

Acute Hormonal Responses to Free Weight and Machine Resistance Exercise

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Abstract This study examined acute hormonal responses to multi-joint free weight exercise and single joint machine exercise. Six weight-trained males performed 3 sets of 10 repetitions at 70% of 1RM with one minute rest between each set on either the barbell squat (FW) or three single joint machine weight exercises (MW; i.e., leg curl, leg extension, back extension) using similar primary movers in a randomly-ordered crossover design. Testosterone (T), cortisol (C), growth hormone (GH), and lactate (HLA) were determined from blood samples 15 minutes before (PRE) and 5 minutes after (POST) each exercise session performed at the same time of day. The MW group completed significantly more estimated external work than the FW group (J; MW = 30776±2152, FW = 19728±2399), but the FW protocol resulted in a greater HLA response (mmolL⁻¹; MW, PRE = 1.2±0.1, POST = 6.7±0.7; FW, PRE = 1.5±0.1, POST = 10.5±1.6). Both exercise modalities exhibited similar increases in T (nmolL⁻¹; MW, PRE = 13.4±2.7, POST = 17.6±2.9; FW, PRE = 15.5±2.8, POST = 17.6±3.5) and GH (µgL⁻¹; MW, PRE = 1.4±0.3, POST = 6.8±3.3; FW, PRE = 1.1±0.1, POST = 4.3±2.0), despite the lower work performed by the FW protocol. Although C increased for both protocols, the FW session induced a greater C response (nmolL⁻¹; MW, PRE = 463.2±147.8, POST = 448.1±144.1; FW, PRE = 444.4±174.0, POST = 696.9±220.4). While using similar muscle mass, these results suggest that the acute hormonal response is partially dependent on exercise modality. Despite completing less estimated external work, FW exercise protocol yielded similar or greater endocrine responses when compared to MW resistance training modality.

Keywords: *endocrine, training, testosterone, growth hormone, lactate, cortisol*

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1. Introduction

Circulating hormones are secreted by endocrine tissues and regulate many biological functions in the human body [1]. Hormone secretion is magnified when the body is placed under physiological stress such as an acute bout of resistance exercise (RE). It has been shown that RE increases systemic concentrations of several hormones including testosterone (T), cortisol (C), growth hormone (GH), catecholamines, and other growth factors [1]. The long-term chronic resting concentrations of these hormones are related to performance [2,3] and physiological adaptations [4]. While there is a debate concerning the relevancy of post-exercise increases in anabolic hormones [5], certain hormones (e.g., T, C, GH) appear to be important to the remodeling response to RE and subsequent chronic adaptations [1]. Research is conflicting on the importance of the acute exercise endocrine response in chronic adaptations, with studies indicating an integral role for strength and hypertrophy [6,7], and others suggesting a putative role [8,9]. The

discrepancy in these studies may be due to a number of factors, including the choice of exercises implemented and the training status of participants selected when assessing the acute endocrine responses.

The acute RE program variables include exercise choice, order, volume, intensity (or load), and the inter-set rest intervals [10,11,12]. These variables influence the endocrine responses to resistance exercise [13,14,15]. Also, it is well known that manipulation of the acute program variables influences the degree and specificity of skeletal muscle adaptation and performance [16,17]. However, the precise role of acute increases in the hormonal milieu from RE and its contribution to chronic adaptations remains underexamined. Exercise selection determines the degree of musculature utilized during a RE training bout. Furthermore, greater total muscle mass used during a RE bout results in significantly greater increases in T, C, and GH [11,12,18,19]. Cumulatively, the combination of exercise intensity and volume of exercise performed ultimately influences the subsequent hormonal responses. Research also suggests that the number of repetitions performed to failure at a prescribed intensity depends on the exercise that is being performed [20,21].

Thus, one question that requires further inquiry is whether the acute exercise hormonal response differs between different exercises using similar muscle mass accumulated over an exercise training session.

While exercise choice utilized during chronic training dictates the specificity of muscular performance and adaptation [17], the importance of exercise choice and endocrine responses has received less attention in the scientific literature. Kang et al. [22] compared GH responses during the back squat and leg press across three different loading paradigms. Their results suggested the greatest GH response depended on the exercise choice and the load used [22]. Shaner et al. [23] reported a difference in T and GH responses, but not C, immediately post-exercise when subjects performed a squat and leg press protocol of 6 sets of 10 repetitions at 80% 1RM. In addition, C was greater at 30 minutes post-exercise for the back squat compared to leg press [23]. While it is apparent that the choice of exercise influences the acute endocrine responses, it is common for training programs to utilize more than one exercise in a training bout. Therefore, the question still remains whether the hormonal milieu differs between one exercise using the entire lower body, and several exercises using the same muscle mass accumulated over an acute training session.

Fitness enthusiasts and strength and conditioning practitioners often prescribe accessory exercises such as the leg curl and knee extension to develop lower body strength and hypertrophy. Previous studies have utilized the leg press as an alternative modality to a barbell squat when comparing the hormonal response between exercises. To our knowledge, there is a lack of scientific literature that has compared the endocrine response between back squats and a lower body resistance training protocol targeting single muscle groups individually (e.g., hamstrings, quadriceps, back extensors). It has yet to be elucidated whether the acute hormonal response during lower body resistance exercise depends on the muscle mass being activated simultaneously (e.g., back squat) versus being used over the course of a workout (e.g., leg extension, leg curl, back extension successively). Therefore, the purpose of this study was to determine potential differences in T, C, GH, and lactate (HLA) concentrations when performing a protocol using the barbell back squat as a free weight exercise modality (FW) versus a protocol that utilized leg extension, leg curl, and back extension exercises in succession as the machine weight resistance training modality (MW).

2. Materials and Methods

2.1. Experimental Approach

Using a within-subjects, crossover design, resistance-trained men completed two acute resistance exercise protocols. One of the protocols used only FW resistance exercise movements, whereas the alternative MW protocol trained similar musculature using only resistance exercise machines. Performance of the two resistance-exercise protocols was separated by one week. The order in which the protocols were performed was randomized and balanced. To analyze the hormonal impact of a free weight

resistance exercise bout versus a resistance exercise machine bout, blood samples were collected before and after the exercise bout. Subsequently, T, C, GH, and HLA concentrations were determined.

2.2. Subjects

Six resistance-trained men ($\bar{X} \pm SD$; age = 26.7 \pm 3.6 years, resistance exercise training experience = 9.2 \pm 1.8 years) completed the investigation. Subjects reported no history of anabolic steroid use and were free of any medical conditions that might have impacted the results of the investigation. Prior to participation, subjects signed an informed consent document as approved by the University Institutional Review Board for the use of human subjects.

2.3. Resistance Exercise Protocols

One week prior to performance of the first resistance exercise protocol, subjects completed one repetition maximum (1RM) tests for the parallel barbell squat, and the machine resistance exercises leg extension, leg curl, and back extension using previously described methods [24]. The back extension exercise was performed on a Nautilus back hyperextension machine (Nautilus Industries, DeLand, FL, USA), and leg extension and leg curl exercises were performed on a York dual leg extension and leg curl machine (York Barbell Co., York, PA, USA).

Prior to performing the resistance exercise protocols, subjects completed a standardized warm-up procedure consisting of two minutes of low intensity work on a stationary cycle ergometer (Monark 928 G3, Vansbro, Sweden). After the warm-up, subjects completed one of the two protocols. The FW protocol consisted of 3 sets of 10 repetitions in the squat at 70% 1RM with one-minute rest periods between sets. The MW protocol included 3 sets of 10 repetitions each for the leg extension, leg curl, and back extension at 70% 1RM with one-minute rest periods between sets. Load was reduced to 65% of 1RM if subjects were unable to complete 10 repetitions in the previous set. One week following the initial training bout, subjects returned to the lab and completed the alternative resistance exercise protocol. All subjects completed their training protocols between 1130 and 1430 hours. The exact start time of each protocol was controlled on an individual basis to minimize the influence of time of day on hormonal concentrations. External work (J) performed for each session was estimated from the mass lifted and the distance moved for the entire session using previously described methods [24].

2.4. Blood Sample Collection and Analysis

Fifteen minutes before (PRE) and five minutes after (POST) each exercise protocol a blood sample was collected from an antecubital vein and collected in a serum vacutainer. The blood was allowed to clot for 15 minutes, after which it was centrifuged at 1500 g at 4°C for 15 minutes using a Biofuge 17R fixed-angle centrifuge (Baxter Scientific Products, Germany). The resulting serum samples were aliquoted and stored at -80°C for subsequent analysis. Prior to allowing the blood samples

to clot, a small portion of the sample was drawn into a heparinized microcapillary tube (Oxford Labware, Saint Louis, MO, USA), centrifuged (Adam's Readacrit, New York, NY, USA), and analyzed for hematocrit (Oxford Labware, Saint Louis, MO, USA). Additionally, whole blood samples were used to measure lactate using a YSI Sport Lactate Analyzer (Yellow Springs, OH, USA).

Serum aliquots were analyzed in duplicate to determine T, C, and GH concentrations. T and C values were measured in duplicate via enzyme immunoassay (EIA; Diagnostic Systems Laboratories, Inc., Webster, TX, USA) with intra-assay variances of 3.1% and 2.4%, respectively. GH concentrations were measured in duplicate via enzyme-linked immunosorbent assay (ELISA; Diagnostic Systems Laboratories, Inc., Webster, TX, USA) with an intra-assay variance of 1.9%.

2.5. Statistical Analysis

Descriptive statistics and standard errors were calculated for each of the dependent variables ($\bar{X} \pm SE$). T, C, GH, and HLa data were analyzed via four 2 x 2 (protocol x time) mixed model, repeated measures

analyses of variance. When necessary, post-hoc tests were performed using Tukey's HSD. For this investigation, the alpha level was set at $p < 0.05$. All statistical analyses were performed using SPSS statistical software (Version 24.0; IBM Corp., Armonk, NY, USA).

3. Results

T and GH exhibited no significant protocol x time interaction, but significant main effects for time (Figure 1 and Figure 2). Both the FW and MW protocols significantly increased T and GH concentrations. C exhibited a significant protocol x time interaction (Figure 3). Post-hoc analyses indicated that only the FW protocol significantly increased C concentrations. A significant interaction was also observed for HLa concentrations (Figure 4). Both protocols increased HLa from PRE to POST. However, greater POST HLa values were observed following the FW protocol. Estimated external work for the MW protocol was significantly greater than for the FW protocol ($J; MW = 30776 \pm 2152$, $FW = 19728 \pm 2399$).

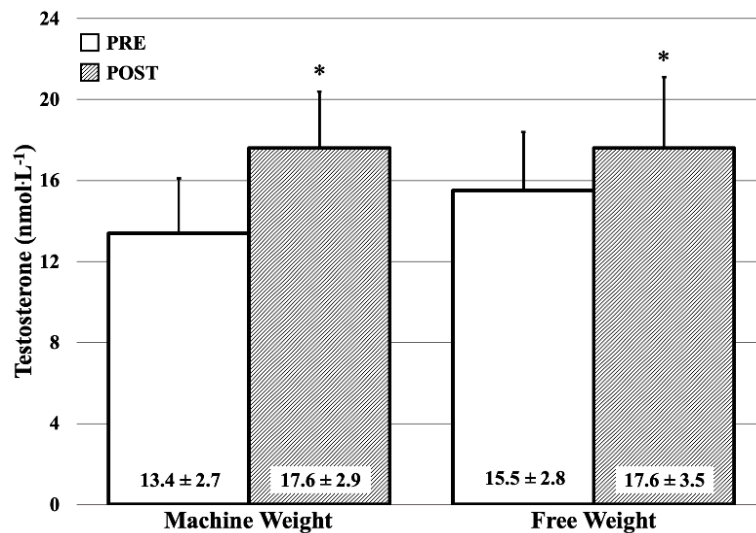


Figure 1. Testosterone response to machine and free weight training regimens ($\bar{X} \pm SE$). (*) - denotes significant change from PRE to POST.

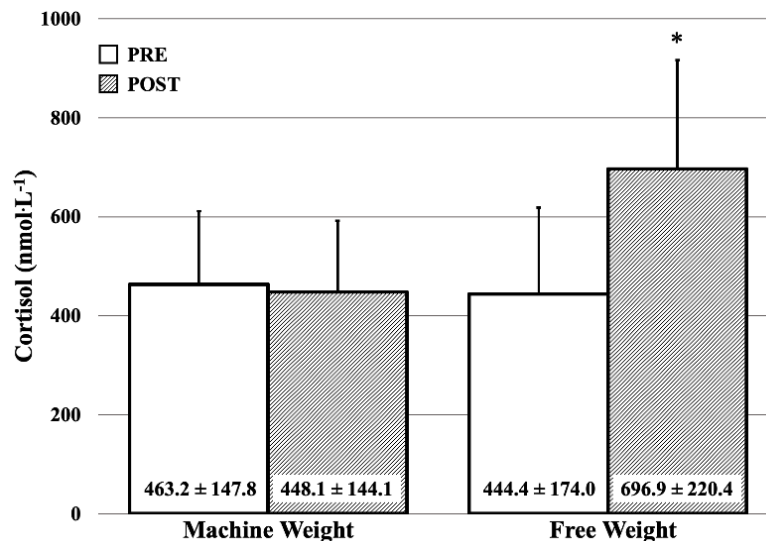


Figure 2. Cortisol response to machine and free weight training regimens ($\bar{X} \pm SE$). (*) - denotes significant change from PRE to POST.

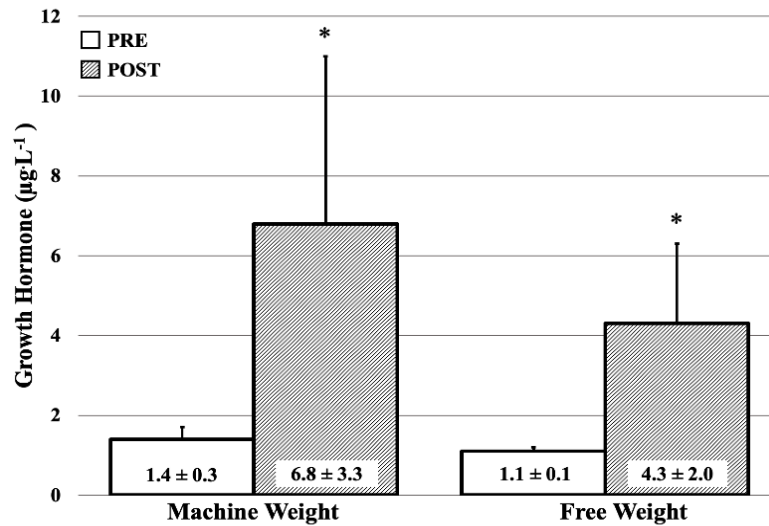


Figure 3. Growth hormone response to machine and free weight training regimens ($\bar{X} \pm SE$). (*) - denotes significant change from PRE to POST.

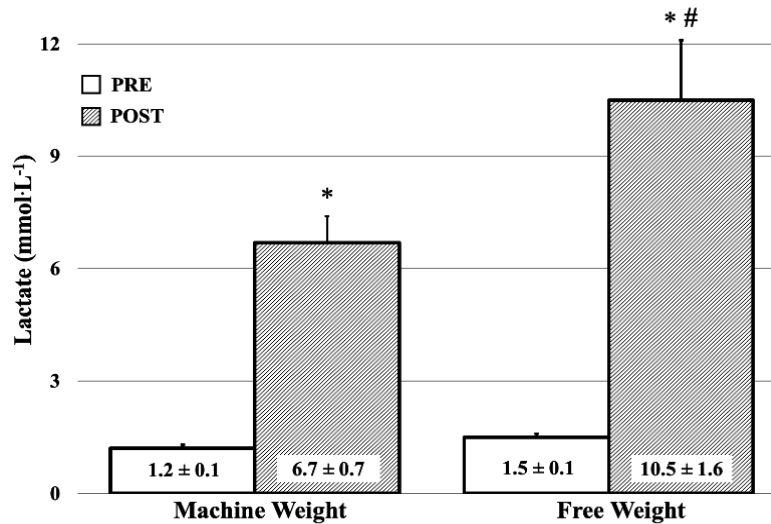


Figure 4. Lactate response to machine and free weight training regimens ($\bar{X} \pm SE$). (*) - denotes significant change from PRE to POST. (#) - indicates significant difference between the groups.

4. Discussion

The results of the present investigation indicate there are similar endocrine responses for most hormones following a RE session consisting of FW using the barbell back squat compared to MW using similar muscle mass over separate exercises. While others have reported the endocrine responses to FW and MW using the leg press exercise, the current study highlights that the hormonal milieu is similar between the two protocols utilizing similar muscle mass over the course of a workout using separate small muscle mass exercises. The exception to this trend was the elevated C in the FW condition that may have been due to a greater work rate (i.e., J/time). The FW group completed 64% of the total work completed by the MW group in only 33% of the session time. This may have also contributed to the significantly higher HLA.

In the present study, the acute POST exercise T response was not different between FW and MW training modalities. These results differ from those reported by Shaner et al. [23] who found significantly higher T concentrations immediately post exercise in the barbell squat compared to the leg press condition. The difference

between our results and Shaner's is likely due, at least in part, to the different RE stimuli used by the two studies. Shaner et al. [23] utilized 6 sets of 10RM, while the present study utilized 3 sets of 10 at 70% 1RM. Previous reports suggest that at a given intensity, additional RE volume (sets performed) substantially increases the secretion of T after exercise [25]. Thus, subjects in the FW session in the present study performed half the volume as utilized by Shaner et al. [23], resulting in similar T concentrations between FW and MW. Additionally, the MW session utilized three different exercises rather than just one, resulting in the overall greater external work. Although the timing of the blood collection after the RE stimulus in the present study might have contributed to the differences from Shaner's results, the POST exercise blood draw was collected 5 minutes after the completion of the exercise bout, which has been shown to best reflect the acute RE T responses [1,13,14]. Also, when compared to the present data, Shaner et al. [23] reported greater T concentrations in general. However, it should be noted that all values were within normal physiological ranges and that relative increases in T for both studies were very similar. As such, the lack of acute T differences between

FW and MW for our data indicate that even though more work was performed during the MW session (3 exercises, 3 x 10 at 70% 1RM, >30 kJ) compared to the FW session (1 exercise, 3 x 10 at 70% 1RM, <20 kJ), the T response was similar. Therefore, the findings of the present study imply greater endocrine efficiency with the FW protocol.

C was elevated in the FW condition, whereas there was no significant change POST exercise in the MW trial. The higher POST exercise C in the FW condition may be indicative of greater metabolic stress, due to the amount of musculature activated during the barbell back squat exercise as compared to MW. Glucocorticoids mobilize substrates and amino acids in the systemic circulation [26], and it is plausible that the higher C in the FW was indicative of greater exercise stress placed on the exercised muscle tissue. Shaner and colleagues [23] also reported higher C values following barbell back squats as compared to the leg press exercise. Spiering et al. [11,12] reported anabolic intramuscular signaling was attenuated following resistance exercise that resulted in significant elevations of C. Interestingly, West et al. [8] reported a modest, yet significant correlation between C area under the curve, changes in lean body mass, and type-II myofiber hypertrophy. While the exact role of the C response after resistance exercise remains to be fully elucidated, it is clearly associated with the tissue remodeling process [1,4]. Researchers and practitioners should be cognizant that the acute increases in C following RE are due in part to the exercise choice and may be necessary element for adaptation to a training stimulus.

In the current investigation, both MW and FW protocols induced significant increases in GH from PRE to POST resistance exercise bout. No significant protocol x time interaction was observed, suggesting no significant differences between the two protocols. Previously, Shaner et al. [23] reported greater increases in GH following a series of squats than following leg press and concluded that the greater GH response was likely due to a difference in total work performed. Although numerous studies have reported greater GH responses with increased work or RE volume performed [13,14,27,28], no significant difference was observed in the present study between the FW and MW protocols despite a significant difference in external work. The lack of significant differences between the protocols may be explained by the magnitude of the GH responses. The aforementioned studies demonstrating the influence of work on GH routinely observed mean GH values greater than 20 $\mu\text{g}\cdot\text{L}^{-1}$, whereas mean values of 6.8 \pm 3.3 $\mu\text{g}\cdot\text{L}^{-1}$ and 4.3 \pm 2.0 $\mu\text{g}\cdot\text{L}^{-1}$ were observed for MW and FW, respectively. It is interesting to note that although both the FW and MW sessions resulted in similar GH responses, the FW session produced approximately 64% of the external work produced by the MW session. If body masses were included in these work calculations (i.e., system mass), the differences would likely be considerably less. Regardless, the FW condition produced the same GH response while only requiring three exercise sets rather than nine sets. As previously mentioned, the work rate (i.e., J/time) would have been considerably greater for the FW session.

Significant increases in HLa were observed following both the MW and FW protocols. Despite greater external work being performed in the MW protocol, greater POST exercise HLa levels were observed following the FW

protocol. Although more total work was performed in the MW protocol, the work was performed in nine total sets across three different exercises, each with a one-minute rest period in between each set. In contrast, the FW protocol consisted of only three sets with a one-minute rest period between each set. Consequently, the rate at which work was performed was greater in the FW protocol. A second explanation for the difference in observed HLa response may be due the choice of exercises. The primary movers were similar in both protocols; however, the FW protocol may have recruited additional muscle mass. During the performance of a free weight back squat, the upper body must perform a sustained isometric contraction in order to stabilize the barbell. Previous investigations have shown that upper body exercise may induce a significantly greater increase in HLa than lower body exercise [29,30]. Therefore, the sustained isometric contraction performed by muscles of the arms, shoulders, and upper back to support the barbell may partially explain the higher POST exercise lactate levels observed following the FW protocol.

The practical application of the results from the current investigation indicates that in recreationally trained individuals there are no differences in T or GH when utilizing barbell back squats versus multiple machine exercises. Furthermore, although C and HLa were higher in the FW conditions, the work rate was more efficient in FW compared to MW since the same post exercise concentrations of T and GH were induced in less time. Thus, strength and conditioning coaches and fitness professionals should realize the effectiveness of FW exercises if training time is limited. Alternatively, the present results also suggest activating similar musculature using MW may produce similar increases in anabolic hormones (i.e., T, GH) while concomitantly avoiding increases in C, and might be considered if physiological and psychological training stresses are very high.

5. Conclusion

In conclusion, some endocrine and metabolic responses differ following an exercise bout using FW such as the barbell back squat, versus an exercise bout that utilizes several MW exercises. The differences in HLa and C appear to be due to the rate of which work is performed, although this was not evident for GH. The barbell back squat utilizes similar muscle mass as the exercises used in the MW condition, and while C is lower in the MW condition, an acute C response is likely critical for optimal tissue remodeling. Therefore, the findings of this study suggest that the acute hormonal response is partially dependent on exercise modality and that despite completing less estimated external work, FW exercise protocol yielded similar or greater endocrine responses when compared to MW resistance training modality.

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