



Measuring the Parameters of Maximum Muscle Strength, Muscle Mass, Muscle Damage in Active Adult Males after Low-Load High-Repetition with High-Load Low-Repetition Resistance Training

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Abstract

Objectives. This study aimed to evaluate the effects of high-load, low-repetition (HLLR) and low-load, high-repetition (LLHR) resistance training protocols on muscle strength, muscle mass, and muscle damage in active adult males.

Materials and methods. This quasi-experimental study involved 28 active adult males aged 18-22 years with a body mass index of 19-23 kg/m² selected to actively participate in the study and given HLLR and LLHR interventions with a frequency of 3x/week for 4 weeks. Data collection was carried out by assessing maximum muscle strength, muscle mass, and muscle damage between baseline (pre) and week 4 (post). Statistical analysis used an independent sample t-test, with a significance level of 95%.

Results. There were significant differences between HLLR and LLHR interventions in max strength lower body (effect size (ES): 1.024), max strength upper body (ES: 1.241), and muscle mass (ES: 1.184) ($p < 0.05$). Meanwhile, CK activity was found to be significantly reduced in LLHR compared to HLLR (ES: 0.828) ($p < 0.05$).

Conclusions. This study demonstrated that high-load, low-repetition (HLLR) training was more effective for increasing muscle strength and muscle mass, while low-load, high-repetition (LLHR) training reduced muscle damage, as indicated by lower creatine kinase levels.

Keywords: maximum muscle strength, muscle damage, muscle mass, resistance training.

Introduction

Resistance training is integral to physical fitness, rehabilitation, and athletic performance, being widely recognized as a foundational element for enhancing muscle strength, promoting hypertrophy, minimizing muscle damage, and sustaining functional capacity across diverse populations (Lopez et al., 2020). As an exceptionally adaptable form of exercise, resistance training can be customized to address the specific requirements of athletes, older adults, and individuals undergoing rehabilitation (Fragala et al, 2019; Bjarnason-Wehrens et al., 2022;

Papa et al., 2017). Among the most commonly utilized resistance training modalities are high-load, low-repetition (HLLR) and low-load, high-repetition (LLHR) approaches (Liu et al., 2024). HLLR, characterized by heavier loads (exceeding 70 % of one-repetition maximum, 1RM) and fewer repetitions, is traditionally preferred for maximizing strength via the recruitment of high-threshold motor units and generating greater mechanical tension on type II muscle fibers (Schoenfeld et al., 2015; Nóbrega & Libardi, 2016). In contrast, the LLHR protocol, which employs lighter loads (at or below 50% of 1RM) with higher repetitions, is frequently associated with hypertrophy through mechanisms involving metabolic stress and sustained motor unit activation, offering an alternative for populations emphasizing reduced muscle damage and expedited recovery (Dobson, 2021). Despite the widespread application of these protocols, ongoing investigations focus on their relative efficacy and associated trade-offs concerning key muscular adaptations.

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Prior studies have compared LLHR and HLLR in various contexts. For instance, Ikezoe et al. (2017) reported no significant differences in muscle strength or hypertrophy between the two protocols when repetitions in LLHR were sufficiently increased, suggesting that LLHR could serve as a viable alternative to HLLR. Likewise, Schoenfeld et al. (2017) concluded in their meta-analysis that while hypertrophy can be attained across a spectrum of loads, maximal strength gains are most effectively achieved through higher loading protocols. However, critical distinctions emerge regarding muscle damage and recovery requirements. Yeom et al. (2023) demonstrated that LLHR is associated with lower levels of muscle damage markers, such as creatine kinase (CK) and lactate dehydrogenase (LDH), compared to HLLR, positioning LLHR as advantageous for populations necessitating faster recovery. Additionally, studies by Schoenfeld et al. (2015) and Bello et al. (2024) revealed that while HLLR yields superior strength adaptations, LLHR excels in improving muscular endurance. These findings underscore the necessity of discerning the physiological trade-offs inherent to these resistance training methods.

Nonetheless, several critical gaps persist in the literature. Firstly, existing studies have predominantly concentrated on narrow populations, such as untrained or well-trained young males, limiting the generalizability of results to broader demographics, including older adults or individuals engaged in rehabilitation (Schoenfeld et al., 2015; Fragala et al., 2019). Secondly, while the improvements in hypertrophy and strength resulting from these protocols have been extensively elucidated, the implications for muscle damage and recovery duration remain inadequately explored, particularly in active adult males representing a wider spectrum of fitness levels (Yeom et al., 2023; Dobson, 2021). Thirdly, the long-term consequences of integrating LLHR and HLLR for optimizing both hypertrophy and recovery have yet to be systematically investigated. Lastly, while studies by Ikezoe et al. (2017) and Yeom et al. (2023) infer that LLHR can achieve outcomes comparable to HLLR, evidence remains scarce regarding the applicability of these benefits in populations prioritizing reduced recovery demands or minimized joint stress.

To address these gaps, this study endeavors to directly compare the effects of LLHR and HLLR on muscle strength, muscle mass, and muscle damage within active adult males. Specifically, the research aims to ascertain whether LLHR can achieve comparable hypertrophic and strength adaptations while simultaneously reducing muscle damage relative to HLLR. By examining these variables in conjunction, this investigation aspires to deliver significant insights into the relative advantages and limitations of each training protocol, thus providing practical guidance for the customization of resistance training to align with individual objectives and capacities.

This research enriches the expanding corpus of literature on resistance training by clarifying the trade-offs between load and repetition schemes, emphasizing their integration to achieve balanced training outcomes while considering recovery demands. Ultimately, the findings aim to inform evidence-based practices for athletes, fitness enthusiasts, and clinical populations, addressing both performance enhancement and recovery management.

Materials and Methods

Study Design

This study was a two-group pretest-posttest quasi-experimental design. A total of 28 active adult males aged 18-22 years, body mass index 19-23 kg/m², had normal blood pressure, normal resting heart rate, normal oxygen saturation, and no history of chronic diseases, including heart failure, coronary heart, diabetes mellitus, hypertension, and chronic lung disease and no history of alcohol consumption and no smoking in 5 years were selected to be actively involved in the study. The participant recruitment technique used consecutive sampling and was divided into two intervention groups, namely high-load, low-repetition (HLLR; n = 14) and low-load, high-repetition (LLHR; n = 14). All participants involved in the study had received information about the purpose, benefits, and risks of participation and they had given informed consent. Following informed consent, all subjects underwent health screenings and pretests for maximum muscle strength, muscle mass, muscle damage.

Protocol of high-load, low-repetition (HLLR) and low-load, high-repetition (LLHR)

The HLLR and LLHR training programs were implemented and supervised by professional coaches from the Department of Sports Coaching Education, Faculty of Sports and Health Sciences, Universitas Negeri Surabaya to ensure that the movements performed were correct. HLLR was implemented with bench press and leg extension exercises performed 3-5 sets, 8-12 repetitions, with an intensity of 80-90% 1RM. LLHR was implemented with bench press and leg extension exercises performed 3-5 sets, 25-35 repetitions, with an intensity of 40-50% 1RM. The repetition rhythm was performed in a controlled manner with concentric contractions of about 1 second and eccentric actions of about 2 seconds. Rest between sets was done for 90 seconds. The HLLR and LLHR training programs were implemented with a frequency of 3x/week for 4 weeks.

Data Collection Technique

Assessment of maximum muscle strength, muscle mass, muscle damage was carried out at the baseline (pre) and week 4 (post) in each group. Maximal muscle strength, namely maximum strength lower body and maximum strength upper body was assessed using the 1RM test, namely with leg extension (lower body) and bench press (upper body). Muscle mass was assessed using the TANITA BC-545N. Muscle damage was assessed by measuring Creatine kinase (CK) Activity in serum using an Assay Kit (Cat.No.: E-BC-K558-S; CK Activity; Elabscience Biotechnology Inc., Houston, TX 77079, USA).

Statistical Analysis

Normality was applied using the Shapiro-Wilk Test, then the normally distributed data were tested for differences using the paired sample t-test to observe changes between baseline (pre) and week 4 (post) in each group in all variables. Meanwhile, to observe differences between

groups, the independent sample t-test was applied. Effect size analysis using Cohen's D. All statistical analyses used a 95% significance level. Statistical analyses were performed using SPSS 21.0 for Windows 10.

Results

Details of the baseline characteristics of the study participants are presented in Table 1. No significant differences were found in baseline characteristics of study participants between groups (all $p > 0.05$). Assessment of maximum muscle strength, muscle mass, muscle damage at baseline (pre) and week 4 (post) on each group are presented in Table 2 and Figure 1-2.

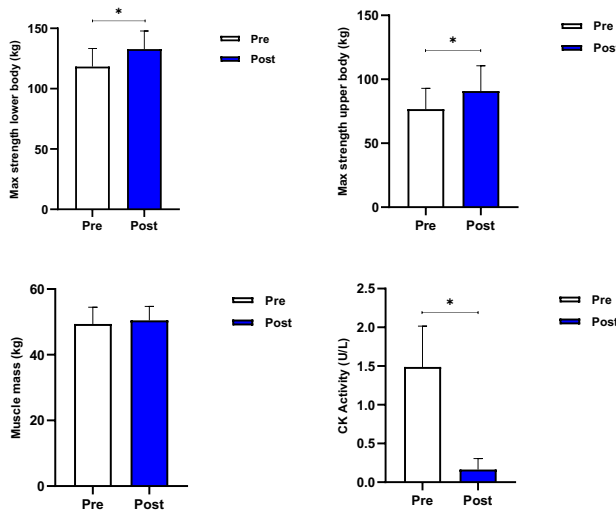


Fig. 1. Assessment of maximum muscle strength, muscle mass, muscle damage at baseline (pre) and week 4 (post) in LLHR group. *Significant at pre ($p < 0.05$). Data are presented as mean \pm SD. p-value was obtained from the results of paired sample t-test analysis. Effect size analysis using Cohen's D

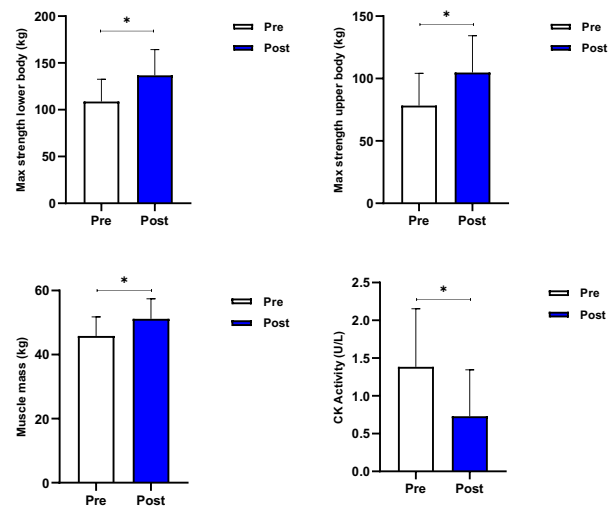


Fig. 2. Assessment of maximum muscle strength, muscle mass, muscle damage at baseline (pre) and week 4 (post) in HLLR group. *Significant at pre ($p < 0.05$). Data are presented as mean \pm SD. p-value was obtained from the results of paired sample t-test analysis. Effect size analysis using Cohen's D

There were significant differences between baseline (pre) and week 4 (post) the intervention of low-load, high-repetition (LLHR) in max strength lower body ($p = 0.001$; effect size (ES): 0.967), max strength upper body ($p = 0.001$; ES: 0.784), and CK Activity ($p = 0.001$; ES: 3.438) ($p < 0.01$). Meanwhile, no differences were observed in muscle mass ($p > 0.05$) (Figure 1).

There were significant differences between baseline (pre) and week 4 (post) the intervention of high-load, low-repetition (HLLR) in max strength lower body ($p = 0.001$; ES: 1.091), max strength upper body ($p = 0.001$; ES: 0.951), muscle mass ($p = 0.001$; ES: 0.875), and CK Activity ($p = 0.031$; ES: 0.941) ($p < 0.05$) (Figure 2).

Table 1. Baseline characteristics of study participants

Parameters	LLHR (n = 14)	HLLR (n = 14)	p-value Independent sample t-test
Age, yrs	19.57 \pm 1.87	19.14 \pm 1.56	0.516
Resting heart rate, bpm	65.72 \pm 8.84	66.79 \pm 6.79	0.722
Oxygen saturation, %	97.29 \pm 1.21	97.50 \pm 1.16	0.636
Systolic blood pressure, mmHg	118.22 \pm 4.63	116.57 \pm 3.96	0.322
Diastolic blood pressure, mmHg	70.36 \pm 5.99	70.86 \pm 7.91	0.852
Body weight, kg	64.14 \pm 6.65	61.43 \pm 7.31	0.314
Height, m	1.71 \pm 0.04	1.69 \pm 0.05	0.224
Body mass index, kg/m ²	21.87 \pm 1.53	21.56 \pm 2.06	0.655
Body fat, %	16.83 \pm 3.11	15.23 \pm 4.38	0.275
Total body water, %	54.61 \pm 3.06	55.34 \pm 3.34	0.548
Bone mass, kg	5.87 \pm 0.69	5.57 \pm 0.91	0.334
Muscle mass, kg	49.39 \pm 5.09	45.81 \pm 5.97	0.100
Max strength lower body, kg	118.26 \pm 14.99	108.79 \pm 23.75	0.221
Max strength upper body, kg	76.71 \pm 16.28	78.33 \pm 25.81	0.844
CK Activity, U/L	1.49 \pm 0.53	1.39 \pm 0.77	0.681

Data are presented as mean \pm SD. p-value was obtained from the results of independent samples t-test analysis

Table 2. Maximum muscle strength, muscle mass, muscle damage assessment at baseline (pre) and week 4 (post).

Parameter	LLHR (n = 14)	HLLR (n = 14)	p-value	Effect Size
Post-Max strength lower body, kg	132.79 ± 15.06	136.82 ± 27.48	0.635	0.181
Post-Max strength upper body, kg	90.87 ± 19.65	104.76 ± 29.59	0.157	0.553
Post-Muscle mass, kg	50.46 ± 4.26	51.17 ± 6.27	0.730	0.132
Post-CK Activity, U/L	0.16 ± 0.14 ^b	0.73 ± 0.62	0.002	1.272
Δ-Max strength lower body, kg	14.54 ± 6.72	28.02 ± 17.37 ^a	0.012	1.024
Δ-Max strength upper body, kg	14.16 ± 7.49	26.43 ± 11.82 ^a	0.003	1.241
Δ-Muscle mass, kg	1.07 ± 3.54	5.36 ± 3.71 ^a	0.004	1.184
Δ-CK Activity, U/L	-1.33 ± 0.53 ^b	-0.66 ± 1.02	0.038	0.828

Δ: Post-Pre. ^aSignificant at LLHR group ($p < 0.05$). ^bSignificant at HLLR group ($p < 0.05$). Data are presented as mean ± SD. p-value was obtained from the results of independent samples t-test analysis. Effect size analysis using Cohen's D

Discussion

This study evaluated the effects of high-load, low-repetition (HLLR) and low-load, high-repetition (LLHR) resistance training protocols on muscle strength, muscle mass, and muscle damage in active adult males. The findings demonstrate that HLLR is superior in increasing maximum muscle strength for both upper and lower extremities, whereas LLHR resulted in significantly reduced muscle damage and meaningful hypertrophic adaptations. These results align with established theories on resistance training and provide insights into optimizing training protocols based on individual goals and recovery needs. The findings of this study are consistent with and extend the results of previous research comparing low-load, high-repetition (LLHR) and high-load, low-repetition (HLLR) resistance training protocols. For example, Ikezoe et al. (2017) found no significant differences between LLHR and HLLR in terms of muscle strength and hypertrophy improvements, suggesting that LLHR can produce similar outcomes to HLLR when repetitions are increased. Our results similarly indicate that LLHR is a viable alternative for promoting hypertrophy while reducing muscle damage, as reflected in lower creatine kinase (CK) levels. Furthermore, the study by Yeom et al. (2023) demonstrated that LLHR induces lower muscle damage markers, such as CK and lactate dehydrogenase (LDH), while still activating key anabolic signaling pathways (e.g., p70S6K1 and 4E-BP1), supporting hypertrophic adaptations. This aligns with our findings that LLHR minimizes muscle damage while eliciting comparable hypertrophic effects. Consistent with Schoenfeld et al. (2015), our study also observed that HLLR produced greater improvements in maximum strength compared to LLHR. This is likely due to HLLR's ability to recruit high-threshold motor units and stimulate neuromuscular adaptations, which is critical for developing maximum force. Similarly, the systematic review by Schoenfeld et al. (2017) highlighted that maximal strength gains are best achieved with high loads, whereas muscle hypertrophy can be achieved across a spectrum of loading ranges. These findings further reinforce our conclusion that HLLR is optimal for strength development, while LLHR provides a safer and more effective alternative for hypertrophy. Bello et al. (2024) also reported that high-load training leads to superior increases in 1-repetition maximum (1RM) strength compared to low-load training, supporting our observation that HLLR is more effective for improving strength outcomes. However,

our findings emphasize that LLHR has the additional advantage of reduced recovery demands, which could be beneficial for specific populations, such as older adults or those in rehabilitation. Additionally, our study complements the findings of Schoenfeld et al. (2017) by confirming that hypertrophic adaptations are not load-dependent, as both LLHR and HLLR protocols produced meaningful muscle mass increases. Overall, our results align with prior studies while providing additional insights into the distinct trade-offs between LLHR and HLLR protocols, particularly in terms of muscle damage and recovery demands. By confirming that both approaches can be effective for different training goals, our study adds to the growing body of evidence supporting the adaptability of resistance training to meet individual needs.

The mechanisms underlying these findings can be explained through distinct physiological pathways and the theoretical basis of resistance training. The superior strength gains observed with HLLR can be attributed to the recruitment of high-threshold motor units, which predominantly engage type II muscle fibers essential for maximum force production (Del Vecchio et al., 2019; Morton et al., 2019). This aligns with the principle of progressive overload, where high-intensity loads promote neuromuscular adaptations and enhanced motor unit synchronization (Pope et al., 2016). Conversely, LLHR leverages metabolic stress to stimulate hypertrophy by activating the Akt/mTOR signaling pathway, promoting protein synthesis, and engaging both type I and type II muscle fibers when performed to failure (Grgic, 2020; McIntosh et al., 2023). This mechanism explains how LLHR achieves meaningful hypertrophic effects with less mechanical tension per repetition, reducing the risk of structural muscle damage. Furthermore, the elevated levels of creatine kinase (CK) observed in the HLLR protocol reflect greater microtrauma induced by heavier loads, which, although beneficial for muscle remodeling, necessitate extended recovery periods to avoid overtraining or injury (Callegari et al., 2017).

The relationship between the protocols and their respective outcomes highlights important trade-offs. For muscle strength, HLLR was significantly more effective due to the high mechanical tension and superior recruitment of type II fibers (Lixandrão et al., 2017). Although LLHR also produced strength gains, its effects were less pronounced, suggesting its potential as a complementary approach for individuals unable to tolerate high loads (Schoenfeld et al., 2015; Evangelou et al., 2021). In terms of muscle mass, HLLR elicited greater increases, consistent with the higher mechanical stress

imposed by heavy loads, while LLHR produced comparable hypertrophy via metabolic stress mechanisms, providing a safer alternative for populations prioritizing joint health or injury prevention (Jenkins et al., 2017). Finally, muscle damage, as indicated by CK levels, was significantly lower in LLHR, further supporting its use for faster recovery and reduced structural stress (Baird et al., 2012).

This study is not without limitations. The intervention period of four weeks may be insufficient to capture the long-term adaptations or cumulative effects of these protocols. The study also focused exclusively on active adult males, which limits the generalizability of the findings to other populations, such as women, older adults, or clinical groups. Additionally, the reliance on CK as the sole marker for muscle damage may not fully represent the complex structural changes occurring at the cellular level, and further studies using imaging or histological techniques are warranted. Lastly, the study did not explore the potential benefits of combining HLLR and LLHR protocols, which may offer complementary advantages for both strength and hypertrophy.

These findings have practical implications for designing resistance training programs. HLLR is optimal for athletes aiming to maximize strength and power, while LLHR is a safer and more sustainable option for individuals prioritizing recovery, joint health, or moderate hypertrophic gains. A combined approach may be beneficial, incorporating HLLR during strength-focused phases and LLHR for hypertrophy and recovery phases, thereby balancing the benefits of both protocols while mitigating their respective limitations.

Future research should investigate the long-term effects of HLLR and LLHR, particularly in diverse populations such as women, older adults, and individuals with pre-existing conditions. Examining the combination of these protocols and their effects on muscle adaptation over extended periods could provide further insights into optimizing training outcomes. Additionally, molecular and structural investigations, such as muscle biopsies and imaging studies, are needed to elucidate the physiological mechanisms underlying these adaptations. By addressing these gaps, future studies could refine resistance training strategies and enhance their applicability across various settings.

This study contributes to the growing body of evidence on resistance training by demonstrating that HLLR is highly effective for maximizing strength and hypertrophy, while LLHR provides comparable benefits with reduced muscle damage and faster recovery. These findings highlight the importance of tailoring resistance training protocols to individual goals, capacities, and recovery demands, thereby optimizing performance outcomes in both athletic and clinical populations.

Conclusions

This study demonstrated that high-load, low-repetition (HLLR) training was more effective for increasing muscle strength and muscle mass, while low-load, high-repetition (LLHR) training reduces muscle damage, as indicated by lower creatine kinase levels. HLLR's superior strength gains result from greater neuromuscular adaptations and high-threshold motor unit recruitment, whereas LLHR offers comparable hypertrophic benefits with less recovery demand, making it suitable for populations prioritizing endurance

or injury prevention. These findings suggest that tailoring resistance training protocols to individual goals—strength versus recovery and joint health—can optimize performance outcomes. Combining HLLR and LLHR may provide a balanced approach to maximize training effectiveness.

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Conflict of Interest

The authors declare that they have no conflict interests in this study.

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Визначення показників максимальної сили м'язів, м'язової маси, пошкодження м'язів у активних дорослих чоловіків після проведення силових тренувань із низьким навантаженням та великою кількістю повторень у поєднанні із високим навантаженням та малою кількістю повторень

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Авторський вклад: А – дизайн дослідження; В – збір даних; С – статаналіз; D – підготовка рукопису; E – збір коштів

Реферат. Стаття: 6 с., 2 табл., 2 рис., 22 джерел.

Мета дослідження. Це дослідження мало на меті оцінити вплив протоколів силових тренувань із високим навантаженням і малою кількістю повторень (HLLR) та низьким навантаженням і великою кількістю повторень (LLHR) на показники сили м'язів, м'язової маси та пошкодження м'язів у дорослих чоловіків, які ведуть активний спосіб життя.

Матеріали та методи. Це квазіекспериментальне дослідження включало 28 активних дорослих чоловіків віком 18-22 років з індексом маси тіла 19-23 кг/м², відібраних для активної участі в дослідженні, які проходили інтервенції з HLLR та LLHR тренувань із частотою 3 рази на тиждень впродовж 4 тижнів. Збір даних проводився шляхом оцінки показників максимальної сили м'язів, м'язової маси та пошкодження м'язів між початковим етапом (до) та завершенням періоду 4 тижнів (після). Для статистичного аналізу застосовано t-критерій для незалежних вибірок з рівнем значущості 95%.

Результати. Достовірні відмінності спостерігалися між інтервенціями HLLR та LLHR тренувань у показниках максимальної сили нижньої частини тулуба (розмір ефекту (ES): 1,024), максимальної сили верхньої частини тулуба (ES: 1,241) та м'язової маси (ES: 1,184) ($p < 0,05$). Водночас встановлено, що активність креатинкінази значно знижена під час виконання LLHR тренувань порівняно з HLLR (ES: 0,828) ($p < 0,05$).

Висновки. Дослідження продемонструвало, що тренування із високим навантаженням і низькою кількістю повторень (HLLR) є ефективнішим з точки зору збільшення м'язової сили і м'язової маси, тоді як тренування із низьким навантаженням і високою кількістю повторень (LLHR) сприяють зменшенню пошкодження м'язів, про що свідчать нижчі рівні креатинкінази.

Ключові слова: максимальна сила м'язів, пошкодження м'язів, м'язова маса, силові тренування.

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