Physiological and Performance Changes From The Addition of a Sprint Interval Program to Wrestling Training

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Abstract

Farzad, B, Gharakhanlou, R, Agha-Alinejad, H, Curby, DG, Bayati, M, Bahraminejad, M, and Mäestu, J. Physiological and performance changes from the addition of a sprint-interval program to wrestling training. *J Strength Cond Res* 25(9): 2392–2399, 2011—Increasing the level of physical fitness for competition is the primary goal of any conditioning program for wrestlers. Wrestlers often need to peak for competitions several times over an annual training cycle. Additionally, the scheduling of these competitions does not always match an ideal periodization plan and may require a modified training program to achieve a high level of competitive fitness in a short-time frame. The purpose of this study was to examine the effects of 4 weeks of sprint-interval training (SIT) program, on selected aerobic and anaerobic performance indices, and hormonal and hematological adaptations, when added to the traditional Iranian training of wrestlers in their preseason phase. Fifteen trained wrestlers were assigned to either an experimental (EXP) or a control (CON) group. Both groups followed a traditional preparation phase consisting of learning and drilling technique, live wrestling and weight training for 4 weeks. In addition, the EXP group performed a running-based SIT protocol. The SIT consisted of 6 35-m sprints at maximum effort with a 10-second recovery between each sprint. The SIT protocol was performed in 2 sessions per week, for the 4 weeks of the study. Before and after the 4-week training program, pre and posttesting was performed on each subject on the following: a graded exercise test (GXT) to determine $\dot{V}O_2$max, the velocity associated with $\dot{V}O_2$max ($\nu\dot{V}O_2$max), maximal ventilation, and peak oxygen pulse; a time to exhaustion test (T_{max}) at their $\nu\dot{V}O_2$max; and 4 successive Wingate tests with a 4-minute recovery between each trial for the determination of peak and mean power output (PPO, MPO). Resting blood samples were also collected at the beginning of each pre and posttesting period, before and after the 4-week training program. The EXP group showed significant improvements in $\dot{V}O_2$max (+5.4%), peak oxygen pulse (+7.7%) and T_{max} (+32.2%) compared with pretesting. The EXP group produced significant increases in PPO and MPO during the Wingate testing compared with pretesting ($p < 0.05$). After the 4-week training program, total testosterone and the total testosterone/cortisol ratio increased significantly in the EXP group, whereas cortisol tended to decrease ($p = 0.06$). The current findings indicate that the addition of an SIT program with short recovery can improve both aerobic and anaerobic performances in trained wrestlers during the preseason phase. The hormonal changes seen suggest training-induced anabolic adaptations.

Key Words conditioning, cortisol, hemoglobin, testosterone, wrestlers

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Introduction

Increasing the level of physical fitness for competition is the primary goal of any conditioning programs for wrestlers. Wrestlers often need to peak for competitions several times over an annual training cycle. Additionally, the scheduling and spacing of these competitions do not always match an ideal periodization plan and may require a modified training program to achieve a high level of competitive fitness in a short-time frame. This is also the case after periods of inactivity because of injury or illness when it is necessary to make sudden changes in the training program (31). In these cases, sprint-interval training (SIT) can be considered. The potency of SIT to induce rapid improvement in performance capacity and skeletal muscle energy metabolism has been widely examined (5,11,22,24).

Sprint-interval training has been employed with various forms of cycling (22–31) or repeated sprints on a treadmill (3,8,29) to examine the effects on physiological adaptations. The effects of the addition of a running-based SIT to wrestler's training, to our knowledge, have not been examined. The added SIT protocol consisted of 6 35-m runs at maximum effort with a 10-second recovery between each sprint. This type of training protocol with a short recovery mainly involves anaerobic processes leading to high blood lactate (BLa^-) concentrations (39) and may be useful for wrestlers aiming to improve lactate tolerance and H^+ buffering capacity. The blood lactic acid concentrations in response to a wrestling match can be over 19 $mmol \cdot L^{-1}$ (16). Wrestlers must be able to buffer the high-acidic muscle and blood concentrations to demonstrate optimal strength and power during training and competition (18).

A wide range of adaptations have been shown after SIT, including increased resting glycogen content (2,31), increased activity of various glycolytic and oxidative enzymes (5,14,30), H^+ buffering capacity (11), and time to exhaustion (5,8,11). Increased (8,31,34) or unchanged (5,23) values of $\dot{V}O_2max$ after SIT have also been reported. The extent of these changes in response to SIT varies from 1 program to another. In contrast to the studies describing the physiological adaptations to SIT in physically untrained active individuals (2,5,11,12,24,29,31), relatively few studies have examined the physiological and performance responses of trained athletes (8,21,22,32). Because these athletes have initially high aerobic and anaerobic capacities, the physiological adaptations that generally account for improved performance in sedentary or recreationally active individuals may not necessarily apply to highly trained athletes (20). Therefore, this study examined physiological adaptations to an SIT program in trained wrestlers.

Assessment of the changes in circulating hormones following different types of training programs may be used as the objective tools to evaluate training loads. Testosterone/cortisol ratios (TCRs) and free testosterone/cortisol ratios (FTCR) are particularly important in monitoring the status of anabolic and catabolic activities (1,13,36). Furthermore, the response of hematological parameters associated with improved performance as a result of SIT programs is not well documented. We hypothesized that SIT programs might influence these biochemical parameters.

Accordingly, the purpose of this study was to examine the effects of 4 weeks of the SIT program on selected aerobic and anaerobic performance indices, and hormonal and hematological adaptations, when added to the traditional Iranian training of wrestlers in the preseason conditioning phase.

Methods

Experimental Approach to the Problem

Wrestlers often need to reach several peaks over an annual cycle. Therefore, when designing a conditioning plan, the goal is to prevent overtraining while peaking physiologically for competition, sometimes required on shorter than desired notice. The addition of SIT was studied to establish its effectiveness in helping wrestlers prepare physiologically in a short period of time (4 weeks) when compared to the traditional Iranian training used in the preseason conditioning phase. We used a SIT protocol for 4 weeks. Subjects were recruited and assigned to either the EXP or CON group. Body mass and height of the participants were measured to the nearest 0.05 kg and 0.1 cm, respectively, using a Martin metal anthropometer and a medical balance scale (A&D Instruments Ltd., Abingdon, United Kingdom). Their body composition was analyzed using Inbody 3.0 (Biospace Co, Ltd., Seoul, Korea). Pretesting of the aerobic and anaerobic performances, along with blood and biochemical parameters was conducted before the beginning of the preseason phase of the athletes' yearly training program, with posttesting after the 4-week training program. In both pre and posttesting, the subjects first performed a graded exercise test (GXT) to determine their $\dot{V}O_2max$, the velocity associated with $\dot{V}O_2max$ ($\nu\dot{V}O_2max$), maximal ventilation, and peak oxygen pulse ($\dot{V}O_2max/HR_{Peak}$; the ratio between $\dot{V}O_2$ and HR, which estimates the product of the stroke volume (SV) and arteriovenous O_2 (A-$\dot{V}O_2$) difference) (19) using an online gas collection system ($K4b_2$, Cosmed, Rome, Italy). Expired air was analyzed for fractions of expired oxygen and carbon dioxide (F_EO_2 and F_ECO_2) every 30 seconds during this exercise test. The second test was a T_{max} test used to determine the time to exhaustion at $\nu\dot{V}O_2max$. On the third day, the subjects performed 4 consecutive 30-second Wingate tests with a 4-minute recovery between the trials to determine peak power output (PPO) and mean power output (MPO). All 3 test days were separated by 48 hours, and the subjects were asked not to participate in any physical activity 24 hours before each test. After the 4-week training period, subjects repeated the same testing battery as the pretraining in the same order and under similar conditions. All laboratory testing was conducted in the Physiology Laboratory at the National Olympic Academy and Tarbiat Modares University at the same time of the day (8:30–11:30 AM).

Subjects

Fourteen trained male freestyle wrestlers with 6–7 years of wrestling-training experience, who had national ($n = 8$) and provincial ($n = 7$) ranking, volunteered to participate in this study. Subjects were randomly assigned to either an experimental (EXP) or control (CON) group (Table 1). Both groups were supposed to participate in a national match. Wrestlers who did not have the need for any major weight loss were selected. The wrestling match was held 2 weeks after the end of the study, meaning wrestlers were not regulating their bodyweight at the time of the study. Both groups were self-motivated to perform well at this training camp. Subjects were completely familiarized with all of the experimental procedures and possible risks before they gave their written consent to participate in the study. During

Table 1. Physical characteristics of participants.*

Variables	Control group ($n = 7$)	Experimental group ($n = 8$)
Age (y)	21.2 ± 2.9	18.6 ± 1.4
Height (cm)	172.7 ± 9.4	176.2 ± 7.2
Mass (kg)	70.5 ± 10.6	75.5 ± 16.7
Percent body fat (%)	13.9 ± 4.7	12.2 ± 4.8

*Values are given as mean ± *SD*.

the training and testing periods, all subjects reported that they did not participate in any other training. The study was approved by the Ethical Committee of the School of Medical Sciences of Tarbiat Modares University and was in accordance with the Declaration of Helsinki.

Procedures

Gas Analysis during the Graded Exercise Test. The graded treadmill exercise test consisted of a 3-minute walking warm-up at 6 $km \cdot h^{-1}$ with 0% slope, followed by velocity increment of 1 $km \cdot h^{-1}$ each minute until exhaustion. $\dot{V}O_2max$ was confirmed when 3 or more of the following criteria were met: (a) a plateau in $\dot{V}O_2$ despite an increase in running speed; (b) a respiratory exchange ratio >1.1; (c) peak heart rate at least equal to 90% of the age-predicted maximum; and/or (d) visible exhaustion.

Time to Exhaustion at $v\dot{V}O_2max$. The second test performed was a T_{max} test used to determine the time to exhaustion at $v\dot{V}O_2max$ that was defined as the minimal velocity associated with $\dot{V}O_2max$ in an incremental test. This test was conducted after a 10-minute warm-up on a treadmill (Vision Fitness, T9700HRT, Lake Mills, WI, USA) and was terminated volitionally by the subject if the desired speed could not be maintained and the time running at $v.\dot{V}O_2max$ (T_{max}) was recorded (8). The subjects were verbally encouraged to maximal performance.

Wingate Test. The PPO and MPO were assessed over 4 consecutive Wingate tests on a mechanically braked cycle ergometer (model 894E, Monark, Sweden) with 4-minute recovery between each 30-second trial. Subjects performed Wingate test against a resistance equivalent to 0.075 $kg \cdot kg^{-1}$ body mass. Subjects were instructed to begin pedaling as fast as possible against the ergometer's inertial resistance, and then the appropriate load was manually applied. Subjects were verbally encouraged to continue pedaling as fast as possible throughout the 30-second test. The PPO, MPO, and fatigue index were subsequently determined using an online data-acquisition system (24).

Training Program. The whole training program is presented in Table 2. Both groups followed the same wrestling training

Table 2. Training program for both groups.*

Days of week	CON group	EXP group
Monday	Wrestling training	Wrestling training
Tuesday	Weight training	Weight training
Wednesday	Wrestling training	Wrestling training
Thursday	Weight training	Sprint-interval training (MO) Weight training (EV)
Friday	Rest	Rest
Saturday	Wrestling training	Wrestling training (MO) Plyometric training (EV)
Sunday	Plyometric training	Sprint-interval training

*MO = morning; EV = evening; EXP = experimental; CON = control.

sessions, including technique drills, wrestling practice, and strength training (pull-ups, parallel bars dips, and sit-ups) for 4 weeks, 3 sessions per week. Also, both groups had 2 sessions of weight training in the weight room (back squat, bench press, military press, bicep curl, and power clean exercises) and 1 session of plyometric training (press-ups and hand clap, jumps down and up off box, squat jumps, explosive start throws, overhead throws, and tuck jumps). They were in the phase of conversion of maximal strength into explosive power. This training is typical of what has been traditionally followed in Iranian training camps during the preseason conditioning phase of the annual cycle. In addition to this training, the EXP group performed a running-based SIT protocol. This protocol was performed in 2 sessions per week and consisted of sets of 6 35-m sprints at maximum effort with a 10-second recovery between each sprint. In the first week, 3 sets were performed, with 3 minutes of rest between each set. A set was added in each subsequent week with the same 3-minute rest between sets. Each SIT session consisted of a 10-minute warm-up, followed by sets (3–6) of 6 × 35-m sprints with 3 minutes of rest between sets and then a 10-minute cool-down period.

Blood Lactate. Capillary blood samples were taken (by finger prick) from the forefinger at 3, 15, and 30 minutes after the fourth Wingate trial. A small puncture in the skin was made with a lancet. Blood samples were analyzed on site using a Lactate Analyzer (Lactate Scout, Senslab GmbH, Leipzig, Germany).

Blood Sampling and Analysis. All subjects were asked to restrain from exercise and intense physical activity 2 days before blood collections. Venous blood samples were

Table 3. Pretest vs. posttest values for $\dot{V}O_2$max, the $\nu\dot{V}O_2$max, maximal ventilation, T_{max}, and $\dot{V}O_2/HR_{Peak}$.*†

	Pretest	Posttest
$\dot{V}O_2$max(ml·kg^{-1}·min^{-1})		
EXP group	49.3 ± 4.4	52.0 ± 3.4‡
CON group	51.2 ± 6.1	50.1 ± 4.7
$\nu\dot{V}O_2$max (km·h^{-1})		
EXP group	16.0 ± 1.0	16.5 ± 0.9
CON group	16.5 ± 1.6	15.8 ± 1.0
Maximal ventilation (L·min^{-1})		
EXP group	141.1 ± 23.5	143.8 ± 21.8
CON group	138.6 ± 23.1	133.8 ± 17.2
T_{max} (s)		
EXP group	356.5 ± 95.1	471.2 ± 128.6‡§
CON group	326.4 ± 97.1	322.0 ± 89.4
$\dot{V}O_2/HR_{Peak}$ (ml·b·min^{-1})		
EXP group	19.4 ± 3.2	20.9 ± 3.2‡
CON group	19.3 ± 2.8	19.2 ± 2.0

*EXP = experimental; CON = control; $\dot{V}O_2$max = maximal oxygen consumption; $\nu\dot{V}O_2$max = velocity associated with $\dot{V}O_2$max; T_{max} = time to exhaustion at $\nu\dot{V}O_2$max; $\dot{V}O_2/HR_{Peak}$ = peak oxygen pulse.
†Values are means ± *SD*.
‡Significantly different to pretest values ($p < 0.05$).
§Significantly different compared with control group ($p < 0.05$).

collected by venous puncture from an antecubital vein (10 mL) before and after the 4-week training period in the morning (10–11 AM). Subjects reported to the laboratory after having a standardized light breakfast at 7 AM (27) with approximately 60% of carbohydrates, 25% fat, and 15% protein. Subjects also reported an adequate hydration status and sleep before the day of each blood sampling. Blood samples were collected after 20 minutes of rest in a seated position at the same time and room temperature (25°C) on all days for all subjects to eliminate fluctuations in circulating analyte concentration because of circadian rhythm. For the measurements of serum total testosterone (TT), free testosterone (FT), cortisol, urea, and creatine kinase (CK), 7-ml blood samples were centrifuged (3,000 rpm, 15 minutes, 4°C), and the resultant serum was then removed and stored at −80°C until subsequent analysis, and the remaining 3-mL blood samples in Tetra Acetic Diamine Ethylene Acid (EDTA) vacutainers were measured for complete blood count using an automated cell counter (Diatron, Abacus C, Vienna, Austria). Serum concentrations of TT (DRG Diagnostics, Marburg, Germany; intraassay coefficient of variation [CV], 3.6%), FT (dbc-Diagnostics Biochem Canada Inc, London, Canada; intraassay CV, 8.9%), and cortisol (dbc-Diagnostics Biochem Canada Inc; intraassay CV, 5.8%) were determined by enzyme linked immunosorbent assay kits according to the instructions of the manufacturers. A photometric method was used for serum urea and CK (Chemistry analyzer, Roche/Hitachi 904, with Pars Azmoun kits, Tehran, Iran; intraassay CV, 1.2 and 3.3%, respectively) assays. All measurements were performed in duplicate and analyzed in the same batch by technicians who were blinded to the order of the samples and grouping of subjects.

Questionnaire. A standardized questionnaire assessing signs of overtraining was developed to detect early disturbances in tolerance to intensive training. This questionnaire contains 54 self-report questions requiring answers of "yes" or "no."

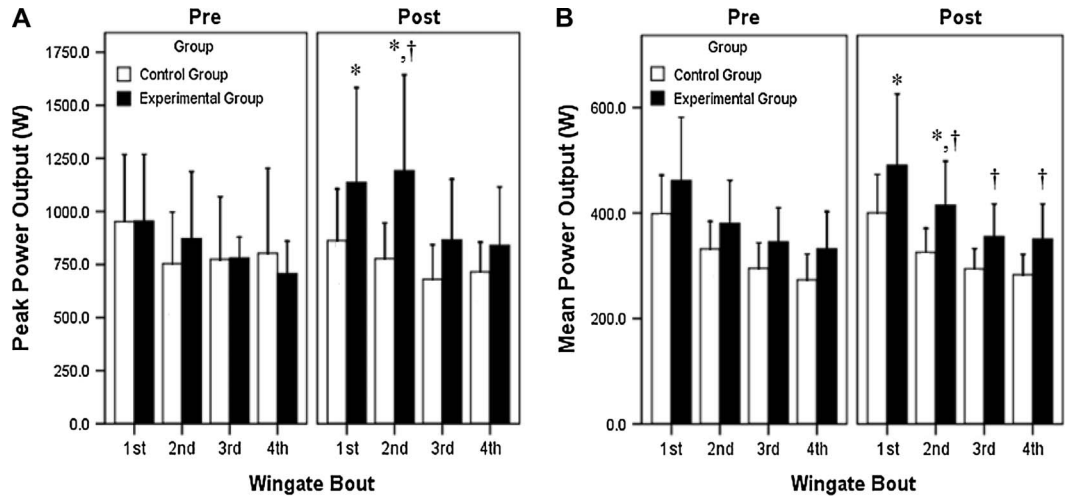

Figure 1. A) Peak power output elicited during 4 consecutive Wingate trials. B) Mean power output elicited during 4 consecutive Wingate trials. Values are means ± *SD*. *Significantly different from pretraining values ($p < 0.05$). †Significantly different compared with control group ($p < 0.05$).

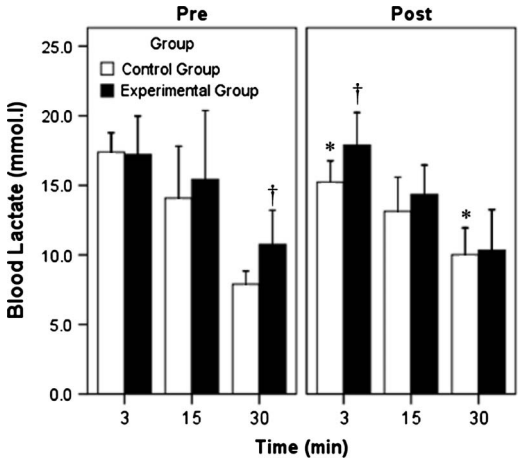

Figure 2. Blood lactate concentrations at 3, 15, and 30 minutes after the last Wingate trial. Values are means ± *SD*. *Significantly different from pretraining values ($p < 0.05$). †Significantly different compared with control group ($p < 0.05$).

The score is given by the sum of "yes" answers (25). The questionnaire was administered on the day that the blood samples were taken.

Statistical Analyses

All results are reported as mean ± *SD*. The Kolmogorov–Smirnov test was used to test the normality of the distribution. Student's *t*-tests were used to compare pre and posttest values for the CON and EXP groups to determine statistical significance. A Bonferroni correction was applied to statistical comparisons to correct for possible inflation of the overall type I error rate. Two samples were excluded from the hormonal analysis because of outlier numbers (lower or >3 *SD* scores). Blood lactate and Wingate data were analyzed using an analysis of variance for repeated measures (2 trials × 3 or 4 times). When a significant difference was revealed, Tukey's post hoc test was used to specify where the difference occurred. The alpha level for statistical significance was set at $p \leq 0.05$. Effect size was calculated using Cohen's *d* (d).

Results

Performance Measurement

Changes in physiological variables associated with the GXT are presented in Table 3. After the 4-week training program, $\dot{V}O_2max$ ($p = 0.01$, $d = 0.69$) $\dot{V}O_2/HR_{Peak}$ ($p = 0.009$, $d = 0.47$) and T_{max} ($p = 0.002$, $d = 1.03$) were significantly increased in the EXP group, but $v\dot{V}O_2max$ and maximal ventilation did not change significantly. No variables were significantly changed in the CON group ($p > 0.05$).

The PPO during the first (Post: 1,137.2 ± 446.2 vs. Pre: 954.5 ± 314.0 w; $p < 0.05$, $d = 0.48$) and the second (Post: 1,191.9 ± 451.2 vs. Pre: 871.6 ± 316.5 w; $p < 0.05$, $d = 0.83$) Wingate bouts increased significantly in the EXP group compared with pretraining. Also, MPO during the first (Post: 490.6 ± 135.1 vs. Pre: 461.4 ± 119.9 w; $p < 0.05$, $d = 0.23$) and the second (Post: 414.7 ± 83.4 vs. 380.0 ± 82.1 w; $p < 0.05$, $d = 0.42$) Wingate bouts increased significantly in the EXP group when compared with pretest levels (Figure 1).

Table 4. Resting serum values of urea, CK, TT, FT, cortisol, TCR, and FTCR before and after the training.*†

	Pretest	Posttest
Urea ($mg \cdot dL^{-1}$)		
EXP group	24.8 ± 3.8	24.6 ± 3.5
CON group	26.7 ± 3.9	26.8 ± 3.8
CK ($U \cdot L^{-1}$)		
EXP group	124.3 ± 19.4	156.0 ± 16.4‡
CON group	133.1 ± 39.3	135.2 ± 26.2
TT ($ng \cdot mL^{-1}$)		
EXP group	6.7 ± 1.9	8.0 ± 1.7‡
CON group	6.3 ± 1.2	7.2 ± 1.7
FT ($pg \cdot mL^{-1}$)		
EXP group	12.7 ± 7.3	13.7 ± 7.2
CON group	11.1 ± 6.1	12.7 ± 5.6
Cortisol ($\mu g \cdot dL^{-1}$)		
EXP group	9.5 ± 3.4	8.3 ± 2.6
CON group	9.3 ± 3.1	9.2 ± 2.9
T/C ratio		
EXP group	0.75 ± 0.2	0.99 ± 0.2‡
CON group	0.74 ± 0.2	0.84 ± 0.3
FT/C ratio		
EXP group	1.31 ± 0.7	1.63 ± 0.9
CON group	1.38 ± 1.1	1.46 ± 0.7

*CK = creatine kinase; TT = total testosterone; FT = free testosterone; TCR = testosterone/cortisol ratios; FTCR = free testosterone/cortisol ratios.
†Values are means ± *SD*.
‡Significantly different from pretest values ($p < 0.05$).

Blood Lactate

After the 4-week training period, maximal BLa^- was significantly higher in the EXP group compared with CON group (17.8 ± 2.3 vs. 15.2 ± 1.5 $mmol \cdot L^{-1}$; $p < 0.05$, $d = 1.33$), but it was not significant compared with pretraining (Post: 17.8 ± 2.3 vs. Pre: 17.2 ± 2.7 $mmol \cdot L^{-1}$; $p > 0.05$, $d = 0.24$). Blood lactate recovery (15th and 30th minutes) did not change in the EXP group when compared with pretesting and the CON group after the training ($p > 0.05$, Figure 2).

Blood Biochemical Parameters

No significant changes were observed between groups or over time in serum urea concentration (Table 3). Serum concentration of CK significantly increased in the EXP group compared with the pretesting value (Post: 156.0 ± 16.4 vs. Pre: 124.3 ± 19.4 $U \cdot L^{-1}$; $p = 0.007$, $d = 1.77$; Table 4).

Table 5. Pre and posttest values for hematological variables.*†

RBC (10^6 μL^{-1})		
EXP group	5.0 ± 0.2	5.1 ± 0.3
CON group	4.9 ± 0.3	5.0 ± 0.2
Hb ($g \cdot dL^{-1}$)		
EXP group	13.3 ± 1.4	14.2 ± 0.9
CON group	13.5 ± 0.8	14.0 ± 0.7
Hct (%)		
EXP group	42.2 ± 4.0	43.0 ± 2.8
CON group	43.0 ± 3.2	43.5 ± 1.7
MCH (pg)		
EXP group	26.4 ± 3.0	27.7 ± 2.4‡
CON group	27.5 ± 1.0	28.3 ± 1.2

*RBC = red blood cell; Hb = hemoglobin; Hct = hematocrit; MCH = mean corpuscular hemoglobin; MCHC = mean corpuscular hemoglobin concentration.
†Values are means ± *SD*.
‡Significantly different from pretest values ($p < 0.05$).

Serum Hormones

Table 4 presents the resting hormone concentrations before and after the 4-week training period. After training, significant increases were observed in TT ($p = 0.01$, $d = 0.72$), and TCR ($p = 0.006$, $d = 1.20$) in the EXP group compared with pretraining, whereas cortisol tended to decrease (−12.6%, $p = 0.06$, $d = 0.40$) and FTCR remained unchanged ($p > 0.05$). Total testosterone, FT, TCR, FTCR, and cortisol remained unchanged in the CON group ($p > 0.05$).

Hematological Changes

Changes in the values of hematological variables for both groups are presented in Table 5. After training, significant changes were observed in mean corpuscular hemoglobin (MCH, $p = 0.01$, $d = 0.48$), and MCH concentration ($p = 0.005$, $d = 1.75$) in the EXP group, but red blood cells, hemoglobin (Hb), and hematocrit did not change significantly. No significant changes were observed in the CON group ($p > 0.05$).

Psychological Assessment

After the training, the mean score obtained in the overtraining questionnaire was not changed significantly in the EXP group (Post: 16.0 ± 4.5 vs. Pre: 14.2 ± 3.7; $p > 0.05$).

Discussion

The effect of the SIT program was present in several of the measured parameters in the EXP group. The $\dot{V}O_2max$ from the GXT increased 5.4% ($p = 0.01$, $d = 0.69$) after the training period. This is in agreement with the increases reported in studies using trained subjects (21,22). Improvement in $\dot{V}O_2max$ can be attributed to the increases in both oxygen delivery (i.e., increases in SV as higher $\dot{V}O_2/HR_{Peak}$ recorded in our study) and/or oxygen use by active muscles (i.e., increases in capillarization/mitochondrial density) (19,20). Several authors have studied $\dot{V}O_2/HR$ and the theoretical relationship with SV and A-$\dot{V}O_2$ difference. They suggested an important correlation between the evolution of SV and $\dot{V}O_2/HR$ during maximal treadmill exercise (19,38). In our study, $\dot{V}O_2/HR_{Peak}$ increased significantly by 7.7% in the EXP group after the training ($p = 0.009$, $d = 0.47$). On the other hand, Laursen et al. (22) reported no change in hematological variables and plasma volume in response to an SIT program and suggested that peripheral, rather than central adaptations, are likely responsible for the improved performances. In our study, Hb did not increase significantly after the training, which is in line with their findings (Table 5). Because, prior studies showed a significant correlation between SV and $\dot{V}O_2/HR$, we can probably assume that the higher $\dot{V}O_2max$ in the EXP group may in part be caused by an increased SV, along with the other aforementioned factors. Another important adaptation after the training period was an increased time to exhaustion (Table 3) in the EXP group. T_{max} was increased significantly from 356.5 to 471.2 seconds (+32.2%, $p = 0.002$, $d = 1.03$). This points toward a significant improvement in the running velocity at the lactate threshold; however, this was not measured in this study (7). In line with our findings, Esfarjani and Laursen (8) demonstrated that in moderately trained runners, an SIT program performed over 10 weeks increased time to exhaustion at $v\dot{V}O_2max$ by 32% (8). Franch et al. (9) also reported a significant increase (65%) in time to exhaustion after 6 weeks of short-interval training. From a metabolic point of view, the decrease in rate of glycogen depletion, when associated with the increase in the storage of glycogen, contributes to an improved exercise tolerance, the glycogen depletion being strongly linked with fatigue during prolonged exercise (7). Another possible reason for the improved T_{max} found in the EXP group after the training period may be a greater muscle buffering capacity, which has been demonstrated in repeated 30-second sprint training (11).

In agreement with other investigations (23,29,35), PPO and MPO increased in the EXP group as a result of training (Figure 1). Linossier et al. (23) demonstrated that peak anaerobic power increased after 7 weeks of SIT (2 series of 8–13 repeated 5-second all-out sprints with 55-second rest). Parra et al. (30) reported increases in PPO and MPO after 6 weeks of SIT (15-second and 30-second all-out repetitions). Increased muscle phosphocreatine concentration (31), anaerobic enzyme activities (24,30), and a significant increase in FTa fibers, along with a decrease in ST fibers (6,14,15), are possible explanations of our findings.

We also found that neither maximal BLa^- nor BLa^- recovery changed significantly with either training regimen. In contrast to our data, Stokes et al. (33) reported higher postexercise BLa^- and lower BLa^- in recovery period after 6 weeks of SIT. Jacobs et al. (14) also showed increased peak BLa^- after 6 weeks of SIT. However, our subjects already had

a higher peak BLa^- compared with their subjects (17.2 ± 2.7 vs. 11.4 ± 1.0 $mmol \cdot L^{-1}$) in pretraining testing, which could explain the discrepancies between the studies. Furthermore, it should be mentioned that the lack of a resting blood draw complicated the interpretation of the data in this study.

The need to modify a training program, to reach the best performance in an upcoming competition, may be indicated by an athlete's current physical status. Furthermore, the long-term intensive training may result in insufficient recovery, which may lead to overtraining. The TCR and FTCR have frequently been used to monitor the balance between anabolic and catabolic activities (1,13,26,36,37). Therefore, their increases after the training may indicate anabolic adaptations. However, no changes were reported in TCR and FTCR by high-relative-intensity resistance exercise overtraining (10). Data concerning TCR and FTCR adaptations to repeated SIT are scarce. Recently, Meckel et al. (26) showed that testosterone and TCR increased in response to a brief sprint-interval session (4 × 250-m run at 80% of the personal maximal speed), but cortisol did not change. In this study, TT, and TCR increased significantly in the EXP group (Table 4). Similarly, we did not observe significant changes in serum cortisol in the EXP group despite a 12.6% decrease ($p = 0.06$). It should be mentioned that the small sample size might have limited our statistical power to detect significant changes in some hormonal variables, particularly where substantial variation between subjects existed. In the CON group, no changes in TCR and FTCR were found. The TT elevation found in the EXP group has been attributed to potential adaptations in testosterone synthesis and/or the secretory capacity of the Leydig cells in the testes (17). Because it has been shown that this type of training protocol (short intervals and short recovery periods) mainly involves anaerobic processes and leads to high BLa^- concentration (39), we can probably attribute this elevation to lactate-stimulated secretion. This increase in TT, however, was not accompanied by significant increases in FT, resulting in a lowered FT:TT ratio. In this respect, it would have been interesting to determine whether most of the posttraining circulating TT was bound to sex hormone–binding globulin or albumin, because the latter has been reported to represent, along with FT, the biologically active fraction of testosterone (28). The TCR changes were not only because of TT increase but also because of a nonsignificant decrease in cortisol concentration. The inclusion of 2 sessions of SIT a week in the EXP group had no disturbing effect on stress hormone concentrations, despite the higher amount of stressful training. Moreover, after the training program, subjects in the EXP group did not show significant changes in the overtraining questionnaire score. The significant increase in CK in the EXP group can be attributed to both metabolic and mechanical causes. It has been suggested that an increase in serum CK concentrations, if associated with reduced exercise tolerance, could be a marker of overtraining (4). However, the performance of the subjects in the EXP group was not decreased at the end of the study period, suggesting that the increase in CK in our subjects reflects an average degree of muscular damage.

In conclusion, this study showed that $\dot{V}O_2max$, $\dot{V}O_2/HR_{Peak}$ and T_{max} could be significantly improved in trained wrestlers through the addition of an SIT program into the typical preseason conditioning phase training. Our results indicate that repeated sprint-interval runs with short passive recovery periods, over a 4-week period are useful in increasing both aerobic and anaerobic performances. The training period also significantly influenced serum hormone concentrations. These results indicate that the SIT performed by the EXP group led to an anabolic-type hormonal adaptation, suggesting a positive training response.

Practical Applications

The most important finding of our study was that by adding the SIT protocol over 8 sessions (with a maximum of 4 minutes per session of total exercise) during the preseason conditioning phase was an effective way of enhancing both aerobic and anaerobic performances in trained wrestlers. Considering that such training protocols have a very low volume, wrestlers, and their coaches can use this type of training program in preseason conditioning phase and when wrestlers have to reach several peaks over an annual cycle, particularly when the aim is to increase performance in a limited-time period. However, it must be considered that anaerobic types of training are very intensive; thus, the volume of the training should be monitored and increased with caution; otherwise, the performance may be reduced. Therefore, the use of a higher number of sprints should be investigated further.

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