JOURNAL FOR SOCIAL SCIENCE STUDIES
*An International Peer-Reviewed Open Access Journal*

ISSN (Online): 3006-2071 | ISSN (Print): 3006-2063
Volume 4 • Issue 5 • September 2026

# HORMONAL ADAPTATIONS FOLLOWING HIGH-INTENSITY AND HIGH-VOLUME RESISTANCE TRAINING AND THEIR SUBSEQUENT ROLE IN MUSCULAR HYPERTROPHY IN MALE PHYSIQUE ATHLETES

**Syed Muhammad[1], Dr. Syed Zia ul Islam[*2], Dr. Tasleem Arif[3]**

*[1,*2,3]Ph.D. Scholar, Sport Science and Physical Education, Department of Sport Science & Physical Education, The University of Haripur, KPK. ORCID:*

[1]sm.fitnes0376@gmail.com, [*2]zia.islam@uoh.edu.pk, [3]tasleem.arif@uoh.edu.pk

DOI: https://doi.org/10.5281/zenodo.23058693

**Keywords**
*Resistance-training, muscular-hypertrophy, testosterone, endocrine-adaptations.*

**Article History**
Received: 01 June 2026
Accepted: 23 August 2026
Published: 30 September 2026

***Copyright @Author***

**Corresponding Author: ***
**Dr. Syed Zia ul Islam**

**Abstract**

*Current study examined and compared the effectiveness of high-intensity (HI) and high-volume resistance training (HV-RT) in modulating serum testosterone, growth hormone (GH), and cortisol, and to investigate their role in predicting subsequent muscular hypertrophy in male physique athletes. After recruitment, forty-five study participants were randomized to HI-RT, HV-RT, or control group (CG) (n=15) to each group for 12-weeks intervention. Serum hormones were tested 24-hours pre- and post-intervention along with recording muscle anthropometrics of arms and legs through circumference measurements. Statistical analyses including multivariate analysis of covariance (MANCOVA), follow-up ANCOVAs, Pearson correlations, and multiple linear regression were employed to analyze the data. A significant effect on the combined hormonal profile (Pillai's Trace = .412, p = .002) was documented. ANCOVA confirmed greater increases in testosterone in HI-RT compared with HV-RT and control (p < .001). Changes in testosterone were strongly correlated with arm (r = .56) and leg circumference gains (r = .62) (both p < .001). Regression confirmed Δ testosterone as the sole predictor of arm (β = .631, p = .005) and leg hypertrophy (β = .501, p = .020), explaining 31–35% of the variance. Findings showed that both HI-RT and HV-RT elicited significant increases in anabolic hormones, with greatest increase induced by HI-RT followed by HV-RT. Resting testosterone were independently associated with muscular hypertrophy. While GH and cortisol could not significantly predict muscle growth despite growth supportive effect by GH.*

## INTRODUCTION

Hypertrophy of skeletal muscles apart from being a foundational biological reserve to support various health-related functions including metabolic health, bone health, functional independence, healthy aging, injury prevention, recovery and resilience, and weight management (Kirk et al., 2024; Abdul-Al et al., 2024; Gates et

JOURNAL FOR SOCIAL SCIENCE STUDIES
*An International Peer-Reviewed Open Access Journal*

ISSN (Online): 3006-2071 | ISSN (Print): 3006-2063
Volume 4 • Issue 5 • September 2026

al., 2024); is widely recognized as a fundamental physical adaptation that supports physical conditioning and performance in athletic population (Tromaras et al., 2024; Havers et al., 2025). Hypertrophy is a fundamental adaptation to resistance training and a key contributor to performance in strength athletes including physique athletes and bodybuilders (Isola et al., 2024). A study shows that RT is the main stimulus to induce growth in muscle mass and structural adaptations, with consistent hypertrophic outcomes observed in response to various training regimens (Schoenfeld et al., 2021). In the context of sports, specifically for elite athletes, RT has been shown to be promoting substantial gains in skeletal muscle development and sport-specific performance adaptations, underscoring its principal role in structural development and competitive preparation (Makaruk et al., 2024). Remarkably, in physique athletes, bodybuilders, and resistance-trained individuals, muscle hypertrophy supports not only a physiological adaptation but a critical factor of competitive success, as muscle size, proportion, symmetry, and aesthetic muscularity, are the primary evaluation metrics (Moreno et al., 2024; Isola et al., 2024). Therefore, maximizing hypertrophic adaptations employing resistance training continues to be a central focus in the area of applied practice and existing research, with emphasis in populations where maximal muscular adaptation is directly related to performance and judging outcomes.

Apart from its morphological adaptations, RT also induces a variety of endocrine responses which are shown to be strong contributors in hypertrophic responses. Transient and sustained rises in testosterone, GH, and IGF-1 have been linked with stimulus by RT (Mennitti et al., 2024), although their precise role in mediating muscle hypertrophy remains a subject of current investigation. Existing evidence demonstrates that while acute post-exercise hormonal spike may not be the only drivers of muscle growth, they can support muscle protein synthesis (MPS) and tissue remodeling (Morton et al., 2016; Roberts et al., 2023). They further indicate that the interplay between mechanical loading and local intramuscular signaling pathways may be more influential than systemic hormonal fluctuations alone, particularly in trained individuals. Nonetheless, in populations such as physique athletes, where maximizing hypertrophic adaptation is the key objective, discerning the interplay between resistance training–induced hormonal responses and muscle growth remains of significant practical and scientific interest.

Resistance training when performed vigorously has the ability to induce anabolic hormones which are significantly correlate with muscle growth and strength (Shi, 2025). With regard to exercise-induced response in testosterone, a recent systematic review of RCTs concludes that the disparity among acute exercise-induced testosterone responses is due to factors such as mode and intensity of exercise as well as gender, age, and measurement techniques. It further shows that resistance training induces greater responses in testosterone compared to aerobic exercise, and extended high-intensity RT leads to suppression in testosterone due to rise in cortisol levels (Tu et al., 2026). Likewise, a longitudinal study on male adolescent athletes found no acute increase in testosterone in response to bodyweight exercise while testosterone levels were increased during growth after peak height velocity (PHV). Moreover, the positive anabolic status in these youngsters; indicated by C:T ratio, was due to reduced cortisol (Sekine, 2025). This stands-out the loaded resistance training as an inducer of endocrine. Skeletal muscle hypertrophy is a central adaptation to resistance training and a primary objective in athletic and physique-oriented populations. While mechanical tension and local intramuscular signaling pathways are widely accepted as primary drivers of muscle growth, the role of systemic anabolic hormones, particularly testosterone, remains debated (Morton et al., 2016; Van Every et al., 2024). Such ambiguity contextually persists in resistance-

JOURNAL FOR SOCIAL SCIENCE STUDIES
*An International Peer-Reviewed Open Access Journal*

ISSN (Online): 3006-2071 | ISSN (Print): 3006-2063
Volume 4 • Issue 5 • September 2026

trained population, in whom endocrine responses may vary substantially compared to untrained individuals (Mangine et al., 2017).

Testosterone promotes anabolic adaptations through androgen receptor (AR)–regulated transcriptional activity, augmenting MPS, engagement of satellite cell, and myonuclear accretion (Gharahdaghi et al., 2021; Sakai et al., 2024). Of all the hormones; testosterone, growth hormone (GH), and cortisol, are particularly prominent for having a vital role in adaptations to training (Alwan et al., 2019). Adequate natural testosterone appears to be necessary for resistance exercise to effectively activate the molecular processes that lead to muscle growth. Muscle loading by itself cannot fully compensate for low testosterone levels (Gharahdaghi et al., 2022). Acute elevations in testosterone following resistance exercise are well documented; however, the relevance of chronic resting testosterone changes for hypertrophy remains unclear (Kraemer et al., 2020). Contrarily, HI-RT is shown to produced stronger transient rise in testosterone levels, if consistently repeated, in a long-term training program, these short-lived hormonal surges could facilitate the activation of anabolic signaling pathways and promote long-term adaptations of muscles (Räntilä et al., 2023) This pattern of adaptation was further underscored by Fink (2020). A number of studies report inadequate or negligible associations between systemic testosterone and muscle growth, claiming that local muscle factors control hypertrophic outcomes (Morton et al., 2016; Roberts et al., 2023). Hence, some contemporary and early studies also suggest that chronic hormonal modulation can still notably enhance, energy metabolism, MPS, and recovery capacity from training-induced stress and promote anabolic environment in resistance-trained men (Kraemer et al., 2017; Mennitti et al., 2024).

Training modality may further influence endocrine responses. Resistance training with higher work-load focusing on heavier weights to generate greater mechanical tension, while HV-RT emphasizes metabolic stress through longer time under tension. Earlier studies describe that both HI and low-load RT illicit same hypertrophic adaptations and systemic testosterone responses when volume is matched (Mangine et al., 2017; Suchomel et al., 2018), albeit presence of inconsistency in the literature regarding this area creates an urgency for further investigations. Thus, our study aimed to examine (1) whether HI-RT and HV-RT differentially influence resting testosterone levels, and (2) whether changes in testosterone independently predict upper and lower limbs' hypertrophic outcomes in male physique athletes.

## Methodology

### Study Design

This study employed a 12-weeks randomized controlled experimental to examine the differential effects of HI and HV-RT on key hormones including testosterone, cortisol, and GH and to explore their predicting role in hypertrophic adaptations in arms and legs. A total of 45 male physique athletes were recruited and randomly assigned to HI-RT (n = 15), HV-RT (n = 15), or control (n = 15) for 12-week intervention. Pre- and post-intervention samples collection of selected hormones, and proximal arms and legs' anthropometrics were taken at both time-points. The schematic diagram presented in Figure 1.

JOURNAL FOR SOCIAL SCIENCE STUDIES
*An International Peer-Reviewed Open Access Journal*

ISSN (Online): 3006-2071 | ISSN (Print): 3006-2063
Volume 4 • Issue 5 • September 2026

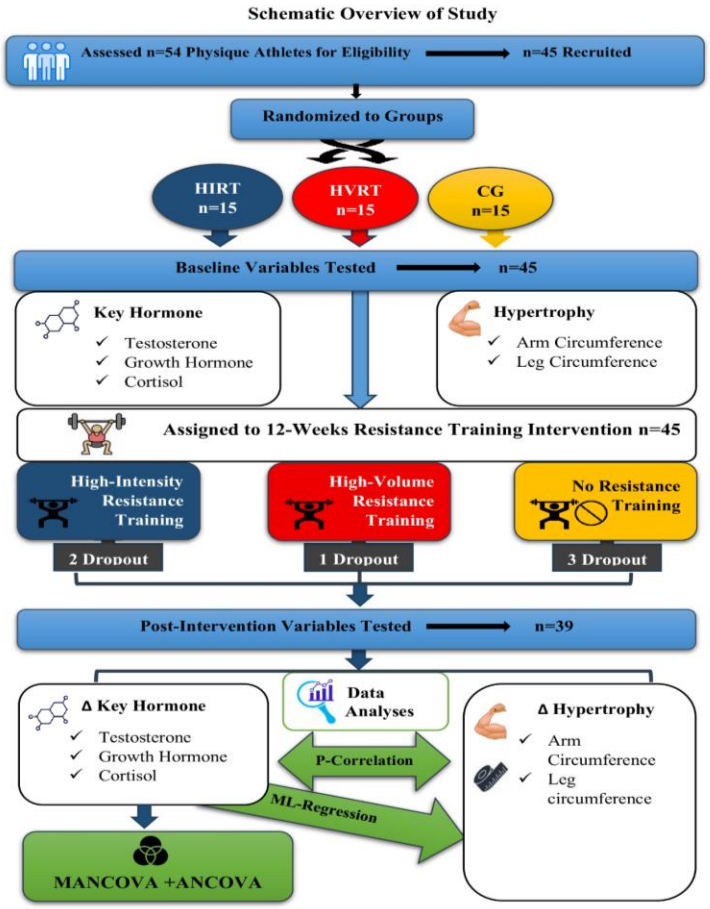


**Figure 1 Schematic Presentation of Study**

**Participants**

Forty-five eligible physique athletes were recruited after assessing n=54. Individuals were invited via open call using social media and researcher's personal visits to the local gym with the consent of gym administrators and local association of physique and bodybuilding. Selected participants had 2-8-years of resistance training experience and with no history of hormonal disorders or recent (1-year) use of performance-enhancement drugs (PEDs). The range of training experience was selected to ensure selection of sufficiently trained participants and avoiding highly advanced training status in which physiological and hormonal adaptations to a standardized stimuli may be attenuated. These criteria were adopted to reduce heterogeneity in training responsiveness and potential confounding from hormonal disorders or recent PEDs exposure.

**Ethical Approval**

The study was approved by Advanced Studies and Research Board (ASRB) of University of Haripur, Pakistan on 27th of February 2025. Informed consent from all study participants were obtained and the study was conducted in accordance with Helsinki Declaration.

**Sample Size**

The sample size was calculated using guidelines consistent with the nature training intervention, computing with G* power 3.1.9, attaining a statistical power of 80% (p = 0.05) and an effect size of (0.967). The required sample size calculated

JOURNAL FOR SOCIAL SCIENCE STUDIES
*An International Peer-Reviewed Open Access Journal*

ISSN (Online): 3006-2071 | ISSN (Print): 3006-2063
Volume 4 • Issue 5 • September 2026

for the study was 13 per group which was increased to 15 participants.

**Inclusion and Exclusion Criteria**

Male amateur physique athlete, age 21-30 years, having training experience ≥2 years, who were ready to undertake the intervention and render blood samples were included. The participants who had any injury, medical condition, hormonal issues, or current or recent (≤1 year) history of usage of performance enhancement drugs (PEDs) were excluded from intervention.

**Description of Training Protocol**

HI-RT emphasized high external loads of 80–90% of one repetition maximum (1RM), performing 3–6 repetitions/set, 2–3 sets of 2 exercises per muscle group. The HV-RT group followed prescription consist of 60–70% of 1RM, performing 8–15 repetitions/set, 3 sets of 3–4 exercises per muscle group. Employing whole-body training (e.g., quadriceps, hamstring, latissimus dorsi, pectoralis major, biceps, triceps, and deltoids). Both regimens of intervention were periodized as per FITT principle and supervised by a certified sports conditioning specialist. The control group maintained habitual physical activity without structured resistance training. Six participants lost the follow up with training intervention, leaving HI-RT (n=13), HV-RT (n=14), and CG (n=12) at the end of intervention. Detailed description of training protocol is presented in Table 1. Adapted from Mangine et al. (2015).

**Table 1:Experimental Training Protocol**

| Program Variable | Orientation Week | HI-RT | HV-RT |
|---|---|---|---|
| Frequency | 4 sessions | 4 sessions | 4 sessions |
| Intensity | 75-85% 1RM | 80-90% of 1RM | 60-80% of 1RM |
| Volume | 8-12 reps ×3 sets | 3-6 reps ×3 sets | 10-12 reps ×3 sets |
| Rest between sets | 1-2 min | 2-3 min | 1-2 min |
| **Exercise Prescription** | | | |
| Day 1 Monday | Day 2 Tuesday | Day 3 Thursday | Day 4 Saturday |
| Barbell Squats<br>Leg-press<br>Laying leg curl<br>Laying triceps ext:<br>Cable push-down<br>Over-head bar ext:<br>Barbell curl<br>Preacher curl | Bench press<br>Inclined dumbbell press<br>Cable crossover<br>Bent-over bar row<br>Seated row<br>Shoulder bar press<br>Lateral raises<br>Rear delt fly | Barbell Squats<br>Leg-press<br>Laying leg curl<br>Laying triceps ext:<br>Over-head bar ext:<br>Dumbbell curl<br>Preacher curl<br>Hamer curl | Bench press<br>Inclined bench press<br>Lat pulldown<br>Bent-over bar row<br>Seated row<br>Shoulder press<br>Barbell upright row<br>Rear delt fly |

Volume= Reps × sets, Reps=Repetitions, Ext=Extension, Delt=Deltoid, 1RM=One repetition Maximum

JOURNAL FOR SOCIAL SCIENCE STUDIES
*An International Peer-Reviewed Open Access Journal*

ISSN (Online): 3006-2071 | ISSN (Print): 3006-2063
Volume 4 • Issue 5 • September 2026

**Hormonal Assessment**

Resting serum testosterone, GH, and cortisol were collected pre- and post-intervention during 08:00-09:00 hours to minimize diurnal changes (Torres et al., 2021). Samples were assessed using validated immunoassay techniques.

**Hypertrophic Measurement**

Hypertrophic effect of proximal arms and legs muscles were evaluated via circumferences measurement using standardized anthropometric techniques by the same investigator to reduce inter-tester error. Mean of 3-measurements from both arms were taken and the average was documented, similarly method used for legs anthropometrics. Measurement for upper arms were taken at the midpoint between scapular acromion process and olecranon process of ulna, whereas legs' circumferences were taken at the midpoint between the greater trochanter and the lateral epicondyle of the femur.

**Statistical Analysis**

The post-test hormonal changes were analyzed by MANCOVA follow-up by univariate and Bonferroni-adjusted pairwise comparisons. Pearson correlations for associations between hormonal changes and hypertrophy, and ML regression models for identification of independent hormonal predictors of hypertrophy were performed.

## RESULTS

Baseline demographic characteristics of study participants across groups are presented in Table 2.

**Table 2: Baseline Characteristics of Participants by Group**

| Variable | HI-RT (n = 15) M±SD | HV-RT (n = 15) M±SD | CG (n = 15) M±SD |
|---|---|---|---|
| **Age (years)** | 25.53 (2.75) | 25.07 (2.19) | 25.40 (2.53) |
| **Weight (kg)** | 78.27 (4.65) | 75.17 (3.35) | 76.70 (4.14) |
| **Body Mass Index** | 25.18 (1.32) | 24.42 (0.84) | 24.88 (1.16) |
| **Total Body Fat (%)** | 16.96 (2.29) | 15.53 (2.01) | 15.87 (2.33) |

HI-RT = High-Intensity Resistance Training; HV-RT = High-Volume Resistance Training; CG = Control Group; n=number; SD = Standard Deviation.

Group-wise baseline characteristics including age, body weight, body mass index (BMI), and total body fat percentage (TBF%) of participants were fairly comparable across study groups showing equal number of participants at the onset of intervention indicate the excellent randomization.

**Assumption Diagnostics**

Assumption assessment for equality variances was carried out via Levene's and Box's M tests which revealed minor violations in homogeneity of variance for testosterone and cortisol (Levene's $p < .05$) and in covariance matrices (Box's M, $p = .041$). Normality of residuals was acceptable across all models. Since MANCOVA is robust to these violations especially when using Pillai's Trace, which is the preferred statistic under non-ideal conditions, the analyses remained appropriate and valid.

Multivariate analysis of covariance (MANCOVA), conducted to check the effect of all exploratory groups (HI-RT, HV-RT, CG) on the combined post-test hormonal outcomes (testosterone, GH, cortisol), adjusting for pre-test values, presented in Table 3.

JOURNAL FOR SOCIAL SCIENCE STUDIES
*An International Peer-Reviewed Open Access Journal*

ISSN (Online): 3006-2071 | ISSN (Print): 3006-2063
Volume 4 • Issue 5 • September 2026

**Table 3: Multivariate Tests for Group Differences on Hormonal Outcomes (MANCOVA)**

| Effect | Test | Value | F | Hyp df | Error df | p | Partial $\eta^2$ | Observed Power |
|---|---|---|---|---|---|---|---|---|
| Group | Pillai's Trace | .412 | 3.87 | 6 | 72 | .002 | .24 | .91 |
| Covariate (Hormone Pre-test) | Pillai's Trace | .085 | 1.12 | 3 | 35 | .352 | .09 | .28 |

Values represent MANCOVA multivariate test statistics (Pillai's Trace, Wilks' Lambda, Hotelling's Trace, Roy's Largest Root) with corresponding F, df, p, partial $\eta^2$, and observed power; baseline hormone levels were included as covariates ($p < .05$).

The multivariate effect of group was significant, Pillai's Trace = .412, $F(6, 72) = 3.87$, $p = .002$, showing meaningful differences among groups across the combined endocrine profile. Baseline hormones as covariate did not exhibit a significant multivariate influence, Pillai's Trace = .085, $p = .352$, suggesting that post-test hormonal differences primarily reflect the impact of training interventions rather than initial differences, hence we rejected the null hypothesis based on the current result.

ANCOVA as follow-up analyzed the training groups effect on all three hormonal markers, consistent after controlling for baseline values as covariate, shown in Table 4.

**Table 4:Tests of Between-Subjects Effects for Testosterone, GH, and Cortisol (ANCOVA)**

| Source | Type III SS | df | MS | F | P | Partial $\eta^2$ |
|---|---|---|---|---|---|---|
| **Testosterone** | | | | | | |
| Pre-Test (Covariate) | 1.921 | 1 | 1.921 | 2.93 | .096 | .07 |
| Group | 18.233 | 2 | 9.117 | 12.45 | < .001 | .41 |
| **GH** | | | | | | |
| Pre-Test (Covariate) | 2.111 | 1 | 2.111 | 5.88 | .020 | .14 |
| Group | 12.822 | 2 | 6.411 | 16.60 | < .001 | .43 |
| **Cortisol** | | | | | | |
| Pre-Test (Covariate) | .714 | 1 | .714 | 1.62 | .210 | .04 |
| Group | 9.727 | 2 | 4.864 | 7.92 | .001 | .30 |

Values represent ANCOVA Type III sums of squares with corresponding *F*, df, mean square, *p*, partial $\eta^2$, and observed power; baseline levels were included as covariates ($p < .05$).

Significant group differences were observed in testosterone partial $\eta^2 = .41$, even larger effect in

JOURNAL FOR SOCIAL SCIENCE STUDIES
*An International Peer-Reviewed Open Access Journal*

ISSN (Online): 3006-2071 | ISSN (Print): 3006-2063
Volume 4 • Issue 5 • September 2026

GH level partial $\eta^2$ = .43 (both p < .001), while minimal effect on cortisol p = .001, partial $\eta^2$ = .30. These large effect sizes indicate that training protocols produced substantial physiological impact, with HI-RT generally producing the largest improvement across hormones.

Post hoc Bonferroni's pairwise comparison was used to examine contrasting effects on key hormones by intervention groups. Illustrated in Table 5, meaningful between-group differences were documented.

**Table 5: Pairwise Group Comparisons with Bonferroni Adjustment**

| Dependent Variable | (I – J) | Mean Diff | SE | 95% CI | p (Bonferroni) |
|---|---|---|---|---|---|
| Testosterone | HI-RT – HV-RT | 1.22 | .33 | [.48, 1.97] | .004 |
| Testosterone | HI-RT – Control | 2.11 | .36 | [1.36, 2.86] | < .001 |
| Testosterone | HV-RT – Control | .89 | .34 | [.16, 1.61] | .021 |
| GH | HI-RT – HV-RT | .56 | .22 | [.06, 1.05] | .041 |
| GH | HI-RT – Control | 1.42 | .27 | [.86, 1.99] | < .001 |
| GH | HV-RT – Control | .86 | .24 | [.33, 1.39] | .002 |
| Cortisol | HI-RT – HV-RT | -.91 | .38 | [-1.69, -.13] | .032 |
| Cortisol | HI-RT – Control | -2.07 | .41 | [-2.94, -1.20] | < .001 |
| Cortisol | HV-RT – Control | -1.16 | .39 | [-1.95, -.38] | .008 |

Values represent pairwise group comparisons of covariate-adjusted post-test hormone levels, reported as mean differences (I–J) with standard errors (SE), 95% confidence intervals, and Bonferroni-adjusted p values, derived from ANCOVA controlling for baseline (pre-test) values. Values of Testosterone and GH as ng/ml, and of Cortisol as µg/dl.

Bonferroni-corrected pairwise comparisons revealed that HI-RT yielded statistically significant greater hormonal enhancements compared to both the HV-RT and Control groups across all measured variables. Particularly, HI-RT exhibited the greatest increase in testosterone and GH, along with the most significant decrease in cortisol. HV-RT also exceeded the performance of the Controls, albeit with minimal effect sizes. The above results prove that although both training regimens are efficacious, HI-RT induces a more robust endocrine response.

Pearson correlation was performed to explore relationship between training-induced hormonal changes and hypertrophic changes in arms and legs circumferences. Presented in Table 6.

**Table 6: Pearson Correlations Among Group, Hormonal Changes, and Hypertrophic Outcomes**

| Variable | Group | Δ Testosterone | Δ GH | Δ Cortisol | Δ Arm | Δ Leg |
|---|---|---|---|---|---|---|
| Group | 1 | | | | | |

JOURNAL FOR SOCIAL SCIENCE STUDIES
*An International Peer-Reviewed Open Access Journal*

ISSN (Online): 3006-2071 | ISSN (Print): 3006-2063
Volume 4 • Issue 5 • September 2026

| | | | | | | |
|---|---|---|---|---|---|---|
| | | | | | | |
| Δ Testosterone | −0.305 | 1 | | | | |
| | (.059) | | | | | |
| Δ GH | −0.264 | 0.766† | 1 | | | |
| | (.105) | (<.001) | | | | |
| Δ Cortisol | 0.484† | 0.353* | 0.352* | 1 | | |
| | (.002) | (.027) | (.028) | | | |
| Δ Arm Circ | −0.456† | 0.562† | 0.420† | −0.014 | | |
| | (.004) | (<.001) | (.008) | (.934) | | |
| Δ Leg Circ | −0.442† | 0.616† | 0.545† | 0.139 | 0.701† | 1 |
| | (.005) | (<.001) | (<.001) | (.397) | (<.001) | |

Values are Pearson correlation coefficients (r) with 2-tailed P values in parentheses. Δ indicates change score (post–pre). $P < .05$ (*); $P < .01$ (†). Values of Testosterone and GH are presented as ng/ml, and of Cortisol as µg/dl. Measurement of arm and leg presented as circumference in centimeters.

Pearson's results demonstrated the differential correlations between key hormonal responses and muscle hypertrophy in upper- and lower-limb. Improvement in testosterone indicates a moderate positive associations with both arms and legs circumferential metrics, suggesting that larger spikes in testosterone level were normally accompanied by greater muscle growth. GH exhibited a relatively smaller, still positive relationship with these outcomes, highlighting a supportive but less salient role. On the other hand, cortisol showed no meaningful correlation with improvement in limbs hypertrophic outcomes, implying its limited role in predicting hypertrophic effects. Taken together, the results show that increases anabolic hormonal, particularly testosterone, are more closely relevant in hypertrophic adaptations compared GH and catabolic hormones, however the documented relationship is still modest in magnitude.

Moreover, the visual assessment of correlational scatterplots in Figure 2 confirmed the moderate positive trends for testosterone with growth in arms and legs muscles, minimal yet positive relationship for GH, and slight to no negligible role of cortisol. The spread of data points indicates differences in individual adaptations, relative to patterns favoring a substantial correspondence of anabolic hormones with hypertrophy outcomes than cortisol.

JOURNAL FOR SOCIAL SCIENCE STUDIES
*An International Peer-Reviewed Open Access Journal*

ISSN (Online): 3006-2071 | ISSN (Print): 3006-2063
Volume 4 • Issue 5 • September 2026

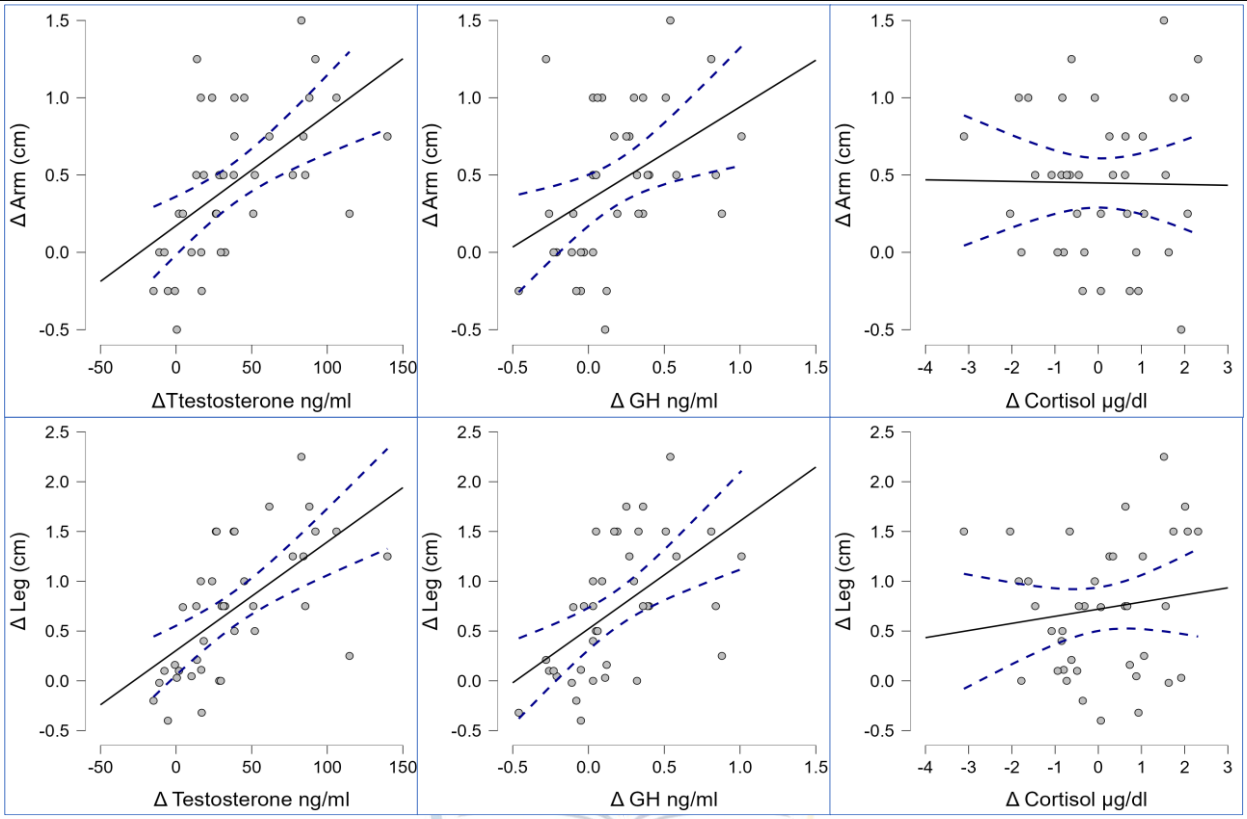


**Figure 2 correlation of Δ Testosterone, GH, and Cortisol with Arm and Leg Hypertrophy**

Additionally, the multiple linear regression was applied to investigate the predictive role of Δ hormones in limbs' hypertrophic outcomes across training groups, as presented in Table 7 and 8, while visually depicted in partial regression plots grouped in Figure 3.

**Table 7: Multiple Linear Regression for Hormonal Responses Predicting Changes in Hypertrophy (Arm Circumference) in centimeters**

| Predictor | B | SE B | β | t | p | 95% CI for B | VIF |
|---|---|---|---|---|---|---|---|
| Constant | 0.137 | 0.097 | | 1.41 | .167 | [−0.06, 0.33] | |
| Δ Testosterone | 0.008 | 0.003 | .631 | 2.99 | .005 | [ 0.003, 0.014] | 2.47 |
| Δ GH ( | 0.033 | 0.303 | .023 | 0.11 | .913 | [−0.58, 0.65] | 2.47 |
| Δ Cortisol | −0.091 | 0.054 | −.245 | −1.69 | .101 | [−0.20, 0.018] | 1.16 |

$R^2$ = .368, Adjusted $R^2$ = .314, F (3,35) = 6.79, p = .001, N = 39. **p < .01, *p < .005. Values of Testosterone and GH are presented as ng/ml, and of Cortisol as µg/dl. Circ=circumference in

JOURNAL FOR SOCIAL SCIENCE STUDIES
*An International Peer-Reviewed Open Access Journal*

ISSN (Online): 3006-2071 | ISSN (Print): 3006-2063
Volume 4 • Issue 5 • September 2026

centimeters. Δ= Changes score.

Holistically, the model revealed statistically significant results and accounted for 36.8 % of the difference in arm hypertrophy (adjusted $R^2$ = .314, p = .001). Consistently, controlling for the other hormonal changes, the spikes in testosterone emerged as a strong and significant unique predictor, whereas changes in growth hormone induced no unique increase. The response of cortisol showed a non-significant negative unique relation. Practically, each 50 ng/mL elevation in resting testosterone was independently associated with an additional ~0.40 centimeter of arm circumference growth, much more than the effects of growth hormone and cortisol changes.

**Table 8:Multiple Linear Regression for Hormonal Changes Predicting Changes in Hypertrophy (Leg Circumference) in centimeters**

| Predictor | B | SE B | β | t | p | 95% CI for B | VIF |
|---|---|---|---|---|---|---|---|
| Constant | 0.311 | 0.130 | | 2.39 | .022 | [0.05, 0.58] | |
| Δ Testosterone | 0.009 | 0.004 | .501 | 2.44 | .020 | [0.001, 0.016] | 2.47 |
| Δ GH | 0.395 | 0.408 | .199 | 0.97 | ..340 | [−0.43, 1.22] | 2.47 |
| Δ Cortisol | −0.055 | 0.072 | −.108 | −0.76 | .451 | [−0.20, 0.09] | 1.16 |

$R^2$ = .402, Adjusted $R^2$ = .351, F (3,35) = 7.84, p < .001, N = 39. Values of Testosterone and GH are presented as ng/ml, and of Cortisol as µg/dl. Circ=circumference in centimeters.

Collectively, the model was statistically significant, describing 40.2 % of the changes in leg hypertrophy (adjusted $R^2$ = .351, p < .001). While adjusting for the effect of other hormones, change in testosterone proved to be a significant independent predictor, however, neither GH nor change in cortisol mediated a significant independent effect. Thus, every 50 ng/mL rise in testosterone was uniquely associated with a further ~0.45 centimeter of leg circumference growth, greater than changes in growth hormone and cortisol.

JOURNAL FOR SOCIAL SCIENCE STUDIES
*An International Peer-Reviewed Open Access Journal*

ISSN (Online): 3006-2071 | ISSN (Print): 3006-2063
Volume 4 • Issue 5 • September 2026

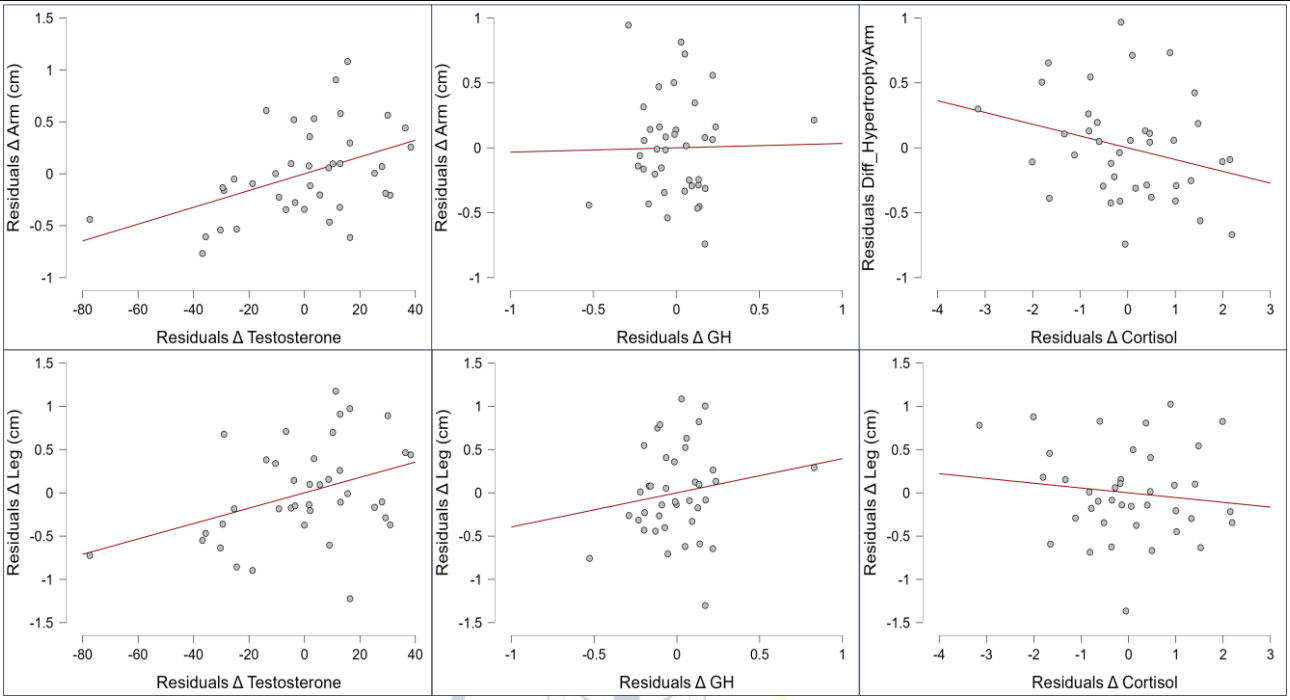


**Figure 3 Partial Regression Plots for Arm and Leg Hypertrophy Predicted by Δ Hormones**

Regarding changes in testosterone, the partial regression plot showed a positive linear trend with residuals mostly spread around the zero line, suggesting that testosterone maintains a significant positive partial effect on when controlling for other hormones in the model. About Δ GH, the plot revealed a comparatively flatter slope and larger residual dispersion, indicating a weaker partial correlation. Collectively, these PR plots supported the multiple regression coefficients and confirmed that the key predictors' effects were not substantially distorted by omitted variable bias or influential cases.

## Discussion

The primary finding of this study is that sustained increases in resting testosterone are strongly and independently associated with skeletal muscle hypertrophy than GH, in resistance-trained physique athletes. Moreover, HI-RT elicited superior testosterone and GH elevations and hypertrophic outcomes compared with HV-RT and control. The findings of this study are aligned with investigations which explored mechanistic role of testosterone in MPS and androgen receptor signaling (Gharahdaghi et al., 2021; Sakai et al., 2024). They also confirmed recent findings that exercise-induced testosterone holds predictive role for hypertrophy in resistance-trained populations, despite earlier agnosticism (Mangine et al., 2017). A study, involving physically active males and females, concluded that testosterone related single nucleotide polymorphism SNPs were linked to increase in muscular strength and hypertrophy as well as overall fat-free mass (Guilherme et al., 2022). Indicated in a review, the acute MPS related to RT and protein diet did not reliably predicted muscle hypertrophy, particularly in individuals undertaking an unaccustomed exercisers program, albeit its information is useful for predicting muscle growth in specific group, providing insights into a protein's quality, turnover, recovery, adaptation, and offering mechanistic information for developing a training and nutritional plan (Witard et al., 2022).

Additionally, a brief review by Brunsden, (2023)

JOURNAL FOR SOCIAL SCIENCE STUDIES
An International Peer-Reviewed Open Access Journal
ISSN (Online): 3006-2071 | ISSN (Print): 3006-2063
Volume 4 • Issue 5 • September 2026

showed that exercise can induce only short-term increase in testosterone and GH with no significant long-term elevation. He further suggested that exercise volume over 3 sets/exercise can trigger protein signaling p70S6K1, which can promote muscular strength and hypertrophy. Evidence shows that testosterone exert action as supportive factor in anabolic processes of skeletal muscle tissue growth by enhancing protein synthesis and myogenic reactions after the onset of mechanical stress which is the primary driver to hypertrophic adaptation (West & Phillips, 2010). In the same vein, sufficient testosterone produced in the body, plays an important role in regulating the cellular mechanisms of muscle hypertrophy induced by resistance training (Gharahdaghi et al., 2022).

While in direct comparison between HI-RT and HV-RT a clearly observable hormonal shifts in HI-RT prefer the intensity and mechanical tension over volume per set to exert greater influence on systemic endocrine adaptation in trained individuals. This divergence reflects findings from reviews and meta-analyses in which heavy-load, low-to-moderate volume RT induced similar responses or superior outcomes compared to HV protocols in strength and hypertrophy adaptations (Vann et al., 2022), particularly when overall volume is matched or sufficiently met the specific demand in both protocols (Schoenfeld et al., 2017). Furthermore, studies manipulating tempo, repetition speed, and time-under-tension suggest that while metabolic stress contributes to adaptation (Wilk et al., 2021), mechanical tension remains a primary stimulus for androgenic response and muscle growth (Bamman et al., 2023). When hormone changes are considered alongside physical outcomes in our dataset, interesting relationships emerge. Elevated resting testosterone was strongly associated with increases in muscle circumference (arm and leg), supporting the theory that systemic androgenic endocrine adaptation may facilitate muscle hypertrophy under chronic training (Mangine et al., 2017; Gharahdaghi et al., 2022).

However, regarding specific outcomes of hypertrophy, our findings partially converge with those of a recent study on resistance training employing unilateral upper and lower limbs assessment; concluded that RT produces significant hypertrophy despite inter-individual differences (Lees et al., 2025). Similarly, both our HI-RT and HV-RT induced reasonable strength and hypertrophic outcomes in the current study. Nevertheless, contrary to the reports suggesting that hypertrophy is independent of external load if the exercise sets are executed to volitional fatigue, our findings show superior hypertrophic outcomes by the HI-RT group compared to the HV-RT. Such contrast may be due to methodological variability, such as multi-joint training, assessing whole-body rather than unilateral, adaptability to high mechanical loading, and the addition of systemic hormonal responses examined in the current investigation.

In contrast to studies reporting load-independent hypertrophy when training is performed to failure (Morton et al., 2016). In the same vein, a nine weeks of high- and low-load study revealed similar hypertrophic outcomes in resistance-trained men without significant changes in endocrine, underscoring the importance of intra-muscular signaling induced by training to failure in either high or low-load RT (Bello et al., 2025; Roberts et al., 2023). In support of this, a review suggests that manipulating volume of RT may significantly help retain lean mass during restricted calorie diet, with effects influenced by training status and baseline characteristics (Roth et al., 2022). Moreover, the RT is shown to be the strongest driver of the mechanisms (e.g. mTOR signaling, translational capacity, and transcription) which pave the way for muscular hypertrophy (Lim et al., 2022). Likewise, a study's pioneering work demonstrated that acute AR signaling in muscle was most likely driven by higher load that induces mechanical stress and β-catenin protein (a helper protein), rather than an increase in hormones or AR protein, during resistance training that was volume and intensity-equated (Cardaci et al., 2020).

JOURNAL FOR SOCIAL SCIENCE STUDIES
*An International Peer-Reviewed Open Access Journal*

ISSN (Online): 3006-2071 | ISSN (Print): 3006-2063
Volume 4 • Issue 5 • September 2026

Van Every et al. (2025) claim that mechanical loading and local intracellular signaling predominately govern the resistance training-induced muscle growth, whereas acute systemic testosterone plays a negligible casual role in this hypertrophy. On the other hand, Flewwelling and fellows (2025) suggests that fatigue-driven metabolic stress promotes hypertrophic mechanism during low-load resistance exercise via increased motor unit recruitment and metabolic signaling, potentially independent of acute testosterone elevations. Interestingly, an umbrella review concludes that muscular hypertrophy could be achieved through a variety of resistance training regimens, where systemic hormonal responses poorly predict the adaptations (McLeod et al., 2024). Our findings suggest that training intensity influences hormonal levels that may expedite muscle anabolism. Although, mechanical tension persists to be the primary hypertrophic stimulus, consistent elevations in resting testosterone could notably bolster muscle anabolic potency in resistance-trained populations engaging in HI training. Discrepancies in the literature may be resultant of methodological divergence including training regimens incorporating whole-body to segmental training, training exposure of participants, and assessment of chronic resting hormones (Van Every et al., 2025; McLeod et al., 2024).

Surprisingly, GH and cortisol did not independently predict hypertrophy despite having moderate bivariate associations, indicating alignment with studies reporting the role of growth hormone as metabolic rather than muscle tissue promoter (Donato et al., 2021; Kraemer et al., 2020), and the role of cortisol may be more relevant to influence strength and recovery (Torres et al., 2021). Overall, these findings support a nuanced pattern in which circulating testosterone acts as important factor, and potential promoter of hypertrophic adaptation in trained population, especially when following high-intensity regimens (Mangine et al., 2017; Gharahdaghi et al., 2022).

**Limitations**

The study has several methodological limitations including its modest sample size, and reliance on anthropometric measures rather than imaging-based assessments of hypertrophic outcomes. Likewise, the total testosterone was assessed rather than bioavailable fractions, which may more closely reflect tissue-level activity (Alexander et al., 2025). In addition to this, intramuscular signaling pathways were not measured.

**Practical Applications**

Tracking resting testosterone trends may provide useful insight into training effectiveness and recovery status for resistance-trained athletes seeking hypertrophy. HI-RT may offer superior anabolic hormonal adaptations, while HV may benefit in situations where metabolic stress is critical, for instance, during fat shredding phases.

**Conclusions**

The current study concludes that both HI-RT and HV-RT protocols induced significant responses in resting serum testosterone and GH levels, with HI-RT producing the largest increase followed by HV-RT. The subsequent response in testosterone emerged to be the independent predictor of hypertrophy in arms and leg muscles while GH and cortisol could not independently predict hypertrophy. These findings support a facilitative role of systemic testosterone in hypertrophic outcomes within resistance-trained populations.

**Acknowledgments**

The author has used AI for the purpose of refinement of language, restructuring of paragraphs, and grammatical clarity. A careful editing and verification have been carried out to ensure data originality and work authenticity.

**Funding**

The current study received no funds from any external source

**Conflict of Interest**

The author declares no conflict of interest

ISSN (Online): 3006-2071 | ISSN (Print): 3006-2063
Volume 4 • Issue 5 • September 2026

**REFERENCES**

Abdul-Al, O., Zunquin, G., & El Hage, R. (2024). Effects of two types of resistance training modalities (hypertrophy vs. contrast training) on bone parameters in a group of healthy elderly women. *Journal of Clinical Densitometry, 27*(4), 101521. https://doi.org/10.1016/j.jocd.2024.101521

Alexander, S. E., Gatto, B., Knowles, O. E., Williams, R. M., Fiebig, K. N., Jansons, P., Della Gatta, P. A., Garnham, A., Eynon, N., Wadley, G. D., Aisbett, B., Hiam, D., & Lamon, S. (2025). Bioavailable testosterone and androgen receptor activation, but not total testosterone, are associated with muscle mass and strength in females. *The Journal of Physiology, 603*(18), 5181–5208. https://doi.org/10.1113/JP286803

Alwan, N., Moss, S. L., Elliott-Sale, K. J., Davies, I. G., & Enright, K. (2019). A narrative review on female physique athletes: The physiological and psychological implications of weight management practices. *International Journal of Sport Nutrition and Exercise Metabolism, 29*(6), 682–689. https://doi.org/10.1123/ijsnem.2019-0037

Bello, M. L., Arent, S. M., Gillen, Z. M., & Smith, J. W. (2025). Muscle hypertrophy, strength, and salivary hormone changes following 9 weeks of high- or low-load resistance training. *Journal of Functional Morphology and Kinesiology, 11*(1), 17. https://doi.org/10.3390/jfmk11010017

Bamman, M. M., Roberts, B. M., & Adams, G. R. (2023). Mechanisms of mechanical overload-induced skeletal muscle hypertrophy: Current understanding and future directions. *Physiological Reviews*, 103(4), 2679–2757. https://doi.org/10.1152/physrev.00039.2022

Brunsden, T. J. (2023). Hormonal responses to resistance training and its effects on strength adaptations: A brief overview. In R. Gurunathan (Ed.), *Research developments in medicine and medical science* (Vol. 6, pp. 1–10). B P International. https://doi.org/10.9734/bpi/rdmms/v6/5780A

Cardaci, T. D., Machek, S. B., Wilburn, D. T., Heileson, J. L., & Willoughby, D. S. (2020). High-load resistance exercise augments androgen receptor–DNA binding and Wnt/β-catenin signaling without increases in serum/muscle androgens or androgen receptor content. *Nutrients, 12*(12), 3829. https://doi.org/10.3390/nu12123829

Donato, J., Jr., Wasinski, F., Furigo, I. C., Metzger, M., & Frazão, R. (2021). Central regulation of metabolism by growth hormone. *Cells*, 10(1), 129. https://doi.org/10.3390/cells10010129

Fink, J. E. (2020). The role of hormones in exercise-induced muscle hypertrophy. In A. C. Hackney & N. W. Constantini (Eds.), *Endocrinology of physical activity and sport* (pp. 391–398). Springer. https://doi.org/10.1007/978-3-030-33376-8_21

Flewwelling, L. D., Hannaian, S. J., Cao, V., Chaillou, T., Churchward-Venne, T. A., & Cheng, A. J. (2025). What are the potential mechanisms of fatigue-induced skeletal muscle hypertrophy with low-load resistance exercise training? *American Journal of Physiology-Cell Physiology, 328*(3), C1001–C1014. https://doi.org/10.1152/ajpcell.00266.2024

Gates, A. T., Kjaer, M., & Andersen, J. L. (2024). One year of heavy resistance training modifies muscle fiber characteristics in the elderly. *Sports Medicine International Open, 8*, a23388226. https://doi.org/10.1055/a-2338-8226

ISSN (Online): 3006-2071 | ISSN (Print): 3006-2063
Volume 4 • Issue 5 • September 2026

, V., Hulmi, J. J., Mbay, T., Kyröläinen, H., Häkkinen, K., Ahola, V., Helms, E. R., & Ahtiainen, J. P. (2025). Changes in hormonal profiles during competition preparation in physique athletes. *European Journal of Applied Physiology, 125*(2), 393–408. https://doi.org/10.1007/s00421-024-05606-z

Gharahdaghi, N., Phillips, B. E., Szewczyk, N. J., Smith, K., Wilkinson, D. J., & Atherton, P. J. (2021). Links between testosterone, oestrogen, and the growth hormone/insulin-like growth factor axis and resistance exercise muscle adaptations. *Frontiers in Physiology, 11*, 621226. https://doi.org/10.3389/fphys.2020.621226

Gharahdaghi, N., Rudrappa, S., Brook, M. S., Farrash, W., Idris, I., Abdul Aziz, M. H., Kadi, F., Papaioannou, K., Phillips, B. E., Sian, T., Herrod, P. J., Wilkinson, D. J., Szewczyk, N. J., Smith, K., & Atherton, P. J. (2022). Pharmacological hypogonadism impairs molecular transducers of exercise-induced muscle growth in humans. *Journal of Cachexia, Sarcopenia and Muscle, 13*(2), 1134–1150. https://doi.org/10.1002/jcsm.12843

Guilherme, J. P. L. F., Semenova, E. A., Borisov, O. V., Larin, A. K., Moreland, E., Generozov, E. V., & Ahmetov, I. I. (2022). Genomic predictors of testosterone levels are associated with muscle fiber size and strength. *European Journal of Applied Physiology, 122*(2), 415–423. https://doi.org/10.1007/s00421-021-04851-w

Havers, T., Held, S., Schönfelder, M., Geisler, S., & Wackerhage, H. (2025). Effects of skeletal muscle hypertrophy on fat mass and glucose homeostasis in humans and animals: A narrative review with systematic literature search. *Sports Medicine, 55*(8), 1867–1885. https://doi.org/10.1007/s40279-025-02263-w

Kirk, A., Steele, J., & Fisher, J. P. (2024). Machine-based resistance training improves functional capacity in older adults: A systematic review and meta-analysis. *Journal of Functional Morphology and Kinesiology, 9*(4), 239. https://doi.org/10.3390/jfmk9040239

Kraemer, W. J., Ratamess, N. A., Hymer, W. C., Nindl, B. C., & Fragala, M. S. (2020). Growth hormone(s), testosterone, insulin-like growth factors, and cortisol: Roles and integration for cellular development and growth with exercise. *Frontiers in Endocrinology, 11*, 33. https://doi.org/10.3389/fendo.2020.00033

Kraemer, W. J., Ratamess, N. A., & Nindl, B. C. (2017). Recovery responses of testosterone, growth hormone, and IGF-1 after resistance exercise. *Journal of applied physiology (Bethesda, Md. : 1985), 122*(3), 549–558. https://doi.org/10.1152/japplphysiol.00599.2016

Lees, M. J., McLeod, J. C., Morton, R. W., et al. (2025). Resistance training load does not determine resistance training-induced hypertrophy across upper and lower limbs in healthy young males. *Journal of Physiology*. Advance online publication. https://doi.org/10.1113/JP289684

ISSN (Online): 3006-2071 | ISSN (Print): 3006-2063
Volume 4 • Issue 5 • September 2026

Lim, C., Nunes, E. A., Currier, B. S., McLeod, J. C., Thomas, A. C. Q., & Phillips, S. M. (2022). An evidence-based narrative review of mechanisms of resistance exercise-induced human skeletal muscle hypertrophy. *Medicine & Science in Sports & Exercise, 54*(9), 1546–1559. https://doi.org/10.1249/MSS.0000000000002929

Makaruk, H., Starzak, M., Tarkowski, P., Sadowski, J., & Winchester, J. (2024). The effects of resistance training on sport-specific performance of elite athletes: A systematic review with meta-analysis. *Journal of Human Kinetics, 91*(Spec. Issue), 135–155. https://doi.org/10.5114/jhk/185877

Mangine, G. T., Hoffman, J. R., Gonzales, A. M., Townsend, J. R., Wells, A. J., Jajtner, A. R., & Miramonti, A. A. (2015). The effect of training volume and intensity on improvements in muscular strength and size in resistance-trained men. *Physiological Reports, 3*(8), e12472. https://doi.org/10.14814/phy2.12472

Mangine, G. T., Hoffman, J. R., Gonzalez, A. M., Townsend, J. R., Wells, A. J., Jajtner, A. R., Beyer, K. S., Boone, C. H., Wang, R., Miramonti, A. A., LaMonica, M. B., Fukuda, D. H., Witta, E. L., Ratamess, N. A., & Stout, J. R. (2017). Exercise-induced hormone elevations are related to muscle growth. *Journal of Strength and Conditioning Research, 31*(1), 45–53. https://doi.org/10.1519/JSC.0000000000001491

McDowell, K. W., Long, A., Gahreman, D., Nelson, D. A., Goode, N. J., Lis, R. P., Chae, S., Mizuguchi, S., Baur, M., Breuel, K. F., Duca, M., Wagle, J. P., Fry, A. C., & Stone, M. H. (2024). The endocrine and body composition responses to accentuated eccentric loading performed in cluster sets during a strength–endurance training block. *Applied Sciences, 14*(23), 11332. https://doi.org/10.3390/app142311332

Mcleod, J. C., Currier, B. S., Lowisz, C. V., & Phillips, S. M. (2024). The influence of resistance exercise training prescription variables on skeletal muscle mass, strength, and physical function in healthy adults: An umbrella review. *Journal of sport and health science, 13*(1), 47–60. https://doi.org/10.1016/j.jshs.2023.06.005

Mennitti, C., Farina, G., Imperatore, A., De Fonzo, G., Gentile, A., La Civita, E., Carbone, G., De Simone, R. R., Di Iorio, M. R., Tinto, N., Frisso, G., D'Argenio, V., Lombardo, B., Terracciano, D., Crescioli, C., & Scudiero, O. (2024). How does physical activity modulate hormone responses? *Biomolecules, 14*(11), 1418. https://doi.org/10.3390/biom14111418

Moreno, E. N., Hammert, W. B., Montgomery, T. R., Abe, T., Loenneke, J. P., & Buckner, S. L. (2024). Skeletal muscle mass in competitive physique-based athletes: A case series. *American Journal of Human Biology, 36*(1), e23978. https://doi.org/10.1002/ajhb.23978

ISSN (Online): 3006-2071 | ISSN (Print): 3006-2063
Volume 4 • Issue 5 • September 2026

Morton, R. W., Oikawa, S. Y., Wavell, C. G., Mazara, N., McGlory, C., Quadrilatero, J., Baechler, B. L., Baker, S. K., & Phillips, S. M. (2016). Neither load nor systemic hormones determine resistance training-mediated hypertrophy or strength gains in resistance-trained young men. *Journal of Applied Physiology, 121*(1), 129–138. https://doi.org/10.1152/japplphysiol.00154.2016

Räntilä, A., Ahtiainen, J. P., & Häkkinen, K. (2023). Effects of acute loading induced fatigability, acute serum hormone responses and training volume to individual hypertrophy and maximal strength during 10 weeks of strength training. *Journal of Sports Science and Medicine, 22*, 559–570. https://doi.org/10.52082/jssm.2023.559

Roberts, M. D., McCarthy, J. J., Hornberger, T. A., Phillips, S. M., Mackey, A. L., Nader, G. A., Boppart, M. D., Kavazis, A. N., Reidy, P. T., Ogasawara, R., Libardi, C. A., Ugrinowitsch, C., Booth, F. W., & Esser, K. A. (2023). Mechanisms of mechanical overload-induced skeletal muscle hypertrophy: Current understanding and future directions. *Physiological Reviews, 103*(4), 2679–2757. https://doi.org/10.1152/physrev.00039.2022

Roth, C., Schoenfeld, B. J., & Behringer, M. (2022). Lean mass sparing in resistance-trained athletes during caloric restriction: The role of resistance training volume. *European Journal of Applied Physiology, 122*(5), 1129–1151. https://doi.org/10.1007/s00421-022-04896-5

Sakai, H., Uno, H., Yamakawa, H., Tanaka, K., Ikedo, A., Uezumi, A., Ohkawa, Y., & Imai, Y. (2024). The androgen receptor in mesenchymal progenitors regulates skeletal muscle mass via Igf1 expression in male mice. *Proceedings of the National Academy of Sciences, 121*(39), e2407768121. https://doi.org/10.1073/pnas.2407768121

Schoenfeld, B. J., Grgic, J., Van Every, D. W., & Plotkin, D. L. (2021). Loading recommendations for muscle strength, hypertrophy, and local endurance: A re-examination of the repetition continuum. *Sports, 9*(2), 32. https://doi.org/10.3390/sports9020032

Schoenfeld, B. J., Grgic, J., Ogborn, D., & Krieger, J. W. (2017). Strength and hypertrophy adaptations between low- vs. high-load resistance training: A systematic review and meta-analysis. *Journal of Strength and Conditioning Research, 31*(12), 3508–3523.

Sekine, Y. (2025). Maturity-associated longitudinal variations in exercise-induced acute hormonal responses in adolescent male athletes. *Pediatric Exercise Science, 37*(4), 397–402. https://doi.org/10.1123/pes.2024-0052

Shi, S. (2025). Effect of exercise-induced hormonal changes on skeletal muscle physiology. *Clinical Endocrinology*. Advance online publication. https://doi.org/10.1111/cen.70086

Suchomel, T. J., Nimphius, S., Bellon, C. R., & Stone, M. H. (2018). The importance of muscular strength: Training considerations. *Sports Medicine, 48*(4), 765–785. https://doi.org/10.1007/s40279-018-0862-z

ISSN (Online): 3006-2071 | ISSN (Print): 3006-2063
Volume 4 • Issue 5 • September 2026

Torres, R., Koutakis, P., & Forsse, J. (2021). The effects of different exercise intensities and modalities on cortisol production in healthy individuals: A review. *Journal of Exercise Nutrition, 4*(4). https://doi.org/10.53520/jen2021.103108

Tromaras, K., Zaras, N., Stasinaki, A. N., Mpampoulis, T., & Terzis, G. (2024). Lean body mass, muscle architecture and powerlifting performance during preseason and in competition. *Journal of Functional Morphology and Kinesiology, 9*(2), 89. https://doi.org/10.3390/jfmk9020089

Tu, Q., Li, G., & Wang, S. (2026). Effect of acute exercise on the dynamics of testosterone levels: A systematic review of randomized controlled trials. *PeerJ, 14*, e20615. https://doi.org/10.7717/peerj.20615

Van Every, D. W., D'Souza, A. C., & Phillips, S. M. (2024). Hormones, hypertrophy, and hype: An evidence-guided primer on endogenous endocrine influences on exercise-induced muscle hypertrophy. *Exercise and Sport Sciences Reviews, 52*(4), 117–125. https://doi.org/10.1249/JES.0000000000000346

Van Every, D. W., Lees, M. J., Wilson, B., Nippard, J., & Phillips, S. M. (2026). Load-induced human skeletal muscle hypertrophy: Mechanisms, myths, and misconceptions. *Journal of Sport and Health Science, 15*, 101104. https://doi.org/10.1016/j.jshs.2025.101104

Vann, C. G., Sexton, C. L., Osburn, S. C., et al. (2022). Effects of high-volume versus high-load resistance training on skeletal muscle growth and molecular adaptations. *Frontiers in Physiology, 13*, Article 857555. https://doi.org/10.3389/fphys.2022.857555

West, D. W. D., & Phillips, S. M. (2010). Anabolic processes in human skeletal muscle: Restoring the identities of growth hormone and testosterone. *The Physician and Sportsmedicine, 38*(3), 97–104. https://doi.org/10.3810/psm.2010.10.1814

Wilk, M., Zajac, A., & Tufano, J. J. (2021). The influence of movement tempo during resistance training on muscular strength and hypertrophy responses: A review. *Sports Medicine, 51*(8), 1629–1650. https://doi.org/10.1007/s40279-021-01465-2

Witard, O. C., Bannock, L., & Tipton, K. D. (2022). Making sense of muscle protein synthesis: A focus on muscle growth during resistance training. *International Journal of Sport Nutrition and Exercise Metabolism, 32*(1), 49–61. https://doi.org/10.1123/ijsnem.2021-0139

Zamir, A., Ben-Zeev, T., & Hoffman, J. R. (2021). Manipulation of dietary intake on changes in circulating testosterone concentrations. *Nutrients, 13*(10), 3375. https://doi.org/10.3390/nu13103375