Knee flexion range of motion does not influence muscle hypertrophy of the quadriceps femoris during leg press training in resistance-trained individuals.

LARSEN, S., WOLF, M., SCHOENFELD, B.J., SANDBERG, N.Ø., FREDRIKSEN, A.B., KRISTIANSEN, B.S., VAN DEN TILLAAR, R., SWINTON, P.A. and FALCH, H.N.

2025

Journal of Sports Sciences

ISSN: (Print) (Online) Journal homepage: www.tandfonline.com/journals/rjsp20

Knee flexion range of motion does not influence muscle hypertrophy of the quadriceps femoris during leg press training in resistance-trained individuals

Stian Larsen, Milo Wolf, Brad J. Schoenfeld, Nordis Ø. Sandberg, Andrea B. Fredriksen, Benjamin S. Kristiansen, Roland van den Tillaar, Paul A. Swinton & Hallvard N. Falch

To cite this article: Stian Larsen, Milo Wolf, Brad J. Schoenfeld, Nordis Ø. Sandberg, Andrea B. Fredriksen, Benjamin S. Kristiansen, Roland van den Tillaar, Paul A. Swinton & Hallvard N. Falch (2025) Knee flexion range of motion does not influence muscle hypertrophy of the quadriceps femoris during leg press training in resistance-trained individuals, Journal of Sports Sciences, 43:10, 986-994, DOI: 10.1080/02640414.2025.2481534

To link to this article: https://doi.org/10.1080/02640414.2025.2481534

JOURNAL OF SPORTS SCIENCES
2025, VOL. 43, NO. 10, 986–994
https://doi.org/10.1080/02640414.2025.2481534

PHYSICAL ACTIVITY, HEALTH AND EXERCISE

OPEN ACCESS Check for updates

Knee flexion range of motion does not influence muscle hypertrophy of the quadriceps femoris during leg press training in resistance-trained individuals

Stian Larsen [a,b], Milo Wolf [c], Brad J. Schoenfeld [c], Nordis Ø. Sandberg [a], Andrea B. Fredriksen [a], Benjamin S. Kristiansen [a], Roland van den Tillaar [a], Paul A. Swinton [d] and Hallvard N. Falch [a]

[a]Department of Sports Science and Physical Education, Nord University, Levanger, Norway; [b]Academy for Personal Training, Fredrikstad, Norway; [c]Department of Exercise Science and Recreation, Applied Muscle Development Lab, CUNY Lehman College, Bronx, NY, USA; [d]Department of Sport and Exercise, School of Health Sciences, Robert Gordon University, Aberdeen, UK

ABSTRACT

This study investigated the effect of knee flexion range of motion (ROM) during the leg press exercise on quadriceps femoris muscle hypertrophy in resistance-trained individuals. Twenty-three participants (training age: 7.2 ± 3.5 years) completed a within-participant design, performing four sets of unilateral leg presses to momentary failure twice weekly for 8 weeks. In one leg, the knee flexion range of motion (ROM) was fixed at approximately 5–100°, while for the other leg, participants used their maximum individualized ROM (5–154 ± 7.8°). Quadriceps muscle thickness was assessed via B-mode ultrasonography in the proximal, central, and distal regions of the mid- and lateral thighs. Bayesian analyses were conducted to quantify treatment effects and provide inferential estimates using credible intervals and Bayes Factors (BF). Univariate and multivariate analyses indicated 'moderate' (BF = 0.14 to 0.22) and 'extreme' (BF < 0.01) evidence in support of the null hypothesis, respectively. Within-condition analyses revealed small-to-medium hypertrophic adaptation in both conditions, with absolute increases ranging from 1.08 mm to 1.91 mm. These findings suggest that both knee flexion ROMs are similarly effective for promoting quadriceps femoris muscle hypertrophy over a relatively short training-period in resistance-trained individuals.

ARTICLE HISTORY
Received 11 Jan 2025
Accepted 12 Mar 2025

KEYWORDS
Muscle length; knee extensors; resistance training; ultrasonography; regional hypertrophy

Introduction

Resistance training (RT) has been widely employed to induce skeletal muscle hypertrophy (Roberts et al., 2023). Over the past decade, the range of motion (ROM) used in various resistance exercises has received increased attention and remains a controversial topic in the research community (Wolf et al., 2023). One muscle group reported to be influenced by knee flexion ROM is the quadriceps femoris (Bloomquist et al., 2013; Kubo et al., 2019; McMahon et al., 2014; Pedrosa et al., 2022). In multi-joint exercises like squats, superior muscle growth of monoarticular vastii muscles has been reported with greater knee flexion ROM (Zabaleta-Korta et al., 2021). Conversely, single joint exercises like the leg extension may be beneficial when targeting the biarticular rectus femoris due to a fixed hip joint angle (Burke et al., 2024). Moreover, Bloomquist et al. 2013 compared the effects of squatting with 60° versus 120° of knee flexion and reported superior quadriceps femoris cross-sectional area (CSA) gains for the 120° condition. This may be partly attributable to the quadriceps femoris reaching longer muscle lengths on the descending limb of the length – tension curve (Son et al., 2018). Similarly, McMahon et al. (2014) observed larger CSA increases for the distal vastus lateralis when training several different RT exercises to 90° knee flexion compared to 50°. Importantly, the researchers did not observe statistical differences between knee flexion ROMs in the more proximal parts of the vastus lateralis (McMahon et al., 2014), indicating that a larger knee flexion ROM may exclusively confer favourable hypertrophic adaptations of the distal vastus lateralis.

In addition to the previously mentioned studies, Kubo et al. (2019) examined the effects of 10 weeks of squat training performed to 90° versus 140° of knee flexion on hip extensor and quadriceps femoris muscle volume. The authors reported favourable hypertrophic adaptations for the hip extensors with greater ROM, but no significant between-group differences for the quadriceps femoris. Based on these collective findings (Bloomquist et al., 2013; Kubo et al., 2019; McMahon et al., 2014), some researchers have postulated that squatting to ~90–100° knee flexion ROM (0° represents full knee extension) may be sufficient for maximizing muscle hypertrophy of the quadriceps femoris (Ottinger et al., 2023). Notably, isometric training at ~100° knee flexion has been observed to induce greater mechanical tension on the muscle-tendon complex compared to shorter muscle lengths (Kubo et al., 2006). Since mechanical tension is considered a key stimulus for initiating hypertrophic response to resistance exercise (Schoenfeld, 2010), the greater quadriceps femoris growth typically observed with longer muscle lengths may be attributed to

CONTACT Stian Larsen coachstianlarsen@gmail.com Department of Sports Science and Physical Education, Nord University, Høgskolevegen 27, Levanger 7600, Norway

Supplemental data for this article can be accessed online at https://doi.org/10.1080/02640414.2025.2481534

larger mechanical tension. However, during squatting as used in the study conducted by Kubo et al. (2019), both segment ratios (Demers et al., 2018) and ankle mobility (Fuglsang et al., 2017) may influence an individual's ability to perform a deep squat with a large knee flexion ROM. Importantly, Kubo et al. (2019) stated in their methods that the participants squatted to approximately 140° knee flexion ROM. As a result, it is unclear how many of the participants were in fact capable of descending to a knee flexion ROM of 140°.

The leg press is often regarded as a suitable alternative to back squats for training quadriceps femoris. The leg press may facilitate deeper knee flexion angles than squats by eliminating the need for heel contact and the need to balance the center of mass over the feet. Additionally, the leg press machine can be adjusted with both low foot placement and seat, potentially increasing knee flexion ROM and relative knee extensor torque. Anecdotally, some trainees perform the leg press without heel contact to facilitate larger knee flexion ROMs. However, since Kubo et al. (2019) observed no added benefit for knee extensor hypertrophy beyond 90° of knee flexion – and considering that pressing without heel contact could reduce force output – this approach may offer no advantage versus a ~ 100° knee flexion ROM with heel contact for enhancing quadriceps femoris muscle adaptations. Furthermore, none of the aforementioned studies employed a resistance-trained cohort, which could potentially limit their generalizability to trained populations (Moreno et al., 2024). Given these considerations, the purpose of this study was to compare the effects of performing the leg press with a ~ 100° knee flexion ROM versus maximum individualized knee flexion ROM on muscle hypertrophy in resistance trained participants. We hypothesized that both knee flexion ROMs would be equally effective in inducing quadriceps femoris muscle hypertrophy.

Methods

Participants

Sample size was determined based on previous calculations by our group (Larsen, Sandvik Kristiansen, et al., 2024; Larsen, Swinton, et al., 2025) that investigated manipulations of ROM using a within-participant randomized design and a Bayesian framework. For this study, the Bayesian framework enabled us to quantify plausible values for differences between conditions and assess the strength of evidence in support of our a priori null hypothesis. We used a within-participant design with informative priors to increase the precision of the estimations. A within-participants design was used as this may control for both lifestyle and genetic factors, enhancing the effect estimation precision (Burke et al., 2024; MacInnis et al., 2017). To assess whether plausible sizes given our constraints were likely to be appropriate, we performed a simulation-based calibration of Bayes factors and assessed our ability to provide support for the correct hypothesis with sample sizes of $n = 30$ and $n = 25$. Priors were derived from meta-analyses and similar studies from our group (Larsen, Swinton, et al., 2025; Swinton et al., 2022; Wolf et al., 2023). The priors are set on a standardized scale, including distributions for typical improvement $N(0.44, 0.40^2)$, average treatment effect $N(0.30, 0.27^2)$, heterogeneous response $N(0, 0.15^2)$, and measurement error $N(0, 0.20^2)$. Simulation-based calibrations of Bayes factors were fit across 500 iterations using an average treatment effect of zero (no intervention difference), or from our non-zero distribution, each 50% of the time. The average posterior model probability for $n = 30$ and $n = 25$ were 49.7 (95%CrI: 41.2–55.9%) and 48.6 (95%CrI: 40.0–56.2%). The average percentage of posterior allocated to the alternative hypothesis when it was true was 84% and 81%, respectively, for the two sample sizes. We judged these results to provide an appropriate assessment of the strength of the evidence and attempted to recruit 30 participants, ultimately resulting in 26 which were included (see Figure 1 and Table 1), which is a larger sample size than most resistance training interventions using a within-participant design to measure the effects of different resistance training variables on muscle hypertrophy. The study was performed according to the latest revision of the Declaration of Helsinki and approved by the Norwegian Agency for Shared Services in Education and Research (application number: 578814). Ethical approval was obtained from the Regional Committees for Medical and Health Research Ethics, which deemed the project exempt from presentation (application number: 795724).

Inclusion criteria for participation required that participants: (1) had engaged in resistance training consistently for at least the last 3 years prior to the start of the study with a minimum training frequency of twice a week (except in case of illness, injuries and holidays), (2) were between 18 and 50 years of age, (3) had no illness or injury that could hinder training adherence or performing the resistance exercise to momentary concentric failure, (4) had no previous or present self-reported use of illegal anabolic agents or anabolic steroids.

Risk of bias

To reduce the chance for bias, this study adhered to the Standards Method for Assessment of Resistance Training in Longitudinal Design (SMART-LD) checklist (Schoenfeld et al., 2023) (see supplementary file 1). Also, the aim, hypothesis, and methods of the study were pre-registered prior to data collection in the Open Science Framework (osf.io/847ep). The original manuscript was uploaded as a preprint at the preprint server Sportxriv prior to peer review (Larsen et al., 2025). Finally, the supervised training program consisted of the calf-raise, lateral raise (Larsen, Wolf et al., 2024) and leg press training, where calf-raise and lateral raise training were used to investigate other research questions. Please see pre-registrations (https://osf.io/f26u5) and (https://osf.io/avh5s) for more information.

Resistance training procedures

As this was a within-participant design, the right and left lower-body limbs were randomized prior to the start of the study by an individual not involved in data collection using www.randomizer.org, with the investigators blinded to allocation. Each limb was trained with one of the two following conditions: 1) leg press with ~100° knee flexion ROM or maximum individualized knee flexion ROM (peak knee flexion). In order to recruit trained participants to the study, a full resistance training

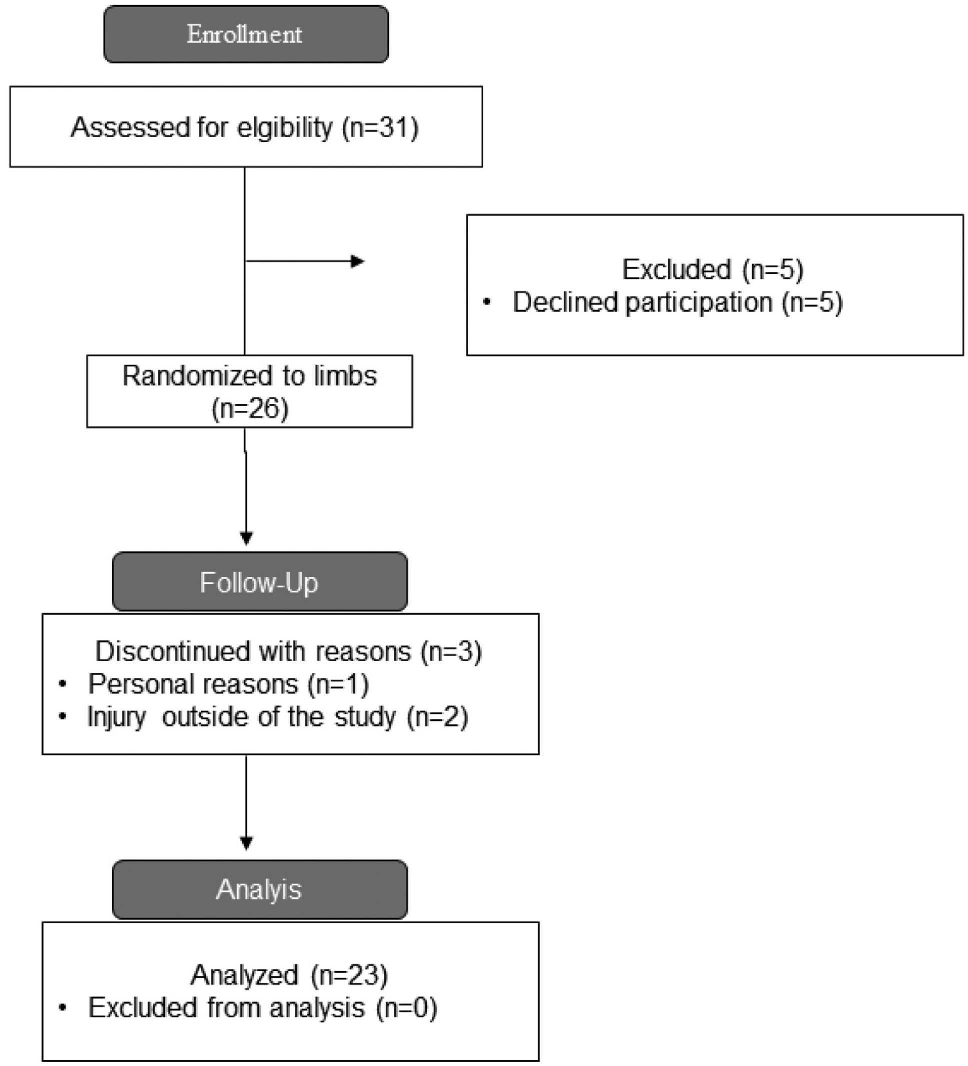

Figure 1. Prisma flow chart of the data collection process.

Table 1. Descriptive summary of participant characteristics.

	Men ($n = 15$)		Women ($n = 8$)	
Variables	Mean (SD)	Range	Mean (SD)	Range
Age (years)	29.7 ± 5.8	22–41	25.3 ± 3.2	21–32
Body mass (kg)	87.1 ± 12.3	–	71.6 ± 15.1	–
Height (cm)	178.9 ± 7.3	168–197	164.9 ± 6.6	160–174
Peak knee flexion (°)	153.0 ± 7.9	138–168	154.3 ± 7.5	138–161
RT experience (years)	7.6 ± 4.0	3–16	6.8 ± 2.5	4–11
RT weekly frequency	4.1 ± 0.8	3–5.5	3.0 ± 0.9	2–4.5
Weekly quadriceps femoris set volume	10.5 ± 3.5	5–18	11.8 ± 4.0	7–21
Weekly quadriceps femoris frequency	1.9 ± 0.5	1–3	2.2 ± 0.4	1.5–3

program was conducted that included additional randomized limb comparisons including lateral raises with a cable or dumbbell, and standing Smith machine calf raises with initial partial repetitions or full ROM repetitions and past-failure partials. The results reported here focus only on the knee flexion ROM conditions and muscle thickness of the quadriceps femoris.

The data collection and resistance training interventions were conducted between August and October 2024 in Levanger, Norway at Care Treningssenter Levanger. At least one researcher (N.Ø.S., H.N.F., A.B.F. and B.S.F.) supervised all training sessions. The supervising researchers had at least a bachelor's degree in sports science and a personal trainer certification. Also, the supervision team had researchers with PhDs and MScs in sports science. The supervisors were instructed prior to the study about the training procedure by the lead researcher and met twice for pilot testing before the resistance training intervention started. This was done to standardize the resistance training techniques and procedures between supervisors before the start of the intervention.

In the second baseline test after ultrasound measurements, the participants worked up to a single set of their 8–12 repetition maximum (RM) performed to momentary concentric failure in the leg press on each leg. Thereafter, the participants performed the leg press exercise twice a week with at least 48 h between workouts and an 8–12 RM repetition range for momentary concentric failure (Refalo et al., 2022). During week 1, the participants performed three sets of leg press twice a week, totaling six sets per week. From weeks two to eight, all participants trained four sets each workout, totaling eight weekly sets. Loads increased with 2.5–5 kg if the participants could perform >12 repetitions on their set to ensure they maintained the given repetition range. This progression method and repetition range was employed as it has been observed to be effective for promoting quadriceps femoris hypertrophy (Plotkin et al., 2022). Alternatively, loads were reduced by 2.5–5 kg on the next set if the participant performed <8 repetitions. Repetition volumes were standardized between limbs. Participants were permitted to perform a self-selected general warm-up before their scheduled training session. Rest intervals were ~30 s between legs and >90 s between sets for the same limb (see supplementary file 1). Participants were instructed to perform concentric actions as fast as possible and employ a cadence of approximately 2 s on the eccentric action consistent with repetition tempo recommendations from Androulakis Korakakis et al. (2024). The limb order varied each week by rotating the limb trained first from week to week to ensure that the limb order trained did not confound the results. Participants were given an optional resistance training program that included the Romanian deadlift and various resistance exercises to target the pectoralis major, triceps brachii, biceps brachii and back musculature (see supplementary file 1). No other leg exercises were allowed during the resistance training intervention. The participants were instructed to perform the optional resistance training program 1–2 times each week. For Romanian deadlifts, participants were instructed to just perform the exercise at one weekly training session. The optional training program was not supervised.

The leg press exercise was performed unilaterally in a Rogue 45 leg press (Rogue Fitness, Columbus, Ohio, USA) (see Figure 2) with ~100° knee flexion ROM on one leg and a maximum individualized knee flexion ROM with the other leg (see Figure 2 and Table 1). The knee extension was performed to ~5° flexion for both legs. To measure knee flexion angles, an electric goniometer (Easy angle, Stockholm, Sweden) was used to ensure the correct knee flexion angle for each leg. The participants were instructed to place both heels in the lowest position on the leg press plate (see Figure 2). For peak ROM conditions, participants were instructed to perform knee flexion as deep as possible without allowing excessive spinal flexion or posterior tilting of the lumbar/thoracic spine. To enable maximal knee flexion angles, participants were permitted to lift their heels from the leg press plate. The supervisor measured the knee flexion ROM during the first repetition and held this point with their finger to ensure that participants performed each repetition with a standardized knee flexion angle.

Nutrition

The participants were recommended to increase caloric intake by consuming slightly larger portions than usual. In addition, the participants were instructed to consume a total daily protein intake of at least 1.6 g per kilogram of body mass (Morton et al., 2018). To monitor fluctuations in body mass, all participants were weighed weekly on the Tanita scale (MC-780 MA, Riga, Latvia) during their first visit to the laboratory. No dietary recalls were conducted.

Measurements

B-mode ultrasonography (Echo Wave 2 Software; Telemed, Latvia) with 9 MHz and a 60 mm probe size, and Chemolan gel for transmission (Chemodis, DA, Alkmaar, The Netherlands) was used to measure mid-thigh (rectus femoris + vastus intermedius) and lateral thigh (vastus lateralis + vastus intermedius)

Figure 2. Illustrates the knee flexion ROM for the 100° (a) and Peak (b) conditions in the leg press exercise.

muscle thickness. Ultrasound displays high reliability and validity compared to magnetic resonance imaging, which is considered the gold standard for measuring changes in muscle hypertrophy (Reeves et al., 2004). All participants were instructed to refrain from any strenuous physical activity or resistance training for 72 h prior to ultrasound measurements. For both the mid and lateral thighs, measurements were obtained at 30% (proximal), 50% (middle), and 70% (distal) lengths between the greater trochanter and the lateral epicondyle of the femur (Plotkin et al., 2022). The anatomical landmarks were detected with palpation. These lengths were marked with a pen. In addition, images of the marks were taken from each participant during the baseline assessment and stored in a locked external flash drive to ensure reliable measurements between baseline and post-intervention measurements. Two sonographers performed ultrasound measurements: One sonographer captured the muscle thickness images, while the other handled the probe. Ultrasound measurements were taken at two distinct baseline tests and two post-intervention tests with at least 24 h between the two baseline measurements and at least 24 h between the two post-intervention measurements. Upon arrival in the laboratory, participants were placed in a supine position on a bench where they rested for 10 min before ultrasound measurements began. A linear transducer was placed on the skin without depressing the skin, and transverse images were obtained at each site. The distance between the internal border of the superficial aponeurosis of the rectus femoris and the vastus lateralis and external border of the femur was used to measure mid-thigh and lateral thigh, respectively. Muscle thickness measurements were averaged across three images at both baseline and both post-intervention tests. If >10% difference was observed for one image compared to the others, a fourth image was taken. For reliability measures, the typical error and coefficient of variation between baseline tests one and two and post-intervention tests one and two were all below 0.79 mm and 2.2%.

Statistics

All analyses were conducted in R (version 4.4.0) using a Bayesian framework. We employed both multivariate and separate univariate linear mixed-effects models, assigning random effects for each condition to account for the repeated-measures, within-participant design (Magezi, 2015). The primary estimand was the difference in hypertrophy induced by the two knee flexion ROM conditions. The estimator used was the average treatment effect (ATE), defined as the mean difference in muscle thickness change scores between the limbs

Within-condition treatment effects were also quantified to evaluate the overall effectiveness of each intervention independently and compared to thresholds specific to strength and conditioning (Swinton et al., 2022). Inferences were based on: (1) the posterior distributions of ATE estimates and their corresponding credible intervals and (2) Bayes factors (BF) to quantify the strength of evidence for either a non-zero ATE (alternative hypothesis H_1) versus a zero ATE (null hypothesis H_0). Standard qualitative labels for interpreting the strength of evidence were applied (Lee & Wagenmakers, 2014). The analyses were performed using the *brms* R package interfaced with Stan to perform sampling (Bürkner, 2017). BFs were estimated using the bridge sampling algorithm (Gronau et al., 2020).

A comprehensive Bayesian workflow was adopted for the analysis and comprised: (1) use of informative priors derived from meta-analyses in the field (Swinton et al., 2022); 2) evaluation of prior appropriateness through prior predictive checks; 3) running models and assessing the stability of estimates via repeated iterations with the same data; 4) evaluation of posterior distributions through posterior predictive checks and sensitivity analyses with non-informative priors; and 5) simulation-based calibration of BFs (Schad et al., 2023). To enhance accuracy, transparency and replicability, the WAMBS-checklist (When to worry and how to Avoid Misuse of Bayesian Statistics) was followed (Depaoli & Van de Schoot, 2017). Summaries of the Bayesian workflow, including prior and posterior evaluations, are reported in supplementary file 3.

Results

Attendance

Participants attended a mean of 15 out of 16 RT sessions, translating to an overall compliance rate of 94%. Specifically, seven participants attended 14 sessions, eight attended 15 sessions, and eight attended all 16 sessions. Out of the 26 individuals originally enrolled, 23 completed the RT intervention and were included in the final analyses. Two participants withdrew due to injuries unrelated to the study, and one withdrew for personal reasons.

Body mass

Participant body mass increased from 80.6 ± 15.8 kg at the baseline to 82.9 ± 16.5 kg post-intervention. The mean increase was 2.3 ± 1.7 kg, with 22 participants increasing their body mass resulting in a range from −0.2 to 7.8 kg.

Muscle hypertrophy

The average muscle thickness increase ranged from 1.08 mm (2.16%) to 1.91 mm (4.8%) after 8 weeks of RT. See supplementary file 3 for all absolute and relative muscle thickness values for the individual quadriceps femoris sites. Univariate analyses of the ATE indicated 'moderate' evidence in support of the null hypothesis for all examined quadriceps regions (Table 2). Combining the regions within a multivariate analysis resulted in similar ATE estimates and provided 'extreme' evidence in support of the null hypothesis (BF < 0.01). Within-condition analyses using standardized mean difference estimates indicated that the interventions were likely to produce small or small-to-medium improvements (Figure 3). Output from the WAMBS checklist and BF simulation-based calibration are presented in the supplementary file and identified with no concerns with the analyses.

Table 2. Univariate analyses of potential group differences across quadriceps regions.

Quadriceps femoris Region	Average Treatment Effect Estimate (95%CrI mm) *Negative values favour peak knee flexion*	Bayes Factor	Strength of evidence
Proximal Mid-Thigh	−0.35 (−1.4 to 0.64)	0.19	'Moderate' support of Null hypothesis
Proximal Lateral-Thigh	−0.15 (−1.1 to 0.80)	0.17	'Moderate' support of Null hypothesis
Middle Mid-Thigh	0.03 (−0.72 to 0.79)	0.14	'Moderate' support of Null hypothesis
Middle Lateral-Thigh	−0.21 (−1.2 to 0.74)	0.15	'Moderate' support of Null hypothesis
Distal Mid-Thigh	0.25 (−0.39 to 0.85)	0.22	'Moderate' support of Null hypothesis
Distal Lateral-Thigh	−0.09 (−0.90 to 0.74)	0.18	'Moderate' support of Null hypothesis

CrI: Credible interval.

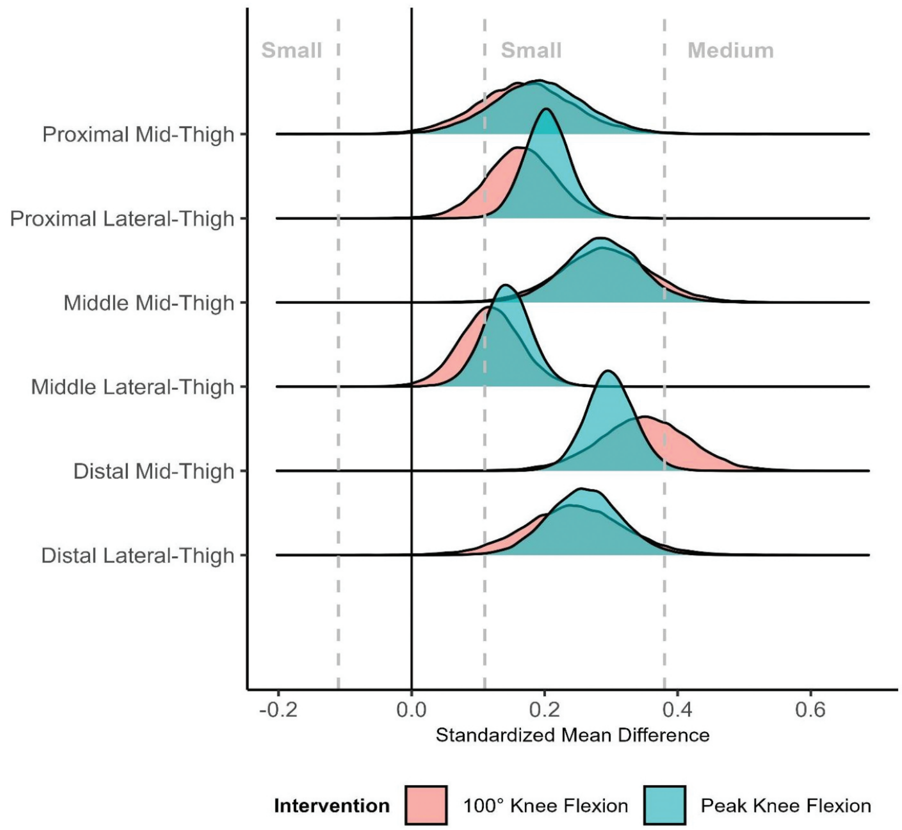

Figure 3. Comparative distribution plot of the estimated standardized mean difference of interventions across quadriceps regions. Density plots illustrate estimates and uncertainties of standardized mean difference changes across the two interventions. Thresholds describing the magnitude of improvements are obtained from strength and conditioning-specific data.

Volume load

The mean volume load in session one and two was 1913 ± 733 and 2005 ± 836 kg for the Peak ROM condition and 2504 ± 971 and 2677 ± 1094 for the 100° condition. When the number of sets increased in the second week, the volume load increased to 2722 ± 1142 kg for the Peak ROM condition and 4109 ± 1774 kg for the 100° conditions. The volume load in the last RT session further increased to 3160 ± 1066 kg and 4822 ± 1733 for the Peak and ~100° conditions, respectively (Figure 4).

Discussion

The aim of this study was to examine the effects of knee flexion ROM during the leg press exercise on quadriceps femoris muscle hypertrophy in resistance-trained participants. The univariate analyses provided 'moderate' evidence in support of the null hypothesis, ATE estimates generally centred on zero and relatively tight credible intervals. Moreover, the multivariate analysis pooling similar data across the regions provided 'extreme' evidence in support of the null hypothesis (BF < 0.01). Additionally, within-condition analyses revealed small-to-medium improvements in muscle thickness, ranging from 1.08 mm to 1.91 mm across the assessed quadriceps regions, providing evidence of hypertrophic adaptations irrespective of knee flexion ROM differences. Consistency in results and relatively narrow credible intervals suggest that the methodological design and sample size were adequate to address the study aims.

Our findings align with those of Kubo et al. (2019) who observed comparable quadriceps femoris hypertrophy when untrained participants performed half-squats to 90° knee flexion and full squats to ~140° knee flexion. However, the technical demands of free-weight squatting and the untrained status of participants in the study by Kubo et al. (2019), differ from those in the current study, which employed a leg press machine

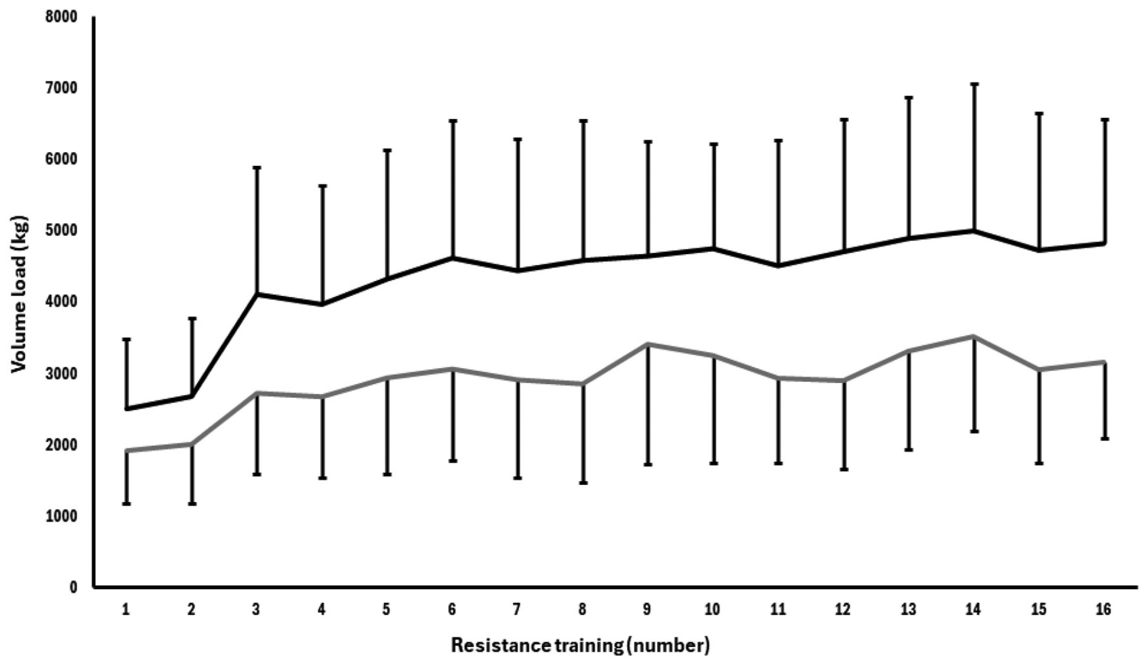

Figure 4. Mean (SD) volume load lifted each RT session. 100 knee flexions (black solid line); Peak knee flexion (grey solid line).

with resistance-trained participants (average of 7.2 years RT experience). Additionally, McMahon et al. (2014) demonstrated that greater knee flexion (90° vs. 50°) elicited superior adaptations in the vastus lateralis of untrained participants, including muscle hypertrophy (18% to 40.1% vs. 12.5% to 22%). Also, Alegre et al. (2014) observed that 8 weeks of isometric knee extension training at a 90° knee flexion angle increased vastus lateralis muscle thickness to a greater extent than training at a 50° isometric knee extension angle. Similar results were observed by Noorkoiv et al. (2014), who compared 6 weeks of isometric knee extension training between ~87.5° and ~38.1° on quadriceps femoris muscle volume and CSA, and found statistically significant increases only for the ~87.5° group. This suggests that ~90° of knee flexion may be more effective than 50° for increasing quadriceps femoris hypertrophy. However, considering that our study and Kubo et al. (2019) did not observe additional hypertrophic benefits from increasing knee flexion beyond 90° or 100°, the collective results suggest that a range of motion of 90–100° may be sufficient to maximize quadriceps femoris hypertrophy when employing multi-joint leg exercises like the leg press and back squat.

Nevertheless, the reader should be aware that conflicting results have been observed in the literature. For example, Kubo et al. (2006) compared 12 weeks of isometric knee extension training at 100° versus 50° knee flexion on quadriceps femoris muscle volume and observed no statistical differences between the protocols. Despite this, it is hypothesized that the lack of additional benefits from greater knee flexion might be related to knee extensor sarcomere lengths potentially exceeding the optimal range for force production beyond 90–100° of knee flexion (Chen et al., 2016). Thus, a knee flexion angle of ~90–100° appears sufficient to provide the potential benefits from lengthened training in multi-joint leg exercises.

Previous reviews have observed that longer muscle length training may be beneficial for muscle hypertrophy compared to shorter muscle length training in some muscles (Kassiano et al., 2023; Kassiano, Costa, Nunes, et al., 2022; Wolf et al., 2023, 2024). However, most studies (7 out of 8) reviewed by Wolf et al. (2024) involved untrained participants, potentially limiting the applicability of their findings to resistance-trained individuals. Thus, as our study is one of the first to address the effects of muscle lengths in resistance-trained individuals, it remains uncertain whether the benefits observed in reviews apply to resistance-trained individuals and/or whether these effects may be muscle-specific regardless of training status (Ottinger et al., 2023). For example, Kassiano et al. (2023) observed greater hypertrophy of the gastrocnemius when training with partial range of motion in the initial portion of the movement (15.2%) compared to both full ROM (6.7%) and final ROM (3.4%). This suggests that some muscles, such as gastrocnemius, may be more responsive to lengthened-focused training for muscle hypertrophy.

It should also be noted that our study consisted of resistance-trained individuals with ~7 years of RT experience. Consequently, observing meaningful differences between conditions may be challenging, as participants demonstrated increases in quadriceps femoris muscle thickness ranging from 1.08 to 1.91 mm after 8 weeks of RT. These gains are comparable to the 0.1 to 1.9 mm increases observed by Burke et al. (2024) who investigated a resistance-trained cohort performing leg press exercises over a comparable period of RT.

Another factor to consider is the potential instability caused by lifting the heel during the peak knee flexion condition, which may reduce the force output due to instability (Saeterbakken & Fimland, 2013). Instability in peak knee flexion conditions is speculated to diminish the potential benefits of greater ROM, as hypertrophy may result from different signals (muscle force vs. muscle stretch) depending on the modality. Employing both methods (force- and stretch-emphasis) in training may provide complementary benefits, although this speculation requires further investigation beyond the scope of the current study.

Limitations

This study has several limitations. First, we focused solely on resistance-trained participants, which may limit the applicability of our findings to untrained or recreationally active populations. Second, the relatively short duration of the intervention may have limited the ability to detect differences in hypertrophic adaptations that may become more pronounced. Third, although participants were given general nutritional counseling, and their body mass was monitored weekly, we did not specifically track their dietary intake. However, the fact that all participants increased body mass over the interventional period indicates compliance with adherence to dietary instructions. Fourth, the participants performed three different exercises. Thus, they performed calf raises before leg presses in approximately half of the training sessions. It is uncertain if, and to what extent, this contributed to the varied depth in the maximum individualized knee flexion ROM, despite participants being allowed to raise their heels off the leg press plate. Finally, our study specifically focused on hypertrophy of quadriceps femoris. It should be noted that the leg press involves other lower body muscles including the gluteals and adductors, which may have been differentially influenced by the employed conditions. This possibility should be investigated in future studies on the topic.

Practical applications

From a practical standpoint, training with a knee flexion ROM of approximately 100° in the leg press appears sufficient to maximize quadriceps femoris hypertrophy in resistance-trained individuals over a short training period. This ROM also accommodates those with limited ankle dorsiflexion. However, training for full knee flexion is a viable tool, as this approach allows for comparable muscle growth with lower loads.

Conclusions

Our findings indicate that both ~100° and maximum individualized knee flexion ROMs in the leg press are similarly effective for inducing quadriceps femoris hypertrophy in resistance-trained individuals after 8 weeks of leg press training. These findings support the use of both ROMs as efficient strategies for resistance training. Future research should explore the effects of ROM on other resistance exercises and examine interactions with variables, such as force–length curves to optimize hypertrophy outcomes.

Disclosure statement

BJS formerly served on the scientific advisory board for Tonal Corporation, a manufacturer of fitness equipment. No other authors report any declaration of interest.

Funding

The work was supported by the Jaquish Biomedical.

ORCID

Stian Larsen http://orcid.org/0000-0001-5254-1747

References

Alegre, L. M., Ferri-Morales, A., Rodriguez-Casares, R., & Aguado, X. (2014). Effects of isometric training on the knee extensor moment–angle relationship and vastus lateralis muscle architecture. *European Journal of Applied Physiology*, *114*(11), 2437–2446. https://doi.org/10.1007/s00421-014-2967-x

Androulakis Korakakis, P., Wolf, M., Coleman, M., Burke, R., Piñero, A., Nippard, J., & Schoenfeld, B. J. (2024). Optimizing resistance training technique to maximize muscle hypertrophy: A narrative review. *Journal of Functional Morphology and Kinesiology*, *9*(1), 9. https://doi.org/10.3390/jfmk9010009

Bloomquist, K., Langberg, H., Karlsen, S., Madsgaard, S., Boesen, M., & Raastad, T. (2013). Effect of range of motion in heavy load squatting on muscle and tendon adaptations. *European Journal of Applied Physiology*, *113*(8), 2133–2142. https://doi.org/10.1007/s00421-013-2642-7

Burke, R., Piñero, A., Mohan, A. E., Hermann, T., Sapuppo, M., Augustin, F., Coleman, M., Korakakis, P. A., Wolf, M., Swinton, P. A., & Schoenfeld, B. J. (2024). Exercise selection differentially influences lower body regional muscle development. *Journal of Science in Sport and Exercise*, 1–11. https://doi.org/10.1007/s42978-024-00299-4

Bürkner, P.-C. (2017). Brms: An R package for Bayesian multilevel models using Stan. *Journal of Statistical Software*, *80*(1), 1–28. https://doi.org/10.18637/jss.v080.i01

Chen, X., Sanchez, G. N., Schnitzer, M. J., & Delp, S. L. (2016). Changes in sarcomere lengths of the human vastus lateralis muscle with knee flexion measured using in vivo microendoscopy. *Journal of Biomechanics*, *49*(13), 2989–2994. https://doi.org/10.1016/j.jbiomech.2016.07.013

Demers, E., Pendenza, J., Radevich, V., & Preuss, R. (2018). The effect of stance width and anthropometrics on joint range of motion in the lower extremities during a back squat. *International Journal of Exercise Science*, *11*(1), 764. https://doi.org/10.70252/BWZE8275

Depaoli, S., & Van de Schoot, R. (2017). Improving transparency and replication in Bayesian statistics: The WAMBS-Checklist. *Psychological Methods*, *22*(2), 240. https://doi.org/10.1037/met0000065

Fuglsang, E. I., Telling, A. S., & Sørensen, H. (2017). Effect of ankle mobility and segment ratios on trunk lean in the barbell back squat. *The Journal of Strength & Conditioning Research*, *31*(11), 3024–3033. https://doi.org/10.1519/JSC.0000000000001872

Gronau, Q. F., Singmann, H., & Wagenmakers, E. J. (2020). Bridgesampling: An R package for estimating normalizing constants. *Journal of Statistical Software*, *92*, 1–29. https://doi.org/10.18637/jss.v092.i10

Kassiano, W., Costa, B., Kunevaliki, G., Soares, D., Zacarias, G., Manske, I., Takaki, Y., Ruggiero, M. F., Stavinski, N., Francsuel, J., Tricoli, I., Carneiro, M. A. S., & Cyrino, E. S. (2023). Greater gastrocnemius muscle hypertrophy after partial range of motion training performed at long muscle lengths. *The Journal of Strength & Conditioning Research*, *37*(9), 1746–1753. https://doi.org/10.1519/JSC.0000000000004460

Kassiano, W., Costa, B., Nunes, J. P., Ribeiro, A. S., Schoenfeld, B. J., & Cyrino, E. S. (2022). Partial range of motion and muscle hypertrophy: Not all ROMs lead to Rome. *Scandinavian Journal of Medicine & Science in Sports*, *32*(3), 632–633. https://doi.org/10.1111/sms.14121

Kassiano, W., Costa, B., Nunes, J. P., Ribeiro, A. S., Schoenfeld, B. J., & Cyrino, E. S. (2023). Which ROMs lead to Rome? A systematic review of the effects of range of motion on muscle hypertrophy. *The Journal of Strength & Conditioning Research*, *37*(5), 1135–1144. https://doi.org/10.1519/JSC.0000000000004415

Kubo, K., Ikebukuro, T., & Yata, H. (2019). Effects of squat training with different depths on lower limb muscle volumes. *European Journal of*

Applied Physiology, *119*(9), 1933–1942. https://doi.org/10.1007/s00421-019-04181-y

Kubo, K., Ohgo, K., Takeishi, R., Yoshinaga, K., Tsunoda, N., Kanehisa, H., & Fukunaga, T. (2006). Effects of isometric training at different knee angles on the muscle–tendon complex in vivo. *Scandinavian Journal of Medicine & Science in Sports*, *16*(3), 159–167. https://doi.org/10.1111/j.1600-0838.2005.00450.x

Larsen, S., Sandvik Kristiansen, B., Swinton, P. A., Wolf, M., Bao Fredriksen, A., Nygaard Falch, H., van den Tillaar, R., & Østerås Sandberg, N. (2024). The effects of hip flexion angle on quadriceps femoris muscle hypertrophy in the leg extension exercise. *Journal of Sports Sciences*. 43(2), 1–12. https://doi.org/10.1080/02640414.2024.2444713.

Larsen, S., Swinton, P. A., Sandberg, N. Ø., Kristiansen, B. S., Fredriksen, A. B., Falch, H. N., van den Tillaar, R., & Wolf, M. (2025). Resistance training beyond momentary failure: The effects of lengthened supersets on muscle hypertrophy in the gastrocnemius. *Frontiers in psychology*. 16. 1494323. https://doi.org/10.3389/fpsyg.2025.1494323 .

Larsen, S., Wolf, M., Schoenfeld, B. J., Sandberg, N. Ø., Fredriksen, A. B., Kristiansen, B. S., van den Tillaar, R., Swinton, P. A., & Falch, H. N. (2024). https://doi.org/10.51224/SRXIV.487. Dumbbell versus cable lateral raises for lateral deltoid hypertrophy: An experimental study.

Larsen, S., Wolf, M., Schoenfeld, B. J., Sandberg, N. Ø., Fredriksen, A. B., Kristiansen, B. S., van den Tillaar, R., Swinton, P. A., & Falch, H. N. (2025). Knee flexion range of motion does not influence muscle hypertrophy of the quadriceps femoris during leg press training in resistance-trained individuals.

Lee, M. D., & Wagenmakers, E.-J. (2014). *Bayesian cognitive modeling: A practical course*. Cambridge University Press.

MacInnis, M. J., McGlory, C., Gibala, M. J., & Phillips, S. M. (2017). Investigating human skeletal muscle physiology with unilateral exercise models: When one limb is more powerful than two. *Applied Physiology, Nutrition, and Metabolism*, *42*(6), 563–570. https://doi.org/10.1139/apnm-2016-0645

Magezi, D. A. (2015). Linear mixed-effects models for within-participant psychology experiments: An introductory tutorial and free, graphical user interface (LMMgui). *Frontiers in Psychology*, *6*, 2. https://doi.org/10.3389/fpsyg.2015.00002

McMahon, G. E., Morse, C. I., Burden, A., Winwood, K., & Onambélé, G. L. (2014). Impact of range of motion during ecologically valid resistance training protocols on muscle size, subcutaneous fat, and strength. *The Journal of Strength & Conditioning Research*, *28*(1), 245–255. https://doi.org/10.1519/JSC.0b013e318297143a

Moreno, E. N., Ayers-Creech, W. A., Gonzalez, S. L., Baxter, H. T., & Buckner, S. L. (2024). Does performing resistance exercise with a partial range of motion at long muscle lengths maximize muscle hypertrophic adaptations to training? *Journal of Science in Sport and Exercise*, 1–9. https://doi.org/10.1007/s42978-024-00301-z

Morton, R. W., Murphy, K. T., McKellar, S. R., Schoenfeld, B. J., Henselmans, M., Helms, E., Aragon, A. A., Devries, M. C., Banfield, L., Krieger, J. W., & Phillips, S. M. (2018). A systematic review, meta-analysis and meta-regression of the effect of protein supplementation on resistance training-induced gains in muscle mass and strength in healthy adults. *British Journal of Sports Medicine*, *52*(6), 376–384. https://doi.org/10.1136/bjsports-2017-097608

Noorkoiv, M., Nosaka, K., & Blazevich, A. (2014). Neuromuscular adaptations associated with knee joint angle-specific force change. *Medicine and Science in Sports and Exercise*, *46*(8), 1525–1537. https://doi.org/10.1249/MSS.0000000000000269

Ottinger, C. R., Sharp, M. H., Stefan, M. W., Gheith, R. H., de la Espriella, F., & Wilson, J. M. (2023). Muscle hypertrophy response to range of motion in strength training: A novel approach to understanding the findings. *Strength & Conditioning Journal*, *45*(2), 162–176. https://doi.org/10.1519/SSC.0000000000000737

Pedrosa, G. F., Lima, F. V., Schoenfeld, B. J., Lacerda, L. T., Simões, M. G., Pereira, M. R., Diniz, R. C., & Chagas, M. H. (2022). Partial range of motion training elicits favorable improvements in muscular adaptations when carried out at long muscle lengths. *European Journal of Sport Science*, *22*(8), 1250–1260. https://doi.org/10.1080/17461391.2021.1927199

Plotkin, D., Coleman, M., Van Every, D., Maldonado, J., Oberlin, D., Israetel, M., Feather, J., Alto, A., Vigotsky, A. D., & Schoenfeld, B. J. (2022). Progressive overload without progressing load? The effects of load or repetition progression on muscular adaptations. *PeerJ*, *10*, e14142. https://doi.org/10.7717/peerj.14142

Reeves, N. D., Maganaris, C. N., & Narici, M. V. (2004). Ultrasonographic assessment of human skeletal muscle size. *European Journal of Applied Physiology*, *91*(1), 116–118. https://doi.org/10.1007/s00421-003-0961-9

Refalo, M. C., Helms, E. R., Hamilton, D. L., & Fyfe, J. J. (2022). 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. *Journal of Sports Sciences*, *40*(12), 1369–1391. https://doi.org/10.1080/02640414.2022.2080165

Roberts, M. D., McCarthy, J. J., Hornberger, T. A., Phillips, S. M., Mackey, A. L., Nader, G. A., Boppart, M. D., Kavazis, A. N., Reidy, P. T., Ogasawara, R., Libardi, C. A., Ugrinowitsch, C., Booth, F. W., & Esser, K. A. (2023). Mechanisms of mechanical overload-induced skeletal muscle hypertrophy: Current understanding and future directions. *Physiological Reviews*, *103*(4), 2679–2757. https://doi.org/10.1152/physrev.00039.2022

Saeterbakken, A. H., & Fimland, M. S. (2013). Muscle force output and electromyographic activity in squats with various unstable surfaces. *The Journal of Strength & Conditioning Research*, *27*(1), 130–136. https://doi.org/10.1519/JSC.0b013e3182541d43

Schad, D. J., Nicenboim, B., Bürkner, P.-C., Betancourt, M., & Vasishth, S. (2023). Workflow techniques for the robust use of Bayes factors. *Psychological Methods*, *28*(6), 1404. https://doi.org/10.1037/met0000472

Schoenfeld, B. J. (2010). The mechanisms of muscle hypertrophy and their application to resistance training. *The Journal of Strength & Conditioning Research*, *24*(10), 2857–2872. https://doi.org/10.1519/JSC.0b013e3181e840f3

Schoenfeld, B. J., Androulakis-Korakakis, P., Coleman, M., Burke, R., & Piñero, A. (2023). SMART-LD: A tool for critically appraising risk of bias and reporting quality in longitudinal resistance training interventions.

Son, J., Indresano, A., Sheppard, K., Ward, S. R., & Lieber, R. L. (2018). Intraoperative and biomechanical studies of human vastus lateralis and vastus medialis sarcomere length operating range. *Journal of Biomechanics*, *67*, 91–97. https://doi.org/10.1016/j.jbiomech.2017.11.038

Swinton, P. A., Burgess, K., Hall, A., Greig, L., Psyllas, J., Aspe, R., Maughan, P., & Murphy, A. (2022). Interpreting magnitude of change in strength and conditioning: Effect size selection, threshold values and Bayesian updating. *Journal of Sports Sciences*, *40*(18), 2047–2054. https://doi.org/10.1080/02640414.2022.2128548

Wolf, M., Androulakis-Korakakis, P., Fisher, J., Schoenfeld, B., & Steele, J. (2023). Partial vs full range of motion resistance training: A systematic review and meta-analysis. *International Journal of Strength and Conditioning*, *3*(1). https://doi.org/10.47206/ijsc.v3i1.182

Wolf, M., Korakakis, P. A., Roberts, M. D., Plotkin, D. L., Franchi, M. V., Contreras, B., Henselmans, M., & Schoenfeld, B. J. (2024). Does longer-muscle length resistance training cause greater longitudinal growth in humans? A systematic review.

Zabaleta-Korta, A., Fernández-Peña, E., Torres-Unda, J., Garbisu-Hualde, A., & Santos-Concejero, J. (2021). The role of exercise selection in regional muscle hypertrophy: A randomized controlled trial. *Journal of Sports Sciences*, *39*(20), 2298–2304. https://doi.org/10.1080/02640414.2021.1929736