Growth Hormone Release Following Single Versus Multiple Sets of Back Squats: Total Work Versus Power

Bruce W. Craig\(^1\) and Ho-Youl Kang\(^2\)

\(^1\)Human Performance Laboratory, Ball State University, Muncie, Indiana 47306; \(^2\)Department of Physical Education, The University of Texas at Austin, Austin, Texas 78703.

Reference Data

ABSTRACT

Human growth hormone (hGH) is required for normal development, but its role in exercise-induced muscle hypertrophy is not well characterized. The purpose of this study was to determine how total work and mean power affect hGH secretion. Male weight trainers with more than 2 yrs experience in the half squat performed three half-squat exercise trials: one set at 75% 1-RM, one set at 90% 1-RM, and a progressive routine of 75% and 90% sets. The latter dealt with total work by allowing the subjects to lift at their own pace until volitional fatigue, with loads and rest periods controlled. The single-set protocol dealt with power output; the subjects performed as many lifts as possible in 15 sec, using the same workloads as in the progressive routine. Immediate postexercise blood levels of hGH were significantly elevated in the progressive protocol, but not in the single-set protocol, regardless of exercise intensity employed. It was found that the progressive workout involved significantly more work whereas the single bouts were more power oriented. The results demonstrate that total work during exercise is a more important component of hGH release than the amount of power generated.

Key Words: acute exercise, single set, multiple set

Introduction

The need for adequate growth hormone (hGH) release for normal development of muscle and bone is well established (20), but its role in exercise-induced muscle hypertrophy is not well defined. It seems logical to assume that hGH controls the muscle growth produced by weight training but the evidence to support this concept is weak. Many investigators have shown that exercise stimulates hGH secretion (1, 3, 5, 13, 18, 19, 22). However, the release patterns of the hormone, a rapid increase and a short-lived peak, 5 to 15 min after exercise ceases (1, 3, 19, 22), would suggest that its release is associated more with stress than with muscle growth. Djarova et al. (7) have shown that hyperventilation and breath holding, two common practices in weight trainers, can significantly increase hGH levels and may explain the hormonal release associated with strength training.

Although the stress of exercise may have an acute effect on hormone release, Chelsey et al. (4) demonstrated that resistance exercise does influence muscle growth. They demonstrated that a single exercise session (four sets of biceps curls with 6 to 12 reps per set at 80% of 1-RM) can elevate protein synthesis activity for up to 24 hrs postexercise.

It has been well established that hGH controls bone and muscle development by producing insulin-like growth factors (IGF). These compounds are manufactured in the liver and have long-term effects on protein synthesis. Using an isolated muscle preparation of the rat, Henriksen et al. (12) demonstrated that IGF-I activity and amino acid uptake are enhanced by a single exercise session (exhaustive swim), and that the effects persist for at least 3-1/2 hrs after exercise. Few investigators have examined the effects of resistance exercise on IGF-I release, but the evidence available does suggest that a single resistive exercise session does not have a strong stimulatory influence immediately following exercise (15, 16).

Although there are no conclusive data that hGH is needed for the exercise-induced muscle hypertrophy of weight training, several investigators (11, 15-17) have provided indirect evidence by demonstrating that exercise routines associated with increased muscle hypertrophy have the greatest effect on hGH release. In order to further clarify the relationship between resistance exercise and hGH secretion, we need to examine the various components of the lifting process. Therefore these experiments measured the influence of total work and mean power output on hGH release patterns.
Methods

Subjects
Four experienced male weight trainers were recruited from the student population of Ball State University. Each had been lifting for over 2 yrs and used the half squat in his normal training regimen. The subjects were informed of the possible risks associated with this research and signed informed consent to participate. Prior to testing, each subject was weighed and his body fat was measured with Lange calipers using the 7-site skinfold method as described by Pollock et al. (21). Subject characteristics are given in Table 1.

Table 1
Subjects’ Age, Height, Weight, and % Body Fat Measurements

<table>
<thead>
<tr>
<th>Subject</th>
<th>Age  (yrs)</th>
<th>Ht  (cm)</th>
<th>Wt  (kg)</th>
<th>% Fat</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>25</td>
<td>175.0</td>
<td>66.5</td>
<td>6.0</td>
</tr>
<tr>
<td>2</td>
<td>23</td>
<td>167.5</td>
<td>78.3</td>
<td>12.8</td>
</tr>
<tr>
<td>3</td>
<td>25</td>
<td>168.6</td>
<td>82.5</td>
<td>13.6</td>
</tr>
<tr>
<td>4</td>
<td>24</td>
<td>178.8</td>
<td>81.5</td>
<td>9.6</td>
</tr>
<tr>
<td>M</td>
<td>24.3</td>
<td>172.5</td>
<td>77.2</td>
<td>10.5</td>
</tr>
<tr>
<td>SE</td>
<td>±0.4</td>
<td>±2.3</td>
<td>±3.2</td>
<td>±1.5</td>
</tr>
</tbody>
</table>

Strength Test
Each subject reported to the laboratory 1 week before the exercise trials to determine his one-repetition maximal lift (1-RM) for the half-squat exercise. The exercise was performed on a squat rack and the subject’s downward motion was stopped when his upper leg was parallel with the floor. Subjects began with their normal training weight and warm-up routine. They then proceeded through a series of single lifts with 4.5 kg added after each successful attempt. The test was terminated when they could no longer perform the lift or could not do it in good form, as determined by two spotters. The weight they were able to lift prior to this failed attempt was used as their 1-RM. After their 1-RM was determined, workloads of 75% and 90% were established and used for the 75% and 90% trials (Table 2).

Exercise Sessions
Each subject was required to perform three exercise trials: a single set at 75% of his 1-RM, a single set at 90% of his 1-RM, and a progressive protocol that included two sets at 75% and 90% of his 1-RM. During the single-set routines the subjects completed as many lifts as possible in 15 sec. In the progressive routine they continued lifting at each intensity until they were fatigued or could not maintain the mechanics of the lift, as determined by two spotters. The subjects were given a 3-min rest period between the 75% and 90% sets of the progressive trial.

All exercise sessions were conducted in the weight room of Ball State University and began at 7:00 a.m.

The subjects fasted for 12 hrs prior to each trial and did not train for 48 hrs prior to the trials. Progressive trials were conducted first, followed 1 week later by the single-set trials, which were separated by 3 days of inactivity. To obtain a true baseline for judging the full effectiveness of the exercise stimulus on hGH release, the trials were conducted in the morning when hGH secretion is at its lowest point of the day. From a practical standpoint the early morning trials fit the subjects’ schedule best and made it easier for them to comply with the 12-hr fasting condition.

The preexercise routine was the same for each trial and consisted of a 15-min rest period in an inclined position, followed by the taking of a blood sample (3 ml) and a 20-min warm-up session. The warm-up session began with stretching and included two preliminary sets, each with 8 to 10 reps at 25 and 50% of the subject’s 1-RM.

Experimental Design
As noted, the subjects reported to the laboratory at 7:00 a.m. and after a 15-min rest period had a 3-ml baseline blood sample drawn from an antecubital vein by a trained phlebotomist. They then warmed up and performed the required workout session. The progressive lifting trial dealt with total work; subjects were allowed to lift at their own pace until volitional fatigue. The single-lift trials, on the other hand, dealt with mean power; the subjects were to perform as many lifts as possible during a 15-sec period.

After each exercise trial the subject was inclined on a training bench and an immediate postexercise blood sample (3 ml) was drawn from an antecubital vein. He remained in this position throughout the postexercise blood draws to minimize the effects of posttrial activity on the hGH response. A second 3-ml postexercise blood sample was taken 15 min later. During the progressive trial pre- and postexercise blood samples were drawn as described for the single session, with an additional blood sample taken between the sets.

Table 2
Subjects’ One-Repetition Maximal, Workloads, and Repetitions

<table>
<thead>
<tr>
<th>Subj.</th>
<th>1-RM Wt (kg)</th>
<th>Workloads (kg)</th>
<th>Repetitions</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>75%</td>
<td>90%</td>
<td>Progressive</td>
</tr>
<tr>
<td>1</td>
<td>120.2</td>
<td>90.7</td>
<td>106.6</td>
</tr>
<tr>
<td>2</td>
<td>170.1</td>
<td>127.5</td>
<td>153.3</td>
</tr>
<tr>
<td>3</td>
<td>170.1</td>
<td>127.5</td>
<td>153.3</td>
</tr>
<tr>
<td>4</td>
<td>190.5</td>
<td>142.9</td>
<td>172.4</td>
</tr>
<tr>
<td>M</td>
<td>162.7</td>
<td>122.2</td>
<td>146.4</td>
</tr>
<tr>
<td>SE</td>
<td>±15.0</td>
<td>±11.1</td>
<td>±14.0</td>
</tr>
</tbody>
</table>
Work and Power Calculations. The amount of work performed in each lift was calculated by multiplying the weight lifted for the 75% and 90% sets by the distance the weight was moved. Total work output was calculated by multiplying the work performed at each exercise load \( \times \) the number of repetitions completed with that load. Mean power produced during each set was calculated by dividing the total work of each set session by the time required to perform it.

Analytical Assay. When the blood was drawn, a 0.5-ml aliquot was deproteinized with 0.6 M perchloric acid for lactic acid determination, and both the lactic acid and serum samples were centrifuged for 15 min at 3,000 rpm. The resultant PCA extract and serum were then removed and frozen at -20°C for later analysis. Human growth hormone (hGH) was determined in duplicate using \(^{125}\)I hGH radiolmmunoassay kits from Diagnostic Products Corp. (Los Angeles). The coefficient of variance for the assay was less than 3.8%. Lactic acid was measured using lactic acid kits from Sigma Chemical (St. Louis).

Statistical Analysis. The intra- and intertrial differences were analyzed with a two-way ANOVA comparison, and the post hoc differences were measured with a Fisher PLSD, Scheffé F test, and Dunnett t test of significance. A Macintosh SE computer and a StatView 512+ statistical package (Brainpower Inc., Calabasas, CA) were used for the statistical analysis.

Results

Growth Hormone Response

Progressive Trial. Although the serum levels of hGH immediately following the 75% set were higher than preexercise values, they were not statistically significant (Table 3). However, by the end of the 90% set the blood levels of hGH were significantly higher than preexercise values or those of the 75% set. The serum levels of hGH remained significantly higher than the preexercise or 75% set for the 15 min following activity. In fact the 15-min postexercise hGH values were 26.3% higher than those measured immediately following the 90% set.

Single Trial, 75%. A single set at 75% of 1-RM more than doubled the blood levels of hGH, but due to subject variability was not statistically different from preexercise levels. The immediate hGH response to the single 75% trial was also higher than the immediate postexercise response of the 75% set of the progressive trial, but again did not represent a significant change. The blood levels of hGH remained elevated for 15 min following the single 75% trial.

Single Trial, 90%. Neither the immediate nor 15-min postexercise hGH response differed significantly from the preexercise hormone level. Serum levels of hGH were elevated in both cases but did not reach significance.

Lactic Acid Response

Progressive Trial. Unlike the hGH response, lactic acid levels were significantly elevated after the 75% set and represented a nine-fold increase over resting values (Table 4). The lactic acid concentration following the 90% set was only slightly higher than those after the 75% set, but still significantly higher than preexercise values. The 15-min postexercise lactic acid levels obtained in the progressive trial were significantly below those recorded after the 75% and 90% sets, and significantly higher than preexercise lactic acid concentration.

Single Trial, 75%. The lactic acid concentration achieved during the single 75% set was lower than that produced during the 75% set of the progressive trial, but the rate of disappearance (15-min postexercise levels) in both was approximately the same.

Single Trial, 90%. The lactic acid responses to a single 90% set were almost identical to those found in the single 75% trial, but lower than the immediate

| Table 3 | Acute Growth Hormone Responses (in ng/ml) for Subjects Completing 3 Types of Lifting Protocols |
|----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|
| Sample times  | Progressive MSEM | 75% Single MSEM | 90% Single MSEM |
| Pre Immediate post, 75% | 1.65 0.27 | 1.68 0.3 | 1.58 0.3 |
| Immediate post, 90% | 2.71 0.56 | 5.0 2.5b | 2.0 0.3 |
| 15-Min post | 11.55 4.25a | -- | 2.0 0.3 |
| | 14.59 5.52a | 5.2 2.1b | 3.26 1.5b |

Value significantly (p < 0.05) *higher than pre or immediate post 75% value, †lower than 15-min post of progressive value, *lower than 90% post and 15-min post of progressive value.

| Table 4 | Acute Exercise Lactic Acid Responses (in mM) for Subjects Completing 3 Types of Lifting Protocols |
|----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|
| Sample times  | Progressive MSEM | 75% Single MSEM | 90% Single MSEM |
| Pre Immediate post, 75% | 1.25 0.10 | 1.21 0.11 | 1.18 0.13 |
| Immediate post, 90% | 11.59a | 1.07 8.21a | 0.54 |
| 15-Min post | 12.61a | 1.87 | 7.63a |

Value significantly *above (p < 0.05) preexercise and 15-min postexercise value, *below the immediate 75% post.
postexercise levels found after the 90% set of the progressive trial.

Work and Power Output

Progressive Trial. The amount of work performed per single repetition during the progressive trial was higher during the 90% set of the workout, with the work output being 571.2 ± 39.7 J for the 75% set and 684.2 ± 50.6 J for the 90% set (Figure 1a). However, if the number of repetitions completed for each phase of the progressive trial (Table 2) is factored in, it is obvious that less total work was completed during the 90% set compared to the 75% set: 9,665 ± 1,609 versus 5,146 ± 1,386 J (Figure 1b). Mean power generated for each set of progressive lifts (Figure 2) was essentially the same for the 75% and 90% sets, at 169.0 ± 27.1 and 163.0 ± 31.3, respectively.

Single Trial, 75%. The amount of single repetition work by each subject during the single 75% set was the same as the progressive workout, but total work performed during the single session was well short of the progressive 75% set (Figure 1b). Mean power generated during the single 75% set, on the other hand, was nearly 2.5 times higher than that produced during either the 75% or 90% progressive sets (Figure 2).

Single Trial, 90%. Work differences between the progressive 90% set and the single set at 90% were similar to the 75% comparisons, with the single repetition values being the same and the total work values of the single set of 90% being lower than the progressive 90% set (Figure 1b). Mean power differences between the two trials were not as great, however, the 90% single set being only 1.5 times as high as the 75% and 90% progressive sets (Figure 2).

Discussion

The results indicate that total work may be more important than exercise intensity in stimulating hGH production during resistance training. Plasma levels of hGH were significantly higher immediately after the progressive exercise trial and continued to rise for 15 min postexercise, but were not significantly elevated after either single-set trial. Research by Karagiorgos et al. (13) and Vanhelder et al. (23, 24) has already shown that high intensity intermittent forms of exercise are effective in stimulating hGH release and suggests that exercise intensity is the most important factor in controlling the response. However, our data show that while exercise intensity may have had an effect on hGH release, it was not as important as total work. The greatest mean power output was observed with the 75% single-set protocol, but the hGH levels attained following this protocol were still significantly below the progressive trial, which represented more total work.

Prior research from this laboratory (6) supports the concept that total work is as important as the relative intensity of the exercise in promoting hGH release. In that study, the postexercise release pattern of hGH was measured in three groups of subjects who trained for 10 weeks by using one of three protocols: running for 40 min at 75% of HRmax, weight training for 40 min at 75% of 1-RM, or running and then weight training.
Although the appearance of the hormonal peak following 10 weeks of training varied—8 min for runners and 4 min for the lifters and combination group—the overall hGH release patterns were the same regardless of the form of training. A weight training program based on 75% of 1-RM represents a significantly more intensive form of training than running at 75% of HRmax, but this difference in exercise intensity did not alter the basic hGH secretion pattern.

If exercise intensity is not the only control mechanism for hGH release, other components of continuous exercise or the repeated bouts of activity common in weight training must be involved. Several investigators have suggested that hormone release is stimulated peripherally via afferent nerve fibers within the active muscle (10, 14). Therefore continuous forms of activity should provide constant neural activity and be more effective than intermittent exercises such as weight training.

However, recent work by Kjaer et al. (14) suggests that although these peripheral neural connections are essential for ACTH and B-endorphin secretion, central control mechanisms in the brain are more important for hGH release. Using young male subjects, Kjaer et al. (14) administered an epidural block at vertebrae L2–L3 to eliminate afferent neural feedback during an exercise bout. The subjects cycled for 20 min at 55% of their VO2max; pre- and postexercise blood samples were measured for catecholamines, insulin, glucagon, hGH, ACTH, and B-endorphins. Only ACTH and B-endorphin secretion were affected by the blockage, indicating that afferent neural activity is needed for normal release.

Lactic acid accumulation has also been suggested by some investigators (8, 9) as the controlling factor for hormone release but does not seem to have a direct effect on hGH secretion. Although lactic acid concentration in the blood cannot accurately predict hGH release, it is a good indicator of the metabolic usage of the fuels within the muscle. The higher plasma lactic acid accumulation following the progressive protocol, as opposed to the lactic acid response of single-set trials, suggests that muscle glycogen was utilized to a greater extent during the progressive routine.

Research by Bouissou et al. (2) indicates that glycogen utilization during weight training and the subsequent lactic acid accumulation could be due to muscle hypoxia. The very nature of weight training—short explosive bouts of maximal activity—would create a local hypoxia similar to that shown by Bouissou’s group and could have produced the lactic acid levels achieved in the present study. Therefore the significantly higher lactic acid levels following the progressive trial could be due to the increased hypoxia induced by a longer and more demanding protocol.

Breath control and brief periods of hyperventilation are common characteristics of weight training protocols, and Djarova et al. (7) demonstrated that hyperventilation, breath holding, or both can significantly (p < 0.05) increase plasma hGH by altering pH. They tested three protocols in which the subjects either (a) maintained a paced hyperventilation for 3 min, (b) held their breath for three maximal efforts with a volitional endpoint and 1 min of rest between them, or (c) hyperventilated and then held their breath, as described. Immediate postexercise hGH values for the 75% progressive and 75% and 90% single-lifts protocols were similar to the 5-min posttest hGH levels reported by Djarova et al. (7), which suggests that breathing patterns may have been the main stimulus for the hormone release following single sets of lifts.

The plasma hGH levels achieved during the progressive lift protocol, however, demonstrate that breathing patterns cannot account for the significant (p < 0.05) elevation in hGH secretion; immediate postexercise values for the 90% progressive lift were seven and four times higher than preexercise and 75% progressive lift values, respectively. These values were considerably higher than those reported by Djarova et al. (7) and continued to rise, the 15-min postexercise hGH levels being 26.3% higher than the immediate postexercise ones. Therefore, although the subjects' breathing pattern could explain the initial increase in hGH following a single set of lifts, it is not responsible for the dramatic increases produced by a second set of lifts.

In summary, the data presented here indicate that two sets of lifts produced a significant increase in hGH, whereas a single set, regardless of whether it was performed at 75% or 90% of 1-RM, did not significantly alter hGH release. A comparison of the amount of work and mean power produced by each workout routine indicates that total work was more important than mean power output in stimulating the hormone secretion.

Practical Applications
The results of this study support the concept that progressive training programs employing multiple sets and increasing workloads are the most effective for stimulating the release of growth hormone. Unfortunately, the information presented here does not indicate whether this hormone is involved in the muscle growth associated with this type of training procedure. However, growth hormone has been shown to promote muscle hypertrophy under certain conditions and its presence does suggest an involvement.

References


**Acknowledgments**

This project was funded by grants from the Ball State University Office of Research. We would like to thank the participants of this project who dedicated their time and energy to this study. We would also like to thank Matthew Hickey for his critical review of the manuscript, and Mary-Ann Richards for her secretarial skills in preparing it.
Oops!

Vol. 8(3), page 188, contained a transposition in the superscript numbers indicating author affiliation in the article titled “Does Short-Term Near-Maximal Intensity Machine Resistance Training Induce Overtraining?” The lead author, Andrew C. Fry, was at Ohio University; he was incorrectly listed with The Pennsylvania State University. The affiliation for co-authors William J. Kraemer, J. Michael Lynch, N. Travis Triplett, and L. Perry Koziiris should have read The Pennsylvania State University.