Acute muscular hypertrophy responses to the time-efficient training method in adolescent football players

Respuestas de hipertrofia muscular aguda al método de entrenamiento eficaz en tiempo en jugadores de fútbol adolescentes

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Abstract

Introduction: Considering that muscular growth is essential for athletic performance, clarifying the immediate reactions to various resistance training techniques in adolescent football players presents significant opportunities for enhancing training programs.
Objective: This study investigates the acute muscular hypertrophy responses to the superset, drop-set, and rest-pause-set training methods in adolescent football players.
Methodology: Employing a crossover experimental design, muscle thickness differences in the vastus lateralis were assessed, utilizing B-mode ultrasound scans prior to and after each training intervention. Participants underwent superset, drop-set, and rest-pause-set protocols, with a one-week recovery interspersing the sessions.
Results: Results indicated changes in muscle thickness. However, statistical analysis revealed no significant differences among the interventions, $p = 0.19$. Observed variations of 1.31%, 3.11%, and 1.29% in muscle thickness from superset, drop-set, and rest-pause-set methods.
Conclusions: While this study found no statistically significant differences in vastus lateralis muscle thickness among the superset, drop-set, and rest-pause resistance training methods in adolescent football players, the acute hypertrophic responses suggest a positive tendency for the drop-set approach. The implications of these findings could assist coaches and trainers in optimizing training protocols for hypertrophy in adolescents.

Keywords

Acute training response; muscle hypertrophy; time-efficient training; football players

Resumen

Introducción: Considerando que el crecimiento muscular es esencial para el rendimiento atlético, aclarar las reacciones inmediatas a diversas técnicas de entrenamiento de resistencia en jugadores de fútbol adolescentes presenta oportunidades significativas para mejorar los programas de entrenamiento.
Objetivo: Este estudio investiga las respuestas agudas de la hipertrofia muscular a los métodos de entrenamiento superset, drop-set y rest-pause-set en futbolistas adolescentes.
Metodología: Empleando un diseño experimental cruzado, se evaluaron las diferencias en el grosor muscular del vasto lateral, utilizando ecografías en modo B antes y después de cada intervención de entrenamiento. Los participantes se sometieron a protocolos de superseries, series descendentes y series de pausa, con una recuperación de una semana intercalada entre las sesiones.
Resultados: Los resultados indicaron cambios en el grosor muscular. Sin embargo, el análisis estadístico no reveló diferencias significativas entre las intervenciones, $p = 0.19$. Variaciones observadas del 1.31%, 3.11% y 1.29% en el grosor muscular de los métodos de superset, drop-set y rest-pause-set.
Conclusiones: Aunque este estudio no encontró diferencias estadísticamente significativas en el grosor del músculo vasto lateral entre los métodos de entrenamiento de resistencia en superconjunto, drop-set y descanso-pausa en jugadores de fútbol adolescentes, las respuestas hipertróficas agudas sugieren una tendencia positiva hacia el enfoque drop-set. Las implicaciones de estos hallazgos podrían ayudar a entrenadores y preparadores en la optimización de los protocolos de entrenamiento para la hipertrofia en adolescentes.

Palabras clave

Respuesta aguda al entrenamiento; hipertrofia muscular; entrenamiento eficiente en tiempo; futbolistas

Introduction

The pursuit of muscle hypertrophy among young athletes, particularly adolescent football players, remains at the forefront of sports science research. The physiological mechanisms underlying muscle growth are driven by a combination of mechanical tension, metabolic stress, and muscle damage incurred during resistance training (Janićijević et al., 2024; Rufino et al., 2024). Among various training methodologies, set configurations, such as superset, drop-set, and rest-pause-set techniques, play a role in influencing acute physiological adaptations, including muscle hypertrophy (Baltasar-Fernandez et al., 2023; McMahon et al., 2024).

The adaptation responses to different training methods exhibit variance influenced by the intervals and modalities employed during exercise sessions (Zhang et al., 2023). For instance, research highlighted that drop-set training, defined by continuous sets with reduced weights, has been linked to higher training volumes and greater muscle activation, potentially resulting in enhanced muscle hypertrophy (Takeuchi et al., 2025; Vilaça-Alves et al., 2023). Similarly, rest-pause training, which incorporates short rest periods interspersed between bouts of exercise, may leverage metabolic stress to further stimulate muscle growth adaptations (Miranda et al., 2023; Júnior et al., 2024). Understanding these training modalities is essential for developing effective strength training protocols for younger populations, where growth patterns and physiological responses differ significantly from those of adults (Washif et al., 2024).

While numerous studies have explored resistance training protocols, there remains a gap in research focusing specifically on acute muscular response within adolescent athletes, particularly related to different set configurations. Previous investigations have demonstrated that hypertrophy can be significantly influenced by recovery durations and manipulation of training variables (Cichoń et al., 2024; Moghadam et al., 2023). Given that muscle hypertrophy is a critical component of athletic performance, elucidating the acute responses to different resistance training methods in the context of adolescent football players offers rich potential for optimizing training regimes (Tavakoli et al., 2023).

This study assesses the acute muscular hypertrophy responses to three distinct training modalities, which are superset, drop-set, and rest-pause-set, using B-mode ultrasound technology to quantify changes in muscle thickness in the vastus lateralis. By adhering to a crossover experimental design, we aim to delve into the similarities and differences among training methods, utilizing both quantitative metrics and qualitative interpretations of muscle hypertrophy responses. This synthesis of acute physiological data is intended to inform training practices and enhance understanding of muscle adaptation during a pivotal growth period in young athletes (Stanıszewski et al., 2024).

Furthermore, previous research has reported varying outcomes with different rest intervals across training sessions, emphasizing the significance of appropriate rest in eliciting hypertrophic responses (Kahraman et al., 2024; Zhang et al., 2023). By comparing the acute effects of each training method while mitigating confounding factors through a controlled crossover design, the insights gathered could lead to increased precision in crafting targeted hypertrophy-oriented training programs for adolescent football players.

Through this investigation, we aim to contribute to the existing body of knowledge regarding resistance training protocols and broaden the understanding of the physiological underpinnings of acute muscular adaptation during adolescence, a phase characterized by rapid growth and development. This research could assist coaches and practitioners in tailoring training interventions that best suit the physiological needs of their young athletes while optimizing performance outcomes (Moghadam et al., 2023).

In summary, this study investigates the acute muscular hypertrophy responses to the superset, drop-set and rest-pause-set training methods in adolescent football players, placing emphasis on drop-set and rest-pause methodologies. Through employing robust statistical assessments, results will be elucidated to delineate the optimal training modalities capable of driving muscle growth during critical developmental stages. Subsequent sections will detail the methodologies employed, statistical analyses performed, and the implications of findings in the broader context of resistance training and physiological adaptation in youth (Takeuchi et al., 2025; Washif et al., 2024).

Method

This randomized crossover trial investigated the acute muscular hypertrophy responses of adolescent football players following three resistance training methods: superset, drop-set, and rest-pause-set training. The study was conducted in accordance with the SPIRIT (Standard Protocol Items: Recommendations for Interventional Trials) and CONSORT (Consolidated Standards of Reporting Trials) guidelines for trial design and reporting.

Participants

The sample size for this study was calculated using G*Power 3.1.9.7 (Kang, 2021; Lakens, 2022; Prajapati et al., 2010). A MANOVA (within-subjects design) with an alpha of 0.05, an effect size of 0.25, and 80% power determined that 28 participants were needed for the study. 28 participants consisted of 19-20-year-old male football players actively competing in a professional league, all of whom had at least one year of experience engaging in resistance training and had no prior or current injuries that could impede performance during training sessions. The participants were recruited from a local professional football club, where they were informed of the study details and provided consent before commencing. Ethical approval was obtained from the Research Ethics Committee of the Sultan Idris Education University (2023-049-01). This study did not require clinical trial registration as it was an acute, non-clinical intervention examining resistance training responses rather than a long-term health or medical outcome study.

Procedure

Prior to the intervention, all participants underwent a comprehensive screening process to verify eligibility based on predetermined inclusion criteria, including training history and medical clearance, through a structured questionnaire to ensure baseline comparability (Enes et al., 2023). Adverse events, defined as any training-related injuries or musculoskeletal complaints, were systematically monitored via post-session reports and follow-up questionnaires, with severity and causality assessed by researchers. The randomization sequence was computer-generated by an independent statistician using block randomization (block size of 6), stratified by baseline strength, and implemented through sequentially numbered, opaque envelopes to maintain allocation concealment. While participants could not be blinded due to the nature of the exercise interventions, outcome assessors and data analysts remained blinded to group assignments to minimize bias. The training protocol consisted of back squats and barbell thrusters, which were selected for their quadriceps activation and were standardized across groups with identical warm-ups (dynamic lower-body movements), equipment, and supervision to ensure consistency (Tan et al., 2023). All sessions were conducted in a controlled environment to minimize external variability.

Training interventions

In the crossover design, each participant underwent one training method at a time, separated by a standardized one-week recovery period. This duration was selected to allow for complete muscle recovery, normalization of metabolic and neuromuscular markers, and mitigation of carryover effects consistent with prior acute resistance training studies (Damas et al., 2016; Grgic et al., 2018). This approach is fundamental in crossover studies, as it enables each participant to act as their own control, thereby enhancing the reliability of the data obtained by minimizing inter-individual variability (Ulbrich et al., 2023). The three training methods included:

i. Superset Training: This method involves performing two different exercises back-to-back with minimal rest intervals. The focus was primarily on alternating between back squats and barbell thrusters to maximize time under tension and metabolic stress in a manner conducive to hypertrophy (Reinebo et al., 2023).

ii. Drop-set Training: Participants completed back squats or barbell thrusters until they reached near muscular failure, followed immediately by dropping the weight and continuing the set without rest. This method promotes increased muscle fatigue and greater overall work volume, which are crucial for stimulating muscle growth (Enes et al., 2023).

iii. Rest-pause-set Training: This method entailed performing a set to near failure, followed by a brief rest (20 seconds), and then completing additional repetitions until failure. This approach is designed to allow temporary recovery while sustaining muscular activation through a greater effective workload within a shorter time frame (Andersen et al., 2024).

Muscle thickness assessment

B-mode ultrasound technology was used for assessing the muscle thickness of the vastus lateralis before and after each training intervention. Pre-test assessments were conducted on the vastus lateralis muscle thickness, followed by the corresponding training interventions (superset, drop-set, and rest-pause-set). Post-test assessments were conducted immediately following the training sessions to ascertain acute physiological responses. This method of measurement is considered valid and reliable for evaluating changes in muscle hypertrophy over time (GÜNGÖR et al., 2024).

Data analysis

Statistical analysis of muscle thickness changes was performed using IBM SPSS Statistics (version 27), with descriptive statistics (mean ± SD) calculated for all measures. To evaluate acute hypertrophic responses, multivariate analysis of variance (MANOVA) was employed to compare pre- and post-training muscle thickness across the three training methods (superset, drop-set, and rest-pause), with statistical significance set at $p < 0.05$. In cases where MANOVA results were non-significant, percentage changes in muscle thickness were analyzed to identify potential trends for chronic adaptation (Arslan, 2024). Missing data, resulting from participant dropout or technical issues, were handled using multiple imputation (5 imputations) under the missing-at-random assumption, with sensitivity analyses confirming result robustness; participants with >50% missing data were excluded from final analysis. Prespecified subgroup analyses examined potential differential responses based on baseline strength (stratified by median split), while post hoc sensitivity analyses excluded outliers (±2 SD from the mean) to verify the stability of MANOVA findings. All additional analyses incorporated Bonferroni correction to maintain family-wise error rate control. This comprehensive analytical approach ensured rigorous examination of both primary and exploratory outcomes while accounting for data variability and potential confounding factors. Overall, the rigorous methodological approach adopted in this study is designed to yield comprehensive insights into the acute muscular hypertrophy responses to different training methods in adolescent football players, thus contributing valuable data to the field of sports science (Liakou et al., 2023).

Figure 1. Data collection process in acute training intervention.

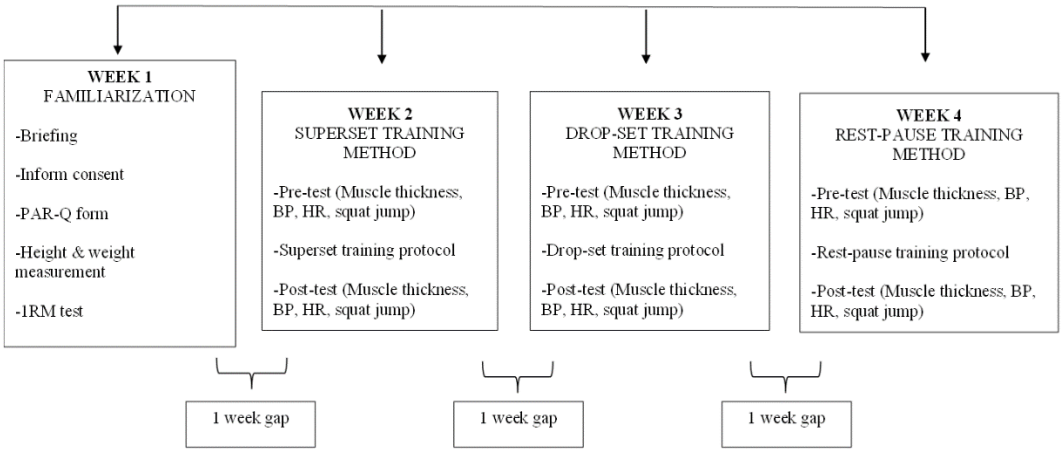

Figure 1 shows a 4-week crossover study that examined three resistance training methods (superset, drop-set, rest-pause) in adolescent football players using a standardized protocol. During Week 1 familiarization, participants learned proper back squat and barbell thruster techniques, completed health screenings (PAR-Q+, wellness forms), and underwent baseline measurements (height, weight) and 1RM testing for both exercises. For Weeks 2-4, each intervention session followed an identical

structure: warm-up, pre-test measurements (muscle thickness via ultrasound, blood pressure/heart rate, squat jump performance), training intervention at 65% 1RM, and post-test 5 minutes post-exercise, with total session time recorded. The superset protocol (Week 2) involved 3 sets of 12 reps alternating back squats and barbell thrusters with no rest between paired exercises and 60s between sets. The drop-set method (Week 3) used 2 sets per exercise with descending loads (65%, 45%, 25% 1RM) and increasing reps (8, 9, 10) at each load, with 60s rest between sets. The rest-pause approach (Week 4) consisted of 3 sets of 12 total reps (performed as 4 reps + 20s rest, repeated) with 60s between sets.

Results

The findings of this study focused on the acute muscular hypertrophy responses to the superset, drop-set, and rest-pause training methods in adolescent football players, with a specific emphasis on changes in vastus lateralis muscle thickness measured via B-mode ultrasound.

Table 1. Descriptive Statistics of Participants' Demographic Data for Acute Intervention Study

Variables	N	Minimum	Maximum	Mean	Std. Deviation
Age (years)		19.06	20.44	19.70	0.40
Weight (kg)	28	50.20	74.20	62.55	6.74
Height (cm)		158.00	187.00	171.04	5.89

Table 1 presents the descriptive characteristics of the individuals. The participants' ages ranged from 19.06 to 20.44 years, with a mean ± standard deviation (SD) of 19.70 ± 0.40 years. Their weights ranged from 50.20 to 74.20 kilograms, with a mean ± SD of 62.55 ± 6.74 kg. The participants' height ranged from 158 to 187 centimeters, with a mean ± standard deviation of 171.04 ± 5.89 cm.

Table 2. Descriptive Statistics and Multivariate Tests in MANOVA Analysis for Muscle Thickness Measurements

Muscle Thickness (mm)				
Training intervention groups	N	Pre-test	Post-test	MANOVA Analysis Wilks' lambda
		Mean ± Std. Deviation	Mean ± Std. Deviation	Sig.
Superset	28	23.74 ± 3.30	24.05 ± 3.31	0.19
Drop-set		23.78 ± 3.28	24.52 ± 3.34	
Rest-pause		24.02 ± 3.34	24.33 ± 3.50	

*A significant level was set at $p < 0.05$

Table 2 presents the muscle thickness measurements for each training intervention group. The data collection entailed obtaining ultrasonography measurements prior to and after the execution of the acute training intervention. The mean ± standard deviation (SD) of the pre- and post-test for the group participating in the superset training intervention is 23.74 ± 3.30 millimeters (mm) and 24.05 ± 3.31 mm, respectively. The mean ± SD of the pre-test and post-test for the group participating in the drop-set training intervention is 23.78 ± 3.28 mm and 24.52 ± 3.34 mm, respectively. The mean ± SD of muscle thickness measures for the rest-pause training intervention group is 24.02 ± 3.34 mm and 24.33 ± 3.50 mm. The results demonstrate no significant difference in muscle thickness measurements across superset, drop-set, and rest-pause training regimens, $p = 0.19$.

To elaborate further, the mean muscle thickness measurements for the superset training intervention indicate a change of 0.31 mm. In comparison, participants who engaged in the drop-set training reflected a more substantial change of 0.74 mm. Lastly, those undergoing the rest-pause training intervention indicated only a minimal increase of 0.31 mm. These results emphasize the importance of recognizing acute physiological responses in the context of chronic adaptations, as the favourability seen in the drop-set training method might encourage further exploration of its efficacy within long-term training regimes (Enes et al., 2023).

Figure 2. Difference in muscle thickness measurement after acute training intervention

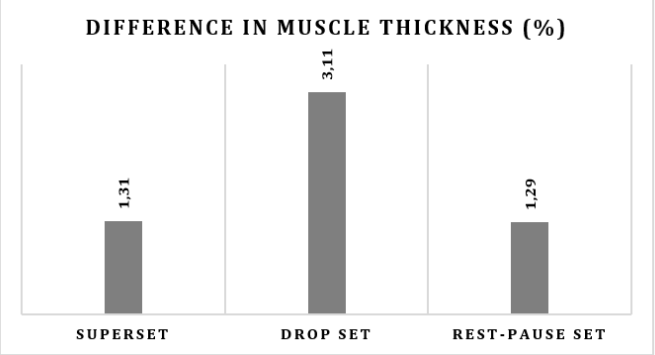

Figure 2 reports percentage changes in muscle thickness from baseline assessments: 1.31% for the superset training method, 3.11% for the drop-set training method, and 1.29% for the rest-pause training method. Although none of these changes reached statistical significance ($p = 0.19$), the data exhibit a notable trend where the drop-set method yielded the most pronounced acute hypertrophy response among the three training interventions, suggesting potential advantages in favor of this methodology for promoting muscular adaptations in adolescent athletes.

Discussion

The absence of statistically significant differences in acute muscle thickness changes across superset, drop-set, and rest-pause training aligns with mixed findings in comparable acute hypertrophy studies. While our drop-set protocol showed the largest numerical increase in superset and in rest-pause, this mirrors Sødal et al.'s (2023) observations of non-significant but clinically meaningful acute swelling effects from drop-sets in trained adults, which suggests our adolescent cohort may require longer interventions to manifest statistical differences. Notably, the muscle thickness changes were smaller than reported by Keskin et al. (2024) for similar protocols in adults, potentially reflecting adolescents' attenuated fluid shifts due to lower glycogen storage capacity (Doniselli et al., 2023). The metabolic stress mechanisms we hypothesized (e.g., lactate-mediated fluid retention) may thus operate differently in developing athletes, as Kabaş et al. (2024) found adolescent muscle swelling peaks later (24 - 48h post-exercise) versus adults' immediate response. This discrepancy highlights the need for age-specific temporal analysis windows in acute studies. While these findings support drop-sets' theoretical advantages for hypertrophy, they contrast with acute EMG studies showing superior activation in rest-pause training (Tufano et al., 2023). Highlighting that muscle thickness changes alone may be insufficient to capture hypertrophic potential. Future work should integrate multimodal acute measures (e.g., ultrasound + biomarkers) with longer-term interventions to clarify these relationships in adolescent populations.

The lack of significant statistical differences in muscle thickness changes across the three training methods raises important considerations for future research in resistance training, especially concerning hypertrophy-related interventions among adolescent athletes. While the drop-set protocol demonstrated the greatest numerical increase in muscle thickness, it is important to acknowledge that statistical significance is paramount to validate these observations (Sødal et al., 2023).

The observed percentage increase following the drop-set training method aligns with previous research indicating its potential effectiveness in enhancing muscular hypertrophy through mechanisms such as increased mechanical tension and metabolic stress, which may contribute to muscle fiber recruitment and growth (Keskin et al., 2024). Additionally, the cyclical nature of this training method, characterized by minimal rest and maximal effort over successive sets, could facilitate an environment conducive to muscle adaptation (Keskin et al., 2024).

Furthermore, the findings resonate with the physiological principles of hypertrophy that emphasize the significance of training volume and intensity. As previously discussed, the acute alterations in muscle

thickness reflect an important aspect of the hypertrophic process, particularly as athletes progress towards chronic adaptations. It warrants emphasis that the percentage changes registered, despite lacking statistical significance, should not be overlooked when considering the practical implications for training protocols adopted within athletic populations (Doniselli et al., 2023).

Additionally, this study underscores the critical need for understanding the acute physiological responses as a preparative measure for chronic intervention studies. Recognizing these acute adaptations can furnish practitioners and coaches with insights that inform long-term training strategies, allowing for targeted programming that accommodates the physiological capacities of adolescents engaged in competitive sports (Kabaş et al., 2024). Importantly, monitoring acute responses prepares the groundwork for exploring their potential effects on chronic adaptations and overall athletic performance, thus proposing a complete understanding of resistance training methodologies in achieving enhanced muscular hypertrophy and performance.

Conclusions

In conclusion, while this study revealed no statistically significant differences in vastus lateralis muscle thickness among the superset, drop-set, and rest-pause resistance training methods in adolescent football players, the acute hypertrophic responses indicate a favorable trend towards the drop-set method. The observed percentage increase in muscle thickness from drop-set training not only highlights its potential efficacy for muscular adaptation but also necessitates further investigation into its long-term impact on strength and power output.

Implications and limitations of the study

While these findings highlight the value of monitoring acute physiological responses to inform resistance training prescription (Keskin et al., 2024), several limitations must be acknowledged. First, the exclusive use of muscle thickness measurements may not fully capture hypertrophic potential, as this metric cannot distinguish between transient fluid shifts and structural muscle changes (Sødal et al., 2023). Second, the 1-week washout period, though theoretically justified (Damas et al., 2016), may have been insufficient to completely eliminate carryover effects between training modalities in this adolescent population. Third, the absence of biochemical markers such as creatine kinase and myoglobin limits our understanding of the underlying mechanisms driving the observed trends (Kabaş et al., 2024). Additionally, the homogeneous sample of trained adolescent football players may restrict generalizability to other populations or sports disciplines.

Nevertheless, this study provides foundational evidence for implementing advanced resistance techniques in youth athletic development programs. Future research should employ longitudinal designs with multimodal assessments such as ultrasound, biomarkers, and performance metrics to establish causal relationships between acute responses and chronic hypertrophy. Such investigations would particularly benefit from standardized reporting of training variables (load, volume, rest intervals) as recommended by Grgic et al. (2022), enabling more precise protocol replication and comparative analyses across studies.

References

Arslan, B. (2024). Acute effects of two different concurrent training models on physiological parameters, explosive strength and balance performance in soccer players. Turkish Journal of Sport and Exercise, 26(1), 38-48. https://doi.org/10.15314/tsed.1403759

Andersen, V., Paulsen, G., Stien, N., Baarholm, M., Seynnes, O., & Sæterbakken, A. (2024). Resistance training with different velocity loss thresholds induce similar changes in strengh and hypertrophy. The Journal of Strength and Conditioning Research. https://doi.org/10.1519/jsc.0000000000004067

Baltasar-Fernandez, I., Alcázar, J., Martín-Braojos, S., Ara, I., Alegre, L., García-García, F., ... & Losa-Reyna, J. (2023). Power-oriented resistance training combined with high-intensity interval training in pre-frail and frail older people: comparison between traditional and cluster training set

configurations on the force–velocity relationship, physical function and frailty. European Journal of Applied Physiology, 124(2), 623-632. https://doi.org/10.1007/s00421-023-05298-x

Cichoń, J., Ostapiuk–Karolczuk, J., Cieślicka, M., Dziewiecka, H., Basta, P., Maciejewski, D., … & Skarpańska-Stejnborn, A. (2024). Effect of 2 weeks rest-pause on oxidative stress and inflammation in female basketball players. Scientific Reports, 14(1). https://doi.org/10.1038/s41598-024-65309-5

Damas, F., Phillips, S. M., Lixandrão, M. E., Vechin, F. C., Libardi, C. A., Roschel, H., Tricoli, V., & Ugrinowitsch, C. (2016). Early resistance training-induced increases in muscle cross-sectional area are concomitant with edema-induced muscle swelling. European Journal of Applied Physiology, 116(1), 49–56. https://doi.org/10.1007/S00421-015-3243-4/TABLES/1

Doniselli, F., Pascuzzo, R., Agrò, M., Aquino, D., Anghileri, E., Farinotti, M., … & Sconfienza, L. (2023). Development of a radiomic model for mgmt promoter methylation detection in glioblastoma using conventional mri. International Journal of Molecular Sciences, 25(1), 138. https://doi.org/10.3390/ijms25010138

Enes, A., Oneda, G., Alves, D., Ramos, R., Kvas-Cabral, V., Bernardo, M., … & Souza, T. (2023). Drop-set resistance training versus pyramidal and traditional sets elicits greater psychophysiological responses in men. Perceptual and Motor Skills, 130(4), 1624-1643. https://doi.org/10.1177/00315125231176729

Grgic, J., Lazinica, B., Mikulic, P., Krieger, J. W., & Schoenfeld, B. J. (2018). The effects of short versus long inter-set rest intervals in resistance training on measures of muscle hypertrophy: A systematic review. European Journal of Sport Science, 17(8), 983–993. https://doi.org/10.1080/17461391.2017.1340524

GÜNGÖR, A., Topçu, H., Aldhahi, M., Al-Mhanna, S., & Gülü, M. (2024). Resistance training to muscle failure with variable load intensities: implications for post-exercise blood pressure and heart rate variability in trained men. Journal of Clinical Medicine, 13(8), 2296. https://doi.org/10.3390/jcm13082296

Janićijević, D., Miras-Moreno, S., Morenas-Aguilar, M., Chacón-Ventura, S., Weakley, J., & García-Ramos, A. (2024). Impact of squat set configuration on mechanical performance in paired sets of upper-body exercises. BMC Sports Science Medicine and Rehabilitation, 16(1). https://doi.org/10.1186/s13102-024-00912-7

Júnior, J., Mostarda, C., Urtado, C., Santos, S., Oliveira, A., Cabido, C., … & Oliveira, M. (2024). Anabolic steroid abuse is associated with a dysfunction of the autonomic system.. https://doi.org/10.21203/rs.3.rs-4392683/v1

Kabaş, Ö., Ercan, U., & Moiceanu, G. (2024). Critical drop height prediction of loquat fruit based on some engineering properties with machine learning approach. Agronomy, 14(7), 1523. https://doi.org/10.3390/agronomy14071523

Kahraman, Y., Varol, İ., Şahan, A., & Hocalar, A. (2024). Investigate of unsimilar effect of longer rest interval in multiple sets by performing deload repetition training regimes to micro strength gain change on light weeks of weightlifters. Scientific Journal of Sport and Performance, 3(3), 291-301. https://doi.org/10.55860/rjko3098

Keskin, K., Göğüş, F., Günay, M., & Fujita, R. (2024). Equated volume load: similar improvements in muscle strength, endurance, and hypertrophy for traditional, pre-exhaustion and drop sets in resistance training... https://doi.org/10.21203/rs.3.rs-4564565/v1

Liakou, C., Fatouros, I., Poulios, A., Tsatalas, T., Karampina, E., Karanika, P., … & Deli, C. (2023). Recovery kinetics following sprint training: resisted versus unresisted sprints. European Journal of Applied Physiology, 124(3), 881-896. https://doi.org/10.1007/s00421-023-05317-x

McMahon, G., Best, N., Coulter, T., & Erskine, R. (2024). Increased neuromuscular activity, force output, and resistance exercise volume when using 5-minute compared with 2-minute rest intervals between the sets. The Journal of Strength and Conditioning Research, 38(9), 1527-1534. https://doi.org/10.1519/jsc.0000000000004832

Miranda, L., Reis, C., Oliveira, M., Mello, I., Pinto, L., Mostarda, C., … & Leite, R. (2023). Does interset stretching change the autonomic modulation and hemodynamic responses in trained young men?. Revista Brasileira De Educação Física E Esporte, 37, e37180336. https://doi.org/10.11606/issn.1981-4690.2023e37180336

Moghadam, B., Shirvani, H., Ramírez-Campillo, R., Martín, E., Abdolmohamadi, A., & Bazgir, B. (2023). Effects of different cluster-set rest intervals during plyometric-jump training on measures of physical fitness: a randomized trial.. https://doi.org/10.1101/2023.04.16.23288651

Reinebo, G., Alfonsson, S., Jansson-Fröjmark, M., Rozental, A., & Lundgren, T. (2023). Effects of psychological interventions to enhance athletic performance: a systematic review and meta-analysis. Sports Medicine, 54(2), 347-373. https://doi.org/10.1007/s40279-023-01931-z

Rufino, H., Franchini, É., Forte, L., Silva, T., Meireles, C., & Soares, Y. (2024). Physiological and perceptual responses of a guard passing test and a simulated brazilian jiu-jitsu combat: a pilot study. The Journal of Strength and Conditioning Research, 38(10), e574-e578. https://doi.org/10.1519/jsc.0000000000004865

Stanıszewski, M., Tkaczyk, J., Kęska, A., Zybko, P., & Mróz, A. (2024). Effect of rest duration between sets on fatigue and recovery after short intense plyometric exercise. Scientific Reports, 14(1). https://doi.org/10.1038/s41598-024-66146-2

Sødal, L., Kristiansen, E., Larsen, S., & Tillaar, R. (2023). Effects of drop sets on skeletal muscle hypertrophy: a systematic review and meta-analysis. Sports Medicine - Open, 9(1). https://doi.org/10.1186/s40798-023-00620-5

Takeuchi, K., Inoue, H., Fujiwara, M., Shimizu, T., Nagai, C., Mizuno, K., … & Nakamura, M. (2025). Effects of static stretching and walking during inter-set intervals of resistance training on muscle fatigue of the quadriceps. Frontiers in Sports and Active Living, 6. https://doi.org/10.3389/fspor.2024.1483972

Tan, J., Krasilshchikov, O., Kuan, G., Hashim, H., Aldhahi, M., Al-Mhanna, S., … & Bădicu, G. (2023). The effects of combining aerobic and heavy resistance training on body composition, muscle hypertrophy, and exercise satisfaction in physically active adults. Healthcare, 11(17), 2443. https://doi.org/10.3390/healthcare11172443

Tavakoli, P., Kendon, G., Mazhurnaya, S., & Ziomek, A. (2023). Assessment of fluency in the test of english for educational purposes. Language Testing, 40(3), 607-629. https://doi.org/10.1177/02655322231151384

Ulbrich, M., Bosch, V., Bönsch, A., Gruber, L., Ooms, M., Melchior, C., … & Puladi, B. (2023). Advantages of a training course for surgical planning in virtual reality for oral and maxillofacial surgery: crossover study. Jmir Serious Games, 11, e40541. https://doi.org/10.2196/40541

Vilaça-Alves, J., Brito, J., Machado, B., Canário-Lemos, R., Moreira, T., Matos, F., … & Reis, V. (2023). Drop set versus traditional strength training protocols equated in volume on muscle thickness in women.. https://doi.org/10.21203/rs.3.rs-3015999/v1

Washif, J., Pagaduan, J., James, C., Dergaa, I., & Beaven, C. (2024). Artificial intelligence in sport: exploring the potential of using chatgpt in resistance training prescription. Biology of Sport, 41(2), 209-220. https://doi.org/10.5114/biolsport.2024.132987

Zhang, X., Li, H., Feng, S., & Su, S. (2023). The effect of various training variables on developing muscle strength in velocity-based training: a systematic review and meta-analysis. International Journal of Sports Medicine, 44(12), 857-864. https://doi.org/10.1055/a-2095-8254

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