ORIGINAL ARTICLE

Nr 2024;14 (3):402-409

More Training, Less Trainability: True? A muscle Swelling Analysis

Gustavo Ferreira Pedrosa[1], Lorenzo Laporta[1,2], Maria E. C. Rigo[1], Lair A. C. de Souza[1], Tiago D. L. Nunes[1], Michele Forgiarini Saccol[3], Henrique de Oliveira Castro[4], Gustavo De Conti Teixeira Costa[5], Arthur B. G. Bischoff[1]

[1] *Grupo de Pesquisa Aplicada em Treinamento de Força (GPATF), Centro de Educação Física e Desportos da Universidade Federal de Santa Maria (UFSM), Santa Maria, Brazil*

[2] *Núcleo de Estudos em Performance Analysis Esportiva (NEPAE), Centro de Educação Física e Desportos, Universidade Federal de Santa Maria (UFSM), Santa Maria, Brazil*

[3] *LaBioC- Laboratório de Biomecânica Clínica, Departamento de Fisioterapia e Reabilitação, Universidade Federal de Santa Maria (UFSM), Santa Maria, Brazil*

[4] *Grupo de Estudos e Pesquisas em Educação Física e Esportes (GEPEFE), Laboratório de Análise Esportiva (LAE), Universidade Federal de Mato Grosso (UFMT), Cuiabá, Brazil*

[5] *Núcleo de Estudo e Pesquisa Avançada em Esportes (NEPAE), Universidade Federal de Goiás (UFG), Goiânia, Brazil*

CORRESPONDING AUTHOR:
Gustavo F. Pedrosa
Research Group Applied to Strength Training (GPATF)
Center for Physical Education and Sports of Federal University of Santa Maria
Av. Roraima 1000
Santa Maria 97105-900, Brazil
E-mail: gustavofpedrosa@gmail.com

DOI:
10.32098/mltj.03.2024.03

LEVEL OF EVIDENCE: 2

SUMMARY

Background. It is still not clear what physiologically differentiates trained individuals from untrained individuals regarding the ability to hypertrophy, with speculation that these individuals may present different swelling levels in response to the same training load.

Objective. This study aimed to compare the response of muscular swelling between eight adults from the More Experienced Group (MEG) and eight participants from the Less Experienced Group (LEG).

Methods. The swelling response in the biceps brachii muscle was assessed by measuring the variation in cross-sectional area at 50% of the arm length (pre *vs* post) using B-mode ultrasound through a paired t-test. This comparison was conducted after the completion of four sets to failure at 70% of the one maximum repetition test in the preacher barbell curl exercise. Additionally, the mean values for the maximum number of repetitions (MNR), time under tension (TUT), and the rate of perceived exertion (RPE) for the four sets were also compared using a paired t-test.

Results. LEG exhibited greater muscle swelling compared to the MEG (22.59 ± 7.05%; 15.71 ± 5.40%, respectively: $p < 0.001$), although no significant differences were observed in MNR, TUT, and RPE.

Conclusions. Experience level appears to influence the response of muscular swelling, indicating that individuals with less experience tend to have greater swelling than those with more experience in strength training. Thus, more trained individuals should seek to implement training strategies, such as an increase in training load, if maintaining muscular swelling is desired.

KEY WORDS

Muscle; resistance training; swelling; metabolic stress; trained individual.

INTRODUCTION

The design of variables in a training program aimed at enhancing strength and muscle hypertrophy necessitates the evaluation of multiple factors, including biological individuality, training specificity, and an individual's level of experience (1). Concerning experience, it is expected that more experienced resistance training individuals are able to lift more weight and present greater muscle size than individuals with less training experience (2). This indicates that training experience leads to specific adaptations resulting in increased muscle mass and the physical and technical capacity to support loads even higher (3, 4). However, and focusing on the muscle hypertrophy response, it is acceptable that increases in muscle mass induced by resistance training become progressively smaller as training duration increases (5, 6). As the hypertrophic response is primarily triggered by the activation of mechanisms in response to mechanical and metabolic stresses (7-9) is it possible that the sensitivity of one of these mechanisms decreases with an increase in training experience? If so, this could help to justify why individuals with more training experience proportionally experience less hypertrophy over time compared to those with less experience (5). Nevertheless, studies exploring the reasons behind the reduction in hypertrophic capacity as training experience increases are limited.

Metabolic stress arises from an ischemic/hypoxic environment, which is believed to promote muscle growth through various mechanisms, including increased recruitment of fast-twitch muscle fibers, elevated systemic hormone levels, heightened production of reactive oxygen species, and cellular swelling (9-11). Regarding the latter, it is believed that during exercises heavily reliant on anaerobic metabolism, muscle swelling occurs due to changes in intracellular and extracellular water balance caused by increased vascular permeability (12). Previous studies employing bioimpedance spectroscopy have indicated correlations between changes in intracellular and extracellular water balance and variations in ion concentration, with metabolic alterations observed in skeletal muscle cells post-exercise (13). Consequently, muscle swelling can be regarded as an indirect indicator of the accumulation of metabolic stress, and thus, it may play a significant role in the hypertrophy process (11). Supporting this argument, prior studies have identified a positive association between acute muscle swelling midway through a training period and hypertrophy (14). Moreover, this connection persists even when muscle swelling is measured on the first training day and linked to hypertrophy (14).

In this context, a question arises: do trained individuals respond with more or less swelling than those with less training experience? Several studies have highlighted a connection between experience in resistance training and a significant increase in monocarboxylate transporter (MCT) ($r = 0.70$, $p < 0.001$) (15) MCT is known to play a crucial role in the process of lactate removal and its reuse (16). This elevated presence of MCT may have an impact on the changes in ionic composition within muscle cells. These changes could potentially reduce the likelihood of acute muscle swelling, which often arises from significant alterations in the body's acid-base balance, hydration status, and electrolyte levels (17). Thus, these alterations can negatively influence the movement of ions and fluids within the muscle cells, compromising the muscle swelling increase (17).

In this scenario, there is a likelihood that individuals with greater training experience might demonstrate lower levels of muscle swelling in comparison to those with less experience. Nonetheless, a direct comparison for confirmation is still pending. The outcome of this comparison could help shed light on the reasons why more trained individuals tend to respond less to training than their less trained counterparts. Therefore, this study aims to compare muscle swelling among groups of individuals with varying levels of experience in resistance training, with the hypothesis that there will be less muscle swelling in the group with greater training experience.

MATERIALS AND METHODS

Overview

Participants were divided into two groups: more experienced group (MEG) and Less Experienced Group (LEG) and both groups underwent three experimental sessions separated by 48-72h. The initial two experimental sessions were designed for participant familiarization and conducting the one-repetition maximum (1RM) test during the seated barbell preacher curl exercise. In the subsequent third experimental session, participants carried out repetitions to failure at 70% of their 1RM over four sets. The duration of time under tension (TUT), rate of perceived exertion (RPE), and the maximal number of repetitions were recorded and utilized as control variables for further assessment. B-mode ultrasound images of the right biceps brachii's cross-sectional area (CSA) were obtained before and after the third experimental session at the midpoint of the humerus for the purpose of analyzing and comparing muscle swelling. **Figure 1** provides an overview of the study design.

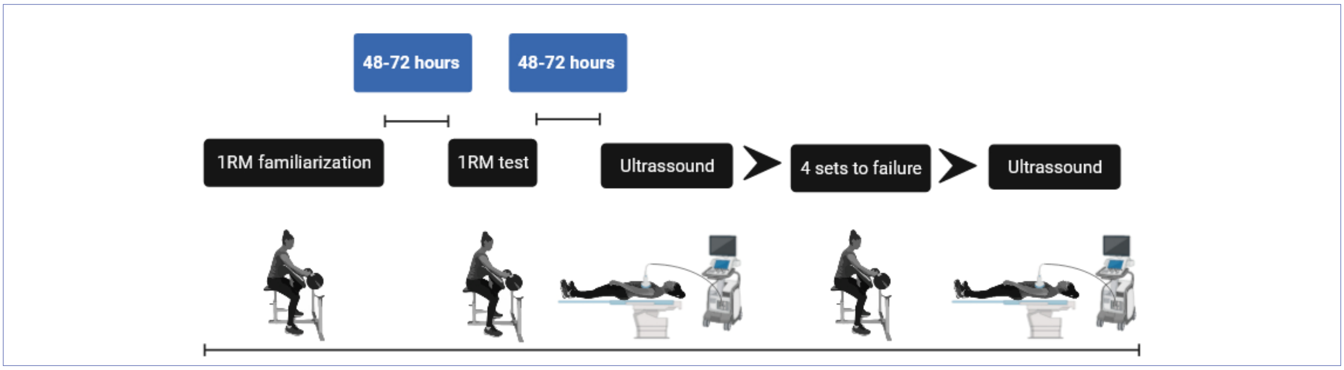

Figure 1. Study design.
1RM = One maximum repetition test.

Subjects

The sample size was determined according to the methodology recommended by Beck (2013) (18) using G*Power 3.1 software. We considered paired comparisons (t-test) of means to calculate the minimum number of participants required to achieve a statistical power of at least 80% ($p = 0.05$). In this calculation, we referred to data on immediate muscle swelling following a strength training session as presented in the study by Hirono *et al.* (2020) (14) (effect size = 0.967), which indicated the necessity of involving a total of 14 volunteers (seven in each group). Considering a sample loss, the present study counted with 16 individuals with age ranged between 18-30 years old and free of injury. For note, each group was composed by six men and two women. For being included in MEG, participant should be training regularly for more than a year, while for LEG, participants should be training between 3-6 months. The study was approved by the Ethics Committee of the Federal University of Santa Maria under the reference number 69325723.2.20000.5346 – date of approval: May 22, 2023 –, ensuring compliance with international standards. Furthermore, participants were instructed to refrain from engaging in any physical activity on the days of the testing sessions. Anthropometric data of each group are available at **table I**.

Procedures

First experimental session: familiarization of 1RM test

In the first experimental session, participants were subjected to measurements, including height, body mass, and skinfold thickness, to determine fat percentage. Following this, they were positioned for the seated barbell preacher curl exercise 1RM test familiarization. The seat height was adjusted to achieve a 45° angle of shoulder flexion between the humerus and the trunk. The participants fully extended their elbows and reached for the bar, which had fixed markers to ensure their hands were at a standardized distance from the center of the bar to the grip location. Hand and seat positions were carefully recorded for future reference.

Subsequently, participants performed 10 repetitions using only the bar's weight (9.63 kg). Each repetition consisted of a 2-second positive (lifting) phase and a 2-second negative (lowering) phase, serving as a warm-up. The tempo of these movements was regulated by a metronome. During each repetition, participants executed a 130-degree elbow flexion, with 0 degrees representing full elbow extension. The range of motion was measured and determined using a goniometer. Following a two-minute rest period after the warm-up, participants commenced the familiarization phase of the 1RM test in the same exercise and position as the warm-up. The 1RM familiarization was conducted throughout the full range of motion, with a 3-minute recovery interval between each attempt. A final 1RM value was established within six attempts. Each attempt began with the elbow fully extended, and participants executed a positive muscle action until reaching 130° of elbow flexion, with the forearm perpendicular to the ground. The bar load was incrementally increased (with a minimum increment of 0.5 kg),

Table I. Groups profile.

Groups	Age (years)	Body mass (kg)	Heigth (cm)	Body fat (%)	Experience (months)
MEG	22.13 ± 2.59	82.09* ± 11.35	178.63 ± 10.46	11.26* ± 5.07	65.45* ± 26.27
LEG	21.13 ± 2.15	68.66 ± 9.54	171.00 ± 8.48	18.91 ± 8.35	3.09 ± 2.07

MEG: more experience group; LEG: less experience group; *different from the other group by paired t test ($p < 0.05$); n = 8 at each group.

and all weights were precisely measured using a three-digit scale. The 1RM value represented the maximum weight lifted in the last successful attempt. Similar procedures for achieving 1RM have been previously documented for the preacher curl exercise (19, 20).

Second Experimental Session: 1RM Test

The second experimental session took place 48-72 hours following the previous session. During this session, a single 1RM test was performed, adhering to the established procedures introduced during the 1RM test familiarization. Data collected from this 1RM test were gathered for subsequent statistical analysis. The Intra-class Correlation Coefficient ($ICC_{3,1}$) was calculated to assess the relationship between the 1RM results of the familiarization session and the test session, yielding a good correlation ($ICC_{3,1} = 0.99$).

Third Experimental Session: ultrasound and training protocol

The third experimental session was conducted 48-72 hours following the second session. During this session, participants underwent ultrasound examinations to assess the cross-sectional area (CSA) of the biceps brachii. Two measurements of biceps brachii CSA were taken at a point situated 50% of the distance from the acromion to the lateral epicondyle of each humerus. The assessments were performed using B-mode ultrasound (ACUSON S2000, Siemens, Germany). The ultrasound images were captured at a rate of 21 frames per second, utilizing a 10 MHz linear transducer set to a depth of 6-8 cm and a gain of 13dB. Individual adjustments were made to optimize the image clarity for the entire muscle and to facilitate subsequent replication. Two skilled technicians carried out the ultrasound scans, ensuring that the transducer moved in a line perpendicular to the humeral region at a relatively constant speed. The captured images were saved to a hard drive and anonymized for blinded CSA calculations using Horos® software (Annapolis, Maryland, USA). The mean CSA value from the two images was used for subsequent statistical analysis. **Figure 2** displays the images of the biceps brachii CSA before and after the completion of the experimental protocols.

Following the ultrasound image collection, participants proceeded with a warm-up for the seated bar preacher curl exercise, following a protocol similar to the one used for the 1RM test warm-up. After a two-minute rest, participants performed the maximum number of repetitions (MNR) from 0° to 130° of elbow flexion across four sets. The intensity was set at 70% of their 1RM, with a 2-minute interval between sets. Each repetition was executed with a controlled tempo of 2 seconds for the positive phase and 2 seconds for the negative phase, guided by a metronome, and the range of motion was monitored by one of the evaluators. A chronometer was

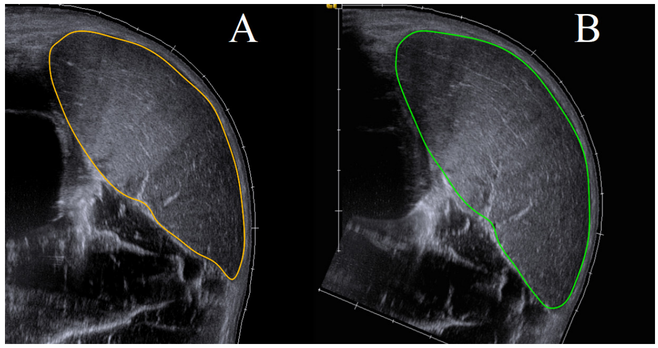

Figure 2. Images of the biceps brachii CSA pre- and post-training protocol.

CSA = cross sectional area at 50% of humorous length; **(A)** Pre-training protocol; **(B)** Pos-training protocol.

initiated as each participant began lifting the weight and was stopped at the point of failure. The time duration from the start to the stop of the timer was recorded as the time under tension (TST). It was observed that as participants approached failure, especially during the last two repetitions, the duration of each repetition increased, often exceeding 4 seconds.

After each set, participants indicated their RPE by selecting a number on a scale ranging from 0 to 10. This scale represented the effort required to complete the entire set, with 0 denoting minimal effort and 10 indicating maximum effort. The MNR, TUT, and RPE were recorded for each set and the mean value between sets were used for groups comparison as control variable.

Furthermore, immediately after the last set, participants underwent another round of ultrasound imaging, following the same procedures as previously. The purpose of this was to obtain two new images and measure the CSA value once more. The relative difference in CSA between the pre- and post-training protocol measurements was indicative of muscle swelling and employed for groups comparison. For the reliability measurement of CSA, we computed the $ICC_{3,1}$ for the two CSA measurements taken during the third experimental session (n = 64 images with $ICC_{3,1} = 0.99$), as previously conducted (19, 21). In these sessions, another researcher assessed 35% of all the images, resulting in an also high measurement reliability ($ICC_{3,1} = 0.98$) between them, procedure performed previously (22).

Statistical analysis

Initially a descriptive analysis of the data was performed. The normality and homogeneity of variances were verifiedf using Shapiro-Wilk and Mauchly's tests, respectively. The biceps brachii CSAs at pre- and post-performance of MEG and LEG were transformed into relative values (%) as indicator of muscle swelling *((pos - pre) / pre) × 100)* and compared by paired t tests. To compare the mean value between sets of MNR, TUT, and RPE paired t tests was also employed. The level of significance was fixed at priori as $\alpha = 0.05$. In addition, Cohen'd effect size was calculated, in which trivial: < 0.20; small: 0.20 to 0.60; moderate: 0.61 to 1.20; large: 1.21 to 2.0; very large: > 2 (23). All statistical procedures were performed in the Social Package Software Statistic (SPSS 22.0 for Windows, Chicago, IL, USA).

RESULTS

The normality of the distribution was confirmed by the Shapiro-Wilk test, and all volunteers who initiated data collection were able to complete it. Additionally, the paired t-test showed no differences between groups in the weight lifted during the 1RM test and the other control variables: TUT, MNR and RPE. **Table II** present mean and standard deviation data and inferential comparisons results between groups.

Muscle swelling

Both groups presented greater CSA values post-training protocol compared to pre, indicating the training protocol was able to provoke muscle swelling regardless the training experience (MEG: $p = 0.001$. ES = 0.462; LEG: $p < 0.001$. ES = 0.536). In addition, biceps brachii CSA pre-training protocol tended to be greater for MEG compared to LEG ($p = 0.095$) and this tendency was reinforced by the ES = 1.067. However, the CSA change immediately post-training protocol performance (muscle swelling) was greater for LEG than MEG ($p = 0.001$. ES = 1.062). **Figure 3** illustrates the CSA variations between MEG and LEG.

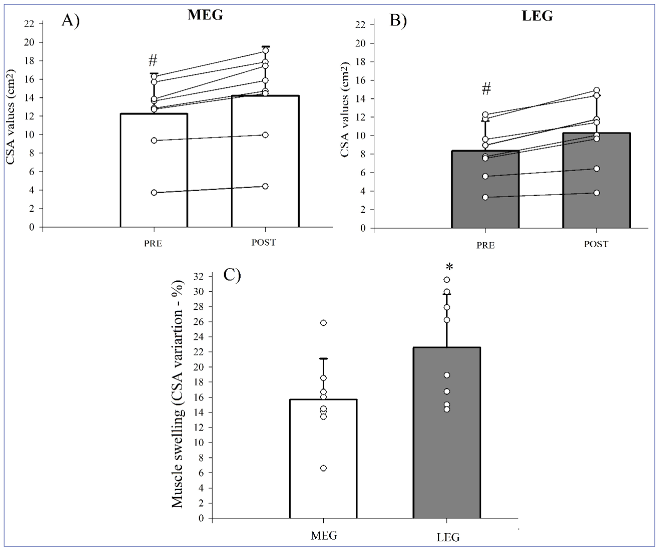

Figure 3. Cross-sectional area (CSA) comparison between MEG and LEG.

MEG: more experience group; LEG: less experience group; **(A)** CSA data of MEG; **(B)** CSA data of LEG; **(C)** Muscle swelling comparison between MEG and LEG; circles: individual data; columns: mean value; *greater than MEG; #lower than post value; $\alpha = 0.05$.

DISCUSSION

The study aimed to compare biceps brachii muscle swelling following a training protocol involving four sets to failure at 70% of the 1RM test between groups differentiated by their resistance training experience. Notably, despite observed similar variables' results, such as TUT, RPE, and the MNR performed, the primary findings revealed a greater degree of swelling in the LEG group compared to the MEG group.

The higher muscular swelling response observed in LEG confirms the initial hypothesis that executing a similar training load between MEG and LEG would promote greater swelling in the latter group. Possible explanations can be drawn to justify these results. Muscle swelling seems to be dependent on an osmotic change induced by the increase in the concentration of metabolites inside the muscle cell (13). In this sense, large accumulations of metabolites in the muscle would, in part, be responsible for the increase in muscle swelling (12, 13). Previous evidence have shown that individuals with more experience in resistance training were able to clear lactate/hydrogen ions faster than individuals with no experience (24).

Table II. Mean and standard deviation data of control variables from LEG and MEG.

Variables	LEG	MEG	P-value	ES
MNR (a.u.)	10.63 ± 2.71	9.88 ± 3.42	0.663	0.32
TUT (s)	46.86 ± 13.69	45.49 ± 14.01	0.872	0.09
RPE (a.u.)	9.38 ± 0.76	9.22 ± 1.34	0.797	0.15
1RM (kg)	27.18 ± 11.92	37.04 ± 13.41	0.225	0.73

LEG: less experience group; MEG: more experience group; ES: effect size; MNR: maximum number of repetitions; TUT: time under tension; RPE: rate of perceived exertion; 1RM: one repetition maximum test; a.u.: arbitrary units.

If more trained individuals can remove metabolites faster than less trained individuals, it is possible to speculate that the adaptations optimizing this process decrease the likelihood of muscular swelling.

This reasoning is reinforced by our results, suggesting that for a similar training load, individuals with more training experience are subjected to lower metabolic stress than individuals with less experience. This would help understand why individuals with less experience are capable of proportionally greater hypertrophy than individuals with more experience during a training period (25). A practical application of our results, combined with the reasoning above, is that individuals more experienced in resistance training require a higher training load than less experienced individuals for a potential equalization in hypertrophy-inducing factors such as metabolic stress. Among the alternatives, an increase in the number of sets or exercises could be one possible solution.

To the best of our knowledge, this is the first study that compares the swelling response among trained individuals with varying levels of experience. Other studies comparing different variables have already been conducted. For example, in the study by Fouré *et al.* (2020) (26), the muscle swelling of the quadriceps femoris was compared between the right and left lower limbs after an electrostimulation session. In each lower limb the vastus lateralis and vastus medialis muscles received the same electrostimulation protocol at two different joint angles: a larger and a smaller muscle length (100° and 30° of knee flexion, respectively, with 0° representing a fully extended knee). The study's results indicated that muscle swelling was greater when the muscles were electro stimulated at the 100° angle. It is worth mentioning that previous studies have shown that training in the lengthened (dynamic (19) or isometric (27)) position was superior to training in the shortened position for promoting muscle hypertrophy. These collective results emphasize the importance of analyzing swelling from a predictive perspective regarding hypertrophic potential.

Considering the response of control variables, there were no significant differences in the MNR, TUT, and RPE between the MEG and LEG. In fact, previous studies suggest the training experience present minimal impact on the MNR performed across sets (28, 29). Therefore, despite individuals with more training time performing repetitions with higher absolute resistance than those less trained, the more trained exhibit greater morphological adaptations and central nervous system adjustments (24, 30). It's interesting that if the number of repetitions were different between the groups, this factor could have an impact on muscular swelling (31) by influencing the metabolic concentration (32). Making it difficult to understand whether the differences in muscular swelling were due to the time of experience or other factors, such as the number of repetitions.

Since the number of repetitions was similar between the groups in the present study and the duration of actions was controlled, it is plausible to expect an equivalence in TUT. It is worth noting that there is evidence that a difference in TUT could impact metabolic concentration (33) and influence muscular swelling. Notwithstanding, the lack of differences between the groups in this variable reinforces the premise that the time of experience was a determining factor for the difference in muscular swelling between the groups. Furthermore, the RPE between the groups was similar, indicating that the perceived stress to perform repetitions across sets was alike among the groups. Since the repetitions were carried out until muscular failure, a uniformity in this response would be expected (31), reinforcing that RPE was also not as decisive factor as training experience for the difference found in muscular swelling.

The present study has several limitations. Firstly, the sample size is small, and a larger sample might yield a different or even more disparate result. Secondly, the combination of men and women in the groups could have increased the variability of the responses, making it difficult to detect differences between the groups. As was possibly the case in the 1RM test result - despite the effect size suggesting differences. Thirdly, blood collection was not conducted to analyze metabolic variables for more accurate directions and discussions. Fourthly, the analysis was limited to a point in the biceps brachii, while other muscle points might have responded differently. Finally, various factors were not controlled, such as nutritional status, ambient temperature, and prior rest before exercise, which could influence the results. Moreover, our results should not be extrapolated to other populations, exercises, or muscles.

CONCLUSIONS

This study found that performing the preacher curl barbell exercise under matched conditions in intensity, sets, number of repetitions, TUT, and RPE may lead to a greater muscular swelling response in less trained individuals compared to more trained individuals. In this sense, the results suggest that individuals with more training experience should train with a higher training load than less experienced individuals to induce an equivalent level of muscular swelling.

FUNDINGS

None.

DATA AVAILABILITY

Data are available under reasonable request to the corresponding author.

CONTRIBUTIONS

GFP, LL, AGBB: conceptualization, writing – original draft, data collection. MECR, LACS: data collection, image analysis. TDL, MFS, HOC, GCTC: conceptualization, data collection. All authors: writing – review & editing.

ACKNOWLEDGEMENTS

We would like to thank all the volunteers.

CONFLICT OF INTERESTS

The authors declare that they have no conflict of interests.

REFERENCES

1. Schoenfeld B, Fisher J, Grgic J, et al. Resistance training recommendations to maximize muscle hypertrophy in an athletic population: position stand of the IUSCA. Int'l J Strength Condit. 2021;1(1):1-30. doi: 10.47206/ijsc.v1i1.81.
2. American College of Sports Medicine. American College of Sports Medicine position stand. Progression models in resistance training for healthy adults. Med Sci Sports Exerc. 2009;41(3):687-708. doi: 10.1249/MSS.0b013e3181915670.
3. Ozaki H, Abe T, Mikesky AE, Sakamoto A, Machida S, Naito H. Physiological stimuli necessary for muscle hypertrophy. J Phys Fit Sports Med. 2015;4(1):43-51. doi: 10.7600/jpfsm.4.43.
4. Crewther B, Cronin J, Keogh J. Possible stimuli for strength and power adaptation: acute mechanical responses. Sports Med. 2005;35(11):967-89. doi: 10.2165/00007256-200535110-00004.
5. Counts BR, Buckner SL, Mouser JG, et al. Muscle growth: To infinity and beyond? Muscle Nerve. 2017;56(6):1022-30. doi: 10.1002/mus.25696.
6. Damas F, Phillips S, Vechin FC, Ugrinowitsch C. A review of resistance training-induced changes in skeletal muscle protein synthesis and their contribution to hypertrophy. Sports Med. 2015;45(6):801-7. doi: 10.1007/s40279-015-0320-0.
7. Wackerhage H, Schoenfeld BJ, Hamilton DL, Lehti M, Hulmi JJ. Stimuli and sensors that initiate skeletal muscle hypertrophy following resistance exercise. J Appl Physiol (1985). 2019;126(1):30-43. doi: 10.1152/japplphysiol.00685.2018.
8. Floco P, Galeoto G. Effect of blood flow restriction training on physiological outcomes in healthy athletes: a systematic review and meta-analysis. Muscles Ligaments Tendons J. 2021;11(1):101-17. doi: 10.32098/mltj.01.2021.12.
9. de Freitas MC, Gerosa-Neto J, Zanchi NE, Lira FS, Rossi FE. Role of metabolic stress for enhancing muscle adaptations: Practical applications. World J Methodol. 2017;7(2):46-54. doi: 10.5662/wjm.v7.i2.46.
10. Pearson SJ, Hussain SR. A review on the mechanisms of blood-flow restriction resistance training-induced muscle hypertrophy. Sports Med. 2015;45(2):187-200. doi: 10.1007/s40279-014-0264-9.
11. Schoenfeld BJ. Potential mechanisms for a role of metabolic stress in hypertrophic adaptations to resistance training. Sports Med. 2013;43(3):179-94. doi: 10.1007/s40279-013-0017-1.
12. Sjøgaard G, Adams RP, Saltin B. Water and ion shifts in skeletal muscle of humans with intense dynamic knee extension. Am J Physiol. 1985;248(2 Pt 2):R190-6. doi: 10.1152/ajpregu.1985.248.2.R190.
13. Taniguchi M, Yamada Y, Ichihashi N. Acute effect of multiple sets of fatiguing resistance exercise on muscle thickness, echo intensity, and extracellular-to-intracellular water ratio. Appl Physiol Nutr Metab. 2020;45(2):213-9. doi: 10.1139/apnm-2018-0813.
14. Hirono T, Ikezoe T, Taniguchi M, et al. Relationship Between Muscle Swelling and Hypertrophy Induced by Resistance Training. J Strength Cond Res. 2022;36(2):359-64. doi: 10.1519/JSC.0000000000003478.
15. Dubouchaud H, Butterfield GE, Wolfel EE, Bergman BC, Brooks GA. Endurance training, expression, and physiology of LDH, MCT1, and MCT4 in human skeletal muscle. Am J Physiol Endocrinol Metab. 2000;278(4):E571-9. doi: 10.1152/ajpendo.2000.278.4.E571.
16. Juel C. Current aspects of lactate exchange: lactate/H+ transport in human skeletal muscle. Eur J Appl Physiol. 2001;86(1):12-6. doi: 10.1007/s004210100517.
17. Philp NJ, Yoon H, Grollman EF. Monocarboxylate transporter MCT1 is located in the apical membrane and MCT3 in the basal membrane of rat RPE. Am J Physiol. 1998;274(6):R1824-8. doi: 10.1152/ajpregu.1998.274.6.R1824.
18. Beck TW. The importance of a priori sample size estimation in strength and conditioning research. J Strength Cond Res. 2013;27(8):2323-37. doi: 10.1519/JSC.0b013e318278eea0.
19. Pedrosa GF, Simões MG, Figueiredo MOC, et al. Training in the Initial Range of Motion Promotes Greater Muscle Adaptations Than at Final in the Arm Curl. Sports (Basel). 2023;11(2):39. doi: 10.3390/sports11020039.
20. Pedrosa GF, Bischoff ABG, Luchese AK, et al. Combination of training to failure and non-failure: an unexplored approach of number of repetitions, rate of perceived exertion, time under tension, volume-load, and muscle swelling in trained individuals. Muscles Ligaments Tendons J. 2024;14 (1):203-18. doi: 10.32098/mltj.01.2024.18.
21. Earp JE, Newton RU, Cormie P, Blazevich AJ. Inhomogeneous Quadriceps Femoris Hypertrophy in Response to Strength and Power Training. Med Sci Sports Exerc. 2015;47(11):2389-97. doi: 10.1249/MSS.0000000000000669.
22. Pedrosa GF, Lima FV, Schoenfeld BJ, et al. Partial range of motion training elicits favorable improvements in muscular adaptations when carried out at long muscle lengths. Eur J Sport Sci. 2022;22(8):1250-60. doi: 10.1080/17461391.2021.1927199.

23. Batterham AM, Hopkins WG. Making meaningful inferences about magnitudes. Int J Sports Physiol Perform. 2006;1(1):50-7.
24. Kotikangas J, Walker S, Toivonen S, Peltonen H, Häkkinen K. Acute Neuromuscular and Hormonal Responses to Power, Strength, and Hypertrophic Protocols and Training Background. Front Sports Act Living. 2022;4:919228. doi: 10.3389/fspor.2022.919228.
25. Ahtiainen JP, Pakarinen A, Alen M, Kraemer WJ, Häkkinen K. Muscle hypertrophy, hormonal adaptations and strength development during strength training in strength-trained and untrained men. Eur J Appl Physiol. 2003;89(6):555-63. doi: 10.1007/s00421-003-0833-3.
26. Fouré A, Ogier AC, Guye M, Gondin J, Bendahan D. Muscle alterations induced by electrostimulation are lower at short quadriceps femoris length. Eur J Appl Physiol. 2020;120(2):325-35. doi: 10.1007/s00421-019-04277-5.
27. Noorkõiv M, Nosaka K, Blazevich AJ. Effects of isometric quadriceps strength training at different muscle lengths on dynamic torque production. J Sports Sci. 2015;33(18):1952-61. doi: 10.1080/02640414.2015.1020843.
28. Pedrosa GF, Da Silva BVC, Barbosa GF, et al. The sling shot increased the maximum number of repetitions in the barbell bench press in men with different resistance training experience. Hum Mov. 2020;21(1):22-31. doi: 10.5114/hm.2020.88150.
29. Nuzzo JL, Pinto MD, Nosaka K, Steele J. Maximal Number of Repetitions at Percentages of the One Repetition Maximum: A Meta-Regression and Moderator Analysis of Sex, Age, Training Status, and Exercise. Sports Med. 2024;54(2):303-21. doi: 10.1007/s40279-023-01937-7.
30. Ahtiainen JP, Häkkinen K. Strength athletes are capable to produce greater muscle activation and neural fatigue during high-intensity resistance exercise than nonathletes. J Strength Cond Res. 2009;23(4):1129-34. doi: 10.1519/JSC.0b013e3181aa1b72.
31. Exner RJ, Patel MH, Whitener DV, Buckner SL, Jessee MB, Dankel SJ. Does performing resistance exercise to failure homogenize the training stimulus by accounting for differences in local muscular endurance? Eur J Sport Sci. 2023;23(1):82-91. doi: 10.1080/17461391.2021.2023657.
32. Goto K, Ishii N, Kizuka T, Kraemer RR, Honda Y, Takamatsu K. Hormonal and metabolic responses to slow movement resistance exercise with different durations of concentric and eccentric actions. Eur J Appl Physiol. 2009;106(5):731-9. doi: 10.1007/s00421-009-1075-9.
33. Goto K, Ishii N, Kizuka T, Takamatsu K. The impact of metabolic stress on hormonal responses and muscular adaptations. Med Sci Sports Exerc. 2005;37(6):955-63.