Relationships Between Serum Testosterone, Cortisol, and Weightlifting Performance

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ABSTRACT
Elite and nonelite junior weightlifters (nonelite: n = 14, X ± SE, age = 17.2 ± 0.4 years; elite: n = 8, age = 18.4 ± 0.4 years) performed identical training programs for 4 weeks. Pre- and postexercise serum samples were collected before and after 1 week of high-volume training and after 3 weeks of normal-volume training. The percent change (% D) in preexercise testosterone/cortisol exhibited different correlations (p < 0.05), with % D weightlifting performance for each training phase and each group (high volume nonelite: r = −0.70; high volume elite: r = 0.00; normal volume nonelite: r = 0.51; normal volume elite: r = 0.92). Correlations for % D testosterone or cortisol and weightlifting performance exhibited no discernible pattern. These data indicate that preexercise testosterone/cortisol of these weightlifters reflect the short-term training volumes and is correlated to changes in competitive weightlifting performances. Furthermore, based on hormonal profiles and weightlifting performances, elite weightlifters appeared to better tolerate high-volume training than nonelite weightlifters.

Key Words: hormonal ratios, endocrine, strength, periodization


Introduction
Both the chronic and acute hormonal responses to various types of resistance exercise have been previously reported (10, 11, 17). When periodized training programs using variations in exercises, training volume, and relative training intensity (21) have been studied, both acute and chronic hormonal responses have been reported to reflect the variations of the training protocol (5, 10). The amount of prior weightlifting experience appears to influence these endocrine responses, since athletes with greater than 2 years of weightlifting experience have demonstrated larger acute testosterone responses than less-experienced athletes (16).

Significant correlations between changes in resting or acute hormonal and catecholamine responses and changes in strength capabilities have been previously reported (8, 10). In addition, changes in hormonal concentrations have been associated with changes in training stresses (5–7, 9, 10, 15, 19, 20), although it is not known if these relationships are causal. The relationship between testosterone and cortisol has been suggested to represent an approximation of the anabolic/catabolic status of an individual (1, 15, 20), with increasing training stress being related to decreased testosterone/cortisol values (1, 15, 19, 20). Periodized resistance exercise training programs typically utilize variations in training volume and intensity to elicit the desired performance adaptations (21). Increases in training volume have previously been shown to influence the endocrine profiles (4, 19, 20), although it is not known if the relationships between hormonal variables and actual lifting performance is differentially affected during varying phases of the periodized program.

To date, no investigations have reported correlations between the training-induced changes in the endocrine system and actual competitive weightlifting performance. In addition, it is not known if such relationships, if they exist, are influenced by competitive status (i.e., elite vs. nonelite) or training phase of the periodized training program. Therefore, the purpose of this investigation was to determine the relationships between changes in resting (chronic) and exercise-induced (acute) serum testosterone, cortisol, or testosterone/cortisol and changes in competitive weightlift-
ing performances during different phases (i.e., high volume and low volume) of periodized weightlifting training. In addition, the effect of competitive status (i.e., weight lifted in competition, training experience) on these relationships will be studied.

Methods

Twenty-two participants in a 4-week, junior age group national weightlifting camp volunteered as subjects for this study. Each subject (as well as a parent/guardian if under the age of 18 years) was informed of the possible experimental risks and signed an informed consent document. All athletes were selected for the training camp based on previous drug-tested competitive performances, for which none had tested positive. Each subject had placed 1–3 in their respective age and body weight categories in national competition. Several subjects were members of the junior age group U.S. national team.

For the purposes of the present study, elite status is operationally defined as being the best weightlifters for their age and weight class in the U.S. The subjects were divided into 2 groups. The elite group \( n = 8 \) consisted of athletes who had been invited by the governing body for the sport (i.e., U.S.A.-Weightlifting) based on their recent competitive results to compete with senior age group athletes in an invitational national-level contest (i.e., Olympic Festival) at the end of the study. The nonelite group \( n = 14 \) consisted of all other athletes at the training camp who were not participating in the invitational weightlifting contest, but did participate in a separate competition at the conclusion of the training camp. Although selection to the elite group was determined from competitive performances, this group also exhibited greater relative strength levels and weightlifting training experience. Body density (12) and relative fat levels (18) were estimated anthropometrically, thus permitting the estimation of fat-free mass. Characteristics for both groups of subjects are listed in Table 1.

The weightlifting training camp consisted of 2 phases, a 1-week, high-volume training phase (3–4 training sessions per day), followed by a 3-week, normal-volume training phase (1–2 training sessions per day). The training program has been previously described in detail (6, 7, 22). All subjects performed identical training protocols, which consisted of snatches, snatch pulls, cleans, clean pulls, jerks, front squats, back squats, and various related weightlifting exercises. Relative intensity for these lifts ranged from 70–100% 1 repetition maximum (1RM) for each exercise, with typical sets consisting of 1–5 repetitions. Test batteries were administered at the beginning of the high-volume phase (Test 1), and at the beginning (Test 2) and end (Test 3) of the normal-volume phase. One subject in the elite group was unable to complete the test battery at Test 3 because of an injury, thus decreasing the sample size of this group for all calculations using Test 3 data.

The test battery was designed to simulate a normal progression during a typical weightlifting session where 1 lift is featured in the training session. The specific protocol consisted of 15 maximum-effort vertical jumps (1 jump every 3 seconds), a series of increasingly heavier (5 kg increments) single repetitions of the snatch lift every 15 seconds until failure, and 3 sets of 10 repetitions of snatch pulls at 65% 1RM for the snatch lift. This protocol has been previously described in detail (7).

Following a 6-hour fast, serum hormonal responses to this exercise protocol were determined from antecubital venous blood samples. Serum samples were collected preexercise and 5 and 15 minutes postexercise using a 21 ga needle and vacutainer with no preservatives. All test batteries were performed between 1400 and 1700 hours with times held constant for each subject for each test. The entire time line and test battery sequence is graphically illustrated in Figure 1.

Clotted blood samples were centrifuged for 15 minutes at 1500 \( \times \) g and 4°C, with the resulting serum

| Table 1. Subject characteristics for the elite and nonelite weightlifting groups \( \bar{X} \pm SE \). |
| --- | --- | --- |
| Variable | Elite \( n = 8 \) | Nonelite \( n = 14 \) |
| Age (y) | 18.4 ± 0.4 | 17.2 ± 0.4 |
| Height (cm) | 165.4 ± 4.0 | 174.2 ± 2.2 |
| Body mass (kg) | 64.2 ± 4.7 | 77.4 ± 3.9* |
| Body fat (%) | 4.4 ± 0.3 | 9.3 ± 1.2* |
| Fat-free mass (kg) | 61.1 ± 4.2 | 69.7 ± 2.8* |
| Best weightlifting performance (kg) | 226.6 ± 17.1 | 228.4 ± 10.9 |
| Weight lifting performance/body mass (kg) | 3.5 ± 0.1 | 3.0 ± 0.1* |
| Training experience (y) | 3.9 ± 0.6 | 2.4 ± 0.4* |

* \( p < 0.05 \).

Figure 1. Training and testing time line.
stored at −90°C until assayed. Solid phase radioimmunoassays (ICN Biomedicals, Inc., Carson, CA) were performed in duplicate for testosterone and cortisol. Immunoreactivity values were determined with a gamma counter (LKB Clini-Gamma, Turku, Finland) using an automated data-reduction system. Interassay variances for both testosterone and cortisol were <6.8%, while intraassay variances were <3.5%. Plasma volume shifts for this exercise protocol were calculated for each postexercise blood sample and were estimated to be <10% (2), and were not great enough to solely account for the hormonal response patterns of this study. Serum hormone concentrations were not corrected for plasma volume shifts in this investigation; thus all statistical analyses were performed on hormonal values based on actual measured circulating concentrations.

Relative changes (percentage change, %D) during the course of the 4 weeks of training (Tests 1–3) were calculated for competitive weightlifting performances (i.e., 1RM snatch + 1RM clean and jerk). Relative changes were also calculated for serum testosterone, cortisol, and testosterone/cortisol for each phase of the training camp (high volume, Tests 1 and 2; normal volume, Tests 2 and 3). Correlation coefficients were determined from linear regression analyses for both groups of subjects for %D in weightlifting performance and %D hormonal variables during both training phases. Significance for this study was p < 0.05.

Results

Both groups significantly improved their competitive weightlifting performances by the end of the 4-week training camp (X increase; elite = +1.6%, nonelite = +1.0%). As previously reported, each test battery (Tests 1–3) resulted in similar exercise performances, thus indicating a consistent exercise stimulus for the determination of acute hormonal responses (7). Correlation coefficients indicated distinct differences between the elite and nonelite groups when comparing percentage changes in weightlifting performances with percentage changes for preexercise testosterone/cortisol (Figure 2). Changes in preexercise testosterone/cortisol values for the nonelite group were negatively related to changes in weightlifting performances (r = −0.70) during the high training volume phase (Tests 1 and 2), but positively related during the normal training volume phase (r = 0.51; Tests 2 and 3). On the other hand, the elite group exhibited no relationship between these variables during high-volume training (r = 0.00), and a strong positive relationship during normal-volume training (r = 0.92). As indicated by the t-statistic for significance of the regression coefficient (b), the slope of the testosterone/cortisol regression line for the elite group during the high-volume phase (b = 1.6058) was not significantly different from zero, whereas all other calculated slopes were significantly different from zero (nonelite, high volume, b = −28.109; nonelite, normal volume, b = 18.723; elite, normal volume, b = 43.244). Relative changes in pre- and postexercise (5 and 15 minutes) testosterone or cortisol and postexercise testosterone/cortisol did not exhibit any significant correlation coefficients when compared with relative changes in weightlifting performances. Absolute preexercise hormonal concentrations for both testosterone and cortisol, as well as the testosterone/cortisol values for each group, are listed in Table 2. It should be noted that the mean testosterone/cortisol ratios were calculated from individual values for testosterone and cortisol, and not from group means.

Discussion

Significant correlations previously have been reported between changes in resting hormonal concentrations or hormonal ratios and weightlifting performance (11) or muscular strength tests (9). This investigation is the first report of significant correlations between actual competitive weightlifting performances and testosterone/cortisol associated with alterations in the short-term training program. Whether these relationships are causal, however, cannot be determined from these data. These relationships were not identical for the elite and nonelite weightlifters, indicating that weightlifting strength/power and training experience may
influence these relationships. Like previous investigations, the characteristics of the training program (i.e., high vs. low training volumes) were reflected in the endocrine profiles (5–7, 9, 10, 19, 20). This is in agreement with previous studies that have implicated the testosterone/cortisol ratio as a marker of severe training stress and, in some cases, overtraining (1, 15, 19, 20). It should be noted that only the preexercise testosterone/cortisol ratio was significantly correlated with changes in competitive weightlifting performances. All other hormonal variables (i.e., preexercise testosterone or cortisol and all postexercise hormonal variables) were not correlated with the changes in performances. As a result, it appears that resting or preexercise hormonal concentrations provide the most insight on the short-term training status of a weightlifter.

Assuming that resting testosterone/cortisol levels indicate the overall training stress (1, 4, 5–7, 9, 10, 19, 20), the correlations between changes in preexercise testosterone/cortisol and weightlifting performance indicate that the elite group better tolerated the high-volume training phase than did the nonelite group. Contributing factors may have included the greater training experience of the elite group (16). The important role of serum testosterone was also indicated for the elite group since weightlifting performance for these subjects increased most when preexercise testosterone was augmented during normal training volume (Tests 2 and 3; data not shown). The nonelite group, however, benefited from the severe stress of the high-volume phase, since those subjects with the most attenuated testosterone/cortisol during the week of high-volume training (Tests 1 and 2) ended with the greatest weightlifting improvement. This potentially beneficial effect of such high-volume weightlifting training has been reported for athletes exposed to such training for 2 successive years (6).

Despite the distinctly different correlation coefficients for changes in testosterone/cortisol and changes in weightlifting performance during the high-volume phase, both groups exhibited significant positive correlations between preexercise testosterone/cortisol and weightlifting performance during the normal-volume training phase (Tests 2 and 3). This “taper” phase of training preceding the poststudy weightlifting competitions appeared to permit recovery as indicated by serum testosterone/cortisol, and was associated with enhanced performance. Positive relationships have also been observed during various phases of weightlifting training (10, 11), but never as strong as the r = 0.92 exhibited by the elite group. Since serum hormonal concentrations reflect the characteristics of the training protocol (5, 10, 11), the elite group appears to respond more readily to the low-volume taper phase (Tests 2 and 3), as is indicated by the strong positive correlations with weightlifting performance for the elite group during this period (see Figure 2). Although potential outliers were observed in several of the scatter grams (see Figure 2), removal of these data points did not affect the results of the study, with one exception.

When the subject with the greatest improvement for weightlifting performance was removed from the elite group for the high-volume phase, the resulting correlation coefficient became strongly positive (r = 0.66), which was even more distinctly different from the results for the nonelite group. No outliers were removed for the final statistical analyses since this would have unfairly biased the data from what was actually observed during this investigation.

Whether there was a cause and effect relationship between preexercise serum testosterone/cortisol and weightlifting performance cannot be determined with a correlational analysis. A number of investigations have implicated an important role for testosterone in weightlifters (5–7, 16). Suggested mechanisms have included interactions of testosterone with the nervous system, as well as with growth hormone and insulin-like growth factor (14). It is likely that sympathetic nervous system regulation plays an important role in this relationship. Since sympathetic activity via b-receptors augments testosterone secretion (3, 13), and changes in circulating acute epinephrine have been correlated to short-term alterations in strength (8), it is possible that the testosterone/cortisol responses in the present study may be regulated in part by sympathetic re-

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**Table 2.** Absolute preexercise testosterone and cortisol concentrations (nmol·L⁻¹) and testosterone/cortisol ratios (Tes/Cort) for the elite (n = 8) and nonelite (n = 14) groups (X ± SE).

<table>
<thead>
<tr>
<th>Variable</th>
<th>Group</th>
<th>Test 1</th>
<th>Test 2</th>
<th>Test 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Testosterone</td>
<td>Elite</td>
<td>14.4 ± 2.2</td>
<td>20.2 ± 1.5</td>
<td>20.2 ± 3.1*</td>
</tr>
<tr>
<td></td>
<td>Nonelite</td>
<td>12.0 ± 1.0</td>
<td>17.6 ± 2.1</td>
<td>19.6 ± 2.2</td>
</tr>
<tr>
<td>Cortisol</td>
<td>Elite</td>
<td>287.1 ± 27.9</td>
<td>354.9 ± 39.9</td>
<td>386.3 ± 56.5*</td>
</tr>
<tr>
<td></td>
<td>Nonelite</td>
<td>226.1 ± 20.9</td>
<td>333.4 ± 26.9</td>
<td>307.4 ± 19.5</td>
</tr>
<tr>
<td>Test/Cort</td>
<td>Elite</td>
<td>0.056 ± 0.011</td>
<td>0.062 ± 0.008</td>
<td>0.060 ± 0.012*</td>
</tr>
<tr>
<td></td>
<td>Nonelite</td>
<td>0.050 ± 0.006</td>
<td>0.056 ± 0.007</td>
<td>0.068 ± 0.010</td>
</tr>
</tbody>
</table>

* n = 7 for elite group during Test 3.
In conclusion, numerous significant correlations were observed between changes in preexercise testosterone/cortisol and changes in competitive weightlifting performances. Preexercise testosterone or cortisol and postexercise testosterone, cortisol, or testosterone/cortisol did not exhibit significant relationships with competitive weightlifting performances, and thus do not appear to be as closely associated with the short-term training status of these weightlifters. It should be noted here that the correlations with preexercise testosterone/cortisol do not infer causality. Since both the endocrine and skeletal muscular systems are influenced by the sympathetic nervous system, previously reported changes in sympathetic activity with stressful resistance training may account for some of the relationships observed in the present study. Further research is necessary to determine the specific physiological mechanisms responsible for these phenomena. Regardless of the mechanism(s) at work, the relationships between serum testosterone/cortisol and weightlifting performance are at least partially dependent on the characteristics of the short-term training program. In addition, the more accomplished and experienced young male weightlifters (elite group) respond to changes in training volume with different endocrine profiles than do less accomplished and experienced lifters (nonelite group).

**Practical Applications**

These data indicate the importance of highly stressful phases of training (increased training volume) for the less-experienced weightlifter, as has been previously suggested (6). Furthermore, the elite weightlifters appear to be particularly sensitive to a decrease in training volume following the high-volume phase, as is evident from the strong correlation between preexercise testosterone/cortisol and weightlifting performance ($r = 0.92$). In general, including high-volume phases of weightlifting training for all weightlifters appears to enhance subsequent weightlifting performances.

**References**


Acknowledgments
This project was supported by funding from the United States Olympic Committee and U.S.A.-Weightlifting.