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Acute Testosterone Responses to Different Resistance Exercise Intensities

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ACUTE TESTOSTERONE RESPONSES TO DIFFERENT RESISTANCE
EXERCISE INTENSITIES

by

Robert William Rietjens

Bachelor of Science

University of Illinois at Chicago

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A thesis submitted in partial fulfillment
of the requirements for the

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ABSTRACT

Acute Testosterone Responses to Different Resistance Exercise Intensities

by

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We investigated the acute testosterone response to four different resistance-training protocols. We observed testosterone levels pre-workout, immediately post-workout, and 60-minutes post-workout following a bout of upper body exercise at 70%, 1 RM, 90% 1 RM, and lower body exercise at 70% 1 RM and 90% 1 RM. Total training volume was held constant but all amount of weight, sets, and reps were different. 10 healthy, male, resistance trained individuals volunteered for the study. They performed each exercise condition on separate days. Capillary blood was taken via finger prick at the time points specified above. Blood samples were analyzed via Accubind Testosterone ELISA and we found that immediately post-workout following the upper body and lower body moderate intensity (70% 1 RM) workouts testosterone was significantly higher compared to pre-workout ($p < 0.05$). Following the high intensity (90% 1 RM) exercise protocol testosterone levels were elevated but not statistically significant ($p > 0.05$). We concluded that 70% 1 RM is a large enough stimulus to observe a significantly higher testosterone response post-workout. 90% 1 RM has been shown previously to be enough of a stimulus, however, this current study did not support those findings.

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CHAPTER 1

INTRODUCTION

Acute bouts of heavy resistance exercise induce a myriad of physiological responses. These acute responses can lead to adaptations over time that are necessary for increasing muscular strength and hypertrophy. Hormonal responses to resistance training are among the most important for increasing size and strength of the musculature exposed to a significant stimulus. Increased anabolic hormone concentration after an acute bout of resistance exercise can lead to increased protein synthesis within the muscle being trained (Kraemer & Ratamess, 2005). It is important to note that the larger the stimulus the larger the endocrine response will be. A larger training volume or higher training intensity will lead to an increased endocrine response. Ultimately, manipulation of these training variables can lead to tissue remodeling via increased protein synthesis due to the endocrine response following a bout of heavy resistance exercise.

One of the major anabolic hormones associated with increased muscle size and strength is testosterone. Testosterone's primary biological effects are nitrogen retention, stimulation of protein synthesis, and development of secondary sex characteristics such as increased hair growth (Vingren et al. 2010). Testosterone production begins in the Leydig cells located in the testes of men. It is also produced, to a smaller degree, in the ovaries and adrenal cortex in women. The central nervous system stimulates the hypothalamus to begin testosterone production, which suggests a strong link between the nervous and endocrine systems (Vingren, et al., 2010). Fahey and colleagues (1976) demonstrated that testosterone increases immediately post-training after performing 3 sets of 5 repetitions maximum for the bench press, seated press, and leg press. This

shows that heavy resistance training, five repetitions or less with near maximal loads, stimulates a significant release in testosterone following the training bout. This also suggests that the larger the muscle mass that is activated the larger the response will be. Exercises such as bench press, leg press, and latissimus dorsi pulldowns have been shown to increase testosterone post exercise to a greater extent than small muscle mass movements when performed above 80% of one repetition maximum (Weiss, Cureton, & Thompson, 1983). This demonstrates as exercise intensity, or a given load or resistance for a certain exercise increases, testosterone release will increase as well following the bout.

Upper body training exclusively has not been shown to be a strong enough stimulus in order to elicit a significant post-exercise hormonal response. Even three sets of 10 repetitions at 80% of 1 repetition maximum for five different upper body exercises is not enough to observe a significant elevation in testosterone post-exercise (Migiano et al. 2010). Lower body training, however, has been shown to induce a rise in testosterone immediately post-exercise even when only one exercise is performed. When 8 sets of 10 repetitions for the back squat exercise was performed at the subject's 10 repetition maximum, an elevation in testosterone immediately post-exercise was observed (Hough et al. 2011).

The amount of total work in Joules (J) has been shown to be directly related to the amount of testosterone and growth hormone release post-exercise (Hakkinen and Pakarinen 1993). J is calculated by taking the number of sets * number of repetitions * intensity of exercise. Gotshalk et. al. (1997) demonstrated that a protocol consisting of 3 sets of 10 repetitions was superior compared with 1 set of 10 repetitions in regards to the amount of testosterone release post-exercise. The American College of Sports Medicine recommends that an individual complete one set of anywhere from 3 to 20

repetitions for every major muscle group to improve muscular strength. This is in contrast to many exercise programs that require multiple sets of a higher intensity. The purpose of this study is to observe if there is an increased testosterone response to two different exercise protocols. One protocol consists of 2 sets of 9 at 70% 1 RM while the other consists of 5 sets of 3 repetitions at 90% 1 RM. These protocols have the same number of total work (J) but different set, repetition, and intensity schemes. A secondary objective is to observe a difference in the endocrine response to upper versus lower body training while total training volume remains constant.

Purpose of the Study

The purpose of this study is to observe the acute testosterone and growth hormone response to two different resistance-training protocols at different intensities when total overall workload (J) is held constant. A secondary purpose is to see if there is a difference in the endocrine response when comparing an upper body protocol to a lower body protocol. This study could potentially provide insight into the anabolic hormone response to an acute bout of resistance training at high intensity versus moderate intensity via ACSM guidelines when total workload does not change.

Research Hypothesis

Hypothesis #1

H_{01} : There will be no change in the testosterone response from pre-exercise to post-exercise following an acute bout of resistance training at moderate intensity (70% 1 RM).

H_{A1} : There will be a significant increase in the testosterone response from pre-exercise to post-exercise following an acute bout of resistance training at moderate intensity (70% 1 RM).

Hypothesis #2

H₀₂: There will be no change in the testosterone response from pre-exercise to post-exercise following an acute bout of resistance training at high intensity (90% 1 RM).

H_{A2}: There will be a significant increase in the testosterone response from pre-exercise to post-exercise following an acute bout of resistance training at high intensity (90% 1 RM).

Hypothesis #3

H₀₃: There will be no change in the testosterone response from pre-exercise to post-exercise when comparing upper versus lower body training protocols at moderate intensity (70%).

H_{A3}: There will be a significant increase in the testosterone response from pre-exercise to post-exercise when comparing upper versus lower body training protocols at moderate intensity (70%).

Hypothesis #4

H₀₄: There will be no change in the testosterone response from pre-exercise to post-exercise when comparing upper versus lower body training protocols at high intensity (90%).

H_{A4}: There will be a significant increase in the testosterone response from pre-exercise to post-exercise when comparing upper versus lower body training protocols at high intensity (90%).

Significance of the Study

The significance of this study lies in the possibility of finding an increase in testosterone or growth hormone following an acute bout of resistance training at two different exercise intensities when total work performed is held constant. This information could potentially help trainers and coaches elicit a significant anabolic response from their clients or athletes through different training protocols without increasing chance for injury by performing an excess amount of total muscular work.

CHAPTER 2

REVIEW OF RELATED LITERATURE

As mentioned previously, several studies have been published observing the relationship between testosterone release following a bout of intense exercise including resistance training. Exercising at a higher intensity has been shown to increase testosterone to a greater extent than lower intensity training. The amount of total muscular work being performed is also a determining factor in how much testosterone will be released post resistance training. This review of literature will focus on how intensity and total work of exercise performed affect the endocrine response.

Testosterone Release Post-Exercise

Jezova et al. (1985) looked at different intensities of cycle ergometer exercise in seven untrained males. Each participant completed three different cycle ergometer tests in a randomized order. Test A was three, six-minute workloads at 1.5, 2.0, and 2.5 W/kg separated by one minute of rest. Test B was three, six-minute workloads at 2.0 W/kg separated by one minute of rest. Test C was two, 4.5-minute workloads at 5 W/kg separated by one minute of rest. Total workload was 2160 J/kg but the intensity of each test differed. Blood samples were collected immediately pre-exercise, immediately post-exercise, 10-minutes post-exercise, 30-minutes post-exercise, and 60-minutes post-exercise. They found that there were no significant differences in testosterone elevations in test A or B compared to resting levels immediately post-exercise. They did find, however, that after test C plasma testosterone levels were significantly higher immediately post-exercise and 10-minutes post-exercise compared to resting values, rising from 6.5 ng/ml to 8.5 ng/ml. This data suggests that higher intensities of training elicits a significantly higher endocrine response compared to lower intensities of training.

Kuoppasalmi et al. (1976) looked at the effect of strenuous anaerobic running exercise on plasma steroid hormones. They wanted to study the endocrine response to a bout of intermittent strenuous running on an Olympic track at a relatively high intensity. They took five male runners and had them perform a general warm-up for 15 minutes. They then ran 300m at maximal speeds three separate times with five minutes of rest separating the bouts. Each participant was completely exhausted by the end of the workout even though the entire workout lasted only approximately 15 minutes. Venous blood was taken before the warm-up, immediately after the exercise bout, 30-minutes, 60-minutes, 3 hours, 6 hours, and both 1 and 3 days following the exercise bout. They found that immediately post-exercise plasma testosterone was elevated 13% to 23.3 nmol/L ($p < 0.05$). Plasma testosterone returned to resting levels and even slightly lower than resting levels 30-minutes post-exercise. This data suggests that even though the total training time was low the intensity was high enough to stimulate a significant release of testosterone immediately following the bout of running exercise.

Cumming et al. (1986) observed the increased response of reproductive hormones after an acute bout of exercise. They took five active but untrained males and had them cycle on an electrically braked cycle ergometer until volitional fatigue. They cycled at 60 revolutions per minute with a load starting at 0 watts (W) for the first three minutes followed by an increase in 25 W every minute until the subject could not continue activity. Venous blood was taken immediately before exercise and every 15 minutes for the hour after exercise. They found a significant increase in plasma testosterone ($p < 0.05$). They found the highest increase in plasma testosterone (30% increase) above baseline 20 minutes from the start of the exercise bout. Values returned to baseline 10 minutes following the highest observed increase. This data suggests an

intense bout of cycling until failure can induce observable, statistically significant increases in plasma testosterone immediately following exercise.

Galbo et al. (1977) set out to study the effect of two different running protocols on the testicular hormone response following the run. They took eight healthy males and had them each perform different running workouts on two separate days. The first day subjects completed a mild run at 50 % $VO_{2\max}$ followed by 10 minutes of rest. The second run completed that day was a moderate run at 75% $VO_{2\max}$. The third run completed that day was a 75% $VO_{2\max}$ load for two minutes followed by a progressive load increase every 25th second until exhaustion. Blood was drawn from each subject immediately following each run. The second time the participants went to the laboratory they completed three moderate workload runs lasting 20 minutes separated by 10 minutes of rest. Blood was drawn after each exercise bout as well as 30 minutes post-exercise. They found that plasma testosterone concentrations increased 13ng/ml, a 1-24% increase, but was found to be statistically insignificant. An increase of 31 ng/ml, a 14-56% increase, was observed after a 40 minute prolonged run. This suggests that running for 40 minutes at moderate intensity (75% $VO_{2\max}$) can cause an increase in testosterone and that short, mild, or moderate activity is not enough of a stimulus to observe a significant effect, even though a slight increase was observed.

Sutton et al. (1973) observed the androgen response during exercise in fourteen male rowers and seven male swimmers. They collected venous blood before and after the rower's morning and afternoon training sessions. The morning session consisted of maximal exercise through running and calisthenics. The afternoon session consisted of submaximal rowing. They also collected venous blood before and after the swimmer's morning training session which involved a maximal effort 800 meter swim. They found that all androgens were significantly increased following training sessions involving

maximal effort exercise. No increase was observed following submaximal exercise. This data suggests that a high intensity is necessary to significantly stimulate an androgen response following a bout of exercise.

The previous articles demonstrate a trend that shows that higher intensities of exercise elicit a significant hormonal response immediately following the exercise bout. The previous articles only discussed cardiovascular types of exercise such as running, swimming, rowing, and cycling. While these types of exercise have shown to elicit significant hormonal responses post-exercise, resistance training has also shown that trend. The following articles will look at resistance training and how training intensity and training volume are two major factors that affect the anabolic hormonal response following the training session.

Testosterone Release Post-Resistance Exercise

Low intensity resistance training, 50-70% 1 repetition maximum, does not appear to be enough of a stimulus to induce adaptations or even acute changes in testosterone release post exercise. Higher intensities, 80% 1 repetition maximum and above, appear to be a necessary intensity to elicit hormone concentrations post exercise. Low volume of training appears to also have a minimal effect on the hormonal response following an acute bout of training compared to protocols with a higher volume.

Kraemer et al.(1990) looked at the testosterone response to a low volume protocol of resistance training. They took eight healthy, recreationally trained males and measured hormone concentration following four different exercises. Bench press, lat pulldown, leg extension, and leg curl were performed in that order for ten repetitions or until failure, which equates to approximately 75% 1 repetition maximum. Blood was taken after each exercise, 5-minutes post exercise, 15-minutes post, 25-minutes post,

35-minutes post, and 95-minutes post exercise. Subjects were instructed to return home to rest but returned for a blood draw 5 hours, 35 minutes following the exercise program and again at 22 hours 30 minutes and 23 hours 30 minutes post exercise. They found significantly elevated testosterone concentrations after the lat pulldown and leg extension exercises. Testosterone was uncorrected for plasma volume change. Testosterone was not observed to be increased 23 hours 30 minutes following the bout of training. It is probable that the hormone response, a lack of corrected testosterone, was due to the small training volume. Although this study demonstrated that testosterone can be increased following a bout of low volume resistance exercise, that increase can be attributed to hemoconcentration, which suggests the testes are not actually producing more testosterone.

Fry and Lohnes (2009) looked at a high power resistance-training protocol and its effect on testosterone post-workout. Four recreationally trained men were used for this study. The high power workout consisted of 10 sets of 5 repetitions at 70% of the subjects 1 repetition maximum. The rest period were set up at two minutes between sets. Subjects were instructed to move the barbell as fast as possible and barbell velocity was measured to ensure a true high power exercise. Venous blood samples were collected 15-minutes pre-exercise, and 5-minutes post-exercise. They found that there were no significant differences between pre and post exercise values of circulating testosterone. Testosterone concentrations did elevate from 13 nmol/L to 19 nmol/L but this increase was not statistically significant. This data suggests that a power routine at 70% 1 RM is not a strong enough stimulus to elicit a significant post-workout endocrine response. One possible reason for this could be that the training volume was too low.

Yarrow et al. (2007) demonstrated that traditional resistance training at a low to moderate intensity yields no significant results on total or bioavailable testosterone

following a bout of exercise. They looked at 22 college aged males and had them perform four sets of six repetitions for the bench press and squat exercises. The intensity of the resistance training was set at 52.5% of their 1 repetition maximum. Blood samples were acquired ten minutes prior to activity, 15-minutes post exercise, 30-minutes post exercise, 45-minutes post exercise, and 60-minutes post exercise. They found that there were no significant differences between baseline total testosterone values (6.5 ng/mL) and bioavailable testosterone values (4 ng/mL) immediately and up to 30-minutes post training. Total testosterone levels actually fell below baseline 45 and 60 minutes post training (6 ng/mL). Bioavailable testosterone levels also fell below baseline values at 45-minutes and 60-minutes post training (3.5 ng/mL). This suggests that low intensity resistance training (< 70% 1 repetition maximum) is not a sufficient stimulus to cause circulating anabolic hormone concentration to increase following an acute bout of resistance training.

The previous studies demonstrated that an intensity level of around 70% 1 repetition maximum is not enough of a stimulus to elicit a significant hormonal response post-exercise. It has been shown, however, in some studies performed that around 70% 1 repetition maximum is enough of a stimulus to induce a cascade of events leading to increased testosterone following an exercise bout.

Tremblay, Copeland, and Van Helder (2004) wanted to determine the response of steroid hormones to an acute bout of resistance training in subject's with different training backgrounds. They observed seven healthy men who were classified as being recreationally resistance trained, eight healthy men who were recreationally endurance trained, and seven sedentary men. The acute bout of training the subject's performed consisted of a circuit of seven exercises. The exercises performed were knee extension-flexion, chest press-pull, shoulder press-pull, biceps curls, weighted abdominal

crunches, deadlift, calf raise, and triceps dumbbell press. Exercises were performed at the subject's 10 repetition maximum, which corresponds to approximately 75% of 1 repetition maximum. The entire workout routine lasted approximately 60 minutes. Blood was taken prior to exercise to observe resting hormone levels, 30-minutes post exercise, 60-minutes post exercise, 120-minutes post exercise, 180-minutes post exercise, and 240-minutes post exercise. They found that testosterone significantly increased post training relative to baseline values at the 30-minutes post exercise time point for sedentary and recreationally resistance trained males, respectively (3 nmol/L, 3 nmol/L). Free testosterone, interestingly did not significantly increase for the sedentary group (10 nmol/L) but did significantly increase for the resistance trained group (25 nmol/L). These findings suggest that the endocrine response of an acute bout of resistance training is dependent on the fitness status and background of the individual. It also suggests that a training intensity of around 75% 1 repetition maximum is a sufficient stimulus to make changes in the hormonal profile following a bout of resistance training.

Fry, Kraemer, and Ramsey (1998) observed the effect of lifting maximal weights (100% 1 RM) on the endocrine response to the exercise bout. They set out to compare lifting maximal weights against submaximal weights in 17 healthy men. The subjects were split into two groups, an over-training group (OT) and a control group (CON). The overtraining group consisted of 11 men and performed 10 single repetitions at 100% 1 RM with two minutes of rest in between. The control group performed a low intensity, low volume weight training program once per week that was designed to maintain current fitness levels. Blood was taken and analyzed after three test batteries, one before the two week training program, one in the middle, and one at the end. The test battery consisted of lifting 70% 1 RM for 10 consecutive repetitions until failure. They found that the OT group had slightly higher total testosterone immediately post exercise by the third

test battery while the control group had increased levels of total testosterone at rest and immediately post exercise by the third test battery. This could suggest that very high intensities can elicit a significant endocrine response immediately post exercise but that being in a state of overtraining may actually inhibit the total testosterone response to training.

McCaulley et al. (2008) observed the acute endocrine response to three different resistance-training workouts, a strength, hypertrophy, and power protocol while total training volume was held constant. They took ten recreationally trained males and had them complete four different lower body only resistance-training workouts. The back squat exercise was utilized for the hypertrophy and strength protocols. The hypertrophy program utilized four sets of 10 repetitions at 75% 1 repetition maximum. Rest periods were 90 seconds between sets. The strength protocol consisted of 11 sets of three repetitions at 90% 1 RM. Rest periods were 5 minutes between sets. The power protocol consisted of eight sets of six jump squats at the subject's body mass. Rest periods were 3 minutes between sets. All set and repetitions schemes were set up in such a way in that total training volume was the same or similar enough to not be statistically significantly different. Blood samples were taken immediately pre-exercise, immediately post-exercise, and 1, 24, and 48 hours post-exercise. They found that the hypertrophy program elicited significant elevations in testosterone immediately post-workout. Testosterone concentrations went from 17 nmol/L to 25 mmol/L, representing a 32.3% increase. Testosterone levels went back to resting values at 60-minutes post-exercise. The strength and power protocols found 19.6% and 10.7% increases in testosterone, respectively, however these were not statistically significant. This data suggests that rest periods play an important role in the acute endocrine response to resistance-training

because the protocol with the lowest rest periods showed the only significant increase in testosterone although total training volume for all protocols was controlled.

Kraemer et al. (1998) also demonstrated that an intensity level of around 70% 1 repetition maximum is a high enough intensity to elicit a significant testosterone release response. Eight healthy men were observed performing four sets of ten repetitions for the back squat exercise. They were given rest periods of 90 seconds in between sets. The intensity was set at approximately 70% of their 1 repetition maximum. Blood samples were obtained before exercise, immediately following the bout, 5-minutes post exercise, 15-minutes post exercise, and 30-minutes post exercise. They found that the total testosterone was significantly higher than baseline values at every time point following cessation of the bout. Baseline values for total testosterone was 15 nmol/L, immediately post was 22 nmol/L, 5-minutes post was 21 nmol/L, 15-minutes post was 20 nmol/L, and 30-minute post was 19 nmol/L. Free testosterone was also significantly higher at every time point following exercise compared to the baseline. Baseline was 60 pmol/L, 5-minutes post was 83 pmol/L, 15-minutes post was 80 pmol/L, and 30-minutes post was 75 pmol/L. Their findings suggest that a large muscle mass movement such as the back squat, when paired with a significant intensity, 70% 1 repetition maximum, is sufficient to stimulate the release of both total and free testosterone up to 30 minutes following the bout of resistance training.

These studies show that moderate intensity levels (around 70% 1 repetition maximum) is enough to observe a significant effect regarding steroid hormone release immediately post-exercise. This discrepancy indicates that it is not entirely known what mechanisms regulate the testosterone release immediately post-exercise. A plethora of factors could play a role in determining what intensity level is sufficient enough to observe a significant release of testosterone post-exercise.

Other studies have shown that the higher the intensity of exercise performed the more pronounced the immediate post-exercise endocrine response is observed.

Raastad, Bjoro, and Hallen (2000) observed nine resistance trained athletes and had them perform two training protocols. Protocol 1 consisted of 100% intensity for 3 sets of 3 repetitions for back squat and front squat exercises and 3 sets of 6 repetitions for leg extension. The other protocol consisted of 70% of the weight used for the previous protocol for the same exercises as well as set and repetition scheme. Blood samples were taken 30-minutes prior to exercise, 30-minutes into the strength training routine and every 15 minutes during the first hour of exercise. They found that the group that exercised at an intensity of 100% 3 repetition max had significantly higher testosterone release post training compared to the 70% intensity group. Resting testosterone values were 18 nmol/L while post exercise values rose to 22 nmol/L for the 100% intensity group. An increase of 4% was observed 30 minutes into the protocol. It is important to note that there were no differences between groups after one hour post training. Their findings suggest that a higher intensity is appropriate to stimulate the increase of testosterone during and for up to one hour post workout. Their study demonstrated that a higher exercise intensity, 100% of 3 repetition maximum compared to 70% of 3 repetition maximum, resulted in a greater acute testosterone response.

Hough et al. (2011) observed the effect of a short duration (<30 minutes), high intensity resistance-training workout on testosterone levels post-exercise. They took ten recreationally trained males and found their 10-repetition maximum for the back squat exercise. The resistance-training workout consisted of 8 sets of 10 at the subject's 10-RM. There were 90 seconds of rest in between each set. Venous blood samples were collected pre-exercise, immediately post-exercise, and 10, 20, 30, 40, 50, and 60-minutes post exercise. They found that testosterone was significantly elevated

immediately post-exercise. Values went from 27 nmol/L to 37 nmol/L. Values stayed elevated 10-minutes post-exercise but returned to pre-exercise values 30-minutes post-exercise. This data suggests that 8 sets of 10 repetitions utilizing a subject's 10 RM is a strong enough stimulus to elicit a significant post-exercise hormonal response.

This significant release of testosterone post-exercise following a bout of high intensity resistance training appears to only be seen when the entire body is performing work. Upper body training alone, even at a high intensity, has not been shown to significantly increase testosterone post-exercise.

Migiano et al. (2010) observed the acute endocrine response to a bilateral and unilateral resistance-training workout. The same exercises were used during both protocols but there was a different volume of training between them. Ten recreationally trained men performed both a unilateral and bilateral workout in a random order. The exercises utilized were dumbbell bench press, dumbbell bent row, dumbbell military press, dumbbell bicep curl, and dumbbell tricep kickback. The subjects did 3 sets of 10 repetitions with 80% of their 1 repetition maximum. The sets were broken up by two minutes of rest. Total volume of work performed for the unilateral workout was 52.1% of what was performed during the bilateral workout. Venous blood samples were taken immediately pre-exercise, immediately post-exercise, and 5, 15, and 30-minutes post-exercise. They found there were no significant differences in circulating testosterone between the two different protocols. This data suggests that an exercise program of only upper body exercises, even at a relatively high intensity and volume, may not be enough to stimulate a significant testosterone response.

Influence of Total Work on the Endocrine Response

Gotshalk et al. (1997) set out to determine the influence of total work, measured in Joules (J), on the body's hormonal response to an acute bout of resistance training. J is a measure of volume and is determined by taking the amount of weight lifted multiplied by the number of sets and then multiplied again by the number of repetitions. They took eight healthy males and had them perform two different exercise protocols, one involving 1 set of 10 repetitions for eight major muscle groups and the other involving 3 sets of 10 repetitions for the same eight major muscle groups. The smaller volume training protocol was measured at $19,821 \pm 4121$ J while the higher volume protocol was 58272 ± 9211 J. Participants performed each protocol on separate days. Blood was taken prior to exercise, immediately post exercise, 5-minutes post, 15-minutes post, 30-minutes post, and 60-minutes post exercise. They found that the higher volume protocol yielded significantly higher testosterone levels when compared to the lower volume set protocol. Significant differences were observed at all time points following exercise, immediately post, 5-minutes, 15-minutes, 30-minutes, and 60-minutes. This suggests that the total amount of muscular work performed, measured in J, is a strong determinant of the amount of testosterone released following the acute bout of resistance training.

Kraemer et al. (1990) observed the acute hormonal response during and immediately after a resistance training workout session in which the rest period length, load, and total work was different. They took nine recreationally trained males and had them perform six different resistance-training protocols in a random order. One workout was more strength based where a load of 5 repetitions maximum was used. The other was more hypertrophy based where a load of 10 repetitions maximum was used. Both types utilized one or three minute rest periods and a control workout. The eight exercises performed, in order, were bench press, leg extension, military press, bent leg

incline sit ups, seated row, latissimus dorsi pulldown, arm curls, and leg press. The 5 RM load was performed for 3-5 sets while the 10 RM load was performed for 3 sets. Venous blood was taken immediately pre-workout, midexercise, immediately post-workout, and 5, 15, 30, 90, and 120-minutes post-workout. They found that each resistance training protocol elicited a significant increase in testosterone during exercise and immediately post-exercise. Pre-exercise testosterone concentrations were around 20 nmol/L while midexercise concentrations were elevated to anywhere from 26 nmol/L to 30 nmol/L depending on the training protocol. Immediate post-exercise values were also elevated compared to pre-exercise values hovering around 25-27 nmol/L. The total workload for all the strength-based protocols was 49, 161 J while the total workload for the hypertrophy protocol was 59, 859 J. These results suggest that a total training volume of 49, 161 J is enough to elicit a significant hormonal response mid and immediate post-exercise. This data also suggests that manipulating simple variables such as rest period length and total training load different hormonal responses can be observed.

Hakkinen, et al. (1997) observed isometric muscle actions for the upper and lower extremities and their effect on the acute hormonal response to the exercise bout. Each of the 10 young men performed a unilateral knee extension for the lower body, unilateral bench press extension for the upper body, and both activities performed simultaneously in a third condition. Each exercise was performed one time at 100% intensity for a hold of 5 seconds. This was repeated 10 times with a recovery of 5 seconds in between each repetition. This protocol was performed 4 total times with 1 minute of rest in between sets. Blood was taken and analyzed immediately pre and post exercise. They found that the mean concentration of serum testosterone was significantly increased during each exercise condition but to a the greatest extent in the upper and lower body simultaneous condition (19.6 nmol per liter to 24.9 nmol per liter).

This suggests that heavy resistance training including the upper and lower body simultaneously can elicit the highest acute endocrine response. While the upper body exercise still elicited a significant increase, the lower body exercise in combination with upper body exercise elicited a higher response. This suggests that the more muscle mass being used the higher the acute endocrine response will be.

Smiliios et al. (2002) looked at the hormonal response to various types of resistance training protocols. They wanted to see if there was an effect on the endocrine system after performing two versus four versus six sets of certain resistance training exercise programs. They took 11 recreationally trained men and had them perform eight different workouts. There was a muscular strength program, muscular hypertrophy program, and a strength endurance program performed on separate occasions. The four exercises performed were bench press, lateral pulldown, squat, and overhead press. The muscular strength program consisted of training at between 80 and 90% 1 repetition maximum for five repetitions for each exercise with three minutes of rest in between sets. The subjects performed two sets, four sets, and six sets on three separate occasions. The muscular hypertrophy program consisted of training at around 70% 1 repetition maximum for ten repetitions with two minutes of rest in between sets. The subjects also performed two, four, and six sets on three separate occasions. The strength endurance program consisted of training at between 50 and 60% 1 repetition maximum for 15 repetitions with one minute in between sets. Only two sets and four sets were performed on separate occasions. Blood was collected immediately pre-exercise, immediately post-exercise, 15-minutes post-exercise, and 30-minutes post-exercise. They found that serum testosterone was slightly but not significantly higher after the maximal strength and muscle hypertrophy programs compared to a control group immediately post-exercise. Pre-exercise values were between 17-20 nmol/L while

immediately post-exercise values were about 21 nmol/L for the maximal strength protocol. They also found a significant increase in testosterone post-exercise following the strength endurance protocol. This suggests that total training volume plays a significant role in the endocrine response to resistance training immediately post-exercise.

Weiss, Cureton, and Thompson (1983) looked at 20 recreationally trained males and had them perform 3 sets of four exercises in circuit fashion for the lateral pulldown, bench press, arm curl, and leg press at around 80% of a measured 1 repetition maximum. The number of repetitions was not stated, however, typical repetition ranges for 80% 1 repetition maximum is between 10-12 repetitions. Blood samples were taken 30-minutes pre-exercise, 15-minutes pre-exercise, immediately post-exercise, 30-minutes post-exercise, 60-minutes post-exercise, and 120-minutes post-exercise. They found that immediately post-exercise there was a significant increase in serum testosterone by 0.76 ng/ml which corresponded to an increase of 22%. Values returned to resting levels 30-minutes post-exercise. While the total training time, approximately 30 minutes, was relatively low, the overall training volume was high. Three sets of 10-12 repetitions for four different exercises appears to be a high enough training volume to elicit a significant endocrine response immediately post-exercise.

This review of literature focused on intense exercise, both cardiovascular and resistance training, and how it affects the hormonal response post exercise. It has been demonstrated in the literature that heavier weights, a greater total volume of work, and a higher intensity of exercise in general stimulates a significant hormonal response to a greater degree than submaximal exercise.

CHAPTER 3

METHODS

Participant Characteristics

Using the data from Gotshalk et al. (1997) for the pre to post difference in testosterone when three sets were completed, an effect size of 0.7035 was calculated. Utilizing the G*Power software with an α of 0.05, and β of 0.80, a power analysis revealed that a total of nine participants would be sufficient to detect significant effects if present. To take a conservative approach, ten recreationally active, apparently healthy males volunteered to participate in this study. Apparently healthy was defined as receiving a passing score on the American College of Sports Medicine (ACSM) Health/Fitness questionnaire. Recreationally trained was defined as individuals who participated in regular weight training at least twice per week for the past six months.

	Age (yrs)	Height (cm)	Weight (kg)	Body fat (%)
Mean	22.8	176.784	79.73	16.39
STDEV	1.549193338	11.11683328	11.45300058	4.457565354

Table 1. Participant characteristics who completed acute upper and lower body resistance training exercises at 70% and 90% of their 1-repetition maximum.

Collection of Data

Preliminary Data

Prior to the visit, participants were instructed to wear appropriate athletic attire, be adequately hydrated, and not consume anything with calories at least 3 hours before

testing. The participants were also instructed to not consume any alcohol 24 hours prior to testing and to refrain from vigorous exercise at least 6 hours prior to testing.

When the subjects arrived at the Exercise Physiology Laboratory they were briefed on the purpose, requirements, procedures, risks, and rewards of participating in the study. Participants were then asked to sign an informed consent form approved by the UNLV Institutional Review Board (protocol number 1311-4642). Participants then completed an ACSM health/fitness questionnaire to confirm that they were healthy enough to be a subject in the study. Subjects were then assigned a number for identification purposes. Basic anthropometric data, height, weight, and age were taken. A Lunar Prodigy Dual Energy X-ray Absorptiometry (DEXA) scan was performed to determine each participant's body composition. The Lunar Prodigy DEXA machine is calibrated each day before use. Participants entered the laboratory and height and weight was taken. They then lied down on the measuring table with their knees and ankles secured together with a Velcro strap to prevent unnecessary movement. A total body scan was performed and upon completion of the test participants received a copy of the print out from the machine. Body composition, (% body fat) was recorded and used for analysis.

Exercise Protocol

Session 1

Participants completed a general warm-up for 5 minutes on a treadmill. They then began the protocol for a 1 RM max test for the bench press exercise. Following the general warm-up they completed one set of 10 repetitions at 50% of their perceived 1 RM. The weight was then increased to 70% of their perceived 1 RM for 8 repetitions. Weight was increased again to 90% perceived 1 RM for 3 to 5 repetitions. Weight was

then incrementally increased 5% until the participant could not perform one repetition. Participants then followed the same protocol for determining 1 RM for the bent barbell row, and military press exercise.

Session 2

Participants completed the same protocol for determining one repetition maximum for the squat and deadlift exercises.

Session 3

Sessions 3 through 6 were performed in a counterbalanced order.

Participants completed a general warm-up for 5 minutes on a treadmill at 3 miles per hour. Participants then performed 2 set of 9 repetitions at 70% 1 RM for the bench press, bent barbell row, and military press exercises per American College of Sports Medicine guidelines. One and a half minutes of rest were given between each set. Total work (J) was controlled for by taking sets * repetitions * total amount of weight lifted (Gotshalk et. al. 1997).

Session 4

Participants completed a general warm-up for 5 minutes on a treadmill at 3 miles per hour. They then performed a high intensity resistance training protocol consisting of 5 sets of 3 repetitions at 90% 1 RM for the bench press, bent barbell row, and military press exercises. Three minutes of rest were given between each set.

Session 5

Participants completed a general warm-up for 5 minutes on a treadmill at 3 miles per hour. They then performed 2 sets of 9 repetitions at 70% 1 RM for the squat and deadlift exercises. One and a half minutes of rest were given between each set.

Session 6

Participants completed a general warm-up for 5 minutes on a treadmill at 3 miles per hour. They then performed 5 sets of 3 repetitions at 90% 1 RM for the squat and deadlift exercises. Three minutes of rest were given between each set.

Total Training Volume

In order to keep training volume constant for each participant throughout each workout the number of sets and repetitions were adjusted accordingly. Some participants need to complete more or less sets and repetitions based on their total weight lifted. Total work was held constant between each workout, both high intensity and moderate intensity as well as between the upper and lower body training sessions.

Blood Sample Collection

A blood sample (600 micro liters) was taken from the participant via finger prick into an anticoagulant tube (Multivette 600 LH, Sarstedt, Fisher Scientific, Pittsburgh, PA). Before every blood draw the site was cleaned by an alcohol swab. Samples were taken pre-exercise, post-exercise, and 60-minutes post-exercise. Samples were labeled according to each participant identification number and put in a sealed and labeled biohazard bag (primary container) inside of a sealed and labeled biohazard cooler (secondary container). Blood samples were kept cool in an ice bath and then stored in a -80 degree C freezer prior to being analyzed in accordance with the parameters described in the University of Nevada, Las Vegas Institutional Biosafety Manual (Section

VIII, page 19). The personal protective equipment used by the research team was latex free gloves, laboratory coats, and safety goggles. Any sharps and other biological materials were disposed of in a sealed sharps container and decontamination was conducted in accordance with the University of Nevada, Las Vegas Institutional Biosafety Manual (Section IX, page 23).

Blood Sample Analysis

Testosterone was measured using an AccuBind ELISA kit (Lake Forest, CA, 92630, USA). In order to prepare for the plasma samples to be analyzed reagent preparation was necessary. A working enzyme reagent was made by using 0.7 ml of "Testosterone Enzyme Reagent" and adding it to the vial that contained Steroid Conjugate buffer. It was stored at a temperature between 2-8 degrees Celcius (C). A wash buffer was then made using distilled or deionized water added to a wash solution of 1000 ml. it was stored at 2-30 degrees C. Finally a Working Substrate Solution was created by pouring the contents of the vial labeled Solution "A" into the vial labeled Solution "B". It was stored at 2-8 degrees C.

Upon completion of the preparation all reagents, serum references, and controls were brought to room temperature (20-27 degrees C). The microplates' wells were formatted for each serum reference, control, and patient specimen. They were assayed in duplicate. Then 0.010 ml of the appropriate serum reference was pipetted into the assigned well. Then 0.050 ml of the working Testosterone Enzyme Reagent was added to all wells. The microplate was then swirled gently for 20-30 seconds. 0.050 ml of Testosterone Biotin Reagent was then added to all wells. The microplate was swirled gently for a second time for 20-30 seconds. The microplate was then incubated for 60

minutes at room temperature. Upon completion of the incubation period the contents of the microplate were discarded and 350 microliters of wash buffer was added, and then decanted. This process was repeated two additional times for a total of three washes. Then 0.1 ml of working substrate solution was added to all wells and incubated for 15 minutes at room temperature. Then 0.05 ml of stop solution was added to each well and gently mixed for 15-20 seconds. The absorbance in each well was read at 450 nm using a reference wavelength of 620-630 nm in a Biotek Epoch microplate reader. The absorbance values were entered into a program on Readerfit.com to determine the concentration of testosterone.

Statistical Analysis

A 2 * 2 * 3 ANOVA with repeated measures will be used to analyze the data. There are two groups comparing two different exercise protocols with testosterone being tested at three different time points. The significance level was set at $\alpha = 0.05$. All statistical analyses were calculated using SPSS Version 20 (IBM Corporation, Armonk, NY).

A t-test was used to determine the significance of the post-workout testosterone values for both upper and lower body workout sessions compared to each other. The significance level was set at $\alpha = 0.05$.

CHAPTER 4

RESULTS

Time Comparison

Data for testosterone concentration was analyzed at three different time points and four different conditions. Testosterone was analyzed for pre-workout, post-workout, and 60-minutes post-workout for upper body moderate intensity, upper body high intensity, lower body moderate intensity, and lower body high intensity exercise protocols. Testosterone concentration post-workout was significantly higher ($F = 5.932$, $p = 0.026$) than resting values for the upper body moderate intensity protocol with an. The percent change was 29.4%. The testosterone concentration post-workout for the lower body moderate intensity protocol was also statistically significantly higher ($F = 4.963$, $p = 0.024$). The percent change was 27.1% (see figure 1). Values returned to near baseline levels by 60-minutes post exercise. Testosterone concentration was elevated but not significantly higher ($F = 1.407$, $p = 0.272$) than resting values for the upper body high intensity protocol but did show a non-significant 15.2% increase compared to pre-exercise values. Testosterone concentration post-workout for the lower body high intensity exercise protocol was not statistically significant ($F = 0.428$, $p = 0.658$) but did show a 17.5% non-significant increase compared to pre-exercise values.

Upper Versus Lower Body Comparison

An upper versus lower body comparison was performed for both moderate and high intensity protocols for post-exercise testosterone values. A paired t-test was used to determine if there was any statistical significance. Post-workout testosterone for the moderate intensity exercise protocol was elevated but not statistically significant ($p = 0.248$). Post-workout testosterone for the high intensity exercise protocol was not statistically significant ($p = 0.990$) (see figure 2).

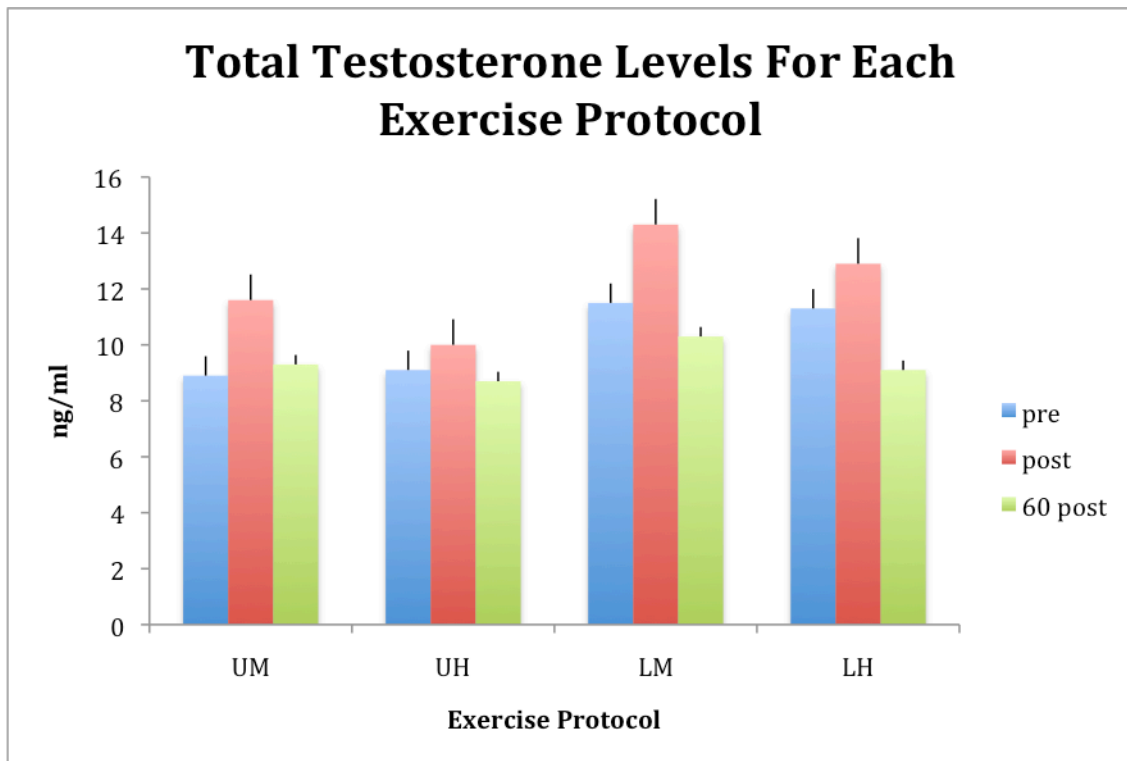


Figure 1. Testosterone response before (pre), immediately after (post) and 1h after (60 post) in subjects ($N = 10$) who completed acute resistance training of upper body moderate intensity (UM), upper body high intensity (UH), lower body moderate intensity (LM), and lower body high intensity protocols (LH). * indicates significant increase compared to baseline levels ($p < 0.05$). Error bars represent standard error.

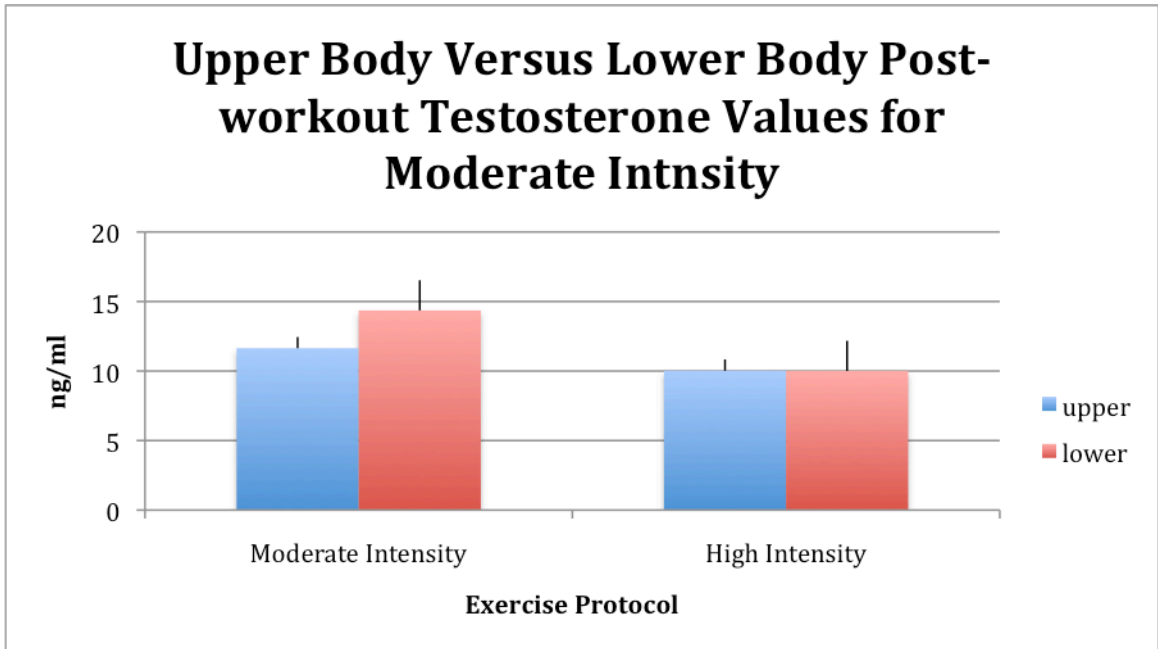


Figure 2. Immediately post-exercise testosterone response for upper versus lower body for both moderate and high intensity exercise protocols for subjects (n=10).

CHAPTER 5

SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

Discussion of Results

Testosterone production begins in the Leydig cells of the testes in men and the ovaries and adrenal cortex in women. The central nervous system signals the hypothalamus of the brain to begin production of testosterone from the Leydig cells mentioned above. There is a strong link between the nervous and endocrine systems (Vingren et al. 2010). Several training variables can cause an increase in the production of testosterone immediately post-workout such as intensity relative to one repetition maximum and total training volume. The purpose of this investigation was to observe the acute anabolic hormone response to different intensities of resistance exercise while total training intensity was held constant. It was hypothesized that resistance training at both 70% and 90% of one repetition maximum would elicit a significantly higher testosterone response post-exercise when compared to pre-exercise. In regards to the moderate intensity resistance training protocol for both upper and lower body a significantly higher testosterone level was observed ($p < 0.05$) when comparing post-exercise values to pre-exercise values. These findings are in accordance with a number of previous studies that showed 70% one repetition maximum is a significant stimulus to observe an elevated testosterone response post-workout (Tremblay, Copeland, and Van Helder (2004), Fry, Kraemer, and Ramsey (1998), Kraemer et al. (1998), and McCaulley et al. (2008). This study confirmed that resistance training around 70% of one repetition maximum is a significant enough stimulus to elicit an elevated testosterone level immediately following the bout of exercise.

Interestingly, resistance training at around 90% one repetition maximum was not shown in this investigation to elicit significantly higher testosterone levels immediately post-workout compared to pre-workout values. Both upper and lower body high intensity training protocols yielded elevated testosterone levels immediately post-workout but was not found to be statistically significant ($p > 0.05$). These findings are in contrast to several studies that found high intensity (90% one repetition maximum or above) was enough of a stimulus to elicit statistically significant elevations in testosterone (Raastad, Bjoro, and Hallen (2000) and Hough et al. (2011)). One possible reason for this could be an overall low training volume despite intensity being high. Amount of total work in Joules (J) has been shown to have an effect on testosterone release post-exercise (Gotshalk et al. (1997)). The training volume in this study was low compared to the training volume Gotshalk et al. (1997) had their participants complete.

Performing resistance exercise at a higher volume of training has been shown to increase testosterone levels post-workout to a greater extent than a lower volume of training in healthy males (Gotshalk et al. 1997). In this study the training volume for the moderate intensity group and the high intensity group were held constant. For this reason it is interesting that both groups did not show significant increases in testosterone levels post-workout since the moderate intensity group did show significant increases. The high intensity group did show an elevation in testosterone immediately post-workout but it was not statistically significant. This could be due to longer rest periods and length of duration of the workout session. Although total training volume was the same for both groups the total length of the workout session and rest periods between exercises differed due to different difficulties.

There were no significant differences in immediate post-workout testosterone levels between upper and lower body exercise protocols for either moderate or high

intensity workout sessions ($p > 0.05$) despite total training volume being equal. Post-exercise testosterone for the lower body moderate intensity session compared to upper body was elevated but not statistically significant. This data is in contrast to Migiano et al. (2010) who showed three sets of 10 repetitions at around 70% intensity of upper body only exercise was not enough of a stimulus to see a change in post-workout testosterone. This study showed that only two sets of 10 repetitions for three different exercises for upper body and two different exercises for lower body was enough of a stimulus to induce a significant testosterone response immediately post-workout, however the two protocols were not statistically different from each other. The high intensity lower body protocol yielded no increase in immediate post-workout testosterone compared to the upper body high intensity protocol. This shows that if the total amount of metabolic work being performed is equal, lower body training alone is not necessarily better than upper body training alone to observe a significant increase in testosterone post-workout. This is important for certain populations such as those confined to a wheelchair. Those individuals can still improve their fitness through upper body training as long as the total volume trained is equal to that of what lower body training could have potentially accomplished. According to this study, resistance exercise at 70% intensity with upper or lower body, with the same total training volume, is enough to induce a significant testosterone response post-workout, however, one is not better than the other when the objective is to increase post-exercise testosterone.

Testosterone levels 60-minutes post-workout returned to pre-exercise values, or slightly lower than that, for every workout protocol. This is in accordance with McCaulley et al. (2008) who showed significant increases immediately post-workout but values that dropped back to resting one hour after the resistance-training bout.

This study demonstrated that a moderate intensity of training and a relatively low training volume is enough of a stimulus to significantly elevate testosterone levels post-workout. It also showed that a high intensity protocol elevated testosterone post-workout but not high enough to be considered statistically significant.

Conclusions and Recommendations For Further Study

Due to this study demonstrating that a high intensity resistance training protocol does not significantly raise testosterone levels post-exercise, more research is needed to observe if a low volume, high intensity protocol can, in fact, significantly raise testosterone following a bout of resistance-training. The current study utilized free weights and a straight set type protocol. Future studies could observe a superset or circuit type resistance training and see how that affects testosterone levels post-workout. Machine weights could also be used and compared to free weights to observe if there is a difference in testosterone levels following the bout of exercise. One possible limitation of this study could be the rest intervals. Rest intervals were shorter during the moderate intensity due to the simpler nature of the task. Rest periods were longer during the high intensity protocol because participants reported having to work harder in order to finish the weight lifting protocol. Another possible limitation could be the time of day. Due to the natural fluctuations in the endocrine system as the day progresses, testosterone levels could have been affected. Not every participant was tested at the exact time every day due to scheduling issues. Future studies could observe the influence of rest periods on testosterone levels following a bout of resistance training.

This study showed that a bout of moderate intensity (70% 1 RM) resistance training for both the upper and lower body can significantly raise testosterone immediately following the bout. This confirms previous studies that demonstrated that a

moderate intensity resistance-training workout could significantly affect the endocrine response. This information can be used practically because it shows the recommendations of many fitness experts, including the ACSM, of around 8-12 repetitions, can increase testosterone immediately following the exercise session. This information is useful for young, recreationally trained males because it showed a moderate intensity (70%) is better for increasing testosterone immediately post-workout than a workout of similar volume at high intensity (90%).

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