Impaired Performances with Excessive High-Intensity Free-Weight Training

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ABSTRACT

The purpose of this study was to determine if 3 weeks of high relative intensity (percent one repetition maximum [1RM]) free-weight resistance training using the parallel barbell squat results in overtraining and to determine what types of performance would be affected. Six weight-trained males ($X \pm SD$; age $= 27.5 \pm 5.4$ year) trained 2 d-wk$^{-1}$ for 4 weeks with a normal protocol (Monday, 3 $\times$ 10 repetition maximum [RM]; Thursday, 3 $\times$ 5 RM), followed by 3 weeks of high-intensity training 3 d-wk$^{-1}$ (Monday, Wednesday, Friday) using $2 \times 1 95\%$ 1RM and $3 \times 1 90\%$ 1RM. A time-series study design was utilized, with each subject serving as his own control (pretest [Pre] = test 1 = normal training; tests 1–4 = high-intensity training; test 4 – posttest [Post] = recovery). One repetition maximum increased ($p < 0.05$) during normal training but did not change during high-intensity or recovery training (Pre $= 139.5 \pm 29.9$ kg; test 1 $= 154.6 \pm 27.7$ kg; test 2 $= 160.3 \pm 26.9$ kg; test 3 $= 163.7 \pm 27.9$ kg; test 4 $= 161.0 \pm 27.2$ kg; Post $= 161.7 \pm 33.3$ kg). Muscular and joint pain and soreness were not evident according to self-report training questionnaires. Also during the high-intensity phase, sprint times for 9.1 m increased (test 1 $= 1.75 \pm 0.12$ seconds; test 4 $= 1.86 \pm 0.12$ seconds) and peak isokinetic squat force at 0.20 m·s$^{-1}$ decreased (test 1 $= 2,473.2 \pm 685.6$ N; test 4 $= 2,193.3 \pm 534.5$ N). In general, no changes were observed for body composition, flexibility, lower body reaction time, vertical jumps, 36.6-m sprints, lateral agility, isokinetic squat force at 0.82 and 1.43 m·s$^{-1}$, or isokinetic back extension at 0.17 and 1.05 rad·s$^{-1}$. Although use of single repetitions at a high relative intensity is often used to increase 1RM, this was not observed in the present study. While 1RM performance did not decrease, other performance measures were adversely affected, suggestive of an excessive use of high relative intensity resistance exercise.

Key Words: strength, power, speed, agility, strength training, overtraining, overreaching, resistance exercise


Introduction

When excessive training produces long-term decreases in performance, overtraining results (7, 9, 13, 15, 27, 28, 35, 36). Overtraining on a short-term basis from which recovery readily occurs is termed overreaching and consists of a planned increase in training volume and/or intensity, resulting in a temporary decrease in performance with subsequent improved performances (7, 9, 13, 15, 27, 28, 35, 36). Although much overtraining research has focused on aerobic-oriented activities (15, 28, 29), it has been hypothesized (38) and suggested (7, 9, 10, 13) that overtraining with resistance exercise may be due to different physiological mechanisms compared to overtraining with aerobic-oriented activities. Regardless of the stimulus used to induce an overtraining syndrome, Selye’s General Adaptation Syndrome serves to describe the stress response of the biological system (33). After being exposed to the stressor (excessive training volume and/or intensity), the system either adapts to the stress or deteriorates to an overtrained state.

Considering the five acute training variables (choice of exercise, order of exercise, volume, load, and rest), resistance exercise can be readily manipulated to produce considerable variation in the training stimulus (6, 16, 27, 37). Much of the previous study of highly stressful resistance exercise has centered on increases in training volume (7, 11, 12, 18, 19, 20, 35, 39), whereas impaired performances due to increases in resistance exercise training intensity have only recently been addressed (7, 9, 10, 13). It appears that the maximal muscular force-producing capacity of an individual is highly preserved, even when other physical performance variables are adversely affected (7, 10, 13). It has been suggested that different resistance exercise modalities result in variable adaptations to different physiological systems (6, 27), among which are modifications of the nervous system (14, 32). Such neural modifications most likely contribute to decreased strength due to high-intensity resistance exercise (14) and may differentially impact free-weight strength
performances compared to machine-measured strength (31). The demarcation between overreaching and an actual overtraining syndrome with concomitant chronic performance decrements is not always clear. Previous resistance exercise research has studied the effects of excessive use of relative intensities of 100% 1RM (13), but the results were specific to the machine modality used. To date, no studies have investigated the role of training modality on the incidence of impaired physical performances due to a high-intensity resistance exercise training program. Because of the physiological requirements of free-weight exercise, it would be expected that free weights may result in impaired performances with a lower training volume or intensity when compared to machines. In order to more fully understand the role of resistance exercise modality on the incidence of overtraining, the purpose of the present investigation was to determine the effectiveness of a 3-week high relative intensity resistance exercise program using a free-weight modality for inducing impaired performances such as found with overtraining. A state of overtraining is operationally defined as an increase in training volume and/or intensity resulting in long-term (i.e., several weeks or months) decrements in training-specific 1RM strength (7, 9, 10, 13, 14). The development of such a protocol would produce a model for the further study of high relative intensity overtraining using the parallel barbell squat.

Methods
Six men served as subjects for this investigation ($X \pm SD$; age = 27.5 ± 5.4 years; body weight = 87.5 ± 12.5 kg). All subjects were currently weight trained using their own resistance exercise protocols, had resistance exercise training experience of 2–12 years, and were capable of at least 1.5 × body weight for 1RM for the parallel back squat. Each subject signed an informed consent document approved by the Institutional Review Board at The University of Memphis prior to participation. Lower-body resistance exercise training was limited to free-weight parallel back squats and leg curls. Proper depth for the squats was defined as the inguinal fold being level with the musculature of the knee (8, 21). Although squat technique varied between subjects (i.e., high bar, low bar, foot position, knee wraps) (8, 21), squat technique was held constant for each subject throughout the course of the study. All lower-body training was supervised to ensure training compliance, proper exercise technique, and safety. Upper-body resistance exercise training for each subject was held constant throughout the course of the investigation.

A time-series design was used with all subjects serving as their own control and participating in the same training and testing protocol (22). This research design was necessitated because none of the subjects were monetarily compensated for participation in the study and it was difficult to recruit currently strength-trained individuals willing to perform the extreme protocol used and risk the onset of an overtraining syndrome. The subjects participated in a 4-week normal training period designed to equilibrate training programs for all subjects, followed by a 1-week break from training (spring vacation) and a 3-week high-intensity training period based on previous overtraining studies (10, 13). Training took place 2 d·wk$^{-1}$ during the normal training period, while training took place 3 d·wk$^{-1}$ during the high-intensity training period. Table 1 illustrates the training protocols for the entire duration of the study. In a training session during the high-intensity training period, if a prescribed lift was missed, all subsequent lifts were decreased by 9.1 kg (20 lbs). In this manner, the proper number of repetitions for each training session could be successfully completed.

All subjects were tested for 1RM on the parallel barbell squat on six different occasions: the week prior to the start of the normal training phase (Pre), the last day of the normal training phase (test 1), each of three Fridays during the high-intensity phase (tests 2–4), and 3 weeks after the completion of the high-intensity phase (Post). During the 3-week period after the high-intensity phase, all subjects resumed their training

<table>
<thead>
<tr>
<th>Phase</th>
<th>Training days</th>
<th>Exercise</th>
<th>Training protocol</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal training (4 weeks)</td>
<td>Monday</td>
<td>Barbell back squat</td>
<td>3 × 10 RM*</td>
</tr>
<tr>
<td></td>
<td>Thursday</td>
<td>Leg curls</td>
<td>3 × 10 RM</td>
</tr>
<tr>
<td>One-week break</td>
<td>No training</td>
<td>Barbell back squat</td>
<td>—</td>
</tr>
<tr>
<td>High-intensity training (3 weeks)</td>
<td>Monday, Wednesday, and Friday</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Leg curls</td>
<td>2 × 1 95% 1RM*</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Barbell back squat</td>
<td>3 × 1 90% 1RM</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Leg curls</td>
<td>3 × 10 RM</td>
</tr>
</tbody>
</table>

* RM = repetition maximum; 1RM = one repetition maximum.
programs used prior to the study. Test batteries were conducted on the Saturday before the high-intensity phase (test 1) and each of the three Saturdays during the high-intensity phase (tests 2–4). Familiarization trials for each item on the test battery were performed during the normal training period. Each test battery consisted of the following tests.

**Body Composition.** Anthropometric measures were used to estimate body density (23), and relative fat, fat mass, and fat-free mass were estimated with the formula of Siri (34). Tester reliability for all skinfold sites was $r > 0.90$, with one tester performing all measurements.

**Flexibility.** The sit and reach test was administered to assess lower-back and hip flexibility (17). After a standardized warm-up, each subject was given two trials, with the best performance recorded.

**Lower-Body Reaction Time.** A Quick Feet reaction board (Sports Robots Co., Hartford, CT) was used to measure lower-body reaction times. Each subject stood on a board that was marked into nine segments, each containing a pressure switch. Upon a light signal, each subject moved a foot as quickly as possible to the indicated segment. Performance was recorded as the accumulated time for 12 different light signals, with the light sequence varied between trials.

**Vertical Jumps.** Counter-movement (CMVJ), non-counter-movement (NCMVJ), and depth (20.5 cm; DVI) vertical jump heights were determined with a Vertec vertical jump tester (Sports Imports, Columbus, OH) (2, 10, 24). CMVJ utilized a dip immediately prior to the jumping motion, while NCMVJ started from a static squat position. DVI involved stepping off a box and immediately rebounding after contacting the ground. Vertical jump height was calculated as the difference between standing reach and jump reach.

**Sprints.** Sprint times for 9.1 m (10 yds) and 36.6 m (40 yds) were assessed during each test battery (10). Each subject started the sprints from a semicrouched position, with one hand placed on the starting line. Hand timing was used, with the timing starting on the first motion of the subject. Each sprint was 36.6 m long, with 9.1-m splits taken during each run. Two timers were used for each sprint, with the same two testers used throughout the duration of the study.

**Lateral Agility.** Lateral agility tests were performed starting in both the left and right directions (5, 10). Three parallel lines were marked, each 4.57 m apart. Using only a shuffle step, the subjects were instructed to shuffle from the middle line to one of the side lines, change directions, and shuffle to the opposite far line, change directions again, and shuffle back across the middle line. Timing was started on the subject’s first movement and was stopped when he crossed the middle line at the end of the test. Hand timing was used for each agility test, with the same tester used throughout the duration of the study.

**Isokinetic Squats.** Velocity-specific peak force (N) for a parallel squat was measured on an Ariel 5000 Computerized Exercise System (Ariel Corp., Trabuco Canyon, CA) using the multijoint assessment station (2, 40). Bar velocities measured were 0.20, 0.82, and 1.43 m·s$^{-1}$. Each subject was given three trials of one repetition at each velocity, with the order of testing randomly assigned. One minute of rest was provided between each trial. Reliability of the isokinetic squat assessments, as determined from coefficients of variation (CV; 54.2 kg calibration load: intratest CV = 7.0%, intertest CV = 0.4%; 101.1 kg calibration load: intratest CV = 0.3%, intertest CV = 0.2%) were always less than the allowable maximum previously suggested for this device (40).

**Isokinetic Back and Hip Extensions.** Velocity-specific peak torque (Nm) for back and hip extension was measured on an Ariel 5000 Computerized Exercise System using the single-joint assessment station (1). Three trials of one repetition each at angular velocities of 0.17 and 1.05 rad·s$^{-1}$ were assessed, the with faster velocity always tested first, much like when isometric tests are included (26). This was done to avoid the possible effects of fatigue from the slow velocity test ($=12.3$ s·rep$^{-1}$), as suggested by pilot work. The subject’s legs and hips were held stable while he moved from hip angles of 70 to 140° ($=180°$ = anatomical position). Due to instrumentation failure, these tests were performed only at tests 1 and 4. Reliability of the isokinetic hip and back extensions, as determined from coefficients of variation (56.0 kg calibration load: intratest CV = 3.0%, intertest CV = 0.5%; 93.9 kg calibration load: intratest CV = 11.0%, intertest CV = 0.6%) were within acceptable ranges.

**Training Questionnaire.** All subjects completed a training questionnaire prior to each training or testing session. Included were three statements each concerning perceptions of muscle soreness, knee pain, and lower-back pain, for a total of nine questions. Items concerning muscle soreness included "my leg and hip muscles are sore," "my leg and hip muscles feel recuperated," and "the muscles of my legs and hips are tender." Items concerning knee soreness and pain included "my knees hurt," "there is pain in my knees," and "my knees are feeling fine." Items concerning lower-back soreness and pain included "my lower back is sore," "my lower back is feeling fine," and "there is pain in my lower back." A five-point Likert scale was used to report how well the statements described the subject’s perceptions at that particular time ($0 = 0$ at all, $1 = a$ little, $2 = moderately, \ldots 4 = extremely$). Composite scores for each of the item groups (i.e., muscle soreness, knee soreness and pain, lower-back soreness and pain) were tabulated after adjusting for inversely scored items. Scores from the normal training phase were compared with scores from each of the 3 weeks of the high-intensity phase.
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The reliability of each item group was analyzed by Cronbach alpha reliability coefficients (4). This questionnaire was an expanded version of one previously used for overtraining-related research (10, 13).

Statistical Analyses

Statistical analyses were performed with a one-way repeated measures analysis of variance using a 1 × 6 for the 1RM data (i.e., Pre, tests 1–4, Post) and a 1 × 4 for the test battery data (i.e., tests 1–4) and the questionnaire data (normal training, weeks 1–3 of the high-intensity phase). Fisher's least significant difference post hoc analyses were performed when a significant difference was found. A dependent t-test was used for the back extensions because they were performed only for the first and last test battery. All data are reported as $\bar{X} \pm SD$. Significance was set at $p \leq 0.05$.

Results

One repetition maximum strength for the parallel barbell squat increased during the normal training phase but did not significantly change at any time during the high-intensity training phase or during the 3-week period following the high-intensity training phase (see Figure 1). In essence, a plateau in 1RM performance was observed during the phase of training emphasizing heavy, near-maximal lifts. Isokinetic parallel squats indicated significant decreases only in slow velocity (0.20 m·s$^{-1}$) squats (see Figure 2). Sprinting speed was attenuated at 9.1 m but not at 36.6 m (see Figures 3 and 4). Times for the 9.1-m sprint increased by 0.11 seconds from test 1 to test 4. While sprint times for 36.6 m increased by 0.20 seconds, this change was not significant and, for the most part, could be accounted for by the slower initial accelerations indicated by the 9.1-m times.

Most of the other variables were not affected by the high-intensity training period (see Table 2). Lower-body reaction times were slower at test 3 but returned to initial values by test 4. Non-counter–movement vertical jumps significantly improved by test 4. Agility times to the right were significantly slower than to the left at test 1, but all following tests indicated no significant differences between agility to the right and to the left. By the end of the study (test 4), the agility right scores had significantly improved from test 1. Perceptions of muscle soreness and soreness and pain in the knees or lower back did not significantly change.

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Figure 4. Sprint times for 36.6 m ($\bar{X} \pm SD$). Tests 1–4 = before and during the 3-week high-intensity training phase. Sprint times did not significantly change during the high-intensity training phase.

Table 2. Subject characteristics and performances for the four test batteries during the high intensity training period ($\bar{X} \pm SD$).

<table>
<thead>
<tr>
<th>Variable</th>
<th>Test 1</th>
<th>Test 2</th>
<th>Test 3</th>
<th>Test 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>% Fat</td>
<td>8.4 ± 5.9</td>
<td>10.7 ± 5.9</td>
<td>10.8 ± 4.9</td>
<td>9.9 ± 4.4</td>
</tr>
<tr>
<td>Flexibility (cm)</td>
<td>36.6 ± 5.6</td>
<td>33.6 ± 6.4</td>
<td>38.1 ± 3.9</td>
<td>35.5 ± 7.3</td>
</tr>
<tr>
<td>Reaction time (seconds)</td>
<td>6.3 ± 0.5</td>
<td>6.4 ± 0.5</td>
<td>7.3 ± 1.0 *</td>
<td>6.5 ± 1.0</td>
</tr>
<tr>
<td>Depth vertical jump (cm)</td>
<td>55.3 ± 5.6</td>
<td>54.3 ± 6.9</td>
<td>56.5 ± 5.6</td>
<td>55.3 ± 8.1</td>
</tr>
<tr>
<td>Counter-movement vertical jump</td>
<td>55.0 ± 5.9</td>
<td>54.8 ± 9.3</td>
<td>55.8 ± 6.4</td>
<td>55.0 ± 6.6</td>
</tr>
<tr>
<td>Non-counter-movement vertical</td>
<td>51.3 ± 6.4</td>
<td>52.0 ± 7.8</td>
<td>53.3 ± 5.6</td>
<td>53.8 ± 7.1 *</td>
</tr>
<tr>
<td>jump (cm)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Agility right (seconds)</td>
<td>5.97 ± 0.59**</td>
<td>5.77 ± 0.56</td>
<td>5.47 ± 0.34</td>
<td>5.56 ± 0.44*</td>
</tr>
<tr>
<td>Agility left (seconds)</td>
<td>5.67 ± 0.27</td>
<td>5.49 ± 0.27</td>
<td>5.47 ± 0.27</td>
<td>5.58 ± 0.37</td>
</tr>
<tr>
<td>Back/hip extension (Nm)</td>
<td>0.17 rad·s$^{-1}$</td>
<td>399.1 ± 123.7</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td></td>
<td>1.05 rad·s$^{-1}$</td>
<td>338.3 ± 101.9</td>
<td>—</td>
<td>—</td>
</tr>
</tbody>
</table>

* $p < 0.05$, different from test 1.
** $p < 0.05$, different from agility left.

during the course of the study and are reported in Table 3. Cronbach alpha reliability coefficients for the questionnaire items addressing either muscle soreness ($a = 0.63$), knee pain ($a = 0.71$), or back pain ($a = 0.75$) indicated that each of the items was reliable, thus supporting their validity as measures of soreness and pain.

Discussion

Overtraining, as defined by a decrease in training-specific strength, did not occur in the present study, although other performance measures were adversely affected. The operational definition of overtraining used in the present study, as well as in previous studies (7, 9, 10, 13), requires an actual decrease in 1RM strength in order to definitively identify a state of overtraining. Other definitions of overtraining have allowed plateaus in performance to be considered as indicative of overtraining (28, 29, 36). Because plateaus in performance are often found in even the best training regimens, such a definition was not used for the

Table 3. Composite scores from the training questionnaire for each of the training phases ($\bar{X} \pm SD$; 0 = low, 4 = high). Values given are mean values for all sessions during the 4-week normal training phase and mean values for all sessions during each of the 3-weeks of the high intensity training phase. No significant differences were observed ($p > 0.05$).

<table>
<thead>
<tr>
<th>Question</th>
<th>Normal training phase</th>
<th>Week 1</th>
<th>Week 2</th>
<th>Week 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Muscle soreness</td>
<td>0.5 ± 0.2</td>
<td>0.8 ± 0.7</td>
<td>0.5 ± 0.5</td>
<td>0.7 ± 1.0</td>
</tr>
<tr>
<td>Knee soreness and pain</td>
<td>0.3 ± 0.2</td>
<td>0.2 ± 0.2</td>
<td>0.4 ± 0.2</td>
<td>0.4 ± 0.5</td>
</tr>
<tr>
<td>Lower back soreness and</td>
<td>0.4 ± 0.2</td>
<td>0.8 ± 0.5</td>
<td>0.9 ± 0.7</td>
<td>1.2 ± 0.7</td>
</tr>
</tbody>
</table>
present study. However, it is well documented that resistance exercise training with maximal or near-maximal loads is conducive to increasing 1RM capabilities (7, 16, 21, 27, 37) and is a method often employed by lifters to optimize competitive performances. Such an increase in 1RM strength was not observed in the present investigation, suggesting the early stages of the onset of a state of overtraining. Indeed, such a plateau in 1RM strength would be of great concern to both competitive athletes and their coaches. Furthermore, when 1RM was retested 3 weeks after the completion of the high-intensity phase and a return to the original training programs, strength levels had remained the same, again suggesting that the plateau in 1RM strength was not just a short-term phenomenon. The plateau in 1RM strength was not associated with perceptions of high levels of muscle soreness or lower-back and knee soreness and pain, similar to what has been previously reported (13). In previous reports, 1RM strength did indeed decrease due to overtraining without the presence of muscle damage as indicated by circulating levels of creatine kinase (7, 9, 13).

Previous high-intensity resistance exercise overtraining research has used machine modalities for the training (7, 9, 10, 13). Decreases in 1RM strength for a machine squat were reported only when training was performed every day for 10 × 1 at 100% 1RM loads (7, 9, 13). When training was performed 5 d·wk⁻¹ for 8 × 1 at 95% 1RM loads, 1RM strength continued to increase (7, 10). In the present study, a much lower training volume (i.e., 3 d·wk⁻¹ with 2 × 1 at 95% 1RM and 3 × 1 at 90% 1RM) resulted in a plateau in 1RM strength. It appears that the training tolerance to free-weight training is considerably less compared to training with a machine modality, most likely due to the increased physiological requirements necessary for controlling the free-weight resistance. As such, these data suggest that an individual’s capacity for intense training with free weights is less than for machine modalities. Since all subjects started the present study after following their own training programs, the purpose of the normal training phase was simply to equalize the resistance exercise training for all subjects prior to the high-intensity phase and to account for a learning effect for 1RM strength, if present. It is felt that this was satisfactorily accomplished and that the lack of increased 1RM strength during the high-intensity phase was indeed due to the training protocol prescribed.

The results of other performances were quite similar to what has previously been reported for high-intensity resistance exercise overtraining (7, 10, 13). Previous research has indicated that isokinetic strength is attenuated during excessive training with high relative intensities (10, 13). When 1RM strength continued to increase in previous research (10), only slow velocity (1.05 rad·s⁻¹) isokinetic knee extension strength decrements were observed. When 1RM strength has significantly decreased (13), decreased isokinetic knee extension strength has been observed at all velocities (0.52, 3.14, and 5.23 rad·s⁻¹). In the present study, isokinetic squat strength was attenuated only at the velocity most similar to the actual training velocities. Using the terminology of Bompa (3), this would indicate attenuated maximal strength. These data suggest that, in the early stages of high-intensity resistance exercise overtraining, only velocity-specific isokinetic strength decreases while all velocities of isokinetic strength are adversely affected when 1RM strength finally succumbs to the stresses of such training. The musculature of the hip and back, which contribute greatly to the parallel barbell squat (8, 21), did not exhibit significant strength decreases at either isokinetic velocity tested (see Table 2). The larger-than-expected variability for this test may have made it difficult to detect strength decrements for these muscles. As such, future research must determine the role of the hip and back musculature during stressful high-intensity barbell squat training.

Another consistent result of the high-intensity resistance exercise overtraining literature is the detrimental effect on sprint performance (7, 10). In previous reports of high-intensity resistance exercise, 9.1-m and 36.6-m sprint times significantly increased (10). The present study also exhibited slower 9.1-m sprint times. The nonsignificant differences for 36.6-m times could be explained primarily by the slower starts as indicated by 9.1-m times. Again, using the terminology of Bompa (3), these sprint results would indicate attenuated starting power and acceleration power. As has been previously observed (10), agility times to the right were initially slower than to the left and significantly improved during the study. Whether this was due to the testing order, a learning effect, or a physiological response to the training protocol is not clear. Regardless, such results suggest the important role of further familiarization for such tests. It is interesting to note that non-counter–movement vertical jump height significantly increased by test 4. Such a response could conceivably be part of a learning effect, but this has not been previously observed during high-intensity resistance exercise training (10). Such data suggest that the physiological response to the training in the present study included no effect on stretch-shortening cycle capabilities, as indicated by no changes in counter–movement vertical jump and depth vertical jump heights. However, again using the terminology of Bompa (3), a slight improvement in take-off power from a static position was indicated by the greater non-counter–movement vertical jump height by test 4. It is speculated that the stressful training adversely affected cyclic power activities such as the 9.1-m sprint, whereas noncyclic power activities, such as the vertical jumps, were primarily unaffected or
slightly improved. It should be noted that a number of other performance variables were not adversely affected (see Table 2). Body composition, flexibility, and lower-body reaction were for the most part not significantly different by the end of the high-intensity period. Previous overtraining literature has suggested that some of these variables may be altered due to stressful training (12, 20, 25, 30); however, performance impairments in the present study did not appear to adversely affect all physical and performance variables.

It is beyond the scope of the present investigation to determine the physiological mechanisms responsible for the unfavorable responses for strength and speed. Previous research, however, has suggested that maladaptations of the peripheral musculature may contribute to high-intensity resistance exercise overtraining (7, 9, 13). Such maladaptation does not include muscle damage (7, 9, 13) but may involve modifications of the sympathetic system and skeletal muscle adrenergic receptors (9, 14). Such maladaptations would fit the model of a sympathetic overtraining syndrome (9, 28, 29, 36) and could account for many of the modifications in muscle performance. Whether modifications of fiber type or protein expression are involved in an overtraining scenario is not presently known.

In conclusion, the high relative intensity resistance exercise training protocol used resulted in a plateauing of 1RM strength for the parallel barbell squat, even though use of near-maximal relative intensities are typically associated with augmented 1RM strength (16, 37). When compared to previous high-intensity resistance exercise overtraining research using a machine modality, it appears that the exercise capacity with free-weight resistance exercise may be less than for a machine modality. The impaired performances observed were not associated with perceptions of muscle or joint soreness but are most likely due to improper exercise prescription. Further research is necessary to determine the effects of greater relative training intensities (i.e., 100% 1RM) with this training modality and to study the physiological and psychological mechanisms that may be responsible for such unfavorable training responses. With this in mind, the training protocol used needs to be further refined before it can be used as an indubitable model of overtraining for research purposes.

### Practical Applications

Three critical implications for the practitioner may be derived from this investigation. First, it is important to note the apparent differences in exercise capacity when comparing free-weight and machine modalities. Considering the five acute training variables (6), these data support the contention that the proper volume of exercise and the proper training load are subject to the choice of exercise (modality). When prescribing resistance exercise, the different training volumes and intensities must be considered when selecting resistance exercise machines or free weights. Second, the effectiveness of a strength and conditioning program cannot be determined purely by 1RM performances. As indicated by the present study and by previous research (7, 10, 13), IRM strength may not be attenuated, but other performance variables may be adversely affected. For many sporting activities, impaired isokinetic strength and sprint performances may prove problematic. And third, the importance of proper exercise prescription is once again reinforced. Only through the proper administration of the many complex acute training variables can optimal performance be achieved. As illustrated by the data presented, the training stimulus must be dosed in an appropriate manner to achieve successful results.

### References

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