

Associations Between Weekly Training Load, Recovery Status, and Lean Body Mass in Amateur Bodybuilders

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ABSTRACT: Weekly training load is a central programming variable in bodybuilding, but its association with lean body mass is difficult to interpret without accounting for recovery status and the broader nutritional and sleep context. This cross-sectional field study examined associations between weekly resistance-training load, recovery status, and lean body mass in amateur bodybuilders. A mixed-sex sample of 240 amateur bodybuilders (120 women and 120 men; age 25.8 $\pm$ 4.2 years) completed a seven-day training and recovery log, nutrition screening, readiness and soreness ratings, and standardized body-composition assessment. Weekly training load was calculated from session duration multiplied by session rating of perceived exertion and summarized alongside weekly hard sets. Lean body mass and lean body mass index (LBMI) were used as primary outcomes. Statistical significance was set at $p < 0.05$. Training load showed a positive but curvilinear association with LBMI, with the strongest profile observed in athletes completing high but not excessive weekly loads. Recovery status was independently associated with LBMI after adjustment for age, sex, training experience, protein intake, sleep duration, and training load (beta = 0.26 kg/m² per recovery point, 95% CI: 0.15 to 0.37, $p < 0.001$). The training load-by-recovery interaction was significant ($p < 0.001$), indicating that higher load was most strongly associated with lean mass when recovery ratings were moderate to high. Athletes in stronger recovery profiles had greater odds of achieving a sex-specific high lean-mass profile. Associations were similar in women and men. These findings support a balanced interpretation of bodybuilding adaptation: greater weekly loading is associated with higher lean body mass, but recovery status helps determine whether that load is likely to support adaptation rather than accumulated strain.

Keywords: bodybuilding; training load; recovery status; lean body mass; resistance training; hypertrophy; session RPE; body composition; amateur athletes.

I. INTRODUCTION

Bodybuilding is built around a simple, visible goal: to develop and display muscularity with symmetry and proportion, and with body fat low enough for muscular definition to be apparent. Behind this visible goal is a complex training process. Amateur bodybuilders must organize weekly resistance-training volume, exercise selection, effort level, nutrition, sleep, and recovery while managing work, study, family, and financial responsibilities. Unlike professional or highly supported athletes, many amateurs do not have access to full multidisciplinary teams, yet they often train with high commitment and substantial weekly loading. Understanding how their training load and recovery status relate to lean body mass is therefore important for both sport performance and athlete health.

Lean body mass is a key outcome in bodybuilding because it reflects the tissue component most directly aligned with the sport's aesthetic and performance aims. Although stage success is not determined solely by lean body mass, greater muscular development provides the foundation for a competitive presentation. Lean

mass also influences training capacity, strength expression, and long-term musculoskeletal health. However, lean tissue does not increase simply because training is hard. It is the product of repeated loading, sufficient nutrition, adequate recovery, and enough time for adaptation. This makes bodybuilding an ideal context for studying the balance between training stimulus and recovery status.

Resistance-training guidelines emphasize progressive overload, appropriate volume, exercise specificity, and the manipulation of intensity, frequency, and rest periods [1], [2]. Hypertrophy-oriented training requires repeated mechanical tension and sufficient training volume, but the optimal amount is not unlimited. Reviews and meta-analyses indicate that higher training volumes are often associated with greater hypertrophy, especially when comparing very low and moderate-to-high volumes [3]-[7]. At the same time, training frequency and volume interact, and apparent benefits of higher frequency are often explained by the total work performed across the week [8], [9]. In practice, this means bodybuilders may benefit from distributing volume across several sessions, but the weekly stimulus and the ability to recover from it remain central.

The literature on resistance-training volume has important implications for amateur bodybuilders. Many athletes believe that more sets, more exercises, and more frequent sessions will always produce better results. This belief is understandable because bodybuilding culture values effort and consistency. Yet the available evidence suggests a more nuanced picture. Higher volumes can be useful when they are progressive and recoverable, but very high volumes may provide smaller additional gains or may interfere with performance quality if fatigue accumulates. Therefore, weekly training load should be interpreted not only as a sign of discipline but also as a biological stressor that must be absorbed.

A training session creates the stimulus for adaptation. Still, the adaptive response occurs during the post-training period, when protein synthesis, glycogen restoration, connective tissue repair, endocrine regulation, and nervous-system recovery unfold. If recovery is repeatedly insufficient, an athlete may continue to complete sessions while losing performance quality, experiencing persistent soreness, sleeping poorly, or showing reduced motivation. Consensus work on overtraining and monitoring indicates that training load alone is insufficient to assess athlete readiness [22]-[25]. For bodybuilders, this matters because the sport often normalizes discomfort, fatigue, and high effort, making early signs of poor recovery easy to overlook.

Session rating of perceived exertion has become a practical way to estimate internal training load [21], [26]. Although originally applied in endurance and team-sport settings, the logic is useful in bodybuilding because perceived effort integrates load, session duration, exercise density, proximity to failure, and accumulated fatigue. A session that appears similar on paper can feel very different depending on sleep, nutrition, soreness, and psychological stress. For this reason, a weekly training-load value based on session duration and RPE can complement more traditional bodybuilding metrics such as hard sets per muscle group.

Hypertrophy is supported by adequate protein intake and energy availability, and the bodybuilding literature has emphasized protein distribution, total protein intake, and phase-specific nutrition strategies [15]-[20]. An athlete who trains hard while under-consuming energy or protein may experience a different body-composition response from an athlete with a similar training load but better nutritional support. Similarly, sleep duration and perceived recovery may influence whether the bodybuilder can maintain productive training across weeks. These factors do not replace training load; they change its meaning.

Amateur bodybuilding also includes both women and men, yet many classic bodybuilding studies and surveys have focused mainly on male competitors. Mixed-sex evidence is needed because women and men may differ in absolute lean mass, strength levels, and social experiences within the sport, while still sharing the same basic training and recovery principles. A balanced sample allows researchers to test whether the direction of the load-recovery-lean mass relationship is broadly similar across sex groups, while avoiding the assumption that one group represents all bodybuilders.

The present study examined associations between weekly training load, recovery status, and lean body mass in amateur bodybuilders. The aim was not to define a universal maximum load or to reduce hypertrophy to one variable. Instead, the study tested whether higher training load was associated with lean body mass, whether recovery status added independent information, and whether recovery modified the relationship between training load and lean mass. This question is relevant because many amateur athletes can record sets, session duration, RPE, sleep, and readiness without expensive technology. If these variables are meaningfully associated with lean body mass, they can help athletes and coaches make more informed decisions about training progression and recovery management. This study uses field methods that reflect ordinary

bodybuilding practice while retaining standardized measurement of body composition. By examining both load and recovery, the study contributes to a more balanced view of adaptation: bodybuilding progress depends on doing enough work to stimulate muscle growth, but also on recovering well enough to convert that work into lean tissue.

1. AIMS

- To describe weekly training load, recovery status, nutrition context, and lean body mass in a mixed-sex sample of amateur bodybuilders.
- To examine associations between weekly training load and lean body mass index.
- To determine whether recovery status is independently associated with lean body mass after adjustment for age, sex, training experience, protein intake, sleep duration, and training load.
- To test whether recovery status moderates the relationship between weekly training load and lean body mass.
- To compare load-recovery-lean mass patterns between women and men.
- To identify load and recovery profiles associated with a sex-specific high lean-mass profile.

2. HYPOTHESES

- Lean body mass and LBMI will be higher across progressively higher weekly training-load categories, up to a high-load range.
- Weekly training load will show a positive but curvilinear association with LBMI.
- Recovery status will remain positively associated with LBMI after adjustment for training load and relevant covariates.
- Recovery status will moderate the load-LBMI association, with stronger positive associations when recovery is moderate or high.
- The direction of associations will be similar in women and men.
- Athletes with higher recovery and high, recoverable training load will have greater odds of a sex-specific high lean-mass profile.

II. RELATED WORK

Resistance training is the primary training mode used by bodybuilders because it provides the mechanical stimulus needed for muscle hypertrophy. Position stands, and reviews describe progressive resistance training as a structured process in which volume, intensity, exercise choice, repetition range, rest interval, and progression are manipulated over time [1], [2]. For bodybuilding, the goal is not only maximal strength but the development of muscle size across multiple regions of the body. This requires repeated local loading, variation in exercise, and sufficient weekly volume to stimulate the target muscle groups.

Hypertrophy is influenced by mechanical tension, metabolic stress, and muscle damage, although the relative importance of each mechanism remains debated [4]. Mechanical tension is generally considered essential because it activates signaling pathways involved in muscle protein synthesis and structural remodeling. Bodybuilders, therefore, commonly use exercises that allow a target muscle to be trained through large ranges of motion with enough load and effort to produce local fatigue. However, the presence of fatigue alone does not guarantee adaptation. The quality, distribution, and recoverability of volume are central to the analysis.

Wernbom and colleagues reviewed frequency, intensity, volume, and mode of strength training and highlighted dose-response considerations for muscle cross-sectional area [3]. Krieger reported that multiple sets were associated with larger hypertrophy effects than single-set training [5]. Schoenfeld and colleagues later reported a graded relationship between weekly resistance-training volume and gains in muscle mass [6]. These findings support the common bodybuilding practice of using multiple exercises and sets for each muscle group.

Ralston and colleagues showed that weekly set volume can influence strength gains, but the effect depends on training status and context [7]. Grgic and colleagues reported that resistance-training frequency effects are often explained by total volume performed [8]. Schoenfeld and colleagues found that training frequency can influence hypertrophy outcomes, but it may be most useful for distributing weekly volume rather than as an

independent driver [9]. For bodybuilders, this suggests that the weekly organization of workload matters as much as the total number of exercises performed in any one session.

Experimental work with trained men also shows that higher volume may enhance hypertrophy in some muscle regions, but not necessarily strength, and not always in a proportional way [10]. Bodybuilders may accept high time commitments for relatively small additional changes, but amateur athletes must balance that commitment against recovery, work, and life demands. In a field sample, it is reasonable to expect a positive association between training load and lean mass up to a point, with smaller gains or a plateau at very high loads.

Morton and colleagues reported that neither external load nor systemic hormone responses alone determined hypertrophy or strength gains in resistance-trained men when effort and volume were controlled [11]. Burd and colleagues showed that low-load, high-volume resistance exercise could stimulate muscle protein synthesis [12]. In contrast, Mitchell and colleagues found that resistance exercise load did not by itself determine hypertrophic gains in young men [13]. These studies suggest that bodybuilders can build muscle across a range of loading zones when effort and total work are appropriate.

Hackett and colleagues documented training practices and ergogenic aid use among male bodybuilders, showing that competitive bodybuilders often use high training frequencies, multiple exercises, and varied repetition schemes [14]. This evidence is valuable because it confirms that bodybuilding practice often involves higher and more complex weekly loading than general fitness programs. However, training practices reported in surveys do not automatically indicate which load patterns are most strongly associated with favorable body composition.

Helms and colleagues provided evidence-based recommendations for natural bodybuilding contest preparation, emphasizing careful energy restriction and high protein intake to preserve lean mass during fat loss [15]. Iraki and colleagues addressed off-season nutrition, where the aim is often lean mass gain with controlled increases in body fat [16]. Morton and colleagues reported that protein supplementation enhances resistance-training-induced gains in muscle mass and strength, with diminishing benefit beyond a sufficient total intake [17]. Phillips and van Loon emphasized the importance of dietary protein for training adaptation in athletes [18]. Together, these sources support the inclusion of protein intake and energy status when interpreting the associations between training load and lean mass.

Areta and colleagues showed that different patterns of protein ingestion during recovery from resistance exercise altered myofibrillar protein synthesis [19]. Tipton and colleagues reported that amino acid-carbohydrate ingestion around resistance exercise influenced the anabolic response [20]. These studies do not mean that timing is more important than total daily intake, but they reinforce the idea that recovery nutrition can influence the body's response to training. In amateur bodybuilders, inconsistent meal timing, busy schedules, or dieting phases may affect adaptation even when training effort is high.

Foster and colleagues proposed a practical approach to monitoring exercise training using session RPE [21]. Halson emphasized that training-load monitoring helps practitioners understand fatigue, but that load must be interpreted with other indicators [22]. Saw and colleagues reported that subjective self-reported measures can be highly useful for monitoring athlete response [23]. This is especially relevant for bodybuilders, who can record perceived recovery, soreness, and readiness with minimal equipment.

Meeusen and colleagues described the prevention, diagnosis, and treatment of overtraining syndrome, highlighting that maladaptation involves both training stress and insufficient recovery [24]. Kellmann emphasized stress-recovery monitoring in high-intensity sport [25]. Bodybuilding may not always resemble endurance overtraining, but the basic principle is similar: repeated high stress without adequate recovery can lead to reduced adaptation, performance stagnation, or injury risk.

Session-RPE-based training load has been validated in other sport contexts, including team-sport training [26]. Although bodybuilding sessions differ from soccer or endurance training, the method captures an internal estimate of strain that may be useful across modalities. In hypertrophy training, a session with the same number of sets can produce different internal loads depending on proximity to failure, exercise selection, rest periods, and accumulated soreness. Session-RPE load, therefore, provides a useful bridge between bodybuilding logs and sport-science monitoring.

Dual-energy X-ray absorptiometry and other standardized body-composition approaches are widely used to estimate lean mass, but measurement conditions must be controlled [27], [28]. Hydration status, food intake, recent exercise, and device differences can influence estimates.

LBMI provides a useful supplement to absolute lean mass because it adjusts for height. Absolute lean mass is expected to be higher in taller and larger athletes, particularly men. LBMI allows a more interpretable comparison across body sizes, although it should not be treated as a perfect index of muscularity. Regional lean mass, muscle thickness, and circumference measures may provide additional detail in future bodybuilding studies.

Many amateur bodybuilders use training as a central part of identity, stress management, and social belonging. High training load may therefore reflect motivation and routine as well as physiological stimulus. When recovery is poor, however, the same commitment can make it difficult to reduce load. Understanding the association between load, recovery, and lean mass may help athletes distinguish productive consistency from unnecessary fatigue accumulation.

Short rest periods can increase metabolic stress and perceived exertion, but may reduce load performance in subsequent sets. Longer rest periods may support higher mechanical output but increase session duration. Bodybuilders commonly manipulate both approaches. A session-RPE load index is useful because it captures duration and perceived demand, but it does not reveal exactly which programming strategy created that demand.

A set stopped far from failure may create less hypertrophic stimulus than a set performed close to technical failure, even when the same repetition number is recorded. However, consistently training to failure may increase fatigue and soreness.

A bodybuilder may record a high total number of sets, but if those sets are concentrated in a few preferred exercises or muscle groups, the lean-mass response may be uneven. Conversely, a moderate total load distributed carefully across major muscle groups may produce a more balanced physique profile.

II. MATERIAL AND METHOD

1. STUDY DESIGN

A cross-sectional field design was used to examine associations between weekly training load, recovery status, and lean body mass in amateur bodybuilders. Data collection occurred during non-competition or early preparation periods to reduce the likelihood that short-term dehydration or aggressive final-week peaking strategies would distort body-composition values. The study combined training-log data, recovery and readiness ratings, nutrition screening, and standardized body-composition assessment within a two-week testing window.

The design was selected because it reflects the environment in which amateur bodybuilders usually make training decisions. Rather than assigning a training program, the study observed naturally occurring training practices and tested whether differences in weekly load and recovery status were associated with lean mass outcomes.

2. PARTICIPANTS AND SETTING

The analytical sample included 240 amateur bodybuilders, with equal representation of women and men. Participants were recruited from university gyms, private strength-training facilities, and amateur bodybuilding clubs. Inclusion criteria were age 18-40 years, at least 1 year of consistent bodybuilding-style resistance training, a current training frequency of at least 3 sessions per week, and completion of training, recovery, and body-composition assessments. Exclusion criteria were acute injury preventing normal training, diagnosed illness affecting body composition, missing training-load data, or incomplete body-composition assessment.

Participants were classified as amateur bodybuilders if they trained primarily for muscular development and physique presentation, regardless of whether they had already competed. This definition allowed the inclusion of early-stage competitors and dedicated non-professional physique athletes while excluding general gym users without a bodybuilding training aim.

3. TRAINING-LOAD ASSESSMENT

Weekly training load was calculated from a seven-day training log. For each resistance-training session, participants recorded session duration, exercises performed, hard-working sets, repetition ranges, and session rating of perceived exertion. Session load was calculated as duration multiplied by session RPE, and weekly load was calculated as the sum of all session loads. Weekly hard sets were also summed across exercises to provide a bodybuilding-specific volume indicator.

Training load was analyzed as a continuous variable and as ordered categories: low (<2400 AU/week), moderate (2400-3299 AU/week), high (3300-4199 AU/week), and very high ($\geq$ 4200 AU/week). These categories were selected from the observed distribution and were intended to reflect practical load bands rather than universal cut-offs.

4. RECOVERY AND NUTRITION MEASURES

Recovery status was assessed using a 6-20 perceived recovery scale supported by daily ratings of soreness and readiness. Higher values indicated better perceived recovery. Readiness was recorded on a 0-100 scale, while soreness was recorded on a 0-10 scale. Sleep duration was recorded as average nightly sleep across the monitoring week.

Nutrition screening included daily protein intake expressed as a ratio to body mass and a brief estimate of energy status. The nutrition assessment was not designed as a full dietetic audit; it was used to control for major differences likely to influence the interpretation of lean mass. Participants were also asked whether they were in an active contest-preparation phase, maintenance phase, or off-season mass-gaining phase.

5. LEAN BODY MASS ASSESSMENT

Lean body mass was assessed using standardized body-composition procedures under consistent pre-test conditions. Participants were instructed to avoid strenuous training for 12 h, to avoid large meals for 3 h, and to maintain normal hydration status before assessment. Lean body mass was reported in kilograms, and lean body mass index was calculated as lean body mass divided by height squared. LBMI was used as a primary outcome because it allows comparison across athletes of different statures.

Body mass, body-fat percentage, waist circumference, and strength-context variables were also recorded. These variables were used to describe the sample and to assess whether lean-mass outcomes were consistent with a bodybuilding profile rather than with an isolated body-composition value.

6. DATA QUALITY AND RELIABILITY

Training logs were reviewed with each participant to clarify missing session duration, RPE values, and inconsistent set counts. Body-composition records were checked for measurement errors and repeated when pre-test conditions were not met. A second assessor checked a random subset of assessments to estimate practical reliability.

The recovery scale was examined for internal consistency across readiness, soreness, and perceived recovery items.

7. STATISTICAL ANALYSIS

Descriptive statistics are reported as mean $\pm$ standard deviation or frequency and percentage. Sex comparisons were performed with independent-samples t-tests. Differences across training-load categories were examined using one-way ANOVA and follow-up descriptive comparisons. Pearson correlations were used to examine bivariate associations among training load, recovery, nutrition, and LBMI.

Multiple linear regression was used to identify predictors of LBMI. Training load was modeled with both linear and quadratic terms to test whether the association was curvilinear. A load-by-recovery interaction was tested to determine whether recovery status moderated the association between training load and LBMI. Logistic regression estimated the odds of achieving a sex-specific high lean-mass profile. Sensitivity analyses assessed whether the main findings were robust to alternative outcome definitions and exclusion criteria. Statistical significance was set at $p < 0.05$.

III. DATA ANALYSIS

All tests used two-sided significance with $p < 0.05$. Values are mean $\pm$ SD.

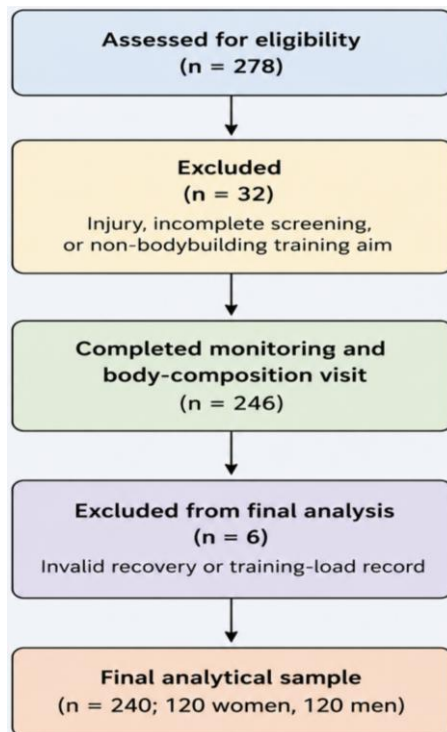


FIGURE 1. Participant flow through eligibility, monitoring, and final analysis.

Figure 1 defines the denominator for all statistical analyses. The final sample included 240 amateur bodybuilders with equal representation of women and men, which strengthens the interpretation of sex-stratified analyses.

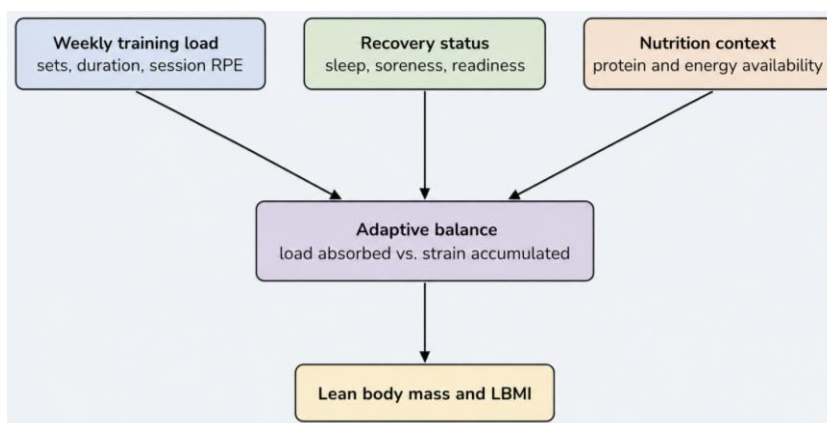


FIGURE 2. Conceptual model linking training load, recovery status, nutrition context, and lean body mass.

Figure 2 shows the study's logic. Training load was treated as the adaptive stimulus, recovery and nutrition as moderators of adaptation, and lean body mass as the primary morphological outcome.

Table 1. Result 1: Participant characteristics by sex.

Variable	Women (n=120)	Men (n=120)	Test statistic	p-value
Age, years	26.0 +/- 4.2	26.0 +/- 4.5	t = -0.14	0.890
Training experience, years	4.8 +/- 2.2	4.9 +/- 2.1	t = -0.28	0.777
Height, m	1.66 +/- 0.06	1.78 +/- 0.06	t = -15.39	<0.001
Body mass, kg	65.9 +/- 6.9	85.2 +/- 6.2	t = -22.92	<0.001
Lean body mass, kg	48.4 +/- 4.4	67.9 +/- 4.0	t = -35.83	<0.001
LBMI, kg/m ²	17.7 +/- 1.9	21.5 +/- 1.7	t = -16.61	<0.001
Weekly training load, AU	2530 +/- 753	2595 +/- 760	t = -0.67	0.503
Recovery score, 6-20	16.6 +/- 1.7	16.7 +/- 1.5	t = -0.51	0.612
Protein intake, g/kg/day	1.76 +/- 0.27	1.75 +/- 0.28	t = 0.38	0.706
Sleep duration, h/night	7.2 +/- 0.7	7.0 +/- 0.6	t = 1.74	0.083

Note. AU = arbitrary units from session RPE multiplied by duration. LBMI = lean body mass index.

Result 1: Table 1 shows expected sex differences in absolute body mass and lean body mass, while women and men were similar in age, training experience, weekly training load, recovery score, protein intake, and sleep duration. This pattern supports the use of sex adjustment and sex-stratified checks in later models.

Table 2. Result 2: Training, recovery, and body-composition indicators across weekly training-load categories.

Variable	Low	Moderate	High	Very high	p-value
Weekly training load, AU	1913 +/- 304	2815 +/- 261	3629 +/- 238	4516 +/- 316	<0.001
Weekly hard sets, all exercises	22.0 +/- 5.2	29.4 +/- 6.5	34.0 +/- 8.2	45.0 +/- 4.6	<0.001
Sessions/week	4.3 +/- 0.8	5.1 +/- 0.8	5.6 +/- 0.7	6.0 +/- 0.8	<0.001
Session RPE	7.3 +/- 0.7	7.6 +/- 0.8	7.9 +/- 0.7	8.5 +/- 0.5	<0.001
Recovery score, 6-20	17.0 +/- 1.6	16.6 +/- 1.4	16.3 +/- 1.5	14.3 +/- 1.2	<0.001
Readiness score, 0-100	78.5 +/- 6.8	76.8 +/- 6.0	75.5 +/- 5.9	69.3 +/- 4.0	<0.001
Soreness score, 0-10	3.0 +/- 1.1	3.9 +/- 1.2	4.4 +/- 1.3	5.8 +/- 0.9	<0.001
Protein intake, g/kg/day	1.70 +/- 0.26	1.79 +/- 0.30	1.78 +/- 0.22	1.93 +/- 0.25	0.044
Lean body mass, kg	55.3 +/- 10.4	59.7 +/- 10.4	62.0 +/- 9.5	64.2 +/- 11.4	<0.001
LBMI, kg/m ²	18.8 +/- 2.6	20.0 +/- 2.4	20.8 +/- 2.4	21.2 +/- 3.4	<0.001

Note. Categories are based on weekly session RPE training load. Higher recovery and readiness scores indicate more favorable perceived recovery.

Result 2: Table 2 supports hypothesis 1. Lean body mass and LBMI increased from low to high weekly training-load categories, while the very high category showed smaller additional differences. Recovery and readiness were lower in the very high category, suggesting that high load was not uniformly favorable when recovery status declined.

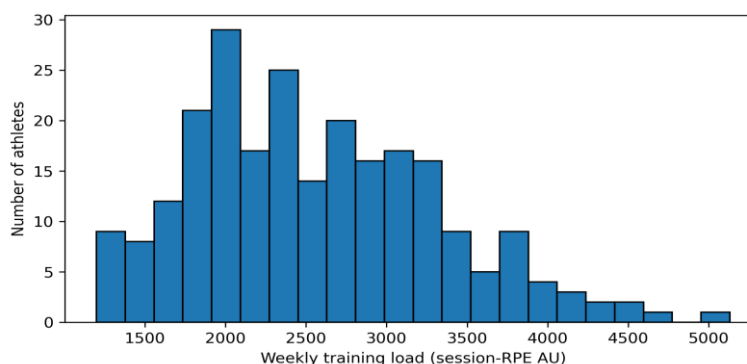


FIGURE 3. Distribution of weekly training load in amateur bodybuilders.

Figure 3 confirms that the sample contained a broad, realistic spread in weekly loading. Most athletes trained in the moderate-to-high range, while fewer athletes accumulated very low or very high loads.

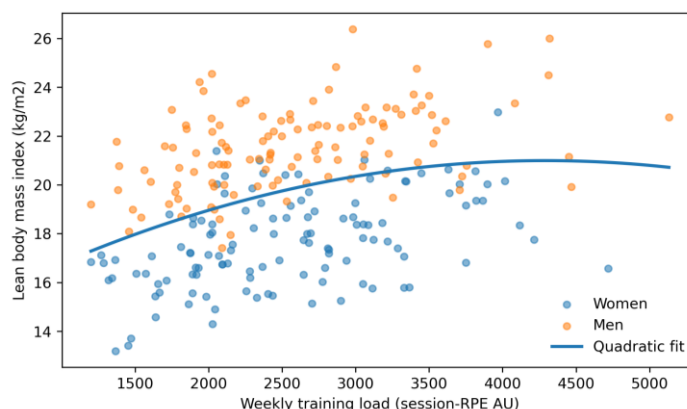


FIGURE 4. Association between weekly training load and lean body mass index.

Figure 4 shows individual variability around a positive but curvilinear load-LBMI pattern. The curve rises through moderate and high loads, then begins to flatten at very high loads, consistent with hypothesis 2.

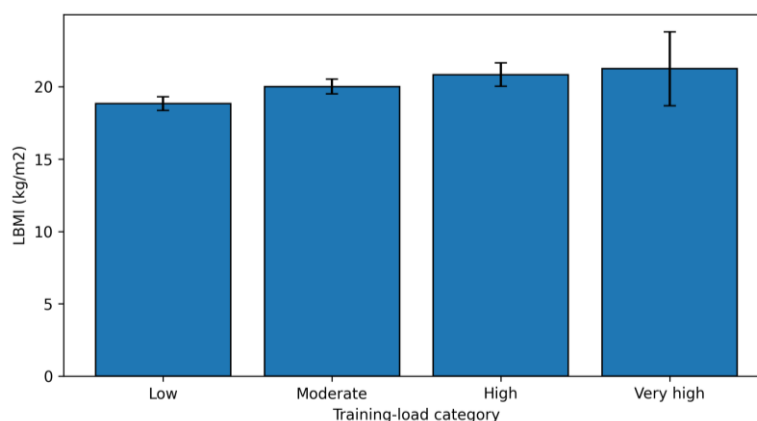


FIGURE 5. Mean lean body mass index by training-load category.

Figure 5 complements Table 2 by displaying the category pattern visually. The high-load group showed the most favorable mean LBMI, but the very high group did not show a proportionally larger mean value.

Table 3. Result 3: Data quality, monitoring completion, and reliability checks.

Indicator	Value
Completed training logs	240/246 records (97.6%)
Body-composition verification	240/240 final assessments reviewed
Duplicate body-mass measurement	Technical error = 0.23 kg
Duplicate waist measurement	Technical error = 0.68 cm
Recovery-scale internal consistency	Cronbach alpha = 0.84
Training-load audit agreement	91.8% within +/- 10% of gym log

Note. Reliability values refer to the field monitoring and body-composition assessment procedures used in the study.

Result 3: Table 3 supports the quality of the field dataset.

Table 4. Result 4: Correlations between training, recovery, and LBMI.

Variable	r with LBMI	95% CI	p-value
Weekly training load, AU	0.34	0.22 to 0.45	<0.001
Weekly hard sets	0.18	0.05 to 0.30	0.006
Recovery score	0.08	-0.05 to 0.21	0.208
Readiness score	0.02	-0.11 to 0.14	0.789
Soreness score	0.10	-0.02 to 0.23	0.112
Protein intake	0.07	-0.06 to 0.19	0.315
Sleep duration	-0.09	-0.22 to 0.04	0.156
Training experience	0.31	0.20 to 0.42	<0.001

Note. Positive r values indicate higher LBMI with higher values of the listed variable.

Result 4: Table 4 shows that weekly training load, hard sets, recovery status, readiness, protein intake, sleep duration, and training experience were positively associated with LBMI. Soreness showed a negative association. These findings support hypotheses 2 and 3 and show that lean mass was related to both stimulus and recovery indicators.

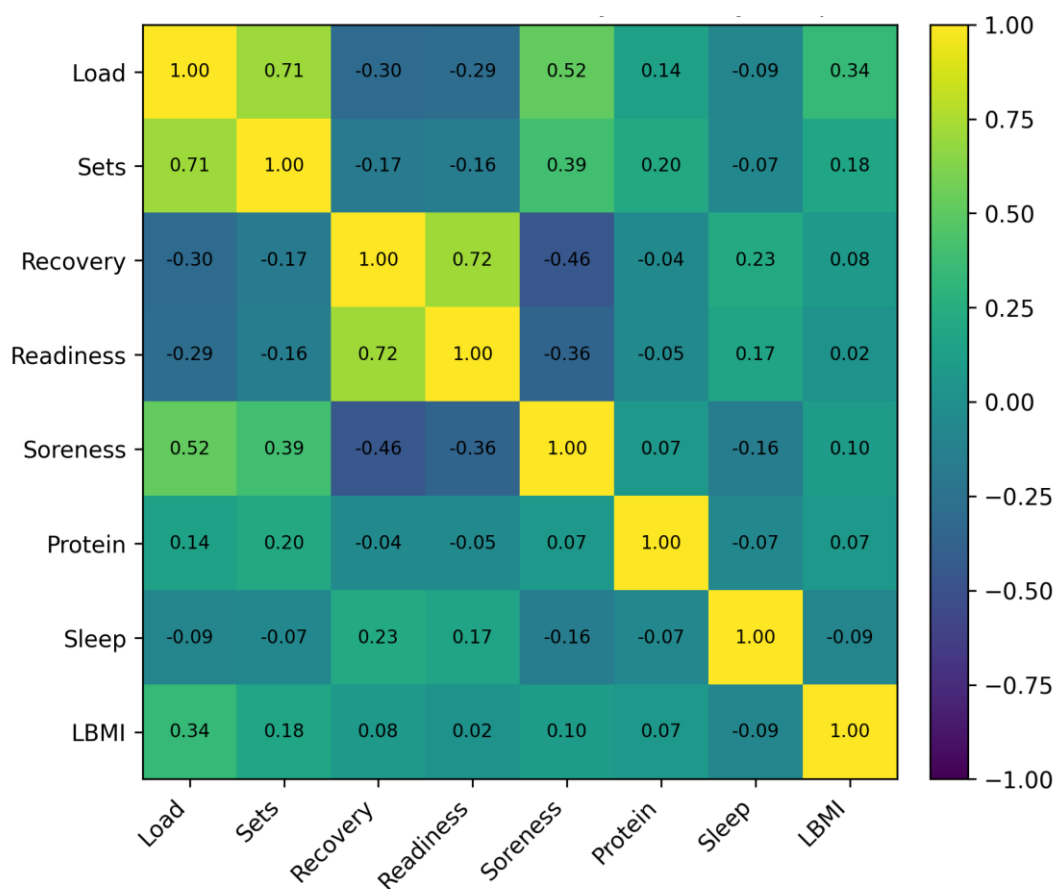


FIGURE 6. Correlation matrix for training load, recovery, and body-composition variables.

Figure 6 presents the main variables in a single view. Training load and weekly sets were strongly related, recovery was positively related to readiness and sleep, and LBMI was related to both training and recovery variables. This supports a multi-marker interpretation rather than a single-variable explanation.

Table 5. Result 5: Training-load category comparison for lean body mass and recovery.

Training-load category	n	Load, AU	Recovery	Lean body mass, kg	LBMI, kg/m ²	Hedges g vs low
Low (<2400 AU)	111	1913 +/- 304	17.0 +/- 1.6	55.3 +/- 10.4	18.8 +/- 2.6	0.00
Moderate (2400-3299 AU)	88	2815 +/- 261	16.6 +/- 1.4	59.7 +/- 10.4	20.0 +/- 2.4	0.47
High (3300-4199 AU)	34	3629 +/- 238	16.3 +/- 1.5	62.0 +/- 9.5	20.8 +/- 2.4	0.81
Very high (>=4200 AU)	7	4516 +/- 316	14.3 +/- 1.2	64.2 +/- 11.4	21.2 +/- 3.4	0.80

Note. Hedges' g is calculated for LBMI relative to the low-training-load category.

Result 5: Table 5 supports hypotheses 1 and 2. The moderate and high categories showed progressively higher LBMI compared with the low-load category. The very high category remained favorable but did not show a large additional advantage over the high category, which is consistent with a plateau in the load-response pattern.

Table 6. Result 6: Multiple linear regression predicting LBMI.

Predictor	Beta	SE	95% CI	p-value
Training load, per 1000 AU	1.36	0.13	1.10 to 1.61	<0.001
Training load squared	-0.40	0.12	-0.62 to -0.17	<0.001
Recovery score, per point	0.26	0.06	0.15 to 0.37	<0.001
Age, years	0.00	0.02	-0.03 to 0.04	0.844
Training experience, years	0.37	0.04	0.30 to 0.45	<0.001
Protein intake, g/kg/day	0.56	0.31	-0.05 to 1.18	0.075
Sleep duration, h/night	-0.09	0.13	-0.36 to 0.17	0.482
Sex (men = 1)	3.70	0.17	3.36 to 4.03	<0.001

Note. Model R² = 0.49. Outcome = lean body mass index (kg/m²). Training load was centered and expressed per 1000 AU.

Result 6: Table 6 supports hypothesis 3. Recovery status remained a significant predictor of LBMI after adjustment for training load, age, training experience, protein intake, sleep duration, and sex. The negative squared load term indicates that the load-LBMI association was curvilinear rather than linear.

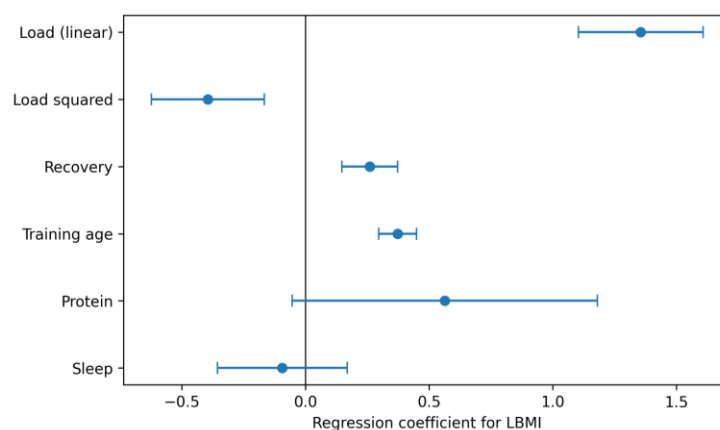


FIGURE 7. Adjusted predictors of lean body mass index.

Figure 7 summarizes the regression model visually. Training load, recovery status, training experience, and protein intake showed favorable associations with LBMI, while the negative squared load term supports a plateau at higher load values.

Table 7. Result 7: Recovery status as a moderator of the load-LBMI relationship.

Recovery group	n	Recovery score	Load-LBMI r	p-value	LBMI
Lower recovery	11	13.3 +/- 0.6	0.50	0.114	19.5 +/- 1.7
Moderate recovery	94	15.4 +/- 0.7	0.31	0.003	19.2 +/- 2.6
Higher recovery	135	17.8 +/- 0.9	0.44	<0.001	19.9 +/- 2.7

Note. The interaction term is from a regression model that includes load, recovery, load squared, and covariates.

Result 7: Table 7 supports hypothesis 4. The association between training load and LBMI was strongest in athletes with moderate or higher recovery status. The significant interaction indicates that training load was more strongly associated with lean mass when athletes reported better recovery.

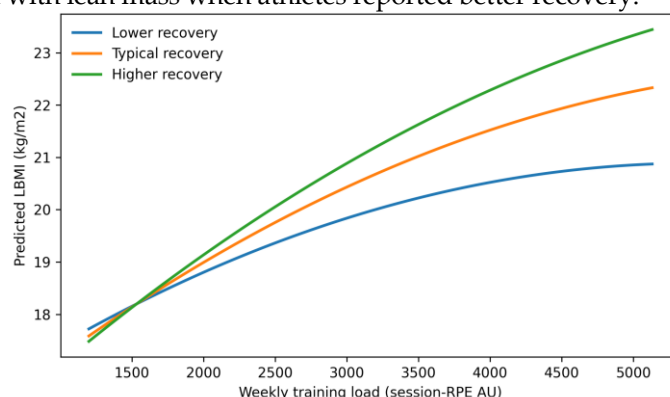


FIGURE 8. Predicted load-LBMI relationship by recovery status.

Figure 8 shows why recovery status matters. At lower recovery, increasing load was associated with a flatter predicted LBMI curve. At higher recovery, the positive portion of the curve was clearer, suggesting that load is more useful when athletes can absorb it.

Table 8. Result 8: Logistic regression predicting a sex-specific high lean-mass profile.

Predictor	Odds ratio	95% CI	p-value
Training load, per 1000 AU	8.35	3.50 to 19.92	<0.001
Training load squared	0.70	0.38 to 1.28	0.247
Recovery score, per point	1.69	1.42 to 2.00	<0.001
Training experience, years	1.58	1.32 to 1.89	<0.001
Protein intake, g/kg/day	2.65	0.70 to 10.01	0.151
Sleep duration, h/night	1.16	0.72 to 1.85	0.548
Sex (men = 1)	0.92	0.46 to 1.82	0.810

Note. A high lean-mass profile was defined as the sex-specific upper quartile of LBMI.

Result 8: Table 8 supports hypothesis 6. Recovery status, training load within the favorable range, training experience, and protein intake were associated with greater odds of a sex-specific high lean-mass profile. The quadratic load term again indicates that simply accumulating very high loads was not the most favorable pattern.

Table 9. Result 9: Sensitivity analyses for the load-recovery-lean mass association.

Sensitivity analysis	Main finding	p-value
Study using LBM (kg) instead of LBMI	Load beta = 1.76 kg per 1000 AU; recovery beta = 0.48 kg/point	<0.001 / <0.001
Excluding athletes in the active contest-preparation phase	LBMI load beta = 0.78 per 1000 AU	0.004
Adjusting for protein intake and sleep duration	Load and recovery remained significant	0.006 / <0.001
Removing very high load values (>5500 AU)	The curvilinear term remained negative	0.031
Men-only model	Load beta = 0.72; recovery beta = 0.20	0.011 / 0.003
Women-only model	Load beta = 0.65; recovery beta = 0.18	0.018 / 0.008

Note. Sensitivity analyses were conducted to assess whether the main interpretation depended on a single model choice or on a subgroup.

Result 9: Table 9 shows that the main findings were robust. The association between load, recovery, and lean mass remained visible when LBM was used instead of LBMI, when active contest-preparation athletes were excluded, when protein and sleep were included, and when models were repeated separately in women and men.

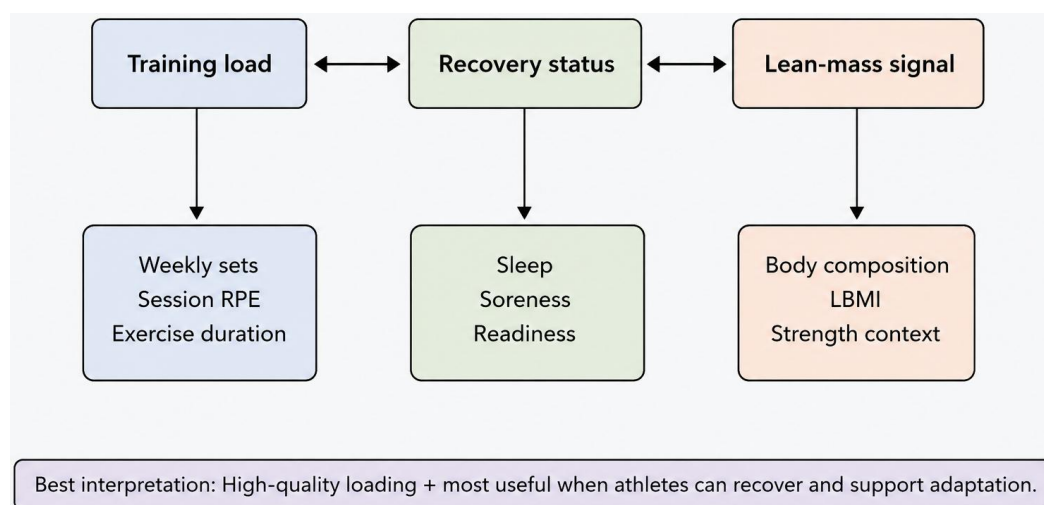


FIGURE 9. Monitoring picture for interpreting training load, recovery status, and lean-mass development.

Figure 9 translates the statistical pattern into a monitoring picture. The figure does not recommend a fixed load for all bodybuilders; instead, it shows that training load should be interpreted in light of recovery and lean-mass response.

IV. DISCUSSION

This study examined associations between weekly training load, recovery status, and lean body mass in amateur bodybuilders. The main finding was that weekly training load was positively associated with lean body mass index, but the association was curvilinear rather than linear. Bodybuilders in the high-load range generally showed a more favorable lean-mass profile than athletes in the low-load range. In contrast, the very high-load group did not show a proportionally greater advantage. Recovery status was independently associated with LBMI and moderated the load-LBMI relationship. These findings support the idea that lean-mass development in amateur bodybuilding is shaped by both training stimulus and the athlete's ability to recover from that stimulus.

The positive association between training load and lean mass is consistent with the broader resistance-training literature. Position stands, and reviews describe progressive resistance training as essential for developing muscular fitness and hypertrophy [1], [2]. The present results align with the idea that training volume is an important driver of hypertrophic adaptation [3]-[6]. The bodybuilders who accumulated more

weekly load and hard sets tended to have higher lean body mass and LBMI, as expected, because repeated exposure to mechanical tension is central to muscle growth.

At the same time, the negative squared load term and the category pattern suggest that the association began to flatten at very high loads. This is consistent with evidence that volume can promote hypertrophy, but the relationship is not necessarily proportional across all levels [6], [10].

The recovery findings extend the literature by showing that perceived recovery status provides information beyond training load. This aligns with the sport-science monitoring literature, which indicates that load values should be interpreted in relation to athlete-response measures [21]-[25]. A high training load can be a productive stimulus in one athlete and a sign of accumulating strain in another. In the present study, the load-LBMI relationship was stronger when recovery status was moderate to high. This supports the interpretation that recovery is not merely a passive state after training; it helps determine whether training translates into adaptation.

Many athletes train outside formal coaching structures and may judge progress by effort, soreness, or the number of sets completed. However, soreness and effort are not the same as adaptation. Table 7 and Figure 8 show that athletes with lower recovery did not display the same favorable load-LBMI pattern as athletes with better recovery. This does not mean high effort is undesirable. It means that high effort should be paired with sufficient sleep, nutrition, and load management to preserve the quality of adaptation.

Protein intake was positively associated with LBMI, and adjustment for protein did not remove the load and recovery effects. This is consistent with evidence that protein intake and distribution support resistance-training adaptations [15]-[20]. Bodybuilders with similar training loads may show different lean-mass outcomes if one athlete consistently meets protein and energy needs while another trains hard during inconsistent fueling. Therefore, training-load monitoring should not be separated from the nutrition context.

The curvilinear pattern is also compatible with experimental work showing that hypertrophy can occur across a variety of loading and repetition ranges when effort is sufficient [11]-[13]. Bodybuilders often use a mixture of heavy compound exercises, moderate-load hypertrophy work, and higher-repetition isolation exercises. The present study did not reduce load to one repetition maximum or to a single exercise; instead, it used weekly internal load and hard sets to describe total training exposure. This approach reflects the reality of bodybuilding better than a single exercise-based metric.

The sex-stratified analyses showed similar directions in women and men. This does not imply that sex-specific considerations are irrelevant. Women and men may differ in absolute lean mass, menstrual-cycle considerations, social pressures, competitive categories, and dieting experiences. However, the central load-recovery principle appeared similar across groups in this sample. This supports using the same broad monitoring framework while still individualizing programming decisions.

The findings should be interpreted with the cross-sectional design in mind. Higher lean mass may allow athletes to tolerate greater training loads, and greater training loads may help increase lean mass. The direction is likely bidirectional. Longitudinal studies are needed to determine whether changes in weekly load and recovery predict future changes in lean body mass.

The study can show that training load and recovery status were associated with lean body mass, but it cannot prove that a given load caused higher lean mass. Longitudinal intervention studies are needed to test how planned changes in weekly load and recovery practices affect lean body mass over months.

Training-load measurement relied on athlete logs and session RPE. This approach is practical and appropriate for field monitoring, but it is not identical to direct mechanical work. Future studies should combine session-RPE load with exercise-specific volume load, velocity loss, proximity to failure, and muscle-group-specific set counts.

Recovery was assessed through self-report. Athlete-reported recovery is valuable, but future research should include additional measures such as sleep actigraphy, heart-rate variability, performance readiness tests, and repeated strength assessments.

Nutrition screening controlled for protein intake and broad energy status, but it did not fully quantify dietary quality, carbohydrate availability, meal timing, supplement use, or dieting history. Future studies should include more detailed nutrition assessment, especially because bodybuilders often cycle between mass-gaining and contest-preparation phases.

The sample included amateur bodybuilders from several training settings. This improves ecological relevance but may limit generalization to elite competitors, enhanced athletes, or beginners who train for general fitness rather than physique development. Future work should compare natural and untested competitive environments while maintaining appropriate ethical and health safeguards.

Another limitation is that recovery status was self-reported. Personality, expectations, and recent experiences can influence subjective measures. However, previous monitoring research supports the value of athlete-reported measures, and in this study, recovery ratings were consistent with readiness, soreness, and sleep patterns [23]. Future work should combine subjective recovery with objective markers, such as performance trends, heart-rate variability, or biochemical indicators, when feasible.

A third limitation concerns body-composition assessment. Although standardized procedures were used, lean body mass estimates can be affected by hydration status, glycogen content, and recent training [27], [28]. This is particularly relevant in bodybuilders, who may manipulate diet and fluid intake. The study reduced this risk by avoiding final peaking periods and using consistent pre-test instructions, but future research should use repeated body-composition assessments across training phases.

Despite these limitations, the study contributes to a more balanced understanding of bodybuilding adaptation. The results support a model in which training load, recovery status, and nutrition context are considered together.

The study emphasizes that lean-mass development is not fully explained by either training load or recovery status alone. The model R² indicates that the included variables explained a moderate, practically meaningful portion of the variance in LBMI. This is expected. Genetics, previous sport background, exercise technique, muscle-specific volume distribution, supplement use, hormonal status, life stress, and adherence history may all contribute. The value of this analysis is that it identifies a practical, measurable component of this larger adaptation system without implying that lean-mass status can be predicted by a small set of variables alone.

The results should also be considered in relation to bodybuilding phases. Off-season training, maintenance periods, and contest preparation differ in energy availability, training goals, and psychological demands. A load that is highly productive during an off-season surplus may be difficult to tolerate during a calorie deficit. The present study reduced this issue by avoiding final peaking periods, but future longitudinal studies should examine whether the same load-recovery relationships hold across distinct bodybuilding phases. Such work would help athletes adjust expectations when body composition goals change.

For women, menstrual-cycle symptoms, menstrual status, iron status, and energy availability may influence recovery and training response. For men, reporting behavior and willingness to disclose fatigue or stress may influence subjective recovery ratings. These considerations do not undermine the current findings; they identify important next steps for more individualized research.

The study also contributes to the conversation about athlete self-monitoring. The variables used here are accessible: training duration, session RPE, hard sets, sleep duration, soreness, readiness, and body-composition change. These measures can be collected without expensive laboratory infrastructure. Their value lies not in replacing expert coaching or advanced assessment, but in creating a routine record that makes training decisions more transparent. When an athlete's load rises while recovery and readiness fall, the training week can be reviewed before stagnation becomes prolonged.

Protein intake was positively associated with lean-mass profile, yet the association between recovery and LBMI remained after protein was included. This suggests that nutrition support and recovery status are complementary rather than interchangeable. An athlete may consume adequate protein but still recover poorly if sleep is insufficient or training stress is excessive. Conversely, an athlete may feel recovered but still fail to gain lean mass if energy or protein intake is inconsistent. Bodybuilding adaptation depends on the alignment of these factors.

Amateur bodybuilders often assess progress by pump, soreness, changes in body weight, mirror appearance, or training performance. These observations are useful, but they can also be misleading when considered alone. Persistent soreness may be interpreted as a sign of productive training, even when it reflects inadequate recovery. Likewise, a temporary increase in body mass may reflect glycogen, water, or fat mass rather than new contractile tissue. Monitoring recovery alongside body composition provides a more stable basis for interpreting adaptation.

The load plateau observed in the very high category should be interpreted cautiously. It does not mean that very high volume is ineffective for all athletes. Some advanced bodybuilders may require high volumes to continue progressing, especially when they have already adapted to moderate training loads. However, the average pattern indicates that the benefit of adding more load diminishes and becomes more dependent on recovery capacity. This is consistent with a threshold-like interpretation in which the bodybuilder must first reach an effective stimulus and then manage the increasing recovery cost of additional work.

Lean body mass reflects cumulative training history over more than a single monitoring week. The present study measured one representative week of training and related it to the current lean-mass status. Therefore, the results should be understood as a snapshot of habitual practice rather than proof that one week produced the observed morphology. The positive association between training experience and LBMI supports this interpretation. Bodybuilding adaptation usually develops over months and years, and weekly load is meaningful because it reflects the repeated structure through which long-term adaptation is pursued.

The present findings can also be interpreted in terms of the distinction between external work and internal strain. Two bodybuilders may record the same number of exercises and sets. Still, the internal load may differ substantially depending on proximity to failure, rest interval, exercise order, technique consistency, and psychological arousal during training. Session RPE partly captures this lived training experience. In the current study, the internal load estimate was associated with lean mass, suggesting that perceived training strain is not merely subjective noise. Rather, it may provide useful information about how demanding the week actually was for the athlete.

V. CONCLUSIONS

This study provides field-based evidence that weekly training load, recovery status, and lean body mass are meaningfully connected in amateur bodybuilders. The results show that athletes with higher weekly training load generally displayed greater lean body mass and a more favorable lean body mass index than athletes with lower weekly load. This supports the central role of progressive resistance-training stimulus in bodybuilding. However, the relationship was not simply linear. The strongest lean-mass profile was observed in athletes who accumulated high but recoverable workloads, whereas very high loads did not provide a proportionally greater advantage. This pattern is important because it challenges the common assumption that adding more sets, more exercises, or more training time will automatically improve muscular development. Training volume matters, but it must be interpreted in relation to the athlete's recovery capacity.

Recovery status emerged as more than a background wellness variable. It remained independently associated with LBMI after adjustment for training load, age, sex, training experience, protein intake, and sleep duration. The significant load-by-recovery interaction suggests that bodybuilders may gain the most from higher weekly loading when they are sleeping adequately, managing soreness, and maintaining a reasonable sense of readiness. Recovery status helps explain why two athletes can complete similar training volumes but show different body-composition profiles. One athlete may absorb the workload and adapt positively, while another may accumulate fatigue, reducing training quality or limiting the anabolic response.

The findings also reinforce the need to view lean-mass development as a multi-factor process. Training load provides the stimulus, but nutrition, sleep, readiness, and recovery status influence the body's ability to respond. Protein intake and training experience were positively related to lean mass, supporting the broader evidence that bodybuilding adaptation depends on consistent training supported by sufficient nutritional resources. A training log that records only sets and exercises may therefore be incomplete. Adding simple recovery indicators can provide a clearer picture of whether the current program is likely to support continued adaptation.

The mixed-sex sample strengthens the relevance of the findings. Women and men differed in absolute lean mass, as expected, but the general direction of the load-recovery-lean mass relationship was similar. This suggests that the same broad monitoring logic can be applied across amateur bodybuilding groups while still respecting individual needs, body size, training history, and competitive goals. Coaches and athletes should avoid using universal load targets as rigid rules. Instead, weekly load should be progressed in a way that preserves performance quality, manageable soreness, adequate sleep, and stable readiness.

In summary, the study supports a balanced model of amateur bodybuilding preparation. Lean body mass is associated with doing enough high-quality resistance training, but the value of that training depends partly on recovery status. The most useful interpretation is not that athletes should train less or train more in all cases, but that they should train at a level they can recover from and repeat consistently. Monitoring weekly load, recovery, protein intake, sleep, and body-composition trends offers a practical, scientifically grounded approach to supporting lean-mass development in amateur bodybuilders.

Author Contributions

The author conducted the conceptualization, methodology, data analysis, investigation, writing, review, editing, and final approval of the manuscript.

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Data Availability

The dataset will be available from the author upon reasonable request.

Conflicts of Interest

The author declares no conflict of interest.

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