Physiological and performance responses to tournament wrestling

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Laboratory for Sports Medicine, The Pennsylvania State University, University Park, PA 16802; The Human Performance Laboratory, Ball State University, Muncie, IN 47306; The Human Performance Laboratory, University of Connecticut, Storrs, CT 06269; and Department of Sport Science, Colorado College, Colorado Springs, CO 80903

ABSTRACT

KRAEMER, W. J., A. C. FRY, M. R. RUBIN, T. TRIPLETT-MCBRIDE, S. E. GORDON, L. P. KOZIRIS, J. M. LYNCH, J. S. VOLEK, D. E. MEUFFELS, R. U. NEWTON, and S. J. FLECK. Physiological and performance responses to tournament wrestling. *Med. Sci. Sports Exerc.*, Vol. 33, No. 8, 2001, pp. 1367–1378. **Purpose:** The purpose of this study was to investigate the physiological and performance responses to a simulated freestyle wrestling tournament after typical weight loss techniques used by amateur wrestlers. **Methods:** Twelve Division I collegiate wrestlers (mean ± SD;19.33 ± 1.16 yr) lost 6% of total body weight during the week before a simulated, 2-d freestyle wrestling tournament. A battery of tests was performed at baseline and before and immediately after each individual match of the tournament. The test battery included assessment for body composition, reaction/movement time, lower and upper body power and isokinetic strength, and a venous blood sample. **Results:** Lower body power and upper body isometric strength were significantly reduced as the tournament progressed ($P \leq 0.05$). Significant elevations in testosterone, cortisol, and lactate were observed after each match ($P \leq 0.05$). However, there was a significant reduction ($P \leq 0.05$) in resting testosterone values in the later matches. Norepinephrine increased significantly ($P \leq 0.05$) after each match, whereas epinephrine increased significantly ($P \leq 0.05$) after each match except the last match of each day. Plasma osmolality was consistently higher than normal values at all times including baseline, with significant increases observed after each match ($P \leq 0.05$). **Conclusions:** Tournament wrestling augments the physiological and performance decrements of weight loss and its impact is progressive over 2 d of competition. The combined effects of these stresses may ultimately be reflected in a wrestler's ability to maintain physical performance throughout a tournament. **Key Words:** WEIGHT LOSS, DEHYDRATION, ATHLETIC, ENDOCRINE, STRENGTH, HORMONES

Historically, amateur wrestling has been a topic of study for well over 50 years. In 1943, W. W. Tuttle was the first to examine the physiological and performance responses to weight loss by dehydration and caloric restriction in collegiate wrestlers (35). In this investigation, it was determined that a 5% weight loss using traditional dehydration methods had no effects on performance measures of strength nor any detrimental effects on measures of cardiorespiratory function. Thus, it was concluded that a wrestler might safely lose up to 5% of body weight without suffering any deleterious effects. In general, it now seems clear that performance is reduced as a result of dehydration-induced weight loss (8,10,12,27,36). The degree of absolute weight loss (i.e., percentage of total body weight) may ultimately be the deciding factor influencing performance (27). Attenuations of strength and anaerobic performance have been observed in wrestlers after a period of weight loss (8,36); however, other studies involving hypohydration and wrestlers have observed no performance changes in wrestling-specific tests (28,29). Variable responses to dehydration-induced weight loss may be attributed to a variety of factors including method of dehydration (e.g., fluid restriction, exercise in the heat), rehydration schedule, and whether or not the athlete is accustomed to weight loss (27). Furthermore, variations in performance tests between studies may make data interpretation difficult. However, over the years, growing concern has developed over the possible life-threatening consequences that may accompany the extreme means some wrestlers use to reduce weight to compete in a lower weight class. The impact of such extreme and severe weight loss practices has since been realized as a result of the tragic deaths of wrestlers over the past few years (22). However, many wrestlers still consider 5 or 6% of body mass weight loss not significant in the sport of wrestling and have the capability of losing it in a relatively short period of time with little impact on

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hydration status (38). We hypothesized that subsequent tournament competition would further exacerbate the already reduced physiological and performance capabilities of wrestlers. Yet no data exist to address this question.

All significant wrestling events take place in a tournament setting (e.g., conference tournaments, national championships, world championships, and Olympic championships), thereby requiring that multiple matches occur within a single day and on successive days. As a result, wrestling tournaments present multivariate stresses beyond those already created by weight loss alone, including the physiological and psychological stresses of competition (11,20). Because a wrestling match requires strength and power of both the upper and lower body musculature as well as isometric force for various wrestling techniques (4,10,11,15), it seems plausible that strength and power production could be further reduced over the course of multiple days of a wrestling tournament.

Dehydration, caloric restriction, and/or physical exertion may also dramatically influence the endocrine environment, specifically the steroid hormones (9,21,31,37). Typically, testosterone and cortisol concentrations increase in response to high-intensity maximal exercise (18,19). In addition, testosterone increases have been observed in wrestlers after a single match (3). Nevertheless, no data are available concerning the hormonal response patterns to multiple wrestling matches in tournament format which will markedly affect the physiological mechanisms of metabolism and tissue repair (19). Additionally, catecholamines (i.e., epinephrine and norepinephrine) have been shown to be sensitive to hydration status and high-intensity physical activity (9,16). A reduction in catecholamines may impair the metabolic processes in skeletal muscle thus affecting substrate availability as well as the "fight or flight" phenomenon, which may be crucial to a wrestler's psychological arousal during a match.

The effects of dehydration-induced weight loss and caloric restriction combined with the extreme physiological/psychological stresses of a wrestling tournament may ultimately impair performance and physiological function. One other study has examined tournament wrestling over the course of 2 d reporting only salivary cortisol to increase and variable responses of testosterone over the 2 d of competition (25). In addition, previous research has focused primarily on hypohydration and various physiological and performance measures in amateur wrestlers (8,10,28,29,36). However, none have truly examined in depth each match of an actual tournament situation with multiple matches where the physiological and psychological stresses are far and away greater than any laboratory assessment or a single match. Therefore, the purpose of this investigation was to examine the performance and physiological responses to consecutive days of wrestling in a tournament format after a typical period of caloric restriction, thermal, and dehydration-induced weight loss. This study was intended to provide novel insights into the physiological environment of competitive freestyle wrestling.

METHODS

Subjects

Twelve men were recruited from the Pennsylvania State University varsity wrestling team and served as subjects in this investigation. This particular squad had been highly successful during the preceding season, finishing third in the NCAA Division I Championships. The experimental period was initiated 3–4 wk after the national championships, which allowed for a recovery period but also ensured that all subjects were in peak wrestling condition. It should also be noted that subjects were representative from all 10 Olympic freestyle weight classifications, with the exception of the heavyweight division, before the rule changes in 1997 (34). Subjects were also all freestyle wrestlers competing in national and international competitions. Subject characteristics were as follows (mean ± SE): age 19.33 ± 1.16 yr; height 175.89 ± 2.12 cm; weight 75.33 ± 2.54 kg.; body fat 7.31 ± 0.72%. Subjects were informed of the potential experimental risks and gave their written informed consent to participate in this study, which was consistent with the human subject policy of the American College of Sports Medicine and approved by the university's Institutional Review board for use of human subjects. Additionally, all subjects were screened by the team physician before participating in the study.

Experimental Design and Approach to the Problem

The purpose of the present investigation was to examine the physiological effects of a 2-d freestyle wrestling tournament after a 1-wk weight loss period. Subjects were instructed to lose 6% of body mass the week leading up to precompetition weigh-in after which the first match took place about 12 h later. Actual weight loss ranged from −4.63% to −6.75%. By the first match, the wrestlers regained 1.8% of their body weight from food and rehydration. Body weight never returned to baseline through the entire tournament. On the second day, a 2% percent weight allowance from the first weigh-in was allowed and within 2 h the first match took place. This resulted in restriction of food and fluid intake in order to make weight the next morning. Each wrestler also exercised (i.e., cycle exercise about 20–30 min) after the first day's competition to help them make weight the next morning. The 2-d wrestling tournament consisted of five freestyle matches (three matches on day 1 and two matches on day 2). Each match was a 5-min Olympic freestyle match that was formally refereed and scored. If a fall occurred, the wrestlers started again on the feet until the full 5-min match was wrestled. To create a demanding competitive environment, each match was contested with an opponent of similar skills and training background and within the same weight class (i.e., wrestle-off competition) to simulate competition. Because each wrestler was competing for a starting position in his weight class, competition within the individuals in that weight class created both the physical and psychological stress of com-

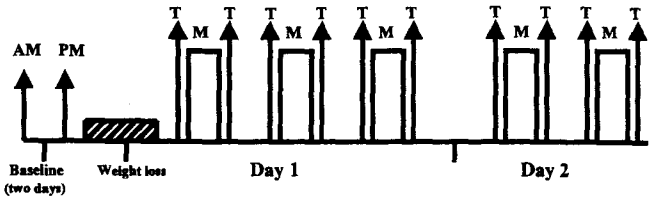

FIGURE 1—Experimental timeline. Subjects performed the test battery (T, symbolized by *arrows*) at the baseline measurement period on two separate days (one in the a.m. and one in the p.m.). The test battery was then performed before and after every wrestling match (M, symbolized by the *open bars*).

petition. The experimental timeline is presented in Figure 1. Unique to this study, the schedule consisted of two baseline testing days, one performed in the a.m. (baseline 1) and another in the p.m. (baseline 2) to account for possible diurnal variations in various hormonal and performance measures. Baseline testing took place after the 3- to 4-wk period after the collegiate competitive season. Testing was again performed prematch and again postmatch for each of the matches wrestled. Matches on day 1 were wrestled at 10 a.m., 2 p.m., and 6 p.m. and on day 2 at 10 a.m. and 7 p.m. Testing was done immediately before and after the match and took about 30 min to complete the test battery. Wrestlers had a 10-min rest before each match after the test battery.

Experimental Procedures

The following test battery was administered at each baseline test and before and after every match. In this order, the test-retest reliabilities (intraclass correlation) of all tests were $R \geq 0.96$. It is also important to point out that the tests were administered in the same order at each time point as presented in the following paragraphs.

Heart rate and fatigue scale. Heart rate was determined by palpation of the carotid artery for a period of 15 s and then multiplied by 4 to calculate an estimated minute value. An overall "fatigue rating" of the wrestler's feelings of fatigue were obtained using a 0–10 Likert scale (i.e., with 0 representing no fatigue and 10 representing maximal fatigue and anchors every other number, magnitude estimation made it possible to pick numbers larger than 10).

Blood sampling. Blood samples were collected via venipuncture from an antecubital arm vein by using a 20-mL disposable syringe equipped with a 20-gauge disposable needle. Subjects were seated in a semirecumbent position in a chair for all blood collections. Whole blood was removed from the 20-mL syringe and used for microcapillary analysis of hematocrit. Ten mL of blood was transferred to a plain Vacutainer® (Baxter, McGraw Park, IL) tube and allowed to clot at room temperature and subsequently centrifuged at 1500 × *g* for 15 min. The resulting serum was placed into separate 1.5-mL microcentrifuge tubes and frozen at −88°C for later analysis of cortisol, testosterone, insulin, lactate, glucose, and creatine kinase. Three mL of blood was also transferred to a Vacutainer® tube containing EDTA and mixed by gentle inversion. One mL of this sample was transferred to a 1.5-mL microcentrifuge tube and frozen at −88°C for later analysis of hemoglobin. The remaining 2 mL was centrifuged at 1500 × *g* for 15 min with the resulting plasma placed into a 1.5-mL microcentrifuge tube and frozen at −88°C for later analysis of plasma osmolality. Seven mL of the syringe sample was transferred to a Vacutainer® containing sodium heparin to prevent clotting. Six mL of this sample were placed into a solution containing EGTA and reduced glutathione. This sample was mixed by gentle swirling and placed in an ice bath for 5 min, then spun in a refrigerated centrifuge (4°C) for 15 min at 1850 rpm. The resulting supernatant was then transferred to 1.5-mL microcentrifuge tubes and frozen at −88°C for later analysis of plasma epinephrine, norepinephrine, and dopamine.

Anthropometric measurements. Body weight was determined using a Detecto® medical scale. Body density was estimated using the standard 7-site skin-fold method (triceps, subscapular, pectoral, mid-axillary, suprailiac, abdominal, and thigh) in duplicate according to the method of Jackson and Pollock (14). For this procedure, a Lange skin-fold caliper (Country Technology, Gay Mills, WI) was used. All skin-fold measurements were taken on the right side of the body by the same investigator for all measures. The average duplicate measure did not differ by more that 4.5%. The Siri equation (30) was then applied to the skin-fold results to estimate percent body fat. Body composition was determined only at baseline 1 and prematch 1 time points.

Reaction/movement time. A test for reaction time/movement time was based on similar technology used to evaluate other wrestling movements (29). Reaction and movement times were determined from high-speed video analysis (120 Hz) of response speed to a light signal. Subjects began in a traditional "bottom" position for freestyle wrestling and were instructed to stand as quickly as possible in response to the light signal. The lighting apparatus consisted of a 60-W bulb attached to a wooden board with a distant switch so that the subject could not see the investigator turn the switch. Time from the "ready" command and the light was randomly varied to avoid any anticipatory response. The best of three trials was used for analysis on a Peak 2D Motion Analysis System (Peak Performance Technologies Inc., Englewood, CO). Reaction and movement times were calculated from the number of frames counted from the light signal to the initial response and movement, with a sampling rate of 60 fields·s^{-1}.

Strength and power tests. Grip strength was determined on a Jaymar model 30 J4 (Country Technologies) handgrip dynamometer with visual feedback. The dynamometer was adjusted to each subject's hand with the best of three maximal trials using the dominant hand used for data analysis. The same adjustment of the dynamometer was used for all tests of each subject. Leg power was determined with a vertical jump on a force platform (Model OR6–5-1, Advanced Mechanical Technology Inc., Newton, MA) interfaced to a computer for data analysis and storage. Each subject performed three trials with the highest peak power used in data analysis. Hip and back strength was determined using the best of three trials on a Jaymar model PC5039B

hip and back dynamometer (Country Technologies). The length of the handle chain was adjusted to fit each subject so that the angle at the knees was 45°.

To measure isometric upper body pull strength of the wrestler, a "bear hug" test was employed using a hand and arm grip configuration similar to an upper-body torso lock up technique commonly used in wrestling matches. A strain gauge was mounted within a padded board configuration that could be size adjusted for each wrestler. The wrestler wrapped his arms around the padded strain gauge using a handgrip similar to a throw in wrestling. Each wrestler used his own grip, and grip position was standardized for each wrestler. From this position, the wrestler was instructed to squeeze as hard as possible for 6 s essentially to maximally perform a "bear hug" on the dynamometer pad in a typical grappling fashion. The strain gauge was interfaced to a Myotech® model DM2000 isometric strength-testing computer (Myotech Corporation, Boca Raton, FL). This test was used to examine the isometric force production of the upper body in a specific configuration similar to many upper body holds used by wrestlers. Thus, it provided a reliable test, albeit no direct data on its validity, for the classic "bear hug" move used in wrestling.

Isokinetic tests. Subjects were tested for limb velocity-specific concentric strength of dominant knee extension and flexion as well as dominant elbow extension and flexion using a Cybex II® isokinetic dynamometer (Lumex Corp., Ronkonkoma, NY). Isokinetic testing was performed at limb velocities of 1.05 $rad \cdot s^{-1}$ and 5.24 $rad \cdot s^{-1}$. Isometric testing consisted of a 30-s action of the (0 $rad \cdot s^{-1}$) knee extensors at a 45° knee angle and elbow flexors testing at a 90° elbow angle. Peak torque was determined from the highest of three maximal attempts for all isokinetic trials. The highest isometric force and the % fatigue (high to low) were determined from the isometric trial (0 $rad \cdot s^{-1}$).

Biochemical Analyses

Hematocrit was analyzed in triplicate using standard microcapillary techniques and hemoglobin analyzed in triplicate using a cyanmethemoglobin method (Sigma Chemical Co., St. Louis, MO). Percent changes in plasma volume were then calculated using these variables according to the methods of Dill and Costill (2). Blood lactate was analyzed using a YSI 1500 Sport Lactate Analyzer (YSI Inc., Yellow Springs, OH). Blood glucose was analyzed using an enzymatic assay (Sigma Chemical Co., St. Louis, MO). Plasma osmolality was determined in triplicate using a Micro Osmette Osmometer (Precision Systems 5004, Natick, MA).

For analysis of plasma catecholamines, a 1-mL plasma sample was used for a preliminary aluminum oxide extraction procedure. Subsequently, high performance liquid chromatography HPLC (Waters, Division of Millipore Corp., Milford, MA), which utilizes an M-45 solvent system and 460 electrochemical detector with data integration system, was used for determination of epinephrine, norepinephrine, and dopamine. Internal standards were used for each sample and analytical procedures followed have been previously described (7).

Plasma volume was determined from total blood volume and hematocrit. Total blood volume was determined using the carbon monoxide dilution technique of Myhre et al. (23). Before the procedure, the subject sat quietly for at least 20 min. Carbon monoxide (99.5% pure) was administered through a 50-mL glass syringe into a rebreathing system that included a spirometer and a two-way breathing valve. The spirometer contained 100% oxygen (O_2), and its volume was maintained at approximately 5 L. A blood sample was drawn from an antecubital vein before and after the 10-min rebreathing procedure.

Serum testosterone, cortisol, and insulin were determined in duplicate using ^{125}I solid phase radioimmunoassays (RIA) (Diagnostic Systems Laboratory, Webster, TX). Determinations of different serum immunoreactivity values were made using an LKB gamma counter (Turku, Finland) and an on-line data reduction system. All intra- and interassay variations were less than 4% and 7%, respectively. The testosterone RIA had a detection limit sensitivity of 0.38 $nmol \cdot L^{-1}$, the cortisol RIA a detection limit of 55.18 $nmol \cdot L^{-1}$, and the insulin RIA a detection limit of 3 $\mu IU \cdot mL^{-1}$. All samples for a specific biochemical assay were decoded only after analyses were completed (i.e., blind analysis procedure).

Statistical Analyses

Data was analyzed using a multivariate analysis of variance (MANOVA) with repeated measures. Where significant main effects were observed, Tukey *post hoc* procedures were performed to determine pairwise differences. Statistical power was determined to be from 0.80 to 0.85 for the sample sizes used at the 0.05 alpha level (nQuery Advisor® software, Statistical Solutions, Saugus, MA). Significance was defined as $P \leq 0.05$.

RESULTS

Prematch heart rates were similar to those obtained at baseline measurements, whereas the postmatch heart rates were significantly elevated above those at baseline and prematch measurements. The postmatch measures of the fatigue rating were significantly elevated above those of baseline and prematch. Additionally, the fatigue measures for matches 3–5 were significantly higher than those at baseline (see Table 1).

Vertical jump power measures were not significantly different from baseline values for any of the matches on day one; however, the prematch 4 value was significantly lower than values for baseline 1, postmatches 1 and 2, and for prematch 3 (see Table 1).

The only significant change in hip and back strength was observed in match 1 between pre- and post-match values, with the postmatch value being significantly lower. Otherwise, no other significant differences were observed. Both pre- and post-match "bear hug" strength measures for matches 4 and 5 were significantly lower than the baseline measures. In addition, postmatch 1 and prematch 2 values

TABLE 1. Vertical jump (VJ, watts), hip/back strength (kg), movement time (MT, ms), reaction time (RT, ms), total movement time (total MT, ms) performance as well as fatigue rating and heart rate (beats · min^{-1}) at AM and PM baselines, matches 1–3 on day 1, and matches 4–5 on day 2 (mean ± SE).

			Match 1		Match 2		Match 3		Match 4		Match 5	
	AM Baseline	PM Baseline	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post
VJ power (W)	4915.82 ± 394.57‡	4639.09 ± 292.87	4758.53 ± 361.51	5020.76 ± 279.99‡	4869.01 ± 278.05	4908.28 ± 231.31‡	5052.76 ± 374.28‡	4886.56 ± 278.81	4318.49 ± 344.09	4447.76 ± 350.86	4429.08 ± 243.76	4612.49 ± 224.20
Hip/back (kg)	163.75 ± 11.33	165.64 ± 12.19	175.17 ± 13.00	160.25 ± 9.77†‡	180.50 ± 13.46	170.17 ± 8.45	174.50 ± 14.29	172.67 ± 10.72	171.50 ± 13.65	173.03 ± 12.27	163.67 ± 12.18	168.50 ± 10.28
MT (ms)	0.492 ± 0.02	0.460 ± 0.012 A	0.472 ± 0.015	0.449 ± 0.016*	0.469 ± 0.014	0.483 ± 0.01	0.472 ± 0.018	0.439 ± 0.012*†	0.470 ± 0.011	0.478 ± 0.015	0.465 ± 0.011	0.436 ± 0.012*
RT (ms)	0.129 ± 0.007	0.137 ± 0.006	0.143 ± 0.006	0.126 ± 0.006†‡	0.148 ± 0.005	0.141 ± 0.007	0.127 ± 0.003	0.127 ± 0.009	0.135 ± 0.006	0.135 ± 0.01	0.136 ± 0.008	0.131 ± 0.009
Total MT (ms)	0.620 ± 0.024	0.594 ± 0.013 A	0.614 ± 0.015	0.574 ± 0.018*†‡	0.617 ± 0.014	0.625 ± 0.016	0.599 ± 0.016	0.565 ± 0.016*	0.603 ± 0.014	0.609 ± 0.018	0.592 ± 0.011	0.567 ± 0.011*†
Fatigue rating	0.63 ± 0.13	1.0 ± 0.31	1.21 ± 0.35	6.75 ± 0.58*†	1.8 ± 0.36*	6.8 ± 0.82*†	2.8 ± 0.58*	6.92 ± 0.80*†	2.38 ± 0.43*	7.33 ± 0.63*†	2.54 ± 0.55*	7.58 ± 0.73*†
Heart rate (bpm)	67.25 ± 2.2	72.90 ± 5.0	72.00 ± 2.7	178.9 ± 4.2*†	72.07 ± 2.1	174.0 ± 1.4*†	84.16 ± 4.5	183.0 ± 2.5*†	72.5 ± 3.1	178.5 ± 3.6*†	74.6 ± 2.8	180.0 ± 5.17*†

A, $P \leq 0.05$ from corresponding AM baseline.
* $P \leq 0.05$ from both baselines.
† $P \leq 0.05$ from corresponding prematch value.
‡ $P \leq 0.05$ from corresponding prematch 4 value.

FIGURE 2—(A) Hand grip and (B) "Bear Hug" test performance at baseline (a.m. and p.m.) and pre and post each match (mean ± SE). * $P \leq 0.05$ from both baselines; Δ $P \leq 0.05$ from corresponding prematch value.

were also significantly lower than those for baseline testing. Postmatch 1 values were significantly lower than those for prematch 1. All grip strength values for the matches were significantly lower than those at baseline testing. Also, the postmatch values for matches 1 and 3 were significantly lower than the corresponding prematch values (see Fig. 2).

The only significant match-induced change in reaction time was observed between the pre- and post-match values for match 1, with the postmatch value being significantly faster. No other differences were observed when comparing the match values with the baseline or between values within a match. Movement time for baseline 2 was significantly faster than baseline 1 measure. Movement times for postmatches 1, 3, and 5 were significantly faster than both baseline measures. Also, the postmatch 3 value was significantly faster than that for prematch 3. Total movement time (reaction + movement times) showed only significant differences from baseline values at matches 1,3, and 5 and a pre- to post-match difference

at match 1, with the postmatch value being faster. The pre- to post-match difference for match 3 for movement time did not hold for total movement time (see Table 1).

Knee extension peak torque at 1.05 rad·s^{-1} was significantly different from baseline measures for both match values in matches 3–5. Conversely, knee extension peak torque at 5.24 rad·s^{-1} was significantly different from baseline measures for both match values in matches 1 and 2. Isometric knee extension peak torque was significantly different from baseline values for prematches 2, 4 and 5, and for postmatch 3. There were no significant differences for any comparisons between match and baseline values for the rate of fatigue for knee extension strength. Knee flexion strength at 1.05 rad·s^{-1} for matches 2–4 and for postmatches 1 and 5 was significantly lower than baseline measures. Knee flexion peak torque at 5.24 rad·s^{-1} was significantly lower than baseline measures for both match values in matches 1 and 2 and for postmatch 4 (see Table 2).

Isokinetic elbow extension and flexion data are summarized in Table 2. For elbow flexion peak torque at 1.05 rad·s^{-1}, only prematch 3 and postmatches 2 and 5 were significantly lower than baseline values. Elbow flexion peak torque at 5.24 rad·s^{-1} showed no significant differences for any comparisons between matches and baseline values. Both prematch values for matches 3–5 and postmatch 2 values for isometric elbow flexion peak torque were significantly lower than baseline values. The rate of fatigue for elbow flexion was significantly different only for the pre- to post-match values at match 2, with the postmatch 2 value displaying higher fatigue percentage. The peak torque of elbow extensors at 1.05 rad·s^{-1} was significantly reduced after matches 2 and 4. Elbow extension peak torque at 5.24 rad·s^{-1} showed no significant differences for any comparisons between matches and baseline values (see Table 3).

Postmatch lactic acid values were significantly elevated above those for the baseline and corresponding prematch values for all matches. All postmatch measures of glucose were significantly elevated above the baseline values and those of the corresponding prematch values. None of the insulin measures for the match values were significantly different neither within matches nor from the baseline values. Also, plasma volume exhibited a nonsignificant slight decrease after each match (see Table 4).

Postmatch osmolality values were significantly elevated above the baseline values and corresponding prematch values for all matches. Resting and postexercise concentrations of creatine kinase were not significantly different from either baseline measure at matches 1 and 2. However by the start of match 3, accumulations of creatine kinase reached significance above baseline and matches 1 and 2. Creatine kinase continued to accumulate at matches 4 and 5 on the second day. Each exercise-induced response was significant and each time point was significantly greater than the corresponding time point on the previous match (see Fig. 3).

All postmatch testosterone values were significantly higher than those of the corresponding prematch values, whereas prematch values for matches 2–5 were significantly lower than the baseline measures. Postmatch values for

TABLE 2. Isokinetic knee extension peak torque (Nm) at 0, 1.05, and 5.24 rad · s^{-1}, percent fatigue (from the 0 rad · s^{-1} trial), and knee flexion peak torque at 1.05 and 5.24 rad · s^{-1} AM and PM baselines, matches 1–3 on day 1, and matches 4–5 on day 2 (mean ± SE).

	AM Baseline	PM Baseline	Match 1		Match 2		Match 3		Match 4		Match 5	
			Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post
Knee extension @0	219.97 ± 17.39	227.76 ± 16.91	214.67 ± 11.99	214.45 ± 12.79	194.06 ± 20.89*	204.24 ± 14.42 P	199.53 ± 18.41 P	196.90 ± 16.83*	191.05 ± 15.74*	199.15 ± 17.49 P	196.82 ± 12.72*	198.86 ± 14.86 P
Knee extension @1.05	256.24 ± 12.14	246.24 ± 12.14	230.99 ± 13.49	237.05 ± 14.34	238.50 ± 12.85	229.92 ± 16.96	228.01 ± 17.33*	226.31 ± 16.61*	220.89 ± 19.29*	227.89 ± 16.41*	227.40 ± 15.64*	226.49 ± 14.75*
Knee extension @5.24	105.42 ± 6.34	105.18 ± 6.48	89.37 ± 3.58*	92.54 ± 4.33*	94.12 ± 4.01*	90.73 ± 5.12*	95.58 ± 5.28	100.81 ± 5.04	96.04 ± 7.16	97.62 ± 6.63	95.46 ± 6.27	98.07 ± 5.94
Knee extension %fatigue	17.98 ± 1.62	18.25 ± 8.16	13.48 ± 1.99	16.03 ± 2.98	13.97 ± 2.75	12.45 ± 2.39	15.84 ± 3.85	14.42 ± 3.75	11.23 ± 1.98	14.57 ± 3.64	15.12 ± 3.42	11.23 ± 2.72
Knee flexion @1.05	156.93 ± 9.85	153.54 ± 11.32	147.12 ± 10.89 A	143.04 ± 11.22*	141.78 ± 10.30*	140.32 ± 10.47*	142.93 ± 10.50*	138.17 ± 11.10*	139.87 ± 11.97*	144.16 ± 10.99*	146.42 ± 11.57 A	141.23 ± 11.78*
Knee flexion @5.24	98.64 ± 7.02	100.78 ± 6.83	87.67 ± 3.94*	85.15 ± 2.86*	88.70 ± 3.39*	81.91 ± 3.92*	92.18 ± 5.39	92.75 ± 5.72	93.81 ± 7.20	88.79 ± 5.89*	91.40 ± 5.23 P	90.49 ± 5.47 P

A, $P \leq 0.05$ from corresponding AM baseline; P, $P \leq 0.05$ from corresponding PM baseline.
* $P \leq 0.05$ from both baselines.

TABLE 3. Isokinetic elbow extension peak torque (Nm) at 0, 1.05, and 5.24 rad · s^{-1}, percent, fatigue (from the 0 rad · s^{-1} trial), and elbow flexion peak torque at 1.05 and 5.24 rad · s^{-1} at AM and PM baselines, matches 1–3 on day 1, and matches 4–5 on day 2 (mean ± SE).

			Match 1		Match 2		Match 3		Match 4		Match 5	
	AM Baseline	PM Baseline	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post
Elbow flexion @0	73.49 ± 4.72	76.04 ± 5.29	71.40 ± 2.95	70.95 ± 3.36	68.81 ± 4.45	66.38 ± 3.33*	65.08 ± 4.16*	63.67 ± 2.99*	63.55 ± 4.16*	62.87 ± 3.40*	63.78 ± 4.25*	63.32 ± 2.88*
Elbow flexion @1.05	69.32 ± 5.06	69.77 ± 4.88	67.57 ± 3.38	65.03 ± 3.45 P	65.24 ± 3.89 P	61.52 ± 3.97*	60.19 ± 5.90*	63.68 ± 4.08	66.15 ± 4.00	63.72 ± 3.77	64.12 ± 4.14	61.46 ± 3.50*
Elbow flexion @5.24	35.59 ± 2.79	36.98 ± 3.14	33.84 ± 1.68	32.56 ± 1.67	33.34 ± 2.29	33.67 ± 1.59	35.02 ± 1.33	35.81 ± 2.17	36.04 ± 1.84	34.41 ± 1.79	35.58 ± 1.75	32.93 ± 1.35 P
Elbow flexion %fatigue	22.22 ± 5.01	21.09 ± 2.64	20.12 ± 3.54	20.98 ± 2.93	17.50 ± 3.37	25.83 ± 3.64†	20.25 ± 2.85	26.92 ± 4.49	16.25 ± 2.61	15.26 ± 3.68	16.92 ± 3.04	18.70 ± 3.92
Elbow extension @1.05	78.13 ± 6.62	72.98 ± 5.39	71.63 ± 4.79 A	70.05 ± 3.89 A	69.93 ± 5.54 A	65.63 ± 4.57*	66.90 ± 5.56 A	67.62 ± 5.30 A	67.85 ± 4.29 A	65.47 ± 4.39*	63.50 ± 4.27*	66.67 ± 4.49*
Elbow extension @5.24	38.07 ± 2.48	39.38 ± 2.55	36.37 ± 1.60	34.92 ± 1.71	36.16 ± 2.09	36.55 ± 1.67	36.72 ± 2.15	36.45 ± 2.30	36.83 ± 1.87	35.81 ± 1.97	35.98 ± 2.16	34.12 ± 1.93

A, $P \leq 0.05$ from corresponding AM baseline. P, $P \leq 0.05$ from corresponding PM baseline.
* $P \leq 0.05$ from both baselines.
† $P \leq 0.05$ from corresponding prematch value.

TABLE 4. Concentrations of glucose, insulin, lactate, dopamine, and total plasma volume at AM and PM baselines, matches 1–3 on day 1, and matches 4–5 on day 2 (mean ± SE).

			Match 1		Match 2		Match 3		Match 4		Match 5	
	AM Baseline	PM Baseline	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post
Glucose (mmol · L^{-1})	5.49 ± 0.32	5.39 ± 0.17	5.41 ± 0.12	8.18 ± 0.42*†	5.27 ± 0.16	7.72 ± 0.57*†	4.88 ± 0.28	7.48 ± 0.45*†	4.86 ± 0.29	7.03 ± 0.37*†	4.90 ± 0.24	6.99 ± 0.26*†
Insulin (pmol · L^{-1})	184.70 ± 36.14	181.47 ± 29.19	168.19 ± 20.19	175.48 ± 32.16	185.57 ± 29.70	166.80 ± 27.16	180.84 ± 28.44	144.94 ± 14.78	191.20 ± 23.29	249.32 ± 70.84	171.57 ± 22.15	152.86 ± 13.65
Lactate (mmol · L^{-1})	2.19 ± 0.18	1.96 ± 0.18	1.95 ± 0.1	20.0 ± 0.7*†	2.32 ± 0.1	18.09 ± 1.3*†	1.72 ± 0.1	17.4 ± 1.2*†	2.0 ± 0.16	18.76 ± 0.9*†	1.98 ± 0.12	17.11 ± 1.02*†
Dopamine (pmol · L^{-1})	1285.42 ± 277.90	1099.67 ± 337.38	725.64 ± 261.42*	2780.56 ± 1028.02*†	387.62 ± 92.03*	1018.80 ± 272.97†	1198.11 ± 363.99	1747.52 ± 487.47†	998.15 ± 303.81	1764.07 ± 843.06*†	1254.02 ± 559.73	1040.46 ± 320.65
Plasma volume (mL)	4638.5 ± 244.1	3894.9 ± 168.8 A	4309.7 ± 257.4	3876.3 ± 200.6	4453.6 ± 270.0	4141.7 ± 227.4	4586.3 ± 242.6	4169.5 ± 210.8	4763.7 ± 244.7 P	4357.8 ± 225.5 P	4864.3 ± 243.9 P	4523.3 ± 249.2 P

A, $P \leq 0.05$ from corresponding AM baseline; P, $P \leq 0.05$ from corresponding PM baseline.
* $P \leq 0.05$ from both baselines; †, $P \leq 0.05$ from corresponding prematch value.

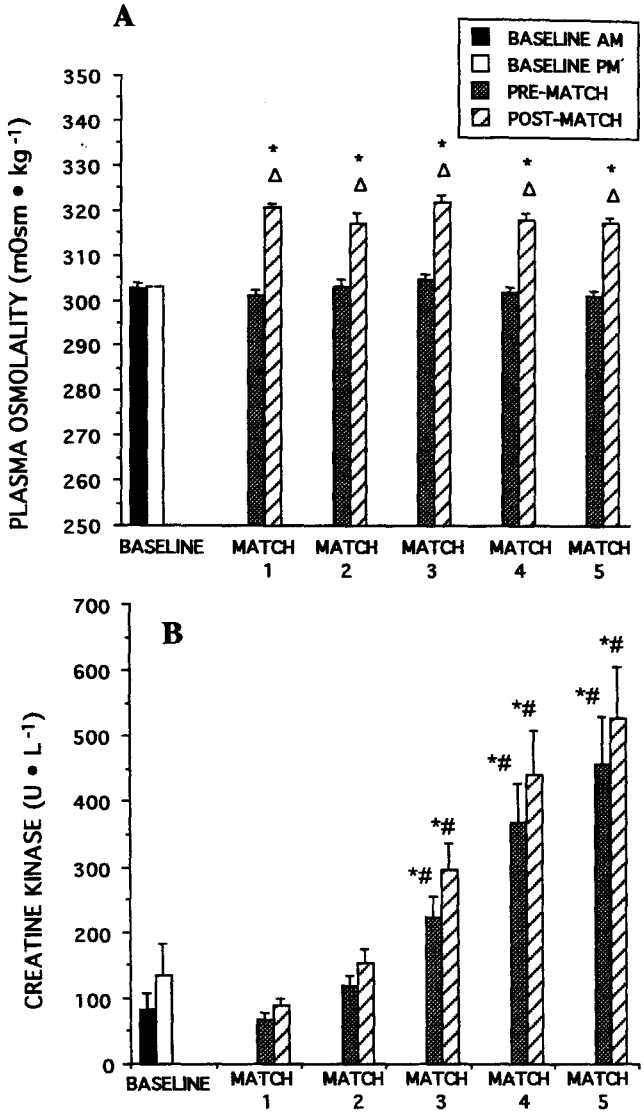

FIGURE 3—(A) Plasma osmolality and (B) concentrations of creatine kinase at baseline (a.m. and p.m.) and pre and post each match (mean ± SE). * $P \leq 0.05$ from both baselines; Δ $P \leq 0.05$ from corresponding prematch value; # $P \leq 0.05$ from corresponding time point at previous match.

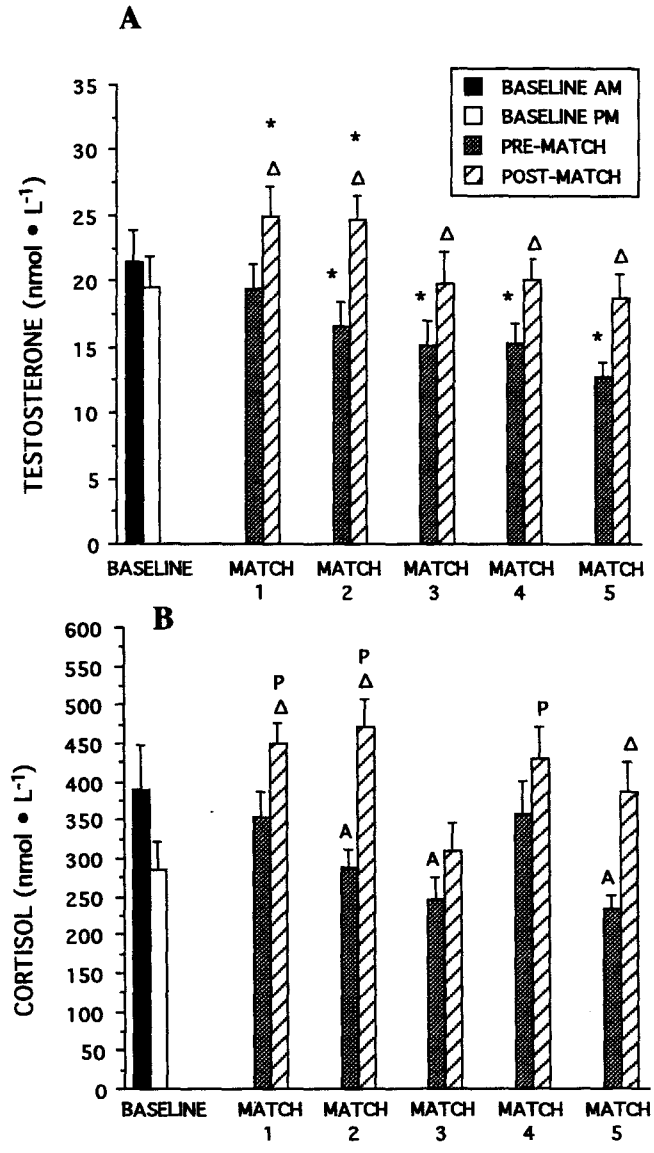

FIGURE 4—(A) Concentrations of testosterone and (B) cortisol at baseline (a.m. and p.m.) and pre and post each match (mean ± SE). A, $P \leq 0.05$ from corresponding a.m. baseline; P, $P \leq 0.05$ from corresponding p.m. baseline; * $P \leq 0.05$ from both baselines; Δ = $P \leq 0.05$ from corresponding prematch value.

matches 1 and 2 were significantly higher than the baseline measures. Cortisol measures were significantly elevated at postmatch for matches 1, 2 and 5. Additionally, prematch values for matches 2, 3, and 5 were significantly lower than the morning baseline values (baseline 1), whereas postmatch values for matches 1, 2, and 4 were significantly higher than the p.m. baseline (baseline 2) (see Fig. 4).

Postmatch epinephrine values for matches 1, 2, and 4 were all significantly higher than their corresponding prematch values. Also, postmatch values for matches 1 and 2 were significantly higher than those of the p.m. baseline, whereas postmatch 4 values were significantly higher than those for both baseline measures. All postmatch values for norepinephrine were significantly higher than those of the baseline values as well as the corresponding prematch values (see Fig. 5). Dopamine concentrations increased dramatically after matches 1–4 (see Table 4).

DISCUSSION

It was apparent in this study of elite collegiate wrestlers that they have a dramatic ability to adapt and rebound from a weight loss/recovery period (i.e., about 12 h) before the first match of a tournament. Although potentially reflective of the most sensitive diagnostic tests for this period before the first match, only grip strength, isokinetic fast velocity knee extension torque, isokinetic slow and fast velocity knee flexion torques, isokinetic slow velocity elbow extension torque, and plasma dopamine concentrations were negatively affected. This attests to the almost adaptive nature of wrestlers to resist any physiological and performance affects with weight loss alone. However, in this study it was shown with the progression of the tournament and the concomitant accumulation of other stressors (e.g., physical competition, psychological stress), a continuous reduction of almost all performance and

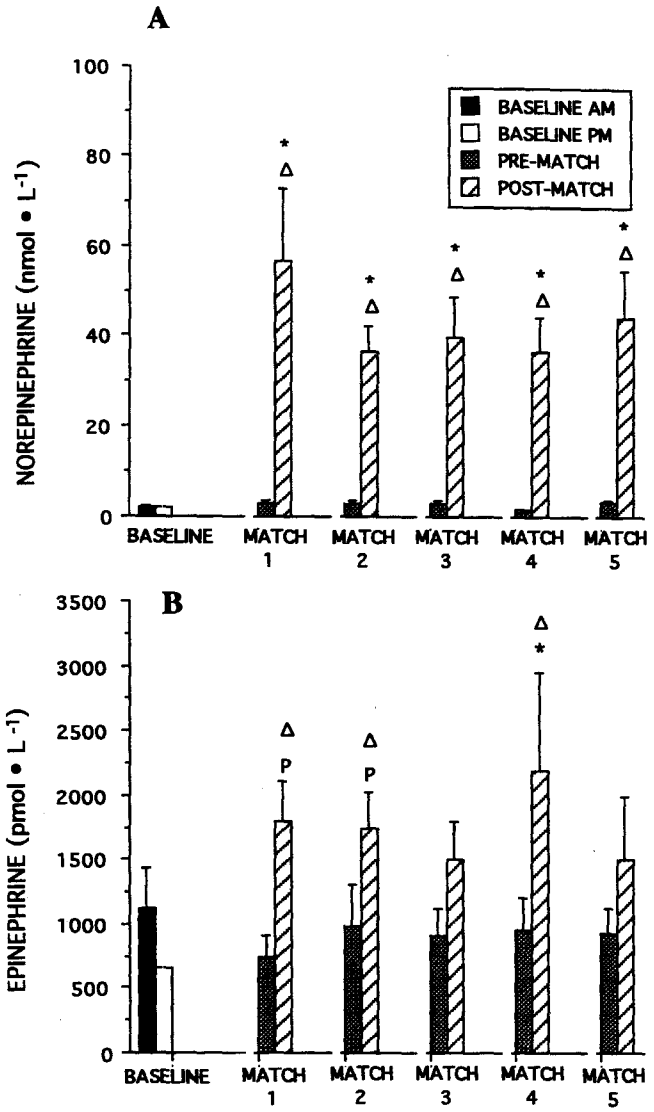

FIGURE 5—(A) Concentrations of norepinephrine and (B) epinephrine at baseline (a.m. and p.m.) and pre and post each match (mean ± SE). P, $P \leq 0.05$ from corresponding p.m. baseline; * $P \leq 0.05$ from both baselines; Δ $P \leq 0.05$ from corresponding prematch value.

physiological variables examined over the 2-d tournament occurred.

The added stress beyond the weight loss and hypohydration occurs from other aspects of the wrestling match. We measured extremely high concentrations of lactate (at or near 20 $mmol \cdot L^{-1}$ immediately after each match) demonstrating the dramatic anaerobic nature of wrestling that has been observed in prior studies (4,13,15). With the associated larger increases in muscle lactate concentrations, a significant disruption in the acid-base balance in the body with each subsequent match occurs (4,13,15). Such stress has been shown to affect contractile capabilities, yet wrestlers most likely adapt by enhancing various intra- and inter-cellular buffering mechanisms (e.g., sodium bicarbonate) (11,12). Because food and fluid restriction did occur over the 2-d tournament on both days, it might also be hypothesized that the high lactate concentrations observed in context of nutrient restriction, maintenance of insulin, and significant elevations in blood glucose reflected further depletion of glycogen stores in the muscle and the liver over the course of the 2-d tournament (13). These metabolic changes may well have contributed to the continuous down regulation of most physical performance capabilities over the 2-d tournament. The reductions in physical performance are also in agreement with the consistent increase of fatigue ratings over the course of the tournament. Prematch fatigue consistently increased and by match 3 of day 1 was significantly elevated, indicating an increase in subjective fatigue with each match. Furthermore, this prematch fatigue was maintained into day 2, showing that recovery did not perceptually occur overnight.

These data demonstrate that physical performance measures were more affected by the time course of the tournament rather than weight loss before the first match. For example, vertical jump power was not affected at the time of the first prematch test on day 1 of the wrestling tournament. However, by the first prematch measure on day 2, there was a significant reduction in vertical jump power. Circulating concentrations of creatine kinase progressively increased throughout the tournament and were greatest on day 2, demonstrating the dramatic impact of actual competition as prior baseline values were obtained within the context of the normal practice training program. The significant elevations in creatine kinase concentrations, especially by the start of the second day, are indirectly indicative of more pronounced muscle tissue damage resulting from the three matches on the first day. Such muscle tissue disruption would affect force production and physical performance and contribute to the reductions in physical performance observed (6).

A unique finding in the present investigation was the attenuation of grip strength from baseline values throughout the tournament, which is in contrast to previous research on grip strength and hypohydration in wrestlers where no reductions were observed (28). Grip strength is a vital performance capability in the sport of wrestling as various take-down and defensive counter maneuvers rely on a strong grip. The present data demonstrate the 6% weight loss and recovery period before the first match significantly impacts this variable, different from the findings of others with weight loss alone (28,35). Even more impressive was the observations of continued reductions from baseline over the 2-d tournament and inability of the wrestling match to elicit any exercise-induced fatigue on day 2. These data indicate a potential lower limit for force production reserves in these wrestlers and show that without adequate recovery performance is not optimal in the later matches which can have the greatest importance attached to their results (e.g., championship bracket matches).

Similar to grip strength, total upper body strength is also vital for a host of wrestling moves used during a match (11). This was the first study to utilize a wrestling-specific test (i.e., "bear hug" test) to observe changes in the upper body musculature. A significant reduction in the isometric force of the muscles of the upper torso and arms were demonstrated in this study after the first match. Once again, a reduction of force capabilities and loss of an exercise-induced change was observed over the tournament. This force reduction may have been influenced by the concomitant reduction in grip strength. It is important to remember

that a wrestling match is made up of dynamic movements of the legs, hips, and back and isometric grasping for position maintenance. Both these patterns of muscular force appear sensitive to the accumulated mechanisms of fatigue (e.g., muscle damage, glycogen depletion, acid-base balance) from multiple matches. These findings are the first to characterize the sports-specific changes that occur with multiple wrestling matches and frame the specific problems where interventions are needed for enhanced performance. Separating the roles of the combined stressors of weight loss, food, and fluid restrictions from physical exertion and psychological stress of wrestling competition remains for future studies.

Previous research examining weight loss in wrestlers and isokinetic performance of the elbow and knee joints revealed that there was no affect of a 5% weight reduction on peak torque at both fast and slow velocities (36). However, the present data do reveal some sensitivity of similar isokinetic performance measures to a 6% weight loss, as was seen with reductions in knee flexion, fast knee extension, and slow elbow extension torque values. As the tournament progressed, there seemed to be a velocity specific pattern of maximal force and torque production, with the slower velocity and isometric movements apparently being more susceptible to fatigue, as was also seen with the "bear hug" and hand grip strength tests, both isometric strength tests. These data indicate that the nature of the wrestling match may allow for greater recovery of the Type II motor units due to more intermittent use and longer recovery within the 5-min match.

The lack of any negative changes in reaction and movement times in the stand-up drill, supports in part a previous study examining the impact of weight loss showing no significant impairment (29). Surprisingly, there seemed to be an improvement of the reaction time as the tournament progressed potentially due some type of warm-up effect and/or heightened arousal (e.g., increased catecholamines) after the match. Further study is needed for wrestling movement and reaction times examining nonvisual cues (e.g., touch cues between competitors or a referee's whistle) or other movements before a complete interpretation of these data are possible.

One of the more remarkable findings in this study was the effect of the wrestling tournament on circulating testosterone concentrations. Increases in testosterone in response to the wrestling matches were seen across the tournament. This is consistent with previous research on serum values performed on hormonal responses to wrestling (3), but salivary changes over 2 d have been shown to be more variable, possibly reflecting the differences between bio-compartments (25). However, in the present study, we observed a chronic reduction in resting serum testosterone concentrations throughout the tournament. Testosterone concentrations fell to well below measured baseline circadian matched values as well as normal resting ranges for men of this age group (i.e., 20–25 $nmol \cdot L^{-1}$). By the end of the study, a mean value of just over 12 $nmol \cdot L^{-1}$ was observed for testosterone. These data put our wrestlers into the zone of prepubescent boys and would potentially impair metabolic recovery processes related to the anabolic functions of testosterone at rest (17–19). Such a phenomenon has been observed in endurance runners over long periods (e.g., months) of high-mileage training (1) and in elite junior weight lifters over the course of a 1-wk high-volume overtraining protocol (5). It was thought that this is indicative of a shut down of the hypothalamic-pituitary-gonadal axis due to chronic overuse and enhancement of catabolic processes at the muscle tissue level (5,18). It is also possible that changes in fluid and blood flow in the testes affect beta-endorphin and nitric oxide mechanisms related to testosterone secretion (unpublished data) and with an increased turnover at the level of the receptor, concentrations would be muted. It is possible that changes in muscular force characteristics observed in the present study, as observed in vertical jump power, were affected at the tissue level by this continuous reduction in anabolic status of the body which may mitigate the magnitude of protein accretion of contractile proteins after physical stress (5,17,18). How and if testosterone's response, if maintained, is related to a wrestler's probability of injury over a season remains to be studied.

In our study, there was food and fluid restriction over the 2 d. We also observed a lower testosterone response. Roemmich and Sinning (26) found that testosterone was reduced late in the season after repetitive weight loss in collegiate wrestlers. Because this study took place after a complete season of collegiate wrestling, the timing of the study may have also have contributed to the attenuation of testosterone concentrations. Similar abnormally low testosterone levels were observed by Strauss et al. (31) in wrestlers during a season with values rebounding back to normal values 2 months after the season. Strauss et al. (31) also demonstrated significant relationships between testosterone values and weight loss, body fat percentage, and body fat loss. Wheeler et al. (37) observed significantly lower testosterone concentrations during competition weeks, presumably when wrestlers are losing weight due to dehydration, combined with caloric restriction to make weight. Although data concerning acute dietary changes and testosterone are limited, it may be possible that the dehydration-induced weight loss and caloric restriction experienced by the wrestlers in the present study combined with the high-intensity nature of the wrestling competition contributed to the dramatically reduced testosterone concentrations.

Norepinephrine concentrations increased significantly after each match, whereas epinephrine values after the last match of each day were not significantly elevated. This is in agreement with previous research where norepinephrine appeared to respond in a more sensitive manner than epinephrine to hypohydration and exercise (9). This reduced epinephrine response at the end of each tournament day may represent a type of adrenal insufficiency that may have further contributed to the reduced force production capabilities observed in this study. The ability of the adrenal gland to secrete epinephrine has been shown to be important in short-term exercise performance (7,16). The exact mechanism behind this adrenal response remains speculative but may be due to accumulated fatigue, lack of epinephrine resynthesis in the chromaffin cell of the adrenal medulla, and/or fluid restriction and dehydration over the course of

each day (9,16). The increase in dopamine concentrations observed in this study have been reported previously with high-intensity resistance exercise (16). It is thought that these exercise-induced dopamine increases are due to limited enzymatic conversion of dopamine to norepinephrine. This "dopamine spillover" from the adrenal medulla could possibly explain the slightly reduced circulating norepinephrine concentrations as the tournament progressed and may be indicative of sympathetic fatigue resulting in reduced force production capabilities (16).

One of the most striking findings in this study is the plasma osmolality values, which support prior studies of urine profiles in elite high school wrestlers over two decades ago. Even at baseline, values were significantly higher than the normal range of about 280–285 $mOsm \cdot kg^{-1}$ (32). Because the baseline measures were obtained within 3–4 wk after the actual season, these data indicate that these elite collegiate wrestlers are in a chronically dehydrated state. Even after a postseason weight gain and a return to "normal" dietary patterns, a state of dehydration still exists. This potential chronic regulation of kidney function was first suggested over 20 yr ago by Zambrowski et al. (39–41), who documented urinary profiles indicative of hypohydration in elite high school wrestlers in Iowa. How long these wrestlers had experienced such increases in plasma osmolality also remains a topic for future research. If it is continuous from high school or earlier, concern exists for long-term health issues. Thus, the effects and possible recovery of such alterations related to the hydration status of the wrestler are currently unknown. It does indicate that through a type of adaptation, wrestlers who make weight many times during a season reset their fluid regulatory systems to a new "normal." Again, when this occurs and how permanent it is also remains unknown. This may be some sort of compensatory response to endure the low volume of fluid intake associated weight-reduction behaviors (39–41). The impact on performance is unclear as no changes at rest were observed for plasma osmolalities across the tournament. However, amazingly, the postmatch osmolality values seemed to have pushed the physiological limits with values reaching about 320 $mOsm \cdot kg^{-1}$ at each immediate postmatch time point. The ability of these wrestlers to produce and sustain such a hyperosmotic state and still compete at an elite level speaks of the tremendous resiliency of this type of athlete. It is important to reiterate the amazing plasticity of the system to elevate to very high levels of plasma osmolalities, again suggesting a new "normal" for the osmol regulatory centers of the hypothalamus.

This study demonstrates the unique physiological status of amateur wrestlers who chronically fluctuate body weight to compete in a desired weight classification. The present data are also the first to demonstrate the performance decrements that occur over the course of a typical wrestling tournament. Interestingly, wrestlers seem to tolerate typical weight loss techniques quite well, and therefore the changes that occur could be due to the stress of competition alone when considering the experimental design used in this study. In addition, wrestlers are not mandated to maintain body weight over a tournament in Olympic competition, but restrictions are employed in collegiate tournaments. Thus, this study does have implications for collegiate and high school wrestling as well. Again, food and fluid intake has been shown to be important as to the physiological status of the wrestler in tournament competition (33). However, it is apparent that the physical and psychological demands of a tournament combined with the dehydration and caloric restriction does not allow for complete recovery between matches, even matches that occur after a 12- to 15-h rest period from the previous match. Because wrestlers are required to maintain weight over the course of the tournament, adequate postmatch recovery is sacrificed (i.e., rehydration, caloric intake). It is the apparent coupling of these stresses (i.e., weight loss combined with tournament competition) that adversely affects performance as the tournament progresses. As a result, wrestlers who participate in various weight loss techniques might be doing so at the expense of peak physical performance, especially later in the tournament. Indeed, it should be understood that the physiological/hormonal profile exhibited by these athletes might have more chronic effects beyond those observed with an acute competition, including increased risk for injury and altered kidney function due to chronic dehydration. Expert recommendations made by the American College of Sports Medicine to address some of the concerns for weight loss in wrestling have even greater credibility within the context of our data (24). In addition, recent attempts by governing bodies to limit weight loss practices and further stabilize weight classes, especially in some high school ranks, may also diminish some of these negative effects observed in this study. Whether such regulations will actually eliminate a variety of scenarios where a wrestler loses 6% body mass in the week leading up to a tournament weigh in remains to be seen. Optimal physical preparation and adequate diet over the course of the tournament may also be vital for limiting such effects. Nevertheless, our data are the first to demonstrate that tournament wrestling is much more dramatic in its physiological demands than one match or weight loss alone.

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