Proof Central

Please use this PDF proof to check the layout of your article. If you would like any changes to be made to the layout, you can leave instructions in the online proofing interface. First, return to the online proofing interface by clicking the Edit button at the top of the page, then insert a Comment in the relevant location. Making your changes directly in the online proofing interface is the quickest, easiest way to correct and submit your proof.

Please note that changes made to the article in the online proofing interface will be added to the article before publication, but are not reflected in this PDF proof.

AUTHOR QUERIES

DATE 3/23/2026
JOB NAME JSCR
ARTICLE JSCR-08-23927
QUERIES FOR AUTHORS Vasconcelos et al

THIS QUERY FORM MUST BE RETURNED WITH ALL PROOFS FOR CORRECTIONS

Please make sure all figures contain error bars where necessary. Attach any updated figures with your returned proofs.

AU1) Please confirm that this study was approved by an Institutional Review Board. Please also confirm the institution's name if not already stated.

AU2) Please provide volume number and page range in reference 9.

AU3) For Fig(s) 1, the source image provided is too low in resolution and not clear enough to use. Please provide a new image with at least 300 DPI and make sure everything is easy to read.

AU4) For Fig(s) 2, the source image provided is too low in resolution and not clear enough to use. Please provide a new image with at least 300 DPI and make sure everything is easy to read.

AU5) For Fig(s) 3, the source image provided is too low in resolution and not clear enough to use. Please provide a new image with at least 300 DPI and make sure everything is easy to read.

Comparative Adaptations to Different Leg Extension Set-termination Strategies in Trained Men and Women: A Unilateral Within-Participant Study

Tiago Vasconcelos,[1,2] Ana Ruivo,[1,2] Martin C. Refalo,[3] Gabriela Chaves Lucas,[4] Pedro R. Vasconcelos,[4] João P. Brito,[1,5,6] José Vilaça-Alves,[1,4,7] and Rafael Oliveira[1,5,6]

[1]*Research Center in Sports Sciences, Health Sciences and Human Development,CIDESD, Covilhã, Portugal;* [2]*Department of Sport Sciences, University of Beira Interior, Covilhã, Portugal;* [3]*JPS Health & Fitness, Melbourne, Australia;* [4]*University of Trás-os-Montes e Alto Douro, Vila Real, Portugal;* [5]*School of Sport, Santarém Polytechnic University, Rio Maior, Portugal; and* [6]*Life Quality Research Center (CIEQV), Santarém Polytechnic University, Santarém, Portugal* [7]*Research Group in Strength Training and Fitness Activities, GEETFAA, Vila Real, Portugal;*

Abstract

Vasconcelos, T, Ruivo, A, Refalo, MC, Chaves Lucas, G, Vasconcelos, PR, Brito, JP, Vilaça-Alves, J, and Oliveira, R. Comparative adaptations to different leg extension set-termination strategies in trained men and women: a unilateral within-participant study. *J Strength Cond Res* XX(X): 000–000, 2026—The purpose of this study was to compare relative adaptations between two set-termination strategies (momentary muscular failure vs. repetitions in reserve) using a unilateral within-participant design under ecologically realistic resistance-training conditions. Nineteen trained subjects (11 men, eight women; mean age: 22.3 ± 3.9 years; body mass: 69.9 ± 10.3 kg) completed an 8-week unilateral intervention. Each subject performed leg extensions, with one limb randomly assigned to the FAIL protocol and the contralateral limb to the repetitions-in-reserve (RIR) protocol. Muscle thickness (ultrasound) of the knee extensors and 1-repetition maximum strength were assessed pre- and postintervention and analyzed using Bayesian linear mixed-effect models. Estimated between-protocol differences for hypertrophy were negligible (knee extensors: −0.019 cm [−0.094 to 0.054]), as were differences for 1-repetition maximum strength (knee extensors: 0.198 kg [−1.87 to 2.6]). Secondary analyses using standardized mean differences also suggested no clear overall advantage for either protocol. These findings suggest that resistance training performed with a 1- to 3-RIR may produce adaptations comparable with training to momentary muscular failure in knee extensors under applied training conditions. Strength and conditioning professionals may therefore consider RIR-based strategies as a practical approach to manage fatigue while maintaining training effectiveness.

Key Words: repetitions-in-reserve, muscular adaptations, autoregulation, set termination

Introduction

Resistance training (RT) is a fundamental modality for eliciting adaptations in skeletal muscle that include hypertrophy of muscle fibers and the enhancement of maximal force-production capacity (13,21,39,48). Effective RT program designs need the appropriate manipulation of numerous training variables, including the total volume completed (40), the load lifted (19,39,41), the selection of specific exercises, the duration of recovery between sets (42), and the frequency of training stimuli (8); all of which may be influenced by individual factors such as biological sex (23,24), genetics, and lifestyle factors. Among these multifaceted components, the degree of effort exerted within individual RT sets, often operationalized by the proximity to which repetitions are performed relative to the point of momentary muscular failure, has emerged as a variable of considerable scientific interest and practical relevance (26,32,36). A common method for quantifying this proximity-to-failure is the use of the repetitions-in-reserve (RIR) scale (3), defined as the estimated number of repetitions remaining before momentary muscular failure is reached, which involves set termination once a target RIR has been achieved. Importantly, a primary limitation in the literature assessing proximity-to-failure is that group-specific RIR is often not monitored or quantified, which complicates direct comparisons between studies and necessitates post hoc estimations in meta-analyses (30). Moreover, even when tools such as the RIR scale are directly used, their application is not without limitations, as subjective estimations of RIR have demonstrated small, but inherent inaccuracies (2,3,32,34). Therefore, further investigations into proximity-to-failure are considered paramount for the development of nuanced, evidence-informed training prescription designed to optimize muscle hypertrophy and strength outcomes (32,36).

Despite the acknowledged importance of manipulating training variables for promoting muscle hypertrophy, debate persists regarding the precise role and necessity of training to, or in close proximity to, momentary muscular failure (15,32,36,47). Traditionally, training to momentary muscular failure has been

Address correspondence to Rafael Oliveira, rafaeloliveira@esdrm.ipsantarem.pt.

Supplemental digital content is available for this article. Direct URL citations appear in the printed text and are provided in the HTML and PDF versions of this article on the journal's Web site (http://journals.lww.com/nsca-jscr).

Journal of Strength and Conditioning Research 00(00)/1–9

advocated as a requisite for ensuring high motor unit recruitment and thereby creating a potent stimulus for adaptation (32,38). Indeed, a recent series of meta-regressions by Robinson et al. (36), found that muscle hypertrophy increases as RT sets near momentary muscular failure. The interpretation of this finding, however, is complicated by notable limitations; namely that the RIR values analyzed were estimated by the researchers post hoc and that the analysis combined data from studies with considerable methodological heterogeneity. These collective limitations underscore the findings from Refalo et al. (32), whereby a robust within-subject design with direct (and highly accurate) RIR prediction revealed equivalent hypertrophic outcomes between training to momentary muscular failure and 1- to 2-RIR. For strength development, Robinson et al. (36) conversely reported a negligible relationship between proximity-to-failure and strength gains, suggesting the influence of this proximity-to-failure is likely outcome-specific. This potential dichotomy, whereby proximity to failure may be a more critical determinant of muscle hypertrophy than for strength, has significant implications for program design, indicating that training prescriptions may need to be tailored to the specific adaptation goal. Moreover, this body of literature is limited by a lack of sex-specific analyses that could provide insights into the influence of proximity-to-failure on sex-specific muscle hypertrophy (14,23,24,33,35). Furthermore, while biological sex is often considered a variable influencing training adaptations, recent evidence suggests that apparent sex differences may be underpinned by disparities in baseline strength rather than sex per se. For instance, when subjects are matched for relative strength, differences in muscle activation patterns (22) and rapid force production characteristics (7) between men and women are largely attenuated. This suggests that in resistance-trained individuals, baseline relative strength may be a more critical determinant of neuromuscular function than biological sex. Consequently, it is plausible that the physiological response to manipulating proximity-to-failure is comparable between sexes, provided that the training status and relative intensity are appropriately controlled.

The primary purpose of this study was to compare adaptations between two set-termination strategies (momentary muscular failure vs. repetitions in reserve) in the knee extensor muscles using a unilateral within-participant design. The outcomes are presented separately for male and female cohorts to investigate potential sex-specific effects and inform the design of future, larger-scale investigations into this topic. It was hypothesized that knee extensors hypertrophy and maximal strength outcomes will be similar between the RT protocols for the whole sample and for men and women separately.

AU1 Methods

Experimental Approach to the Problem

A unilateral, within-subject randomized experimental design was used to compare the effects of an 8-week RT intervention on muscular adaptations, specifically knee extensors muscle hypertrophy and maximal strength. The intervention consisted of two supervised training sessions per week, during which subjects performed 5–6 sets for each leg. Each subject performed the unilateral leg extension, with one limb randomly assigned (through coin flip) to a protocol training to momentary muscular failure (FAIL) and the contralateral limb assigned to a protocol training with RIR. Each repetition was performed through a standardized range of motion.

An example of the standardized range of motion is provided in Supplemental Digital Content 1 (see Supplementary Section 1.2, http://links.lww.com/JSCR/A820). Limb dominance was not considered in the randomization process. This design ensured that each subject served as their own control (31). The primary outcomes of muscle hypertrophy and maximal strength were assessed through ultrasound imaging and 1-repetition maximum (1-RM) testing, respectively. These assessments were conducted at baseline (PRE) and after the intervention (POST), with the RIR familiarization completed only at PRE. To minimize potential bias, the investigators conducting the RIR familiarization process, 1-RM assessments, and ultrasound assessments (both PRE and POST intervention) were blinded to the limb-specific protocol.

Subjects

Initially, 23 resistance-trained young adults (13 men and 10 women) were recruited for this experiment. Before the commencement of the intervention, one female subject was excluded due to an inability to complete all baseline ultrasound measurements. Consequently, 22 subjects (13 men and nine women) began the 8-week training intervention. During the experimental period, three subjects (two men and one woman) were further excluded from the final analysis. The reasons for exclusion were failure to meet the minimum required training session attendance ($n = 2$, men) and an unrelated injury sustained mid-experiment ($n = 1$, woman).

Thus, the final analysis was conducted on a sample of 19 subjects, comprising 11 men (mean ± *SD*: age = 20.4 ± 1.8 years; height = 172.7 ± 5.6 cm; body mass = 74.9 ± 7.6 kg) and eight adult women (mean ± *SD*: age = 24.8 ± 4.7 years; height = 164.1 ± 8.0 cm; body mass = 63.0 ± 10.1 kg). Subjects were recruited from the local University School of Sport through flyers, email announcements, and word-of-mouth. To be eligible for inclusion, subjects were required to be: (a) currently engaged in regular RT for a minimum of two years, consistently at least three times per week (31,42); (b) free from any existing musculoskeletal injuries or medical conditions that would contraindicate participation in a demanding RT program or affect their ability to perform the required exercise and testing procedures; (c) have abstained from the use of anabolic steroid at any point in their lifetime; and (d) not currently involved in any other structured training program specifically targeting the knee extensor musculature. Subjects who were consistently using other ergogenic supplements (e.g., creatine) before the study were permitted to continue their usage, but all the subjects were instructed not to commence any new supplementation during the experimental period.

Furthermore, data from subjects who commenced the intervention were excluded from the final analysis if they failed to adhere to the predetermined minimum attendance requirement of 85% of the scheduled supervised training sessions, commenced any new ergogenic supplementation during the experimental period contrary to initial instructions, or sustained an injury, either related or unrelated to the study protocol, that precluded their continued participation in the training intervention or the completion of all postintervention assessment procedures.

Subjects provided written informed consent before all study procedures, potential risks, and benefits were fully explained. The study was approved by the Research Ethics Committee from the same University and conducted in accordance with the Declaration of Helsinki.

Sample Size Justification

The target sample size for this study was determined a priori. Aiming to retain a minimum of 19 subjects for the final analysis after accounting for potential attrition, a total of 23 resistance-trained young adults were recruited. This sample size was primarily justified based on pragmatic considerations and resource constraints, which are common in supervised 8-week RT interventions that require significant time, personnel, and financial resources (18,31). Furthermore, this sample size is consistent with or greater than that of similar within-subject studies investigating the effects of proximity-to-failure on muscular adaptations (17,31,37). This sample size was further evaluated using a sensitivity power analysis (G*Power, version 3.1.9.7) assuming a standard alpha level (α) of 0.05 and a power (1−β) of 0.80. The analysis revealed a critical effect size (ES) of Cohen's $d = 0.59$, which is well below the anticipated large within-group ESs for muscle hypertrophy ($d = 0.7$–0.8) reported in the literature (37), indicating the study was sufficiently powered to detect the primary within-condition adaptations. Conversely, the analysis acknowledged that the study was not powered to reliably detect small between-protocol differences (e.g., $d = 0.2$). Given these considerations, and the inherent uncertainty in parameter estimated with a limited sample size, a Bayesian statistical approach was selected over traditional frequentist framework. This approach allows for a more intuitive interpretation of the full range of plausible values for the observed effects, rather than relying solely on point estimated and null hypothesis significance testing (16).

Procedures

Subjects completed an 8-week supervised RT intervention, attending sessions twice per week. Each session was separated by a minimum of 48 hours and a maximum of 96 hours to allow adequate recovery (8,26,31,38). All training sessions were directly supervised by an investigator to ensure adherence to the assigned protocols and proper exercise technique. The intervention targeted the unilateral leg extension (for knee extensors), performed on the limb assigned to the FAIL protocol and the limb assigned to the RIR protocol. For the limb assigned to the FAIL protocol, subjects performed all sets to momentary muscular failure. Momentary muscular failure was defined as the inability to complete the concentric portion of the current repetition despite attempting to do so (for at least two-seconds) and with the prescribed technique (10,26,31,43). For the limb assigned to the RIR protocol, subjects terminated sets based on a perceived RIR target. Specifically, they aimed for a target of two RIR within an acceptable range of 1–3 RIR for each set (12,26,31,51). To ensure continued adaptation and apply progressive overload, the total number of sets performed per exercise was increased midway through the intervention (4,28,31,40), as
T1 summarized in Table 1.

The initial training load was selected to correspond to approximately 70–80% of the subject's PRE 1RM, with the goal of performing 8–12 repetition at the prescribed FAIL or RIR end point (13,19,31,39). Progressive overload was implemented throughout the intervention; if a subject successfully completed 12 or more repetitions in a set, the load was increased for the subsequent training session by approximately 2.5–5 kg for the unilateral leg extension (13,31,44). Furthermore, intrasession load adjustments were made if repetition performance consistently fell outside the target 8–12 repetition range while adhering to the specified FAIL or RIR end point. Specifically, for the FAIL condition, if a subject was unable to achieve a minimum of 8 repetitions with the selected load on a given set, the load was reduced (by approximately 2.5–5 kg) for the subsequent set; however, to avoid excessive load manipulation, some decay in repetitions (e.g., down to a minimum of approximately 4–5 repetitions per set) was permitted before such a load reduction was implemented. For the RIR condition, if a subject consistently performed fewer than 8 repetitions to achieve two RIR with the selected load, the load was similarly reduced for the subsequent set. Minor deviations from 8 to 12 repetitions target (e.g., achieving seven repetitions at two RIR) were tolerated on occasion to prevent excessive intrasession load adjustments, with the subject's self-regulation of repetitions to maintain two RIR being the primary mechanism for achieving the target within the given load.

Rest intervals were standardized at 2 minutes between sets. To balance potential fatigue effects between conditions, the starting limb (FAIL vs. RIR) was alternated between training sessions. Subjects were permitted to maintain their habitual resistance-training routines for nontargeted muscle groups to preserve ecological validity and training adherence. Detailed information regarding permitted and excluded exercises during the intervention is provided in Supplemental Digital Content 1 (see Supplementary Section 1.1, http://links.lww.com/JSCR/A820). Adherence to this instruction was verbally confirmed at each supervised session, and no deviations were reported.

Table 1
Training volume progression throughout the 8-week intervention.

Exercise	Sets per limb per exercise	
	Week 1–4	Week 5–8
Unilateral leg extension	5	6

RIR Scale Familiarization

Before baseline data collection, all subjects completed one to two dedicated familiarization weeks focused on calibrating their perception of the RIR scale. These sessions were separated by at least 48 hours. During these familiarization weeks, subjects performed the unilateral leg extension bilaterally. Throughout this process, subjects had continuous visual access to a printed RIR scale displayed prominently in their view. Then, they were asked the following question: 'Do you feel you could do exactly 2 more repetitions?'. On reaching the target perception, subjects would signal verbally, and the investigator would instruct them to continue to failure to verify whether the actual repetitions performed matched the predicted RIR, allowing for immediate calibration of their perception. This procedure, conducted under supervision, aimed to enhance their ability to accurately gauge RIR during the subsequent training intervention, consistent with the familiarization approach used in similar research investigating RIR-based training (12,31).

Muscle Thickness Assessment

Muscle thickness for the rectus femoris (RF) and vastus lateralis (VL) for both the intervention limb (FAIL or RIR protocol) and the contralateral limb was assessed PRE and POST the 8-week intervention period. All measurements were performed using B-mode ultrasound imaging (A6, B&W, Mainland, China) equipped with a multifrequency linear-array transducer probe (L45, Sonoscope, Mainland, China), operating at a frequency of 7.5 MHz and with an image acquisition width of 50 mm. Subjects were instructed to abstain from any strenuous exercise for at least 72 hours before each assessment sessions (PRE and POST). On arrival at the laboratory, subjects rested in a supine position for a minimum of 10 minutes before any measurements were taken to allow for body fluid stabilization.

Measurement sites were precisely identified and marked with an indelible surgical marker. For the quadriceps femoris, the subject remained supine with the assessed limb fully extended and muscles relaxed. The RF muscle thickness measurement site was marked at 50% of the distance from the anterior superior iliac spine to the superior border of the patella. The VL muscle thickness measurement site was marked at 50% of the distance from the greater trochanter to the lateral condyle of the femur (20). To ensure accurate relocation for POST assessments, all measured distances from anatomical landmarks to the precise measurement sites were recorded during the PRE assessment to minimize intersession error. A generous amount of water-soluble transmission gel was applied for acoustic coupling. The ultrasound transducer was oriented perpendicular to the muscle tissue interface, ensuring minimal pressure to avoid tissue compression. At each site, a minimum of two images were captured and saved digitally. If the muscle thickness values from these initial two images differed by more than 0.5 mm, a third image was acquired. Representative ultrasound images for the RF and VL are shown in Supplemental Digital Content 1 (see Supplementary Section 1.3, http://links.lww.com/JSCR/A820).

Image settings were optimized and maintained consistently throughout all assessments. Muscle thickness for RF and VL was defined as the perpendicular distance between the inner edges of the superficial and deep aponeuroses.

Image analysis was performed using on-screen digital calipers of the ultrasound system. The average muscle thickness from the selected images (either two images if their initial difference was ≤0.5 mm, or three images if a third was required) for each site was used for statistical analysis. Muscle thickness assessment sessions were always conducted after a minimum of 72 hours without training or engaging in strenuous physical activity. All ultrasound measurements and image analyses were performed by the same experienced investigator (G.C.L. and P.R.V.). The investigator was blinded to the limb's training protocol allocation (FAIL or RIR) and, where feasible, to the assessment time-point (PRE and POST) through coded image files and randomized analysis order, managed by an independent assistant (J.V.-A.).

Maximal Strength Assessment (1RM Testing)

Maximal strength for the knee extensor was assessed through a one-repetition maximum (1RM) test for each limb PRE and POST the 8-week intervention period. A single testing session was used to determine 1RM at PRE and another single session at POST. A specific warm-up set of 8–10 repetitions was performed using a light load, estimated to be approximately 40–50% of the perceived 1RM. After a 2–3-minute rest period, a second warm-up set of 3–5 repetitions was performed at a moderate load, estimated to be approximately 60–70% of the perceived 1RM. After a 3–5-minute rest period, the first 1RM attempt was made. If the attempt was successful, the load was incrementally increased by approximately 2.5–5 kg for the unilateral leg extension, based on the subject's perceived exertion and the investigator's judgment. After a 3–5-minute rest interval, another attempt was made. This process was repeated until the subject failed to complete a repetition with correct technique (5). The 1RM was recorded as the heaviest load successfully lifted for a single repetition with acceptable form, typically achieved up to 4 maximal attempts. All 1RM tests, and the training intervention, were performed using commercial-grade equipment (Technogym, Gambettola, Italy), including a leg extension machine. The same investigator conducted all 1RM testing sessions (PRE and POST). Standardized verbal instructions were provided before each lift, and consistent verbal encouragement was given during all 1RM attempts to promote maximal effort. The investigator remained blinded to the specific training protocol (FAIL or RIR) assigned to each limb.

Statistical Analyses

All statistical analyses were conducted using R (v 4.0.2; R Core Team, https://www.r-project.org/) within a Bayesian framework. Bayesian linear mixed-effects models were fitted using the brms package (Bürkner, 2023) to assess changes in outcome measures. This approach was chosen to appropriately model the unilateral, within-participant design and allow for probabilistic interpretation of effect estimates using prior distributions. Posterior draws were extracted using "tidybayes" (Kay, 2023), estimated marginal effects were calculated using "emmeans" (Lenth, 2023), and the probability (i.e., percentage value ranging from 0 to 100%) that an estimate was in favor of a given protocol was calculated manually by examining the proportion of posterior draws that met the criteria of interest (e.g., >0) and denoted as the probability of direction (*p*d). For our primary outcomes (i.e., change in muscle thickness and maximal strength), models were generated to assess mean differences in outcome measures between protocols (and within men and women) for the knee extensors (average of RF and VL) muscle thickness and for the knee extensor maximal strength individually. For muscle thickness outcomes, we also calculated the probability that a certain change in muscle thickness exceeded the typical error (TE), which was used to define the 'region of practical equivalence' (ROPE), and denoted it as "pd > ROPE". Noninformative priors (i.e., default "brms" priors) were used for all model parameters across all outcome measures in raw units. However, we also expressed individual changes in muscle thickness in standardized units, by calculating z-scored ESs using a residual-based standardization approach. Raw muscle thickness change scores were first computed and then divided by the residual *SD* from a linear model predicting muscle thickness change from protocol, sex, and their interaction. This residual *SD* reflects the unexplained variation in muscle thickness change and serves as a stable, protocol-independent denominator. As per recommendations by Penney et al. (27), the resulting standardized effect estimates are interpretable as standardized ESs and are preferred over traditional pooled *SD* methods when dealing with unequal variances or unbalanced designs. These standardized mean differences were converted to Hedges's g by applying the small-sample correction factor (J). For models analyzing standardized effect estimates, weakly informative priors (informed by previous data (31)) were used for "protocol" and "sex" parameters. Moreover, we determined the ROPE for standardized effect estimates to be −0.1 to 0.1, which has been corroborated by consulting researchers in the field and used in previous works (11,46). In all models presented in this article, random effects were incorporated to account for

Table 2
Raw pre- and postintervention muscle thickness values (mean ± *SD*) for rectus femoris and vastus lateralis.

Muscle	Protocol	Pre (cm)	Post (cm)
Rectus femoris	FAIL	2.44 ± 0.36	2.53 ± 0.34
Rectus femoris	RIR	2.44 ± 0.33	2.51 ± 0.30
Vastus lateralis	FAIL	2.52 ± 0.32	2.58 ± 0.28
Vastus lateralis	RIR	2.51 ± 0.37	2.63 ± 0.37

individual subject variability in response to the protocols and the nesting of limbs within subjects (e.g., random intercepts for subjects, and random slopes for protocol by subjects). Inferences from all analyses were made from posterior samples generated using the Hamiltonian Markov Chain Monte Carlo method and through the use of high-density credible intervals (HDI). Inferential priority was given to our primary analyses of raw units, followed by our secondary analyses of standardized effect estimates, of which priority was given to models involving weakly informative priors versus noninformative priors. Model convergence and sampling quality were assessed through standard diagnostic checks (e.g., R-hat statistics ≤1.01, visual inspection of trace plots, effective sample sizes, and posterior predictive checks). All raw data of outcome measures (in text and figures) are presented as mean and standard deviation. A comprehensive overview of the statistical analysis along with the R code used is provided on the Open Science Framework (https://osf.io/vqbpe/). Test-retest reliability of ultrasound-derived muscle thickness measures was assessed using intraclass correlation coefficients calculated with a two-way random-effects model, absolute agreement, single measures (ICC [2,1]), alongside TE. ICC values were interpreted as poor (<0.50), moderate (0.50–0.75), good (0.75–0.90), and excellent (>0.90) according to Koo and Li (45), with interpretation based on the lower bound of the 95% confidence interval.

Results

Reliability of Ultrasound Measurements

Reliability of ultrasound-derived measurements of knee extensor muscle thickness demonstrated excellent test-retest reliability (ICC [2,1] = 0.993, 95% CI: 0.991–0.995), with a TE of 0.027 cm (1.08%) (see Supplementary Table 1, Supplemental Digital Content 1, http://links.lww.com/JSCR/A820).

Change in Knee Extensors Thickness

Raw knee extensors' (RF and VL combined) thickness at pre- and postintervention is displayed in Supplemental Digital Content 1 (see Supplementary Figure 2.1, http://links.lww.com/JSCR/A820). Descriptive pre- and postintervention muscle thickness values for RF and VL are summarized in Table 2. Knee extensors thickness was estimated for RIR (0.097 cm [HDI: 0.039 to 0.155]; pd = 100%) and FAIL (0.078 cm [HDI: 0.024 to 0.134]; pd = 100%) from pre- to postintervention. Probability of change in knee extensors thickness above the ROPE was also estimated for RIR (pd > ROPE = 99%) and FAIL (pd > ROPE = 97%). Between-protocol estimate slightly favors RIR but suggests similar increases in knee extensors thickness between RIR and FAIL (−0.019 cm [HDI: −0.094 to 0.054]; pd = 71%), with only 41% of the posterior distribution exceeding the predefined ROPE. Posterior distributions for within- and between-protocol differences are displayed in Figure 1. Muscle-specific between-protocol contrasts extracted from the full multilevel model are presented in Supplemental Digital Content 1 (see Supplementary Table 2, http://links.lww.com/JSCR/A820).

Change in Knee Extensors Thickness for Men and Women Separately

Bayesian estimates for changes in knee extensors thickness for men and women (within- and between-protocol), separately, are summarized in Table 3. Posterior distributions for these estimates are displayed in Supplemental Digital Content 1 (see Supplementary Figure 2.2, http://links.lww.com/JSCR/A820).

Analysis of Standardized Effect Estimates

Hedges' g effect estimates for male and female knee extensors thickness (overall and separate) are summarized in Table 4 and displayed in Figure 2.

Change in Repetition Maximum Strength

Raw knee extensors' maximum strength at pre- and postintervention is displayed in Supplemental Digital Content 1 (see Supplementary Figure 2.3, http://links.lww.com/JSCR/A820). Knee extensors maximum strength was estimated to increase for RIR (16.5 kgs [HDI: 12.6–20.7]; pd = 100%]) and FAIL (16.7 kgs [HDI: 12.5–20.6]; pd = 100%) from pre- to postintervention.

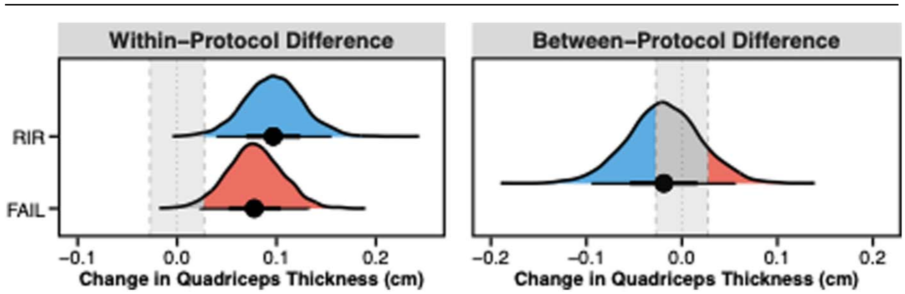

Figure 1. Posterior distribution for within- and between-protocol changes in knee extensors thickness. Knee extensors thickness was calculated as the average of the RF and VL. The plots display the posterior distributions, which show the central tendency (point estimate = mean) and the 95% highest density credible intervals (HDI; thick black lines). The vertical shaded gray area represents the ROPE. In the "Within-Protocol Difference" plots, blue distribution represents the RIR protocol and red distributions represent FAIL protocol. In the "Between-Protocol Difference" plots, negative estimates (blue area) favor the RIR protocol, while positive estimates (red area) favor the FAIL protocol.

AU3

Table 3

Estimates for within- and between-protocol raw changes in men and women.†

Outcome measure and group	Pretest (mean ± SD)	Post-test (mean ± *SD*)	Estimate (cm)	95% HDI	*pd* (%)	*pd* > ROPE (%)
Male – quadriceps thickness						
FAIL (within-protocol change)	2.64 ± 0.30	2.69 ± 0.28	0.054	−0.013 to 0.129	93	77
RIR (within-protocol change)	2.65 ± 0.26	2.74 ± 0.23	0.084	0.011 to 0.163	99	94
Between-protocol difference (RIR vs. FAIL)	—	—	−0.030	−0.123 to 0.072	73	53
Female – quadriceps thickness						
FAIL (within-protocol change)	2.26 ± 0.15	2.37 ± 0.15	0.111	0.026 to 0.190	100	98
RIR (within-protocol change)	2.23 ± 0.26	2.35 ± 0.17	0.115	0.029 to 0.206	99	97
Between-protocol difference (RIR vs. FAIL)	—	—	−0.004	−0.118 to 0.112	53	35

*HDI = highest density interval; *pd* = probability of direction; ROPE = region of practical equivalence.

†For the "Between-Protocol Difference," negative estimates favor the RIR protocol, while positive estimates favor the FAIL protocol. Probability that an estimate is in favor of a given protocol indicated as *pd*, and probability that an estimate exceeds the typical error indicated as *pd* > ROPE.

Between-protocol estimate slightly favors FAIL but suggests similar increases in knee extensors strength between RIR and FAIL (0.198 kgs [HDI: −1.87 to 2.6]; *pd* = 57%). Posterior distributions for within- and between-protocol differences are displayed in Figure 3.

Change in Knee Extensor Maximal Strength for Men and Women Separately

Bayesian estimates for changes in knee extensor maximal strength for men and women (within- and between-protocol), separately, are summarized in Table 5. Posterior distributions for these estimates are displayed in Supplemental Digital Content 1 (see Supplementary Figure 2.4, http://links.lww.com/JSCR/A820).

Discussion

The principal finding of this investigation was that in trained men and women, RT sets with a 1- to 3-RIR may promote similar muscle hypertrophy and strength development as training to momentary muscular failure. Importantly, this pattern of comparable outcomes between the protocols was consistent across both male and female subjects. Unlike many previous research studies that do not involve RIR quantification in the nonfailure protocol (30), these findings provide a direct experimental comparison of RT performed with RIR (involving intraset RIR prediction) versus momentary muscular failure in lower-body muscles/exercises in a mixed-sex cohort, strengthening the evidence base in this area. The excellent test-retest reliability of the ultrasound assessments further supports confidence in the internal validity of the hypertrophic adaptations.

Our primary analysis shows similar overall muscle hypertrophy between FAIL and RIR protocols, demonstrated by a low probability of the between-protocol difference exceeding the ROPE (<50%) for the knee extensors. These findings highlight that reaching momentary muscular failure itself may not confer a clear additional hypertrophic advantage over terminating sets with 1–3 RIR within the present applied context. Thus, training in close proximity to failure seemed to be enough to produce similar hypertrophy between conditions in this design. Nonetheless, recent meta-analysis shows muscle hypertrophy steadily increases as sets are terminated closer to momentary muscular failure (on average) (36). Larger-scale analyses treating RIR as a continuous variable may indeed detect smaller differences in muscle hypertrophy between RIR conditions; however, the true accuracy of post hoc RIR estimations required for meta-analysis is unclear. Therefore, whether a *true* linear relationship between proximity-to-failure and muscle hypertrophy exists across multiple sets is still in question, with more studies quantifying RIR effectively in nonfailure groups required for meta-analysis. Moreover, our analyses revealed a consistent pattern of outcomes across both sexes: for both male and female subjects, the FAIL and RIR protocols were similarly effective for promoting gains in muscle hypertrophy. Indeed, a recent meta-analysis by Refalo et al. (33) found that women have a similar potential to induce muscle hypertrophy as men, particularly when considering relative increases in muscle size from baseline. Overall, the present findings provide further evidence that reaching close proximities-to-failure (1–3 RIR) can provide comparable muscle hypertrophy with momentary muscular failure across both trained men and women.

For knee extensors thickness, the between-protocol differences were more equivocal (for both raw units and standardized effect estimates), with the data suggesting no clear advantage for either RT protocol. It is plausible that training a larger muscle group like the knee extensors to momentary muscular failure likely induces substantially greater neuromuscular, metabolic, and perceptual fatigue. For example, it has been demonstrated that a muscles

Table 4

Estimates for between-protocol standardized effects for the full cohort (both sexes combined) and men and women separately.†

	Standardized effect estimate (95% HDI)	
Variable of interest	Default priors	Weakly informative priors
Knee extensors thickness		
Full cohort (both sexes)	−0.128 (−0.642 to 0.384): *pd* > ROPE = 54%	−0.0562 (−0.373 to 0.272): *pd* > ROPE = 40%
Males	−0.210 (−0.890 to 0.446): *pd* > ROPE = 63%	−0.066 (−0.467 to 0.324): *pd* > ROPE = 44%
Females	−0.0257 (−0.810 to 0.784): *pd* > ROPE = 42%	−0.035 (−0.337 to 0.283): *pd* > ROPE = 34%

*HDI = highest density interval; *pd* = probability of direction; ROPE = region of practical equivalence.

†The table displays the standardizes effect estimates and their corresponding 95% highest density credible intervals. Negative estimates favor the RIR protocol, while positive estimates favor the FAIL protocol. Standardized effect estimates derived using both weakly informative priors and default (noninformative) priors. Probability that an estimate exceeds the predetermined ROPE of −0.1 to 0.1 indicated as *pd* > ROPE.

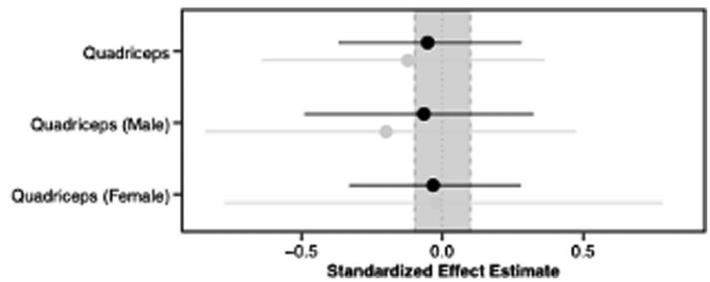

Figure 2. Standardized effect estimates for between-protocol differences in muscle thickness. The figure displays the standardized effect estimates (point estimates = dots) and their corresponding 95% highest density credible intervals (HDI) for the between-protocol difference (FAIL vs. RIR). Estimates are shown for the entire cohort (men and women) and for men and women separately. The solid black dot points represent the estimates derived using weakly informative priors, while the solid gray points represent the estimates derived using default (noninformative) priors. The vertical shaded gray area represents the ROPE. Negative estimates favor the RIR protocol, while positive estimates favor the FAIL protocol.

AU4

oxidative capacity may be constrained as fiber cross-sectional area increases (9), possibly affecting muscular performance and recovery. Theoretically, higher levels of fatigue could then compromise the quality of subsequent sets, thereby attenuating the cumulative hypertrophic stimulus delivered over the course of the workout (1,6). Therefore, while speculative it is plausible that certain anatomical or physiological characteristics of specific muscle groups might make them particularly responsive to a certain proximity-to-failure across a whole workout.

For the outcome of maximal strength, the present investigation found that both the FAIL and RIR protocols were equally effective for enhancing 1-RM performance. Furthermore, this general finding held true when analyzed by sex, as no clear or consistent advantage for either protocol emerged for men or women on the leg extension. The most plausible mechanism for this similarity is that the high load itself was the primary driver of strength adaptations, as demonstrated in multiple meta-analyses (29). Given that both the FAIL and RIR protocols in this study used the same high loads (e.g., 70–80% 1-RM), it is likely that the load provided sufficient stimulus to drive neural and muscular adaptations, rendering the condition of training to momentary muscular failure redundant for this outcome. Indeed, recent meta-regression results show that terminating RT sets closer to momentary muscular failure does not positively affect maximal strength development (36). This flexibility in the influence of proximity-to-failure on RT outcomes is particularly relevant for strength-focused training, as high levels of neuromuscular fatigue can impair neural drive and reduce the capacity to produce maximal force within a training session (1). Over a training block, this repeated attenuation of force production could theoretically blunt the cumulative stimulus for long-term strength adaptations; however, this is yet to be demonstrated in the literature. Overall, the findings of this study show that RT can be effectively performed with a 1–3 RIR target for strength development, possibly allowing for better fatigue management than reaching momentary muscular failure.

The present investigation possesses several methodological strengths that enhances confidence in its findings. A primary strength is the use of a unilateral, within-subject design, which minimizes the influence of interindividual variability and increases statistical power for detecting changes. Furthermore, this study used direct RIR prediction after a dedicated familiarization period, providing a more direct and ecologically valid comparison between the training protocols.

Nonetheless, these strengths are accompanied by limitations that provide clear avenues for future research. The sample size, while consistent with similar research, was primarily justified by pragmatic considerations and may not have been sufficient to reliably detect very small between protocol differences; consequently, future studies with larger cohorts are warranted.

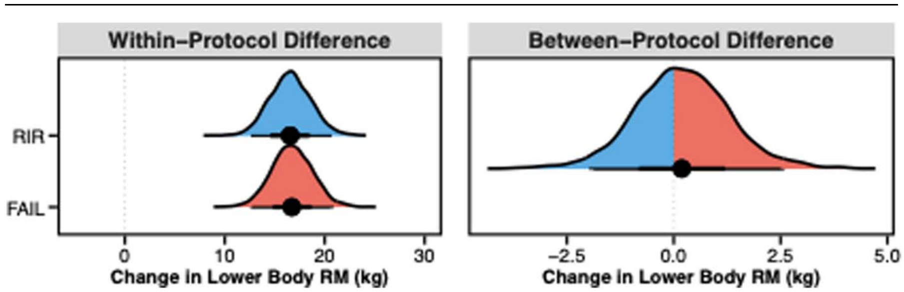

Figure 3. Posterior distributions for within- and between-protocol changes in 1-repetition maximum (1-RM) strength. Lower-body RM refers to the unilateral leg extension 1-RM. The plots display the posterior distributions, which show the central tendency (point estimate = mean) and the 95% highest density credible intervals (HDI; thick black lines). In the “Within-Protocol Difference” plots, blue distributions represent the RIR protocol and red distributions represent the FAIL protocol. In the “Between-Protocol Difference” plots, positive estimates (red area) favor the FAIL protocol, while negative estimates (blue area) favor the RIR protocol.

AU5

Table 5

Estimates for within- and between-protocol changes in 1-RM strength for male and female subjects.†

Outcome measure and group	Pretest (mean ± *SD*)	Post-test (mean ± *SD*)	Estimates (kg)	95% HDI	*pd* (%)
Male knee extensors strength (1-RM)					
FAIL (within-protocol change)	60.3 ± 8.1	76.1 ± 12.4	15.9	10.25 to 21.8	100
RIR (within-protocol change)	60.5 ± 7.9	76.8 ± 10.9	16.3	10.45 to 22	100
Between-protocol difference (RIR vs. FAIL)	—	—	−0.394	−3.40 to 2.59	61
Female knee extensors strength (1-RM)					
FAIL (within-protocol change)	47.6 ± 14.3	65.6 ± 22.9	17.9	10.90 to 24.0	100
RIR (within-protocol change)	47.6 ± 14.3	64.6 ± 22.3	16.9	9.99 to 23.2	100
Between-protocol difference (RIR vs. FAIL)	—	—	1.012	−2.31 to 4.41	74

*1-RM = 1-repetition maximum; HDI = highest density interval; *pd* = probably of direction.

†For the "Between-Protocol Difference," negative estimates favor the RIR protocol, while positive estimates favor the FAIL protocol. Probability that an estimate is in favor of a given protocol indicated as *pd*.

Furthermore, we acknowledge that the within-subject design introduces the potential for cross-education effects, particularly for strength outcomes. While cross-education is most clearly demonstrated when one limb remains untrained, we acknowledge that some degree of neural transfer cannot be fully excluded even when both limbs are trained. Therefore, the internal validity of the strength outcomes may be partially compromised, and strength-related findings should be interpreted with caution.

Although subjects were classified as resistance trained, the intervention focused exclusively on a single-joint exercise for one muscle group, which may limit ecological validity compared with training multi muscle groups and multijoint training programs, typically used by this population. In addition, the findings are specific to the machine-based, single-joint exercise used; therefore, future research should replicate this comparison using multijoint, free-weight exercises where the technical and neurological demands differ.

An important methodological limitation is that knee extensors muscle thickness was assessed at only one site per muscle (RF and VL). Accumulating evidence suggests that hypertrophy can occur nonuniformly along the length of the knee extensors, with regional differences influenced by exercise selection, loading strategies, and proximity to failure (25,49,50). Consequently, it is possible that localized hypertrophic responses to the FAIL and RIR protocols were not detected. Future studies should incorporate multisite ultrasound assessments to better characterize regional hypertrophy and determine whether proximity to failure differentially affects specific knee extensors regions. Future research with larger cohorts, varied exercises and muscle groups, and broader training contexts will help clarify the nuanced role of proximity-to-failure in driving long-term adaptations.

Practical Applications

Under ecologically realistic resistance-training conditions, terminating sets with 1–3 repetitions in reserve seems to yield knee extensor adaptations comparable with training to momentary muscular failure. Coaches and practitioners may therefore use RIR-based strategies to manage fatigue with maintaining training effectiveness, particularly in multiset training contexts.

Acknowledgments

The authors report no conflicts of interest. The results of the present study do not constitute endorsement of any product by the authors or the NSCA. This work was funded by National Funds by FCT–Foundation for Science and Technology under the following project UID/04045/2025 (https://doi.org/10.54499/UID/04045/2025).

References

1. Alix-Fages C, Del Vecchio A, Baz-Valle E, Santos-Concejero J, Balsalobre-Fernández C. The role of the neural stimulus in regulating skeletal muscle hypertrophy. *Eur J Appl Physiol* 122: 1111–1128, 2022.
2. Armes C, Standish-Hunt H, Androulakis-Korakakis P, et al. "Just One More Rep!" – Ability to predict proximity to task failure in resistance trained persons. *Front Psychol* 11: 565416, 2020.
3. Bastos V, Machado S, Teixeira DS. Feasibility and usefulness of repetitions-in-reserve scales for selecting exercise intensity: A scoping review. *Percept Mot Skills* 131: 940–970, 2024.
4. Baz-Valle E, Fontes-Villalba M, Santos-Concejero J. Total number of sets as a training volume quantification method for muscle hypertrophy: A systematic review. *J Strength Cond Res* 35: 870–878, 2021.
5. Brown LE, Weir JP. ASEP procedures recommendation I: Accurate assement of muscular strength and power. *J Exerc Physiol* 4: 1–21, 2001.
6. Cleary B. Fatigue mechanisms and their implications in hypertrophy: A review. *Int J Strength Cond* 5, 2025. Available at: https://journal.iusca.org/index.php/Journal/article/view/381
7. Comfort P, McMahon JJ, Lake JP, Ripley NJ, Triplett NT, Haff GG. Relative strength explains the differences in multi-joint rapid force production between sexes. *PLoS One* 19: e0296877, 2024.
8. Cuthbert M, Haff GG, Arent SM, et al. Effects of variations in resistance training frequency on strength development in well-trained populations and implications for In-Season athlete training: A systematic review and meta-analysis. *Sports Med* 51: 1967–1982, 2021.
9. Degens H, Messa GAM, Tallis J, et al. Diffusion and physical constraints limit oxidative capacity, capillary supply and size of muscle fibres in mice and humans. *Exp Physiol* 2025. AU2
10. Fisher JP, Steele J, Smith D. Intensity of effort and momentary failure in resistance training: Are we asking a binary question for a continuous variable? *J Sport Health Sci* 11: 644–647, 2022.
11. Gschneidner D, Carlson L, Steele J, Fisher J. The effects of lengthened-partial range of motion resistance training of the limbs on arm and thigh muscle cross-sectional area: A multi-site cluster trial, 2024. Available at: https://sportrxiv.org/index.php/server/preprint/view/485/version/624
12. Halperin I, Malleron T, Har-Nir I, et al. Accuracy in predicting repetitions to task failure in resistance exercise: A scoping review and exploratory meta-analysis. *Sports Med* 52: 377–390, 2022.
13. Hass CJ, Feigenbaum MS, Franklin BA. Prescription of resistance training for healthy populations. *Sports Med* 31: 953–964, 2001.
14. Hunter SK, Senefeld JW. Sex differences in human performance. *J Physiol* 602: 4129–4156, 2024.
15. Jukic I, Castilla AP, Ramos AG, Van Hooren B, McGuigan MR, Helms ER. The acute and chronic effects of implementing velocity loss thresholds during resistance training: A systematic review, meta-analysis, and critical evaluation of the literature. *Sports Med* 53: 177–214, 2023.
16. Kruschke JK, Liddell TM. The Bayesian New Statistics: Hypothesis testing, estimation, meta-analysis, and power analysis from a Bayesian perspective. *Psychon Bull Rev* 25: 178–206, 2018.

17. Lacerda LT, Marra-Lopes RO, Diniz RCR, et al. Is performing repetitions to failure less important than volume for muscle hypertrophy and strength? *J Strength Cond Res* 34: 1237–1248, 2020.
18. Lakens D. Sample size justification. *Collabra: Psychol* 8: 33267, 2022.
19. Lopez P, Radaelli R, Taaffe DR, et al. Resistance training load effects on muscle hypertrophy and strength gain: Systematic review and network meta-analysis. *Med Sci Sports Exerc* 53: 1206–1216, 2021.
20. Matta TT, Nascimento FX, Trajano GS, Simão R, Willardson JM, Oliveira LF. Selective hypertrophy of the quadriceps musculature after 14 weeks of isokinetic and conventional resistance training. *Clin Physiol Funct Imaging* 37: 137–142, 2017.
21. Hubal MJ, Gordish-Dressman H, Thompson PD, et al. Variability in muscle size and strength gain after unilateral resistance training. *Med Sci Sports Exerc* 37: 964–972, 2005.
22. Nimphius S, McBride JM, Rice PE, Goodman-Capps CL, Capps CR. Comparison of quadriceps and hamstring muscle activity during an isometric squat between strength-matched men and women. *J Sports Sci Med* 18: 101–108, 2019.
23. Nuzzo JL. Narrative review of sex differences in muscle strength, endurance, activation, size, fiber type, and strength training participation rates, preferences, motivations, injuries, and neuromuscular adaptations. *J Strength Cond Res* 37: 494–536, 2023.
24. Nuzzo JL. Sex differences in skeletal muscle fiber types: A meta-analysis. *Clin Anat* 37: 81–91, 2024.
25. 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* 22: 1250–1260, 2022.
26. Pelland JC, Robinson ZP, Remmert JF, et al. Methods for controlling and reporting resistance training proximity to failure: Current issues and future directions. *Sports Med* 52: 1461–1472, 2022.
27. Penney J. Cautions when normalizing the dependent variable in a regression as a z-score. *Econ Inq* 61: 402–412, 2023.
28. Ralston GW, Kilgore L, Wyatt FB, Baker JS. The effect of weekly set volume on strength gain: A meta-analysis. *Sports Med* 47: 2585–2601, 2017.
29. Refalo MC, Hamilton DL, Paval DR, Gallagher IJ, Feros SA, Fyfe JJ. Influence of resistance training load on measures of skeletal muscle hypertrophy and improvements in maximal strength and neuromuscular task performance: A systematic review and meta-analysis. *J Sports Sci* 39: 1723–1745, 2021.
30. Refalo MC, Helms ER, Hamilton DL, Fyfe JJ. Towards an improved understanding of proximity-to-failure in resistance training and its influence on skeletal muscle hypertrophy, neuromuscular fatigue, muscle damage, and perceived discomfort: A scoping review. *J Sports Sci* 40: 1369–1391, 2022.
31. Refalo MC, Helms ER, Robinson ZP, Hamilton DL, Fyfe JJ. Similar muscle hypertrophy following eight weeks of resistance training to momentary muscular failure or with repetitions-in-reserve in resistance-trained individuals. *J Sports Sci* 42: 85–101, 2024.
32. Refalo MC, Helms ER, Trexler ET, Hamilton DL, Fyfe JJ. Influence of resistance training proximity-to-failure on skeletal muscle hypertrophy: A systematic review with meta-analysis. *Sports Med* 53: 649–665, 2023.
33. Refalo MC, Nuckols G, Galpin AJ, Gallagher IJ, Hamilton DL, Fyfe JJ. Sex differences in absolute and relative changes in muscle size following resistance training in healthy adults: A systematic review with Bayesian meta-analysis. *PeerJ* 13: e19042, 2025.
34. Remmert JF, Laurson KR, Zourdos MC. Accuracy of predicted intraset repetitions in reserve (RIR) in single- and multi-joint resistance exercises among trained and untrained men and women. *Percept Mot Skills* 130: 1239–1254, 2023.
35. Roberts BM, Nuckols G, Krieger JW. Sex differences in resistance training: A systematic review and meta-analysis. *J Strength Cond Res* 34: 1448–1460, 2020.
36. Robinson ZP, Pelland JC, Remmert JF, et al. Exploring the dose–response relationship between estimated resistance training proximity to failure, strength gain, and muscle hypertrophy: A series of meta-regressions. *Sports Med* 54: 2209–2231, 2024.
37. Santanielo N, Nóbrega S, Scarpelli M, et al. Effect of resistance training to muscle failure vs non-failure on strength, hypertrophy and muscle architecture in trained individuals. *Biol Sport* 37: 333–341, 2020.
38. Schoenfeld BJ, Grgic J. Does training to failure maximize muscle hypertrophy? *Strength Cond J* 41: 108–113, 2019.
39. Schoenfeld BJ, Grgic J, Van Every DW, Plotkin DL. Loading recommendations for muscle strength, hypertrophy, and local endurance: A re-examination of the repetition continuum. *Sports* 9: 32, 2021.
40. Schoenfeld BJ, Ogborn D, Krieger JW. Dose-response relationship between weekly resistance training volume and increases in muscle mass: A systematic review and meta-analysis. *J Sports Sci* 35: 1073–1082, 2017.
41. Schoenfeld BJ, Peterson MD, Ogborn D, Contreras B, Sonmez GT. Effects of Low- vs. high-load resistance training on muscle strength and hypertrophy in well-trained men. *J Strength Cond Res* 29: 2954–2963, 2015.
42. Schoenfeld BJ, Pope ZK, Benik FM, et al. Longer interset rest periods enhance muscle strength and hypertrophy in resistance-trained men. *J Strength Cond Res* 30: 1805–1812, 2016.
43. Steele J, Fisher J, Giessing J, Gentil P. Clarity in reporting terminology and definitions of set endpoints in resistance training. *Muscle Nerve* 56: 368–374, 2017.
44. Stone MH, Fleck SJ, Triplett NT, Kraemer WJ. Health- and performance-related potential of resistance training. *Sports Med* 11: 210–231, 1991.
45. Koo TerryK, Li MY. A guideline of selecting and reporting intraclass correlation coefficients for reliability research. *J Chiropract Med* 15: 155–163, 2016.
46. Varovic D, Wolf M, Schoenfeld BJ, et al. Does muscle length influence regional hypertrophy? A systematic review and meta-analysis. *Int J Sports Med* 46: 1027–1036, 2025.
47. Vieira AF, Umpierre D, Teodoro JL, et al. Effects of resistance training performed to failure or not to failure on muscle strength, hypertrophy, and power output: A systematic review with meta-analysis. *J Strength Cond Res* 35: 1165–1175, 2021.
48. Wackerhage H, Schoenfeld BJ, Hamilton DL, Lehti M, Hulmi JJ. Stimuli and sensors that initiate skeletal muscle hypertrophy following resistance exercise. *J Appl Physiol* 126: 30–43, 2019.
49. Zabaleta-Korta A, Fernández-Peña E, Santos-Concejero J. Regional hypertrophy, the inhomogeneous muscle growth: A systematic review. *Strength Cond J* 42: 94–101, 2020.
50. Zabaleta-Korta A, Fernández-Peña E, Torres-Unda J, Garbisu-Hualde A, Santos-Concejero J. The role of exercise selection in regional muscle hypertrophy: A randomized controlled trial. *J Sports Sci* 39: 2298–2304, 2021.
51. Zourdos MC, Goldsmith JA, Helms ER, et al. Proximity to failure and total repetitions performed in a set influences accuracy of intraset repetitions in reserve-based rating of perceived exertion. *J Strength Cond Res* 35: S158–S165, 2021.