SD.
[a] Females significantly different from males.
[b] Pretraining significantly different from post training; age, height, weight (pre and post): females ($N = 27$), males ($N = 13$); body fat and FFM (pre and post): females ($N = 24$), males ($N = 12$).

other chronic illness; 3) unwillingness to abstain from blood donation during the study period; 4) smoking or use of tobacco products; and 5) participation in weight-training exercise within 6 months before enrollment.

Study design. Two separate training programs were conducted over the summer and fall academic semesters. Both programs consisted of 13 wk: 1 wk of orientation, 2 wk of familiarization, and 10 wk of progressive weight training. During the orientation week, all procedures and protocols were explained along with demonstration of proper use of the equipment. No weight-training exercise was conducted during the first week. The orientation period was followed by 2 wk of exercise familiarization in which the subjects performed high-repetition, low-volume weight-training exercise. The purpose of the familiarization was to emphasize proper exercise form and technique, and to reduce the influence of practice or learning on initial strength measures (18). The last 2 d of the familiarization period involved the determination of the 10-repetition maximum (10 RM), conducted on the same equipment used for training. This assessment was also conducted after weeks 8 and 13. Blood samples were obtained at the end of the first week (baseline) and after weeks 5, 9, and 13. Self-reported dietary assessments were recorded for 3 d before each blood sampling period. Body composition was assessed at baseline and during week 13.

Weight training. Weight-training sessions were supervised by qualified personnel and conducted $3\times$ wk^{-1} (Monday, Wednesday, Friday) for up to 1 h per session. A combination of machine (Universal Conditioning Equipment, Cedar Rapids, IA) and free-weight exercises were utilized. A linear periodization program was followed in which each exercise session was performed at either a moderate (70–90% RM) or heavy (80–100% RM) intensity. Rest periods between exercise sets were not monitored; however, the subjects were required to complete all exercises within 1 h.

Exercise days were designated either "push" or "pull," depending on the types of muscle actions performed, and were conducted in an alternating fashion. The following exercises were performed: dumbbell bench press, arm curl, shoulder press, leg curl, leg press, lat pulldown, triceps pushdown, bent over row, calf press, upright row, lunge, Romanian deadlift, abdominal crunches, and abdominal side bends. Each weight-training day also alternated between moderate and heavy intensity. Exercises were conducted in order from large to small muscle groups; four sets were completed for each exercise. The first set for each exercise day was performed at 50% of the 10 RM. For the moderate-intensity days, sets 2, 3, and 4 were performed at 70, 80, and 90% of the 10 RM for eight repetitions. For high-intensity exercise days, sets 2, 3, and 4 were performed at 80, 90, and 100% of the 10 RM. Eight repetitions were performed for the second and third sets. In addition to lifting a greater percentage of the 10 RM for this day, subjects were instructed to complete as many repetitions as possible for the fourth set. If the subject completed more than 12 repetitions, the resistance was increased to the next resistance setting on the machines or 3–5 pounds with the free-weight exercises.

Body composition. The underwater weighing procedure (UWW) was conducted at baseline and upon completion of the training program. Body weight was assessed using a Health-O-Meter body-weight scale (Continental Scale Corp., Chicago, IL) before underwater weighing with subjects clothed in a swimsuit. Residual lung volumes (RV) were estimated as a percentage of the forced vital capacity, which was measured with a Pneumoscan KTC System (K L Engineering Co., Sylmar, CA) (29). A standard value of 0.1 L was added to the RV to account for trapped air in the gastrointestinal system (10). A Chatillian 6-kg autopsy scale was used to measure under water body weight. Body density was estimated from the equation of Goldman and Buskirk (10). Estimation of percent body fat (%BF) for white males and black females (3,24) was calculated from body density using the following equation:

$$\%BF = [495/\text{body density}] - 450 \quad [1]$$

The following equations were used to calculate %BF for white females (3) and black males (23), respectively:

$$\%BF = [(5.054/\text{body density}) - 4.615] \times 100 \quad [2]$$

$$\%BF = [(4.374/\text{body density}) - 3.928] \times 100 \quad [3]$$

Seven to 12 trials were conducted for each subject; the average of the three highest values was used in the calculation of body density.

Dietary assessment. Subjects recorded dietary intakes during a 3-d period before each of the four blood-collection periods. Subjects were provided verbal and written instructions regarding proper recording techniques. Diet records were analyzed using Nutritionist V software (First Data Bank, Inc., San Bruno, CA). Values for total iron, heme iron, and bioavailable iron intakes over each 3-d period were averaged and reported as group mean values. Heme and bioavailable iron intake values were calculated by the method of Monsen et al. (17).

Blood measures and procedures. Blood samples were obtained by trained phlebotomists after weeks 1, 5, 9, and 13 of the study. After the baseline measurement, all

blood samples (weeks 5, 9, and 13) were obtained 1 d after an exercise session. Blood-sampling procedures were performed in the morning before any physical activity and after an overnight fast. Subjects were seated for at least 20 min before blood sampling. Blood was collected in Vacutainer® tubes from an antecubital vein while the forearm was placed on a padded support. Serum samples were stored at −80°C until analysis. Samples were analyzed for SF, SI, TIBC, sTfR, and creatine kinase activity (CK). Hematocrit was measured using a Micro-Hematocrit Reader (IEC, Needham Heights, MA). Hemoglobin levels for subjects in the summer (weeks 1, 5, 9, and 13) and fall groups (week 1) were measured using a blood gas analyzer (AVL Scientific Corporation, Roswell, GA) that is based on the spectrophotometric analysis of hemoglobin from ultrasound hemolyzed blood. Week 5, 9, and 13 hemoglobin levels for subjects in the fall training program were assessed using the cyanomethemoglobin method (Sigma Diagnostics, St. Louis, MO; procedure 525). Results of 50 samples measured in duplicate via the two methods showed excellent agreement (mean ± SD, 13.2 ± 1.1 AVL method; 13.3 ± 2.0 cyanomethemoglobin method). Serum iron and unsaturated iron binding capacity (UIBC) were measured using a commercially available kit (Sigma Diagnostics; procedure 565). Total iron binding capacity was calculated by addition of the SI and UIBC values. Serum ferritin and sTfR levels were assessed by enzyme immunoassay (Ramco Laboratories, Stafford, TX; procedures O-83 and TF-94). Serum CK was measured using a commercially available colorimetric assay (Sigma Diagnostics; procedure 520). A Beckman DU Series 600 spectrophotometer (Beckman Instruments, Inc., Fullerton, CA) and a Powerwave 200 microplate scanning spectrophotometer (Bio-Tek Instruments, Inc., Winooski, VT) were used to measure the optical densities of all samples, standards, and controls. All equipment was subject to routine calibrations and quality control. Subject samples for each assay were analyzed within the same batch to eliminate between-batch analytical variations. All measures were conducted in duplicate except for hematocrit, which was assessed in triplicate. The mean coefficient of variation (CV) for blood measures was calculated from fifty samples measured in duplicate, except for hematocrit, which was measured in triplicate. Mean CV values were (3.2%) for SI, (1.6%) for UIBC, (1.5%) for hemoglobin, (1.1%) for hematocrit, (11.3%) for sTfR, (14.0%) for SF, and (2.9%) for CK.

Statistical analysis. Two-factor repeated-measures ANOVA was utilized to examine changes in strength, blood parameters, and dietary iron intake over time with a between group factor (gender, iron status, and season). Improvements in strength were expressed as percent change scores from baseline to account for the effect of initial strength levels on strength improvement. Degrees of freedom for *F*-tests were modified using the Greenhouse-Geisser procedure when violations in the assumption of homogeneity of covariance (sphericity) were observed. A simple main effect of time was localized using one-factor repeated measures ANOVA when a significant group-by-time interaction was observed. Significant time main effects and group-by-time interactions were analyzed using the Tukey's HSD. One-factor ANOVA was performed on the marginal means of iron status groups to establish the presence of significant between-group main effects. Upon observation of a significant *F*-test, the Scheffé method was used to identify the location of differences between iron status groups. One-factor ANOVA was also utilized to compare responses between the summer and fall training groups with respect to changes in plasma volume. Pearson correlation coefficients were calculated using pairwise exclusion of cases. Descriptive data are reported as means and standard deviations. Statistical significance was accepted as $P < 0.05$. Statistical analysis was performed using SPSS for Windows version 9 (SPSS Inc., Chicago, IL).

RESULTS

Forty subjects completed the weight-training program of 52 who originally participated. Reasons for subject dropout included loss of interest or changes in work or class schedules. Fifteen subjects (10 females and 5 males) completed the summer training program, and 25 (17 females and 8 males) completed the fall training program. Of the 40 subjects, 31 were white (11 males and 20 females) and 9 were black (2 males and 7 females). Adherence to the weight-training program was considered to be excellent. Subjects who missed scheduled sessions made up the training during scheduled makeup sessions. With the exception of two subjects who missed one exercise session, all other subjects attended 33 exercise sessions.

Subject characteristics. Iron status group 1 (FL, $N = 14$) consisted of female subjects with a serum ferritin level $\leq 20\ \mu g \cdot L^{-1}$. Iron status group 2 (FN, $N = 13$) consisted of females with a serum ferritin $> 20\ \mu g \cdot L^{-1}$. Iron status group 3 (ML, $N = 6$) consisted of males with a serum ferritin $\leq 45\ \mu g \cdot L^{-1}$. Iron status group 4 (MN, $N = 7$) consisted of males with a serum ferritin $\geq 50\ \mu g \cdot L^{-1}$.

Subject characteristics by gender are presented in Table 1. The males were significantly taller and possessed greater body weight and FFM compared with the females. Body weight was not significantly altered as a result of the training program. Three female and one male subject who were uncomfortable with the underwater weighing procedure were not able to perform the assessment. Therefore, no body composition data are available for these individuals. Percent body fat was significantly greater in the female group compared with the males. FFM increased and percent body fat decreased significantly after training for both the male and female groups. No significant group-by-time interactions were observed for measures of body weight, FFM, or percent body fat.

Strength assessment. Strength data were obtained at three time points for exercises involving "push" (leg press, leg extension, triceps pushdown, and shoulder press) and "pull" (lat pull, arm curl, upright row, leg curl, and bent over row) muscle groups. Males and females demonstrated similar gains in strength. Absolute strength and percent change

TABLE 2. Absolute values (kg) and percent changes in strength.

Exercises	Week 3	Week 8	Week 13
Leg press			
Female	83.1 ± 20.3	103.3 ± 23.0 (24.3)[a]	118.3 ± 29.2 (42.4)[a,b]
Male	141.0 ± 30.4	161.0 ± 22.8 (14.2)[a]	173.3 ± 21.2 (22.9)[a,b]
Shoulder press			
Female	16.8 ± 2.9	19.6 ± 3.7 (16.7)[a]	21.5 ± 4.7 (30.0)[a]
Male	30.3 ± 8.0	34.6 ± 8.0 (14.2)[a]	37.3 ± 9.7 (23.1)[a]
Triceps press			
Female	13.1 ± 2.9	15.4 ± 3.6 (17.6)[a]	17.0 ± 4.4 (29.8)[a,b]
Male	24.1 ± 6.7	27.1 ± 7.8 (12.4)[a]	29.4 ± 7.6 (22.0)[a,b]
Leg extension			
Female	23.3 ± 8.9	28.6 ± 10.0 (22.7)[a]	34.6 ± 13.5 (48.5)[a,b]
Male	51.9 ± 27.3	57.3 ± 26.3 (10.4)	61.2 ± 24.9 (17.9)[a,b]
Lat pull			
Female	28.0 ± 4.7	31.6 ± 5.7 (12.9)[a]	33.9 ± 7.2 (21.1)[a,b]
Male	49.0 ± 11.9	54.7 ± 11.8 (11.6)[a]	57.5 ± 11.5 (17.3)[a,b]
Arm curl			
Female	5.6 ± 1.2	6.7 ± 1.6 (19.6)[a]	7.2 ± 1.9 (28.6)[a]
Male	12.2 ± 3.0	14.2 ± 3.2 (16.4)[a]	15.0 ± 3.8 (23.0)[a]
Upright row			
Female	16.3 ± 3.0	18.6 ± 3.3 (14.1)[a]	20.1 ± 3.1 (23.3)[a,b]
Male	29.4 ± 7.3	32.9 ± 6.9 (11.9)[a]	35.7 ± 6.9 (21.4)[a,b]
Leg curl			
Female	9.3 ± 3.1	11.2 ± 3.3 (20.4)[a]	12.5 ± 3.6 (34.4)[a]
Male	18.9 ± 6.4	21.0 ± 6.8 (11.1)[a]	23.1 ± 6.1 (22.2)[a]
Bent over row			
Female	9.5 ± 2.6	11.7 ± 2.7 (23.2)[a]	12.5 ± 3.1 (31.6)[a]
Male	17.8 ± 4.1	20.6 ± 4.7 (15.7)[a]	22.9 ± 5.5 (28.7)[a]

Values are mean ± SD. Percent change from week 3 in parentheses.
[a] Percent change values different from week 3 ($P < 0.05$).
[b] Percent change values different from week 8 ($P < 0.05$).

in strength scores for selected exercises are presented in Table 2. Of the weight-training exercises, only the leg press and leg extension displayed significant gender-by-time interactions. For these exercises, the females demonstrated greater percent increases in strength compared with the males at week 13. At week 8, a significant improvement in leg extension strength was only observed for the female group.

Blood chemistry. With the exception of CK, complete data were obtained for 23 females and 13 males. Four female subjects were excluded from the analysis of blood chemistry measures due to missed blood collections. Table 3 displays blood chemistry measures over the course of the training program. Only hemoglobin and SF levels demonstrated significant changes over time. No significant change in hematocrit, SI, TIBC, TS, or sTfR levels were observed. Hemoglobin concentration was significantly lower for the male and female groups at week 13 compared with weeks 1, 5, and 9 (Fig. 1A). Figure 1B displays the hemoglobin concentration by iron status groups. A significant season-by-time interaction was also observed for hemoglobin concentration (Fig. 2). To determine whether the seasonal effect on hemoglobin concentration was associated with changes in plasma volume levels, the method of Dill and Costill (6) was applied to baseline (week 1) and week 13 hemoglobin concentration values to estimate the percent change in plasma volume. Subjects in the summer training session experienced a 9.7 ± 9.7% increase in plasma volume compared with a 2.5 ± 11.2% increase for individuals in the fall training group ($P < 0.05$). A significant gender-by-time interaction was observed for the SF measure (Fig. 3A). Serum ferritin values were significantly lower at week 9 compared with all other time points for the male group. No significant changes in SF values occurred in the female group. Classification of the subjects based on iron status resulted in a significant group-by-time interaction for SF (Fig. 3B). The MN group was the only one of the four iron status groups to demonstrate a significant decrease in SF levels during the training period. All iron status groups exhibited significantly different SF levels from each other at all time points. Serum ferritin levels were not significantly correlated with CK. The sTfR:ferritin ratio was calculated by taking the ratio of the sTfR ($\mu g \cdot L^{-1}$) to the SF ($\mu g \cdot L^{-1}$) level (25); this measure did not demonstrate a significant change over time.

TABLE 3. Hematocrit, iron status, and CK of male ($N = 13$) and female ($N = 23$) groups.

Variables	Week 1	Week 5	Week 9	Week 13	Reference
Hematocrit (%)[a]					
Male	45.2 ± 2.8	45.4 ± 1.9	46.3 ± 2.6	45.4 ± 2.1	40–52
Female	39.8 ± 3.8	39.0 ± 3.4	39.3 ± 3.3	38.4 ± 2.9	35–47
SI ($\mu g \cdot dL^{-1}$)					
Male	91.2 ± 36.5	82.5 ± 31.8	94.5 ± 37.2	105.3 ± 38.8	55–170[b]
Female	72.1 ± 39.9	69.4 ± 43.2	74.7 ± 25.1	86.4 ± 56.0	55–170[b]
TIBC ($\mu g \cdot dL^{-1}$)[a]					
Male	312.1 ± 22.9	320.8 ± 34.4	307.1 ± 25.7	318.0 ± 27.2	260–390[b]
Female	363.0 ± 74.1	368.3 ± 82.4	360.4 ± 64.9	362.6 ± 69.4	260–390[b]
TS (%)[a]					
Male	28.7 ± 10.3	25.4 ± 8.5	30.7 ± 11.9	33.1 ± 12.0	16–60[b]
Female	20.7 ± 11.9	20.2 ± 14.4	21.4 ± 7.6	24.5 ± 16.0	16–60[b]
sTfR ($mg \cdot L^{-1}$)					
Male	4.9 ± 1.3	5.0 ± 1.4	5.3 ± 1.8	5.3 ± 1.6	2.8–8.5[b]
Female	5.1 ± 2.3	5.7 ± 3.0	5.5 ± 2.8	5.8 ± 3.3	2.8–8.5[b]
sTfR:ferritin[a]					
Male	97.5 ± 73.5	128.9 ± 121.0	139.3 ± 99.6	142.2 ± 100.2	<500[c]
Female	624.2 ± 730.1	836.4 ± 1005.7	803.8 ± 973.5	913.9 ± 1167.9	<500[c]
CK ($U \cdot mL^{-1}$)					
Male	28.0 ± 12.5	76.2 ± 126.1	34.0 ± 22.5	31.8 ± 12.5	0–24
Female	16.8 ± 8.1	40.0 ± 59.6	24.4 ± 18.9	23.4 ± 9.5	0–24

Values are mean ± SD. SI, serum iron; TIBC, total iron binding capacity; TS, transferrin saturation; sTfR, soluble transferrin receptor; sTfR:ferritin, soluble transferrin receptor to ferritin ratio; CK, creatine kinase activity.
[a] Group main effect ($P < 0.05$).
[b] Reference values from Worwood (30).
[c] Reference values from Baynes (1).

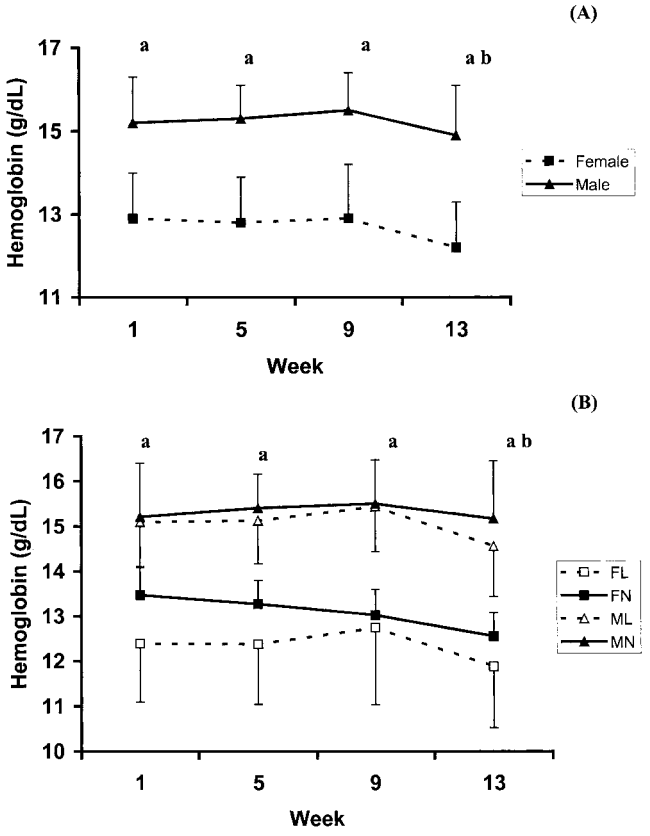

FIGURE 1—A, Hemoglobin concentration of male and female groups. [a]Males significantly different from females ($P < 0.05$); [b]week 13 values significantly different from weeks 1, 5, and 9 (no significant gender-by-time interaction). B, Hemoglobin concentration of iron status groups. [a]Males significantly different from females ($P < 0.05$); [b]week 13 values significantly different from weeks 1, 5, and 9 ($P < 0.05$) (no significant iron status group-by-time interaction). Values are mean ± SD.

Dietary iron intake. Twenty-two females and 10 males completed all four of the self-reported dietary assessments. Subjects who reported the consumption of multivitamins submitted product labels with the dietary assessments. Supplement nutritional data were derived from the labels and included with the nutritional intake data. Mean values for total, heme, and bioavailable iron intakes are presented in Table 4. A significant main effect of time was observed for total iron intake with no significant gender interaction. Heme and bioavailable iron intakes did not significantly change over time. Significant gender main effects were observed for total and heme iron intake values ($P < 0.05$). Marginal means for the female and male groups were 11.3 ± 0.9 and 14.6 ± 1.3 $mg \cdot d^{-1}$ for total iron and 0.9 ± 0.1 and 1.3 ± 0.1 $mg \cdot d^{-1}$ for heme iron, respectively. Dietary iron intakes were not significantly correlated with any of the blood chemistry measures. No significant differences or interactions were observed for dietary iron intake values between subjects participating in the summer and fall training programs.

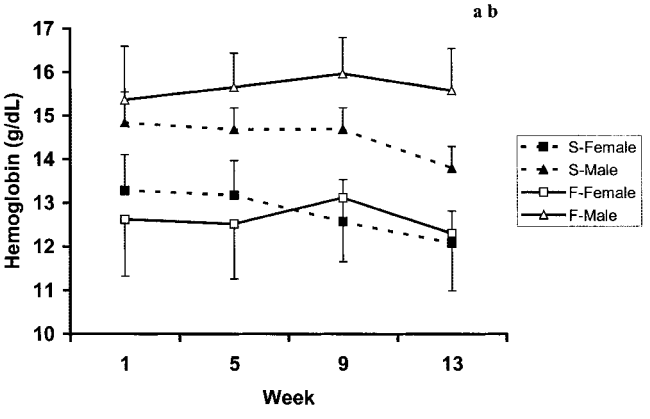

FIGURE 2—Hemoglobin concentration of male and female groups participating in summer and fall programs. In the figure legend, S = summer and F = fall. [a]Significant ($P < 0.05$) time main effect; [b]significant ($P < 0.05$) season-by-time interaction. Values are mean ± SD.

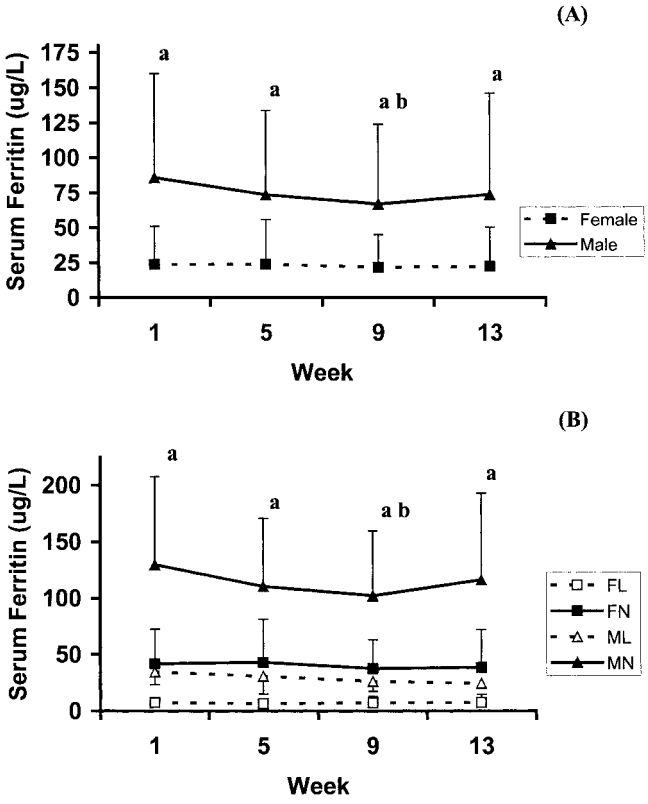

FIGURE 3—A, SF of males and females. [a]Males significantly different from females ($P < 0.05$); [b]males: week 9 significantly different from week 1. B, SF levels of iron status groups. [a]Iron status groups significantly different ($P < 0.05$); [b]MN group: week 9 values significantly different from week 1. Values are mean ± SD.

DISCUSSION

Major findings of this investigation include observations of lower hemoglobin concentration in both males and females after 12 wk of weight training and reduced iron stores after 8 wk in males with initially adequate iron levels. Both the male and female groups demonstrated similar anthropometric and strength changes as a result of the weight-training program. The effectiveness of the program was demonstrated by significant improvements in strength and alterations in body composition. These findings are in agreement with previous investigations involving males and fe-

TABLE 4. Total iron, heme, and bioavailable iron intakes (mg · d^{-1}) for males ($N = 10$) and females ($N = 22$).

	Males			Females		
Record	Total[a]	Heme[a]	BI	Total	Heme	BI
1	16.1 ± 7.4	1.6 ± 0.9	0.9 ± 0.5	12.1 ± 5.8	0.8 ± 0.4	0.8 ± 0.3
2	13.3 ± 3.3	1.2 ± 0.7	0.7 ± 0.2	12.3 ± 4.7	0.9 ± 0.5	0.8 ± 0.3
3	15.3 ± 6.0	1.4 ± 1.0	0.8 ± 0.4	11.7 ± 4.1	0.9 ± 0.4	0.8 ± 0.3
4	13.8 ± 5.9[b]	1.0 ± 0.6	0.7 ± 0.4	9.2 ± 3.4[b]	0.9 ± 1.1	0.6 ± 0.3

Values are mean ± SD. Total, total dietary iron intake; Heme, heme iron intake; BI, bioavailable iron intake.
[a] Marginal means (records 1–4) for males are different from females ($P < 0.05$).
[b] Combined male and female data for total dietary iron intake of record 4 are different from combined data of record 1 ($P < 0.05$).

males (4,26) participating in weight-training programs ranging between 8 and 16 weeks.

The observed decline in hemoglobin concentration was not influenced by gender or initial iron status. A plasma volume change due to seasonal variation is the most likely explanation for the observed decline in hemoglobin concentration. Resting plasma volume levels have been shown to undergo seasonal variation and reach peak levels during the summer months (7). In the present study, plasma volume increased to a significantly greater extent in the summer (9.7%) than in the fall (2.5%). It is currently unknown, however, the extent to which whole-body weight-training exercise contributes to long-term adaptations in the plasma volume level (28). Twelve weeks of lower-body training has not been shown to affect hemoglobin concentration or plasma volume among an older group of previously untrained males (8). Acute decreases in plasma volume with weight training have been reported immediately after weight-lifting exercise, with values returning to baseline within 60 min (21). The acute decrease in plasma volume has been associated with fluid movement from the vascular space into the extracellular space (21) and may be followed by a rebound hypervolemia 24 h postexercise (28). Although biomarkers of red cell hemolysis were not directly measured in the current investigation, the extent of red cell hemolysis may be evaluated through changes in the SI level, which have been shown to increase as a result of increased red blood cell destruction (12). Because no significant alterations in SI or TS were observed in the present study an absence of a measurable degree of red cell hemolysis may be suggested. However, it is important to emphasize caution when making inference to the degree of intravascular hemolysis from SI measures, as Schobersberger et al. (22) observed decreased haptoglobin levels without significant changes in SI or TS levels after 6 wk of weight training. It appears that a seasonal dependent change in plasma volume remains the most likely explanation for the altered hemoglobin concentration with weight-training exercise.

The SF level of the male group in the current investigation was significantly lowered (22%) from baseline (85.8 vs 66.9 $\mu g \cdot L^{-1}$) during the course of the weight training program. A 34% drop in the SF level after 6 wk (74.8 vs 49.3 $\mu g \cdot L^{-1}$) (22) and a 28% drop after 8 wk (83.0 vs 60.0 $\mu g \cdot L^{-1}$) (13) of training have been reported. Despite the adverse effects that weight training may exert on the iron status of young males, an important point to make is that SF levels have remained within the normal range (13,22). However, because the SF level is a positive acute phase protein, levels within the range of 50–100 $\mu g \cdot L^{-1}$ may still be indicative of iron deficiency (2). Upon further analysis, it was observed that only males in the MN group experienced a significant (21.5%) decrease in SF levels at week 9. Lack of a significant change in the SF level of the ML group was likely due to low iron stores among these individuals. The observed changes in the SF level of the MN group were not observed among the females in the FN group. However, despite being classified with normal iron status, females in the FN group possessed low serum ferritin levels. Lack of a significant change in the SF level of the female subjects in the present investigation conflicts with previous reports. Significant decreases (19) and increases (14) in SF levels were observed in older and younger women after 12 wk of weight-training exercise, respectively. A combination of age (19) and differences in exercise program design (14,19) are two factors that may explain the observed differences in SF level between investigations. The older women in the study of Murray-Kolb et al. (19) possessed an initial SF level of 123.1 $\mu g \cdot L^{-1}$, which is much higher than the mean values of the FL (7.3 $\mu g \cdot L^{-1}$) and FN (41.7 $\mu g \cdot L^{-1}$) groups in the present study. Also, the females in previous studies trained only twice per week (14,19) and/or participated in a less rigorous, "aerobic-resistance" exercise protocol (14).

Serum iron levels, TIBC, and TS did not demonstrate significant changes as a result of the weight-training program. The lack of change in measures of iron transport is in agreement with results of Schobersberger et al. (22), who did not observe changes in SI or TS among young males undergoing 6 wk of weight training. However, these data are in contrast to those of Lukaski et al. (13), who observed an increased TIBC ($P < 0.05$) and decreased TS ($P < 0.05$), suggesting impaired iron transport. Although significant alterations in iron transport were found in the study, values were still within the normal range.

Total iron intake, but not heme or bioavailable iron intakes, decreased significantly at week 13 compared with weeks 1, 5, and 9. Lukaski et al. (13) also reported a significant decline in iron intake among a group of young males participating in an 8-wk weight-training program (23 mg·d^{-1} pre vs 19.3 mg·d^{-1} post). The decline in iron intake at week 13 corresponds with the observed decrease in hemoglobin levels; however, none of the dietary iron intake measures were significantly correlated with hemoglobin levels. Additionally, lack of a significant change in bioavailable iron intake suggests that iron absorption did not increase, nor did iron absorption contribute to the observed decline in hemoglobin levels.

To date, only one paper has examined the effect of long-term weight-training exercise (12 wk) on the sTfR level (19). An increased FFM (2.1 kg) was hypothesized to be the reason for the increased sTfR level observed among a group of older males (19). In the present study, however, no difference in the sTfR level was observed despite a significantly increased FFM of 1.4 and 0.9 kg for the males and females, respectively. It is possible that the increased levels of FFM observed among the males and females in the present investigation was not sufficient to produce a measurable difference in sTfR levels. Due to the inverse regulation of the sTfR and SF measures, it has been suggested that a ratio of the two parameters provides a sensitive measure of tissue iron deficiency (25). Murray-Kolb et al. (19) observed an increase in the sTfR:ferritin ratio after 12 wk of weight training among older males and females; however, such a change was not observed in the current investigation. Failure to observe a dramatic increase in circulating levels of CK may be explained by blood sample timing and the protective effect of repeated bouts of exercise on skeletal muscle. It is possible that large elevations in CK occurred in the days after the blood sampling periods. Significant elevations in CK have been typically observed 3–5 d after maximal eccentric exercise involving small muscle groups (20). Peak CK values have been observed after 4–5 d after weight-training exercise among untrained males (27). In the current study, the second blood sample (week 5) was obtained after 4 wk of weight-training exercise; in which time a training effect may have occurred (16). Therefore, it remains a possibility that the nonsignificant change in CK measured at weeks 5, 9, and 13 were due to adaptation of the skeletal muscle to prior bouts of weight-training exercise (16,27). Additionally, failure to observe an increase in SF level (5) and lack of significantly lower SI, TS, and TIBC levels (9) are evidence against the occurrence of an exercise-induced acute phase response.

CONCLUSION

College-age males and females derived favorable strength and body composition alterations after weight-training exercise conducted three days per week for a 12-wk period. Participation in the weight-training protocol resulted in a significant decrease in hemoglobin concentration of males and females, with a greater difference occurring among subjects participating in the summer training session compared with the subjects participating in the fall. Twelve weeks of weight training did not result in altered hematocrit or levels of SI, TIBC, TS, sTfR, or sTfR:ferritin ratio. Weight training lowered SF levels among male subjects with adequate iron status but not among females or males with low iron status. Therefore, hemoglobin levels decline with no alterations in SI, TIBC, TS, or sTfR after 12 wk of progressive weight-training exercise that effectively increased muscle mass and strength.

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