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Abstract

The purpose of this study was to systematically review the literature as to the effects of performing exercise with a full versus partial range of motion (ROM) during dynamic, longitudinal resistance training (RT) programs on changes in muscle hypertrophy. Based on the available literature, we aimed to draw evidence-based recommendations for RT prescription. Six studies were identified as meeting inclusion criteria: four of these studies involved RT for the lower limbs while the other two focused on the upper extremities. The total combined sample of the studies was $n = 135$, which comprised 127 men and 8 women. The methodological quality of all included studies was deemed to be “excellent” based on the modified PEDro scale. When assessing the current body of literature, it can be inferred that performing RT through a full ROM confers beneficial effects on hypertrophy of the lower body musculature versus training with a partial ROM. Alternatively, research on the effects of ROM for the upper limbs is limited and conflicting, precluding the ability to draw strong practical inferences. No study to date has investigated how ROM influences muscle growth of the trunk musculature. Finally, some evidence indicates that the response to variations in ROM may be muscle-specific; however, this hypothesis also warrants further study.

Keywords

Excursion, resistance exercise, repetition, muscle mass

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Introduction

It is well-established that the manipulation of resistance training (RT) variables is an important factor in optimizing RT-induced muscular adaptations.¹ Variables most often discussed in this regard include volume, load, and frequency, among others. One variable that has received relatively little attention is the range of motion (ROM), operationally defined as the degree of movement that occurs at a given joint during exercise performance.² For example, the 2009 American College of Sports Medicine position stand on RT prescription briefly discusses ROM but stops short of making practical recommendations.¹ Despite its relative lack of attention in the literature, ROM potentially can play an important role in muscular adaptations.

Some authors have proposed that training through a full ROM is necessary to maximize the value of an exercise.² Indeed, a majority of research shows that strength adaptations are specific to the joint angle trained; thus, to achieve strength throughout a full ROM, training must involve complete excursion of the joint. Initial work on the topic was

carried out using isometric exercise, with results consistently showing strength increases most apparent within several degrees adjacent to the angle of training.^{3–5} Subsequently, Weiss et al.⁶ showed that these findings translated to dynamic exercise as well. In the Weiss et al.⁶ study, training with quarter squats resulted in higher increases in quarter squat 1 repetition maximum (1RM) strength while training using half squats resulted in greater 1RM improvements in the half squat exercise. Similar results were found by Rhea et al.,⁷ who observed that increases in 1RM squat pursuant to performing 16 weeks of quarter squats, half squats or full squats were greatest at the ROM used in training. Collectively,

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findings are consistent with the principle of specificity, whereby neural adaptations occur with persistent training specific to a given ROM that ultimately translates into greater adaptations within the functional training range.⁴

While the evidence for training-induced variations in ROM on muscular strength appears compelling, its effects on hypertrophy are less clear. There are divergent opinions as to whether training with a partial or complete ROM is optimal for increasing muscle mass. On one hand, some theorize that taking repetitions through their complete ROM elicits greater stimulation of fibers by maximizing the shortening and lengthening of muscle fibers.⁸ Alternatively, others claim that partial ROM training affords the use of heavy loads in a muscle's strongest range, which conceivably leads to greater long-term hypertrophic adaptations.⁹

A recent systematic review concluded that isometric training at longer muscle lengths elicited greater increases in muscle size compared with isometric training at shorter lengths.¹⁰ The authors reported average increases in muscle size of 1.16% per week when training with joint angles $> 70^\circ$ compared with just 0.47% per week with angles $\leq 70^\circ$ (effect size difference = 0.35). This finding seems to suggest that training with a partial ROM may be equally effective as a full ROM provided that the partial excursion is carried out at a long muscle length. However, it is important to note that results are specific to isometric training at a fixed joint angle. Although such protocols are insightful for generating mechanistic hypotheses, their designs are of questionable relevance to ecologically valid RT programs, thereby limiting the ability to draw practical inferences from the findings. If we consider that (a) muscle adapts differently to isometric and dynamic training programs;¹¹ and (b) dynamic training is much more frequent in the practical context,⁸ there is a clear need for critically reviewing studies that explored the effects of training with varying ROM in dynamic RT on hypertrophy.

A number of recent studies have endeavored to investigate how alterations in ROM influence muscle size. These studies provide insight into potential implications on the manipulation of this variable in common training programs. However, no study has synthesized the body of research on the topic in a systematic fashion and provided practical recommendation for RT prescription. Accordingly, the purpose of this article was to systematically review the literature as to the effects of performing exercise with a full versus partial ROM during dynamic, longitudinal RT programs on changes in muscle hypertrophy. Based on critical scrutiny of the current literature, we offer evidence-based recommendations for practitioners and provide recommendations as to directions for future research on the topic.

Methods

Inclusion criteria

Studies were deemed eligible for inclusion if they met the following criteria: (a) were an experimental trial published in

an English-language refereed journal; (b) participants were randomized to the training groups; (c) directly compared RT with different ROMs without manipulation of other variables; (d) assessed markers of muscle hypertrophy using site-specific measures (magnetic resonance imaging (MRI), computerized tomography, or ultrasound); (e) had a minimum duration of 6 weeks; (f) did not involve any structured exercise other than RT; and (g) included adults (18 years of age and older) free from chronic disease or injury.

Search strategy

This review was carried out according to PRISMA guidelines.¹² We searched the PubMed/MEDLINE, Scopus, and Web of Science databases using the following syntax: “range of motion” AND (“muscle thickness” OR “cross sectional area” OR “muscle volume” OR “muscle mass” OR “hypertrophy”). After conducting the initial search, the reference lists of articles retrieved were then screened for any additional articles that had relevance to the topic as described by Greenhalgh and Peacock.¹³

Study coding and data extraction

Independent coding of the studies was carried out by two authors (B.J.S. and J.G.) using the Microsoft Excel software (Microsoft Corporation, WA, USA). We tabulated the following data in a predefined coding sheet: (a) author(s), title and year of publication; (b) descriptive information of participants by group, including the number of participants in each group, sex, age (for age, the following classification was used: 18–35 = young; 36–64 = middle-aged, and; > 65 = older), and RT experience (participants with > 1 year of experience were defined as resistance-trained; participants with less RT experience were classified as untrained); (c) study characteristics (duration of the study, RT variables (i.e. sets, repetitions, frequency, rest interval, etc), and the degree of ROM employed for both groups); (d) the method used to assess in muscle mass (MRI or ultrasound) and the specific muscle(s) measured; (e) pre- and post-treatment mean values for assessing changes in muscle hypertrophy. The coding sheets were crosschecked between coders, with any discrepancies resolved by mutual consensus.

Methodological quality

The 11-point PEDro scale¹⁴ was employed to assess the methodological quality of studies. Two authors (B.J.S. and J.G.) carried out qualitative assessment, with any disagreements resolved by mutual consensus. The first item of the PEDro scale refers to external validity. Based on the guidelines, the assessment of this item did not go in the total PEDro score. Given that it is impossible to blind participants to training with varying ROM, and as the investigators are rarely blinded in such studies, we elected to remove scale items 5, 6, and 7. Based on the removal of these items, the

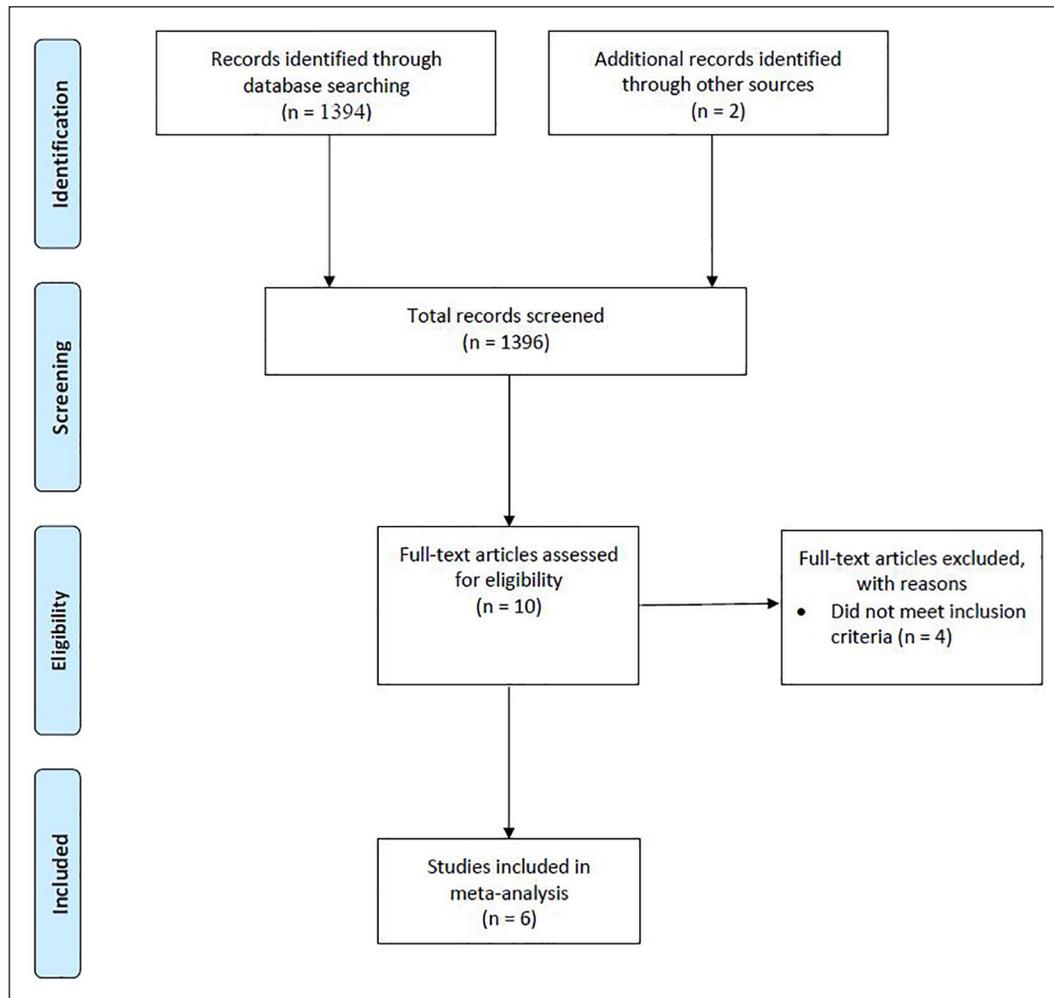


Figure 1. PRISMA flowchart.

maximum obtainable result was seven, categorized as follows: 6–7 = “excellent quality”; 5 = “good quality”; 4 = “moderate quality”; 0–3 = “poor quality,” consistent with previous exercise intervention reviews.¹⁵

Results

A total of 1394 studies were assessed based on search criteria. Scrutinization of the reference lists of article on the topic revealed an additional study as potentially meeting inclusion criteria and another study was identified from the authors’ personal library as relevant to the search. Thus, a total of 1396 studies were initially screened. Of the studies initially reviewed, 10 were determined to be potentially relevant to the article based on information contained in the abstracts. The full texts of these articles were then screened and 6 were identified as meeting inclusion criteria.^{16–21} All included studies tallied 6 points on the PEDro checklist and thus were classified as being of “excellent” methodological quality. Figure 1 provides a flow chart of the search process. Table 1 summarizes the studies analyzed.

Five of the studies included untrained individuals as study participants^{17–21} and one study¹⁶ involved trained individuals. The total combined sample of the studies was $n = 135$, which comprised 127 men and 8 women. Partial ROM in studies that focused on the lower body ranged from 0° to 90° while full ROM ranged from 0° to 140°. In the studies focusing on upper extremity, partial ROMs ranged from 45° to 100° while full ROM ranged from 0° to 130°. The duration of the study period averaged 10.5 weeks. All studies used a single exercise to investigate variations in ROM, except for McMahon et al.¹⁹ whose protocol employed a combination of different lower body exercises. The weekly training frequency varied from two to three sessions per week. All studies employed multiple set protocols, with repetitions ranging from 3 to 20 across trials; half of the included studies periodized training over the study period.^{17,18,20}

Discussion

The aim of our study was to systematically review the literature to determine whether training with a full versus partial

Table 1. Full versus partial range of motion studies.

Study	Sample	Design	Program variables	Hypertrophy measure	Results
Pinto et al. ¹⁷	30 young, untrained men	Parallel design with participants randomly assigned to elbow flexion exercise using either a full 0° to 130° range of motion or partial range 50° to 100° of motion with training carried out 2 d/wk for 10 weeks	Training consisted of 2–4 sets of 8–20 reps in a periodized fashion	MT of the elbow flexors by B-mode ultrasound	Elbow flexor MT significantly increased for both training groups with effect size differences favoring full ROM.
Bloomquist et al. ¹⁸	17 young, minimally trained men	Parallel design with participants randomly assigned progressive squat training performed as either deep squat (0–120° of knee flexion) or (b) shallow squat (0–60 of knee flexion) with training carried out 3 d/wk for 12 weeks	Training consisted of 3–4 sets of 3–10 reps (repetition matched, repetition maximum sets)	CSA by MRI of front and rear thigh; MT of the VL by B-mode ultrasound measured at 50% of femur length	CSA of the frontal thigh was increased at all measured sites in the full ROM group while partial only increased at the two most proximal sites; CSA increases greater in full ROM at all measured sites. Both conditions similarly increase MT of the VL
McMahon et al. ¹⁹	16 young, recreationally active men and women	Parallel design with participants randomly assigned to isoinertial lower body exercise at either a short ROM (0–50° knee flexion) or a long ROM (0–90° knee flexion) with training carried out 3 d/wk for 8 weeks	Training consisted of 3 sets of 10 repetitions at 80% 1RM with a 60- to 90-s inter-set rest interval	CSA of the VL by B-mode ultrasound measured at 25, 50, and 75% of femur length	CSA of the VL increased significantly at all sites in both conditions. Effect size differences favored full ROM at 25% and 75% femur length while favoring partial ROM at 50%.
Valamatos et al. ²⁰	11 young, untrained men	Within-subject design with participants dominant and nondominant legs randomly assigned to isokinetic knee extension exercise using a partial ROM (0–60°) or a full ROM (0–100°) with training carried out 3 d/wk for 15 weeks	Training consisted of 2–7 sets of 6–15 repetitions with a 60-s inter-set rest interval in a periodized fashion. Training volume was equalized based on the TUT by increasing the number of sets and/or repetitions for the partial condition.	Muscle volume of the VL by MRI	Muscle volume of the VL increased similarly between conditions
Goto et al. ¹⁶	44 young, resistance-trained men	Parallel design with participants randomly assigned to elbow extension exercise using either partial (elbow range from 45° to 90°) or full (from 0° to 120°) ROM with training carried out 3 d/wk for 8 weeks.	Training consisted of 3 sets of 8 repetitions with a 60-s inter-set rest interval	MT of the triceps brachii and upper arm circumference of the upper arm measured at the 60% of the upper arm by B-mode ultrasound and a tape measure. CSA calculated as the product of MT and circumference	Greater increases in CSA noted in partial versus full ROM
Kubo et al. ²¹	17 young, untrained men	Parallel design with participants randomly assigned to squat training using either a partial (0° to 90°) or full (0° to 140°) ROM with training carried 2 d/wk for 10 weeks	Training consisted of 3 sets of 8–10 repetitions at 60–90% 1RM	Muscle volume of the quadriceps, hamstrings, adductors and gluteus maximus by MRI	The muscle volumes of the adductors and gluteus maximus showed greater increases in the full ROM condition. Similar increases in muscle volume were noted between conditions for the vasti muscles. Neither condition significantly increased the muscle volume of the rectus femoris and hamstrings

MT: muscle thickness; ROM: range of motion; CSA: cross sectional area; MRI: magnetic resonance imaging; VL: vastus lateralis; RM: repetition maximum; TUT: time under tension.

ROM influences hypertrophic adaptations. Even though we found only six studies conducted on this topic, their methodological quality was classified as “excellent,” which therefore enhances our ability to draw sound inferences. Primarily, the findings suggest (a) for lower body musculature, there appears to be a benefit to training with a full ROM, with three of four studies favoring this style of training; and (b) for the upper body, the evidence is less conclusive with one study suggesting a benefit in favor of partial ROM while another reporting similar increases in muscle size when training both with partial versus full ROM.

Lower body musculature

To date, four studies have investigated the impact of variations in ROM on hypertrophy of the lower body musculature. The studies generally show that training with a full ROM produces similar or greater increases in muscle size than training with partial ROM. Of the three studies that used free weight exercises, two studies reported that for the quadriceps muscle, training with a full ROM may produce greater muscle hypertrophy than training with a partial ROM. These three studies, however, used different exercise ROM prescription. For example, in the study by Bloomquist et al.,¹⁸ the group that trained with a full ROM performed squats from 0° to 120° of knee flexion; the group training with a partial ROM performed this exercise at 0° to 60° of knee flexion. In the McMahon et al.¹⁹ study, the range for full and partial ROM training conditions was from 0° to 90° and from 0° to 50° of knee flexion, respectively. Both of these studies reported similar effects on quadriceps muscle hypertrophy. In the only study that used free weight exercises and did not observe divergent effects of full versus partial ROM training on quadriceps hypertrophy the ROM was from 0° to 140° and from 0° to 90° of knee flexion for the full and partial ROM training groups, respectively. It can be surmised that these between-study differences in ROM explain the discrepancies in findings, although other covariates cannot be ruled out (e.g. training status, intensity of load, etc). The ROM in the Kubo et al.²¹ study was the largest as the group training with partial ROM performed the same ROM as the group training with a full ROM in the McMahon et al.¹⁹ study. Therefore, the ROM in the group training with partial ROM in the Kubo et al.²¹ study was already relatively high, which might explain why similar increases in muscle size were observed between training conditions. Therefore, it could be hypothesized that when a certain ROM threshold is achieved, no additional benefit is obtained by further increases in ROM of a given exercise. This concept can be compared with protein intake and muscle protein synthesis (MPS). Specifically, increasing protein amounts from 20 to 40 grams likely results in greater increases in MPS;²² however, additional increases from 40 to 70 grams do not further augment MPS responses.²³ In the studies by Bloomquist et al.¹⁸ and McMahon et al.,¹⁹ the groups training with partial

ROM performed very limited movement; therefore, it is possible that some components of the quadriceps muscle were not fully activated during the exercise and hence, experienced less muscle growth. This idea is in essence supported by McMahon et al.¹⁹ who observed large differences in muscle CSA at the proximal (33.8% vs. 19.0%) and distal (40.1% vs. 7.5%) sites (both favoring the full ROM condition)—even though the effects reached statistical significance only at the distal site. Alternatively, CSA increases at the mid-thigh were relatively similar between groups.

When using free weight exercises, it may be difficult to standardize the level of effort between the groups training with different ROMs. For example, if we compare the lowest versus highest point of a ROM in a barbell squat exercise, training effort would likely be greater in the lowest part due to internal and external biomechanics. In contrast to free weight exercise, isokinetic dynamometry uses accommodating resistance, which provides maximal resistance throughout the whole exercised ROM given that the external force is accommodated according to the skeletal lever.²⁴ In a study that employed accommodating resistance in the training protocol, Valamatos et al.²⁰ employed a within-subject design whereby 11 untrained men had their dominant and non-dominant limbs randomly assigned to isokinetic leg extension exercise using either a partial ROM (0 to 60° knee flexion) or a full ROM (0°–100° knee flexion). Training was carried out using angular velocities varying between 60° and 180° s⁻¹ in a periodized fashion across the 15-week study period. Training volume was equalized based on the time under tension (TUT) by increasing the number of sets (2–7) and/or repetitions (6–15) for the partial condition. Results showed that the changes in muscle volume of the vastus lateralis were similar between conditions (7.6% vs. 6.7% for the full and partial ROM conditions, respectively). Moreover, both conditions similarly increased growth in the distal and middle regions of the muscle, with smaller increases observed proximally. Based on the results of this study, it seems ROM may be less important when it comes to using isokinetic exercise given that resistance is maximal throughout the entire ROM—provided that effort is also maximal—which therefore might produce similar hypertrophic effects.

Besides the quadriceps muscle complex, Kubo et al.²¹ explored hypertrophic changes in other lower body muscle groups including the hamstrings, gluteals, and adductors. Results showed that the full ROM condition elicited significantly greater increases in muscle volume of the adductors and gluteus maximus (2.7% vs. 6.2%, and 2.2% vs. 6.7%, for the partial and full ROM groups, respectively). These findings suggest that the response to variations in ROM may be muscle-specific.

When attempting to reconcile findings for the lower body, there appears to be a benefit for full versus partial ROM, at least in some muscles. Two of the four studies showed greater hypertrophy of the quadriceps when training with a full versus a partial ROM; no study showed greater gains

when using a partial ROM. That said, the two studies that investigated muscle volume via MRI,^{20,21} which provides the greatest insight as to true hypertrophic changes, showed similar results between conditions in the quadriceps. The results from Kubo et al.²¹ show that other muscles (adductors and gluteals) appear to benefit from the use of a full ROM, but findings are specific to a single study and caution is therefore needed when drawing inferences.

Upper extremity musculature

As previously noted, only two studies have explored the effects of training with full versus partial ROM in RT on muscle hypertrophy in the upper extremities. In one study, Goto et al.¹⁶ observed that training with a partial ROM promoted greater increases in muscle size of the elbow extensors than training with a full ROM. Alternatively, results from Pinto et al.¹⁷ showed modest hypertrophic benefits for full versus partial ROM (9.7% vs. 7.8%; $p=0.07$). It is important to emphasize that these studies differed in their respective training protocols. In the Goto et al.¹⁶ study, the participants performed three sets of elbow extension, three times per week with a load corresponding to 8 RM. In the Pinto et al.¹⁷ study, the training program included less weekly training volume and lower loads, as the participants generally performed three sets of elbow flexion only two times per week with repetition ranges from 8 to 20. This difference in training protocols might have influenced the results given that higher external loads and greater amounts of training volume seem to augment muscle damage.²⁵ As such, it is conceivable that the training protocol in the Goto et al.¹⁶ study resulted in high levels of muscle damage, at least in the early stages of training. When attempting to put this into the context of training with full versus partial ROM, it has been shown that training with a full ROM results in higher levels of muscle damage than training with partial ROM.²⁶ Therefore, it might be that training with a partial ROM may be more conducive for increases in muscle size when the training program is already designed to promote higher levels of muscle damage. This may indeed be the case if we consider that in the presence of muscle damage, increases in MPS may be directed more toward restoring this damage than to building the contractile protein pool.²⁷ Exercise-induced muscle damage was likely lower in the study by Pinto et al.¹⁷ given that protocol included less volume and lower loads—therefore, differences in the performed ROM did not have profound effects on muscle hypertrophy. However, evidence shows that muscle damage is markedly attenuated when the same RT stimulus is applied over time due to the repeated bout effect,²⁷ casting doubt as to the extent to which muscle damage may have influenced results; any effects likely would be relegated to the initial few weeks of training.

Another potential explanatory factor is the difference in training status between studies. Namely, Goto et al.¹⁶ employed trained individuals whereas the sample in Pinto et al.¹⁷ was in

untrained participants. It remains to be determined if and how training status may alter the hypertrophic effects of variations in ROM, but in the apparent absence of an alternative rationale, the possibility at least must be given consideration.

Besides possible differences in muscle damage and RT experience, it is also intriguing that Goto et al.¹⁶ noted a positive correlation between markers of intramuscular hypoxia and the percent increase in muscle CSA ($r=0.70$). The authors attributed the heightened hypoxic effect to training in a range that kept constant tension on the working muscle, thereby maintaining compression of the surrounding vessels. However, Pinto et al.¹⁷ employed a very similar ROM to that of Goto et al.,¹⁶ which would seem to discount the possibility of hypoxia as a contributory mechanism. It is possible that differences in the muscles studied may have influenced findings, as Pinto et al.¹⁷ investigated biceps brachii whereas Goto et al.¹⁶ investigated the triceps brachii; however, a logical rationale for such discrepancies is not readily apparent.

Overall, the limited research as to the effects of ROM on upper body hypertrophy makes it difficult to draw strong practical inferences. Of the two published studies on the topic, Pinto et al.¹⁷ showed a hypertrophic advantage to training through a full ROM and Goto et al.¹⁶ observed superior muscle growth with the use of a partial ROM. Future studies are warranted to elucidate this topic.

Additional factors to consider

When assessing the body of literature as a whole, a clear gap is the dearth of studies on the hypertrophic effects combining partial and full ROMs during RT programs. Research shows that muscle activation varies with the joint angle during exercise performance. For example, Signorile et al.²⁸ demonstrated that electromyographic (EMG) amplitude varied throughout ROM across the different heads of the quadriceps femoris during leg extension exercise.²⁸ Specifically, amplitude of the vastus lateralis was highest during the mid-portion of the ROM, whereas values for the vastus medialis oblique were greatest approaching lockout; no EMG differences were noted for the rectus femoris with respect to the ROM. Similar differences in activation patterns have been displayed during elbow flexion exercise, with the long head of the biceps brachii more active during early phase movement and the short head becoming more involved during the latter portion of the ROM.²⁹ Although EMG findings cannot necessarily be extrapolated to predict long-term hypertrophic outcomes from RT, the possibility remains that a combination of partial and full ROMs may have a synergistic effect on muscle development.

Another consideration in this regard is the ability to employ greater magnitudes of load during partial ROM training and thus heighten mechanical tension on the target musculature. Given that mechanical tension is purported to be the primary driver of RT-induced muscle hypertrophy,^{30,31}

it is conceivable that performing some heavy training in a shortened ROM in combination with full ROM training may elicit alterations in intracellular signaling that positively modulate long-term muscle protein accretion. Moreover, there is evidence that employing partial ROM training with heavy loads enhances the ability to use more weight during full range movements.³² Theoretically, this may serve to augment hypertrophy by increasing the amount of tension placed on muscles over time.

Limitations

There are some limitations to the current body of evidence that need to be addressed. First, the vast majority of participants in studies to date have been young men (~94% of the total sample). Thus, the findings cannot necessarily be generalized to other populations including youth, women, and older individuals. Second, only one study had a sample consisting of individuals with previous RT experience. Given evidence that the same RT stimulus elicits different epigenetic responses in trained versus untrained subjects,³³ the totality of findings has limited generalizability to well-trained individuals.

Conclusion

Current research suggests that performing RT through a full ROM confers beneficial effects on hypertrophy of the lower body musculature when compared with training with a partial ROM. However, at least for the quadriceps and based on our interpretation of the data, evidence implies that these benefits are apparent only up to a certain ROM threshold, with advantageous effects attenuating beyond the given threshold. Alternatively, research on the effects of ROM for the upper extremities is limited and conflicting, thereby precluding the ability to draw strong practical inferences. No study to date has endeavored to investigate how ROM influences muscle growth of the trunk musculature. At this point, no compelling rationale can be made for employing a given ROM versus another in the upper body muscles. On the whole, some evidence indicates that the response to variations in ROM may be muscle-specific; however, this hypothesis warrants further study.

Importantly, RT prescription does not have to be a binary choice and include *only* training with full or partial ROM. Studies to date are limited to having compared larger versus shorter ROMs. It is conceivable that combining ROM variations may promote synergistic effects on muscle growth. This remains a gap in the current literature that requires future exploration.

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