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Adaptations to explosive resistance training with partial range of motion are not inferior to full range of motion

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Abstract

We tested whether explosive resistance training with partial range of motion (ROM) would be as effective as full ROM training using a noninferiority trial design.

Fifteen subjects with strength training experience took part in an explosive –concentric only– leg press training program, three times per week for 10 weeks. One leg was randomly assigned to exercise with partial ROM (i.e. 9º) and the other leg to full ROM. Before and after training, we assessed leg press performance, isokinetic concentric and isometric knee extension torque, and vastus lateralis muscle architecture.

Overall, both training modalities increased maximal strength and rate of force development. Training with partial ROM yielded noninferior results compared to full ROM for leg press peak power (+69 ±47% vs. +61±64%), isokinetic strength (4-6±6-12% vs. 1-6±6-10% at 30, 60, and 180˚s^{-1}), and explosive torque after 100 (47±24 vs. 35±22) and 150 ms (57±22% vs. 42±25%). The comparison was inconclusive for other functional parameters (i.e. isokinetic peak torque (300˚s^{-1}), joint angle at isokinetic peak torque, explosive torque after 50ms, and electrically evoked torque) and for muscle fascicle length and thickness, although noninferiority was established for pennation angle. However, partial ROM was not found statistically inferior to full ROM for any measured variable.

Under the present conditions, the effects of explosive heavy resistance training were independent of joint ROM. Instead, these data suggest that the distinct timing of muscle work in explosive contractions confers more influence to the starting joint angle than ROM on adaptations to this type of training.

Introduction

Heavy resistance training is typically performed with relatively slow movements against constant loads, over the full range of motion (ROM) because a greater effectiveness is assumed than for training with partial ROM [1]. Different studies corroborate the importance of ROM, with superior hypertrophy, strength and performance gains in lower limb muscles observed following training with full ROM in multi- [2-4] or single-joint movements [5], compared to partial ROM. The greater improvements obtained with full ROM than partial ROM may result from longer time under tension and more work production for the involved muscles and joints.

In contrast to conventional, heavy, slow resistance training protocols, the applied ROM may have less importance for muscular adaptations to explosive training. Explosive contractions are characterised by a fast rate of torque development (RTD), which is likely accompanied by fast muscle shortening at the onset of the joint movement, due to concurrent stretch of elastic structures in the muscle-tendon units of the lower limbs [6]. The distinct contraction patterns of slow and explosive movements result in differences in the timing of muscle work. Namely, when torque is produced explosively, muscular excursion, work and power peak earlier (i.e. in the beginning of the movement), which in turn increases the decoupling between muscle and joint work via elastic mechanisms [7]. Additionally, the greater rate of force development during explosive movements results in greater force in the beginning of the movement and hence in a greater acceleration of the training load. This results in larger kinetic energy of the training load and a longer deceleration phase demanding less force in the later part of the movement. Both the increased storage of elastic energy and the greater acceleration of the training mass may reduce the relative contribution of muscular work in the later phase of explosive movements. In contrast to strength training with slow contractions, using the full ROM may thus bear less significance for the improvements in RTD, force and power with explosive-type strength training.

Differences in ROM-specificity between slow and explosive resistance training are also likely found in the hypertrophic response associated with strength gains. Slow resistance training induces hypertrophy via addition of in-parallel sarcomeres, typically measured as increases in muscle thickness and pennation angle [8] that are proportional to joint operating range [5]. Conversely, although hypertrophy induced with different types of training may slightly differ in terms of architectural changes [9], this type of adaptation may also be less dependent on operating ROM with explosive contractions than with slow ones. With the premise that hypertrophy and architectural changes are driven by a mechanical stimulus [10], the relatively larger muscular work and impulse produced in the initial phase of explosive movements may also reduce the importance of the later phase of the movement for the hypertrophic stimulus.

The aim of this study was to assess whether explosive strength training performed with partial ROM would be as effective for functional and structural muscle adaptations as explosive training with full ROM. Specifically, we tested whether partial ROM explosive leg press training can provide similar effects as explosive full ROM training (with identical starting joint configuration in both modalities) on knee extension maximal isokinetic torque, explosive isometric torque, neural adaptations, dynamic power production, and vastus lateralis muscle architecture. Unlike most experiments in this field, the purpose of this study was to demonstrate similarity, not a difference. We therefore used a non-inferiority trial design to compare the effectiveness of the two training strategies. Hence, our research hypothesis was that the partial ROM intervention would induce changes at least as large as full ROM.

Methods

Subjects and experimental protocol

Fifteen recreationally strength trained males (n=10) and females (n=5) (age: 25 ± 4 years; height: 176 ± 10 cm, body mass pre: 72 ± 9 kg, body mass post: 73 ± 9 kg) participated in the experiment. Volunteers were included if they reported no injuries and a minimum of one strength training sessions per week that included leg training during the last six months. The protocol was approved by the ethical committee of the Norwegian School of Sport Sciences and all subjects were fully informed about the study before they provided written informed consent to participate.

The training consisted in unilateral, explosive leg press training three times per week, for ten weeks. For each subject we randomly assigned which leg (left or right) exercised with partial (i.e. 9º change in knee angle) or full ROM. In both modalities, starting joint angle configuration was similar. Testing procedures were similar before and after the training period and were separated by two to four days from the last training session. The tests were distributed over two testing days, with one additional day for a familiarisation session prior to the baseline tests. Testing on day 1 was dedicated to measures of vastus lateralis muscle architecture, voluntary and electrically evoked knee extension explosive torque, and maximal isokinetic knee extension torque. On testing day 2, subjects completed an additional strength test on a pneumatic resistance leg press. In both sessions, subjects completed a standardised warm-up of 10-min cycling.

Training program

All training sessions were supervised. Each week included 3 sessions with 3-6 sets of either 4, 6 or 8 explosive concentric contractions, for both legs. The number of sets increased non-linearly during the training period; **Table S1**). The maximal loads that could be lifted for each type of sets (4, 6 and 8 repetition-maximum (RM)) were determined prior to the first training session over the full ROM of each leg. Subjects trained both legs concentrically in a diagonal leg press machine (Panatta leg press 45˚, Apiro, Italy) with a starting knee joint angle of 90˚ (0˚ is full extension) and 80˚ of hip flexion (0˚ is full extension, **Figure 1**). The order of ROM condition within training session was alternated. Static ropes were used to constrain the foot plate during the partial ROM condition. Together with locking pulleys, ropes also held the load during leg flexion in the individual starting position and prevented the subjects from performing any eccentric actions. Subjects rested three seconds between consecutive contractions and two minutes between sets. Training loads were adjusted each week using a scale of perceived exertion (1-10) [11]. When the effort was rated below 8, the training weight was increased by 5 kg. Subjects were regularly reminded to perform all repetitions as fast as possible and were verbally encouraged during training.

The eccentric phase was excluded to reduce the number of factors influencing adaptations to resistance training. Eccentric training has been found to induce both hypertrophy and architectural changes [12], and thus, may preclude effects of ROM *per se*.

Resting muscle architecture

Muscle architecture measurements were taken before the warm-up, while the subjects lay supine and fully relaxed. The leg position was standardised by immobilising the foot in the sagittal plane with an ankle joint angle of 90°. The vastus lateralis muscle was imaged at 60% of the distance between the greater trochanter and the femoral lateral epicondyle, in its thickest portion on the medio-lateral axis. Unfortunately, the 50 mm ultrasound transducer (L12-5, HD11XE, Philips) used for pre-testing was damaged during the training period. Post-training scans were therefore performed with another apparatus (HL9.0/60/128Z-2, LS 128, Telemed) and a 60 mm transducer. To ensure consistent scaling of the images collected with the two ultrasound scanners, a calibration factor was obtained from images of a custom-made phantom with known distances between three metallic wires.

We used an open source ImageJ/Fiji [13] plugin to automate muscle architecture analysis [14]. Briefly, the script automates image filtering and the segmentation of aponeuroses and fascicle fragments. It then computes muscle thickness as the mean distance between the superficial and deep aponeuroses, pennation angle as the angle between the dominant fascicle orientation and the deep aponeurosis, and fascicle length as the distance between aponeuroses along the dominant fascicle orientation.

Voluntary explosive and electrically-evoked, isometric contractions

Subjects were fastened in a knee extension machine (GYM2000, Geithus, Norway) that was modified with a strain gauge to serve as a fixed-end testing device. Warm-up and testing contractions were performed unilaterally, with a knee angle set to 90°. A specific warm-up consisted of 3 sets of 10, 6 and 4 submaximal, fixed-end contractions. The participants then performed one maximal voluntary contraction (MVC). Voluntary RTD was tested with two sets of five explosive contractions, separated by 5 seconds of rest between consecutive contractions and visual feedback for both legs. Subjects were instructed to attempt to extend their knee “as fast as possible” until their force reached at least 80% of their maximum. An online visual feedback of the strain gauge signal was provided to the subjects on a computer screen.

Electrically evoked contractile properties of the quadriceps were determined in resting condition. Two stimulation electrodes (Veinoplus, 8x13cm, Paris, France) were placed proximally and distally on the frontal part of the thigh. Percutaneous stimulation was delivered with a constant current electrical stimulator (Digitimer Electronics, DS7, Hertfordshire, UK) as single rectangular waves (0.2 ms duration). After a few submaximal electrical stimuli for familiarisation of the subjects, stimulation intensity was incremented by 20 mA until no further increase in twitch force could be observed. This level of intensity was increased by 20% to ensure maximal activation throughout the experiment. Five twitches, with five seconds rest between each twitch, were elicited and recorded for each leg.

During voluntary and electrically evoked contractions, the analogue force signal was collected at 5000 Hz and low-pass filtered offline at 20 Hz using a bidirectional 2nd order Butterworth filter. Data were then multiplied by the length of the external lever, measured as the distance from the lateral epicondyle to the centre of the contact point on the shank, to calculate knee extension torque values.

Surface EMG was used to determine pre-activation. Recordings over the vastus lateralis were made with a wired EMG system (MP150, Biopac, Goleta, CA, USA) during the voluntary contractions. Following skin shaving and cleansing with alcohol, surface EMG electrodes (Ambu Neuroline 720 7200-S/25, Penang, Malaysia) were attached over the vastus lateralis muscle [15]. EMG signals were synchronised to the force signal and sampled at 5000 Hz. Subsequently, EMG signals were filtered at 10-500 Hz using a bidirectional bandpass filter and rectified offline. Signal amplitude was then calculated as the root mean square of the processed EMG signal over a 40 ms window.

For the analysis, torque onset was defined as the point where the torque value exceeded 3 Nm. Contractions with pre-activation and/or countermovement were excluded from the analysis. Pre-activation was defined as an increase in amplitude exceeding 3-times the standard deviation of the baseline signal, 100-500 ms before torque onset. The three best contractions were retained for analysis, based on the torque measured 50 ms after onset.

For voluntary contractions, we calculated mean values for torque after 50, 100 and 150 ms, and for electrically evoked contractions, we calculated mean values for peak torque, torque after 50 ms and the delay between stimulation artefact and torque onset.

Isokinetic torque measurements

Maximal concentric knee-extensor torque under different velocities was measured using an isokinetic dynamometer (Humac NORM 2008, Computer Sports Medicine Incorporated [CSMi], Stoughton, MA). Subjects were seated with a hip angle of 85˚ and the dynamometer rotation axis aligned to the knee rotation axis. Three maximum-effort knee extension were performed at 30, 60, 180 and 300 $˚s^{-1}$, from 90 to 0˚ of knee flexion with two minutes rest between velocities (one minute between the two fastest velocities).

The dynamometer sampled knee extensor torque and joint angle data at 100 Hz. The highest peak torque and the mean angle at peak torque of the three contractions were used for further analysis. Mechanical work produced during leg extension was calculated by integrating torque-angle data over three intervals of 15˚ ROM (80-65˚, 65-50˚ and 50-35˚).

Leg press power test

Unilateral leg press power production was tested by using a standardised test protocol (Keiser 10 repetitions power test) on an instrumented, horizontal leg press (Keiser Air 300). Subjects were positioned with a 70˚ hip angle and 80˚ knee angle before completing a specific warm-up consisting of three sets of 10, 6 and 4 repetitions. Subjects performed a unilateral 1 RM test for each leg prior to the pre-training test, which was used to determine the loads used during pre and post training tests. Subsequently, subjects performed 10 contractions "as hard and fast as possible" with a gradual increase in load from 15% to 95% of the pre 1 RM; the inter-load rest periods increased progressively (5-30 sec).

For analysis, we used the Keiser software to calculate a linear regression for force-velocity data and estimated leg extension power as the product of force and velocity based on the regression line. Peak power was defined as the highest value of the parabolic power-velocity relationship.

Statistical analysis

Since we postulated that explosive training at partial ROM would have at least the same effect as full ROM training, i.e. as opposed to a difference hypothesis in traditional comparative studies, we used a noninferiority design [16,17]. Noninferiority is established, at the α significance level, if the confidence intervals (upper or lower as appropriate) for the difference between interventions do not cross a set equivalence margin (δ). If the confidence intervals of group differences are entirely outside the margin set with δ, results are deemed inferior. Confidence intervals lying wholly within the margin set with δ but including 0 indicate noninferiority but cannot ascertain superiority. Confidence intervals within the margin set with δ and excluding 0 indicate superiority of the partial ROM protocol. In cases where confidence intervals cross the limit δ, the results are inconclusive, denoting that noninferiority or inferiority cannot be statistically established.

Sample size was calculated for peak leg press force and power as main outcome variables. Using an α-level of 5%, a standard deviation of the outcome measure of 3% (data from our laboratory), and δ of 5.3%, the estimated sample size is 14 subjects.

Typically, δ is based on confidence intervals reported in metanalysis, an approach that could not be applied here, because of the few data available for this type of intervention and outcome variables. We therefore set δ conservatively, as the smallest worthwhile change [18], calculated as 0.2 * standard deviation of the baseline tests for each variable (see **Table S2**). Two-sided 90% confidence intervals (to reach a 0.05 level of significance for one-sided testing) were used for the difference in changes between partial and full ROM training.

Results

All 15 subjects completed a minimum of 90% of the training sessions and all tests at baseline and post-intervention. Due to insufficient image quality, we discarded the ultrasound data for one subject, resulting in n = 14 for muscle architecture. Another subject did not complete the electrically evoked contractions, leaving n = 14 subjects for the stimulation data. For all other measurements, results are reported for all subjects (n = 15).

The changes after explosive partial ROM and full ROM leg press training are given in **Figure 2** for different variables. The effects induced by the partial ROM intervention were not found inferior to the full ROM protocol for any variable. Several results were inconclusive but noninferiority was established for pennation angle, RTD_{100ms}, isokinetic peak torque (30, 60 and 180 $°s^{-1}$), and Keiser leg press peak power [16].

Leg press power test

Leg press force-velocity and power-velocity data are presented in **Figure 3**. Mean (± standard deviation) values for peak leg press power increased from 589 (±182) to 658 (±192) W following partial ROM and from 604 (±198) to 665 (±179) W following full ROM training. The effect of the partial ROM protocol on leg press force and power was found noninferior to that of the full ROM protocol. Peak velocities pre- and post-training were 1.88 (± 0.22) and 1.92 (±0.18) $m{\cdot}s^{-1}$ for partial ROM and 1.91 (± 0.20) and 1.94 (±0.13) $m{\cdot}s^{-1}$ for full ROM. Comparison of the changes in leg press peak velocity obtained with either training modalities did not satisfy noninferiority criteria [16] and were deemed inconclusive.

Isokinetic torque measurements

Isokinetic knee-extensor torque was velocity- and joint angle-dependent, with maximal torques being produced at slower velocities and around a knee angle of 55˚ at all velocities. Training resulted in small pre-post increases in torque (**Figure 4A**, **Table 1**). Statistical analysis showed noninferiority of the partial ROM training modality for induced changes in torque at 30 and 180 $^{\circ}s^{-1}$ and superiority for the torque at 60 $^{\circ}s^{-1}$, while the difference between protocols was inconclusive for torque data for 300 $^{\circ}s^{-1}$. Differences in changes in joint angles at peak torque between protocols were inconclusive at all isokinetic conditions (**Figure 4B**, **Table 1**).

Voluntary explosive and electrically-evoked fixed-end contractions

Voluntary explosive torque measured 50, 100 and 150 ms after torque onset are presented in **Figure 5** and **Table 1**. Both training modalities tended to increase voluntary torque at any time interval, and noninferiority testing established that partial ROM training produced similar or greater effects at 100ms and 150ms (inconclusive at 50 ms).

Electrically evoked peak torque and torque measured 50 ms after stimulation was 31 and 22% greater after partial ROM and 35 and 33% greater after full ROM training (**Figure 6**), although the differences between the effects of the two protocols appeared inconclusive.

Resting muscle architecture

Vastus lateralis fascicle length increased by 12% following partial ROM and 9% following full ROM training (**Figure 7**A). However, the two-sided 90% CI of the difference in fascicle length changes crossed the minimum meaningful difference, so that the difference between protocols was deemed inconclusive. On the other hand, we found a 13% decrease in pennation angle following partial ROM and 10% following full ROM training (**Figure 7**B), in which case the partial ROM training modality appeared noninferior. Muscle thickness was little affected by either training condition (**Figure 7**C) and a difference between training protocols was inconclusive.

Discussion

This study examined the role of ROM in explosive heavy resistance training for functional and structural adaptations of the knee extensor muscles. In line with the hypothesis, we discuss here the question of statistical noninferiority of partial ROM modality compared to full ROM, rather than the magnitude of the training effects (which could not be tested within this type of design). Noninferiority testing of 10 weeks of partial ROM vs full ROM leg press training showed that none of the changes induced with partial ROM was statistically inferior to those observed with full ROM, despite the lower mechanical work performed by the knee joint with this modality. Instead, noninferiority or superiority of partial ROM were established for a range of variables related to maximal explosive strength, although the comparison between training conditions remained inconclusive for some variables, most of them related to high angular velocity. Collectively, the results indicate that the partial ROM explosive protocol does not yield inferior adaptations to full ROM in knee extensor muscle function and structure.

Muscle strength and power measurements

Increases in leg press peak force and power after partial ROM training were noninferior to the increases after the full ROM protocol. Hence, the similar outcomes from the two training modalities in a functional test, which is similar to the training exercise, are in line with our hypothesis of explosive training not being ROM-specific. This feature of explosive training contrasts with slow resistance training, where ROM specificity has been shown following several training regimens [2,5,19,20]. On the other hand, the relative effectiveness of training ROM on changes in leg press peak velocity was inconclusive. The lack of conclusive comparison in this case may reflect the non-specificity of the training intervention for this parameter, given the heavy loading that it involved.

In line with the results from leg press test, noninferiority of partial ROM was established for isokinetic knee extension torque at 30, 60 and 180 $^\circ s^{-1}$. A training transfer of strength gains therefore occurred between leg press and this non-specific strength test, although pre- to post-changes were expectably smaller than with the training-specific leg press test [21]. The similar results found with a training-specific and an unspecific strength test could indicate a high generalisability of the current findings. Of note, the relative effectiveness of training ROM for peak torque at the fastest isokinetic velocity (300 $^\circ s^{-1}$) was inconclusive, which may relate to the inconclusive comparison for peak velocity during leg press discussed above and the non-specificity of the present training intervention for velocity-based variables. Similarly, we found inconclusive differences between the partial and full ROM modalities for joint angles at isokinetic peak torque. A shift in the optimal angle for torque production can be induced with training, notably after isometric training at different joint angles [22]. Considering the early timing of peak muscle force/work in explosive contractions, we expected that training-induced changes in joint angle at peak torque would be driven by the starting angle, rather than the operating ROM. We therefore expected that changes in this variable would be similar between modalities, i.e. statistically noninferior. The high variability in pre- to post-testing differences may explain why the comparison between training modalities was inconclusive.

A decisive factor to explain why partial ROM does not yield inferior strength gains to full ROM with explosive heavy resistance training may be the distinct contractile pattern of knee extensor muscles. We propose that the distribution of muscle work towards the initial phase of explosive contractions, compared to slow ones, equalizes the training stimulus with partial and full ROM, when starting at the same joint angle. Although muscle contractile behaviour against matching heavy loads has to date not been directly compared between explosive and slow actions, the implied differences in RTD likely influence work distribution. The greater RTD characterising explosive actions assumes reaching peak force earlier, and peak fascicle shortening may also occur earlier by virtue of additional strain of elastic tissue. Reaching peak force and maximal fascicle shortening earlier in the movement expectably reduces muscle work capacity toward the end of the movement, which is compensated for by a greater contribution from elastic tissues [7,23]. The earlier peak force and work redistribution in explosive movements are also characterised by high muscle activity and high motor unit discharge rate in the beginning of explosive contractions [24], whereas EMG activity has been described as monotonic during slow contractions [25,26]. Further studies are required to demonstrate this hypothesis, but we find logical ties between the assumption of work redistribution (i.e. earlier during explosive contractions) and the results of the present study.

Rapid contractions

Accordingly, our results from explosive isometric tests indicate that torque enhancements after 100 and 150 ms were at least equivalent with partial and full ROM. In agreement with voluntary RTD results, electrically evoked torque production increased after the training in both modalities (Figure 3) although for these tests, differences between the effect of the two training modalities were inconclusive (Figure 1). An increase in explosive torque is consistent with other studies reporting higher RTD following specific isometric training interventions [27,28] and is a desirable outcome to increase joint angular acceleration. Previous studies also point out the high variability of RTD measurement, with the notable difficulty to detect force onset reliably [29], which may have contributed to inconclusive results for $\mathrm{RTD}_{50\mathrm{ms}}$ in this study. On the other hand, partial ROM training had in fact a statistically superior effect upon the rise in torque at 150 ms. Albeit speculative, the distinct influence of ROM on this variable could be connected to a lower total volume of training. The partial ROM modality may be perceived as less fatiguing and may allow a better focus on explosive onset of force exertion, which has been suggested to be connected to RTD increases [30]. Furthermore, the equivalent increases in torque production within the first 150 ms of voluntary contraction (<150 ms) seen with both partial and full ROM suggests similar adaptations obtained in neural activation and contractile properties [31,32]. Similar adaptations in neural drive may notably have occurred as a result of the similar intended actions in these two types of ballistic training [30].

Muscle architecture

From a structural point of view, the present improvements in explosive torque production capacity seen after training do not seem related to changes in maximal force potential. Muscle thickness did not to increase (Figure 3C), suggesting that factors influencing the rate of force production – rather than maximal force – may have been favoured by the present type of explosive training. Apart from intrinsic factors not assessed here, such as fibre type composition and calcium release, changes in muscle architecture may have contributed to this effect. Our results are consistent with previously reported adaptations in muscle architecture to explosive training, characterised by an increase in fascicle length [33-35]. A greater number of sarcomeres and greater fibre lengths are linked to higher muscle shortening velocity and greater capacity of force production at a given velocity [36]. Since contractile velocity may influence explosive force production from 100 ms after the onset of contraction [6], it would have been tempting to attribute the present results to fascicle lengthening obtained via sarcomerogenesis. However, the comparison of the ~10% increases in fascicle length seen with each training modality remained inconclusive. Noninferiority was possibly missed because of the variability in thickness and pennation angle measurements on which the calculation of fascicle length is based. The random error caused by the indirect estimation of fascicle length [37] may have induced a higher statistical noise for this architectural variable.

Interestingly, pennation angle appears smaller after both training modalities. If confirmed, such a decrease would be congruous with the findings of at least one previous study using an explosive type of training [34]. However, another study found explosive strength training not to have any significant effect on pennation angle [33]. Beyond the scope of this noninferiority study, additional research is required to confirm and understand the nature of architectural changes to explosive training.

Limitations

While these findings show the equivalence of ROM modalities for explosive training on several variables, certain considerations delineate their interpretation. Firstly, it is worth noting that the current training was purely concentric. Including an eccentric phase would have added different amounts of negative muscle work, depending on ROM, and may have yielded training ROM specificity. The limit set to limit partial ROM caused an additional isometric contraction at the end of the movement. The effect of this artefact cannot be assessed here, but it likely contributed to the variability of the findings, although its effect on the training outcome is deemed marginal. We measured many parameters related to muscle function and structure but could not include other factors contributing to changes in explosive force production, such as muscle fibre type composition, calcium handling or tissue mechanical properties (e.g. muscle, tendon and connective tissue stiffness). Although we cannot ascertain the relative effects of partial and full ROM on these variables, the present findings do not suggest that partial ROM would have had a different effect on them. Amongst tests included in the present protocol, electrically evoked contractions with singlets were probably sub-optimal. We are aware of the limitations associated with the use of singlets but estimated they would not interfere substantially with the main aim of effectiveness comparison between training modalities. However, this method probably introduced too much noise for this purpose and these results should be interpreted with caution.

Conclusion

Using a noninferiority trial design, we showed that explosive, heavy resistance training with partial ROM was not inferior to full ROM in a concentric leg press exercise, for muscle functional and structural adaptations. We propose that the similar effects observed here are due to the distinct contraction pattern of explosive contractions, matching muscle work more closely between different ROMs than with slow contractions, all other parameters (e.g. starting position) being equal.

According to the specificity principle, training routines should mimic as much as possible the conditions in which the target movement should be improved. The present findings indicate that ROM specificity of heavy resistance training with explosive contractions may partly detract from this principle.

Perspective

The present results indicate that the ROM used during explosive, heavy strength training has a limited influence on neuromuscular adaptations. These findings have direct implications in cases where training with restricted ROM is advised or necessary, but their effective implementation may be bound to two conditions. According to our mechanistic hypothesis, the training resistance should be enough to allow a sufficient rate of force development and force level in the beginning of the contraction. By virtue of the same hypothesis, the starting angle seems to be more important than overall ROM for adaptational changes in force and power. Additional studies are needed to assert the limits of equivalence between partial and full-ROM with explosive, heavy resistance training.

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Figure/Table Legends

Figure 1*. Schematic representation of the leg press training exercise with partial or full range of motion (ROM).*

***Figure 2**. Mean difference with 90% confidence intervals (CI) between the changes induced by the two training modalities full ROM – partial ROM). Vertical dotted lines represent smallest meaningful differences (between-subject standard deviation * 0.2) and delimit the noninferiority margins. The solid vertical line represents the null effect. Noninferiority of the partial ROM protocol relative to full ROM was established when the 90% CI lay within the noninferiority margin. Superiority of the partial ROM protocol was established when the 90% CI was entirely negative.*

***Figure 3.** Mean force-velocity (A) and power-velocity (B) curves for the Keiser leg-press test using the same loads pre and post a 10-week partial or full range of motion training protocol.*

***Figure 4**. Isokinetic peak torque (A) and angle measured at peak torque (B) pre and post a 10 weeks partial or full range of motion training protocol. Noninferiority between training protocols was established when the 90% confidence interval (CI) was within the noninferiority margin and labelled by *. Superiority of the partial range of motion protocol was established when the 90% CI was negative. Values are mean ± standard deviation.*

***Figure 5**. Voluntary explosive knee extension torque after 50, 100 and 150 ms, pre- and post-training at partial or full range of motion. *effect of partial ROM training modality is non inferior to full ROM training. Values are mean ± standard deviation.*

***Figure 6.** Electrically evoked knee extension peak torque (A) and torque after 50 ms (B) pre and post a 10-week training protocol at partial or full range of motion. Statistical analysis for noninferiority was inconclusive for both variables. Individual data points are depicted with transparent hues and means ± standard deviation with opaque hues.*

***Figure 7**. Vastus lateralis (VL) muscle architecture parameters fascicle length (A), pennation angle (B) and thickness (C) pre- and post- 10 weeks of explosive leg press training with partial or full range of motion. Noninferiority between training protocols was established when the 90% confidence interval was within the noninferiority margin and labelled with the symbol *. Individual data points are depicted with transparent hues and means ± standard deviation with opaque hues.*

***Table 1.** Changes in maximal voluntary explosive torque, produced in fixed-end and isokinetic contractions and in knee joint angle at peak torque, for partial and full range of motion (ROM) modalities after the training intervention.*

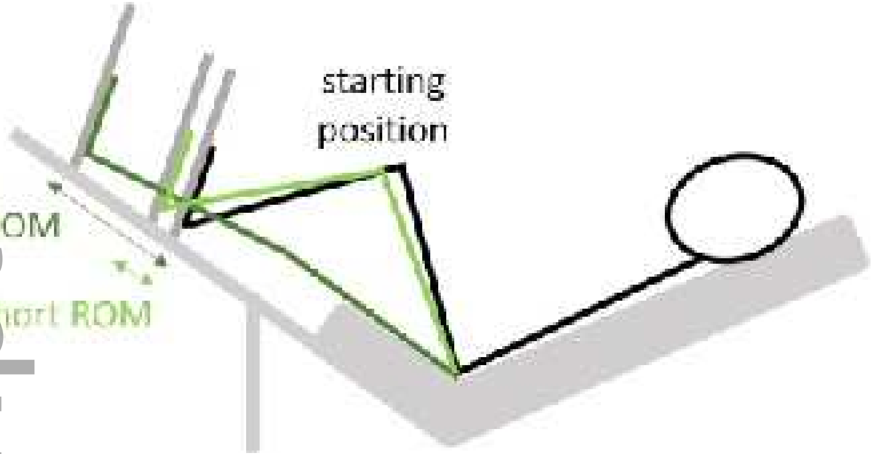
Conflict of interest

No conflict of interests, financial or otherwise, is declared by the authors.

Table 1. Changes in maximal voluntary explosive torque, produced in fixed-end and isokinetic contractions and in knee joint angle at peak torque, for partial and full range of motion (ROM) modalities after the training intervention.

		pre- to post-training differences	
		partial ROM	full ROM
Isokinetic peak torque (Nm)	Velocity (˚s^{-1})		
	30	3.7 ± 10.8	1.7 ± 9.9
	60	6.0 ± 12.0	0.8 ± 6.1
	180	4.6 ± 5.6	5.5 ± 9.2
	300	4.3 ± 6.3	6.3 ± 9.8
Angle at peak torque (˚) (isokinetic)	30	2.2 ± 8.9	1.5 ± 7.2
	60	0.9 ± 5.6	2.7 ± 4.1
	180	-1.1 ± 4.9	-0.1 ± 4.1
	300	1.3 ± 8.6	0.2 ± 1.4
Explosive torque (Nm)	Time after onset (ms)		
	50	26.9 ± 20.2	22.1 ± 18.4
	100	42.1 ± 24.2	30.9 ± 17.8
	150	39.9 ± 23.5	29.7 ± 17.0

Changes are expressed as mean ± standard deviation. Positive values indicate higher post values, negative values indicate higher baseline (pre) values.



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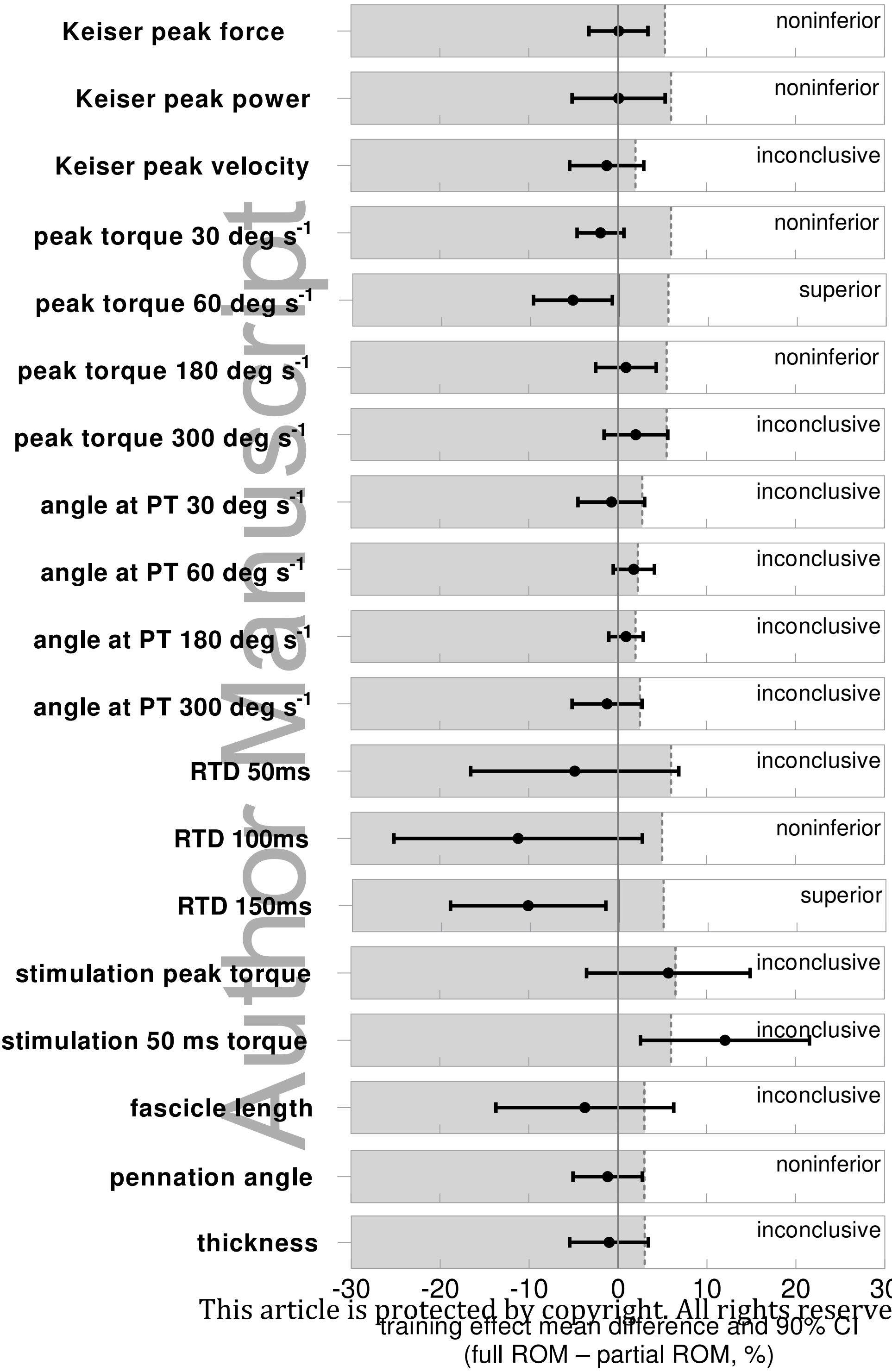
Keiser peak force
noninferior
Keiser peak power
noninferior
Keiser peak velocity
inconclusive
peak torque 30 deg s^{-1}
noninferior
peak torque 60 deg s^{-1}
superior
peak torque 180 deg s^{-1}
noninferior
peak torque 300 deg s^{-1}
inconclusive
angle at PT 30 deg s^{-1}
inconclusive
angle at PT 60 deg s^{-1}
inconclusive
angle at PT 180 deg s^{-1}
inconclusive
angle at PT 300 deg s^{-1}
inconclusive
RTD 50ms
inconclusive
RTD 100ms
noninferior
RTD 150ms
superior
stimulation peak torque
inconclusive
stimulation 50 ms torque
inconclusive
fascicle length
inconclusive
pennation angle
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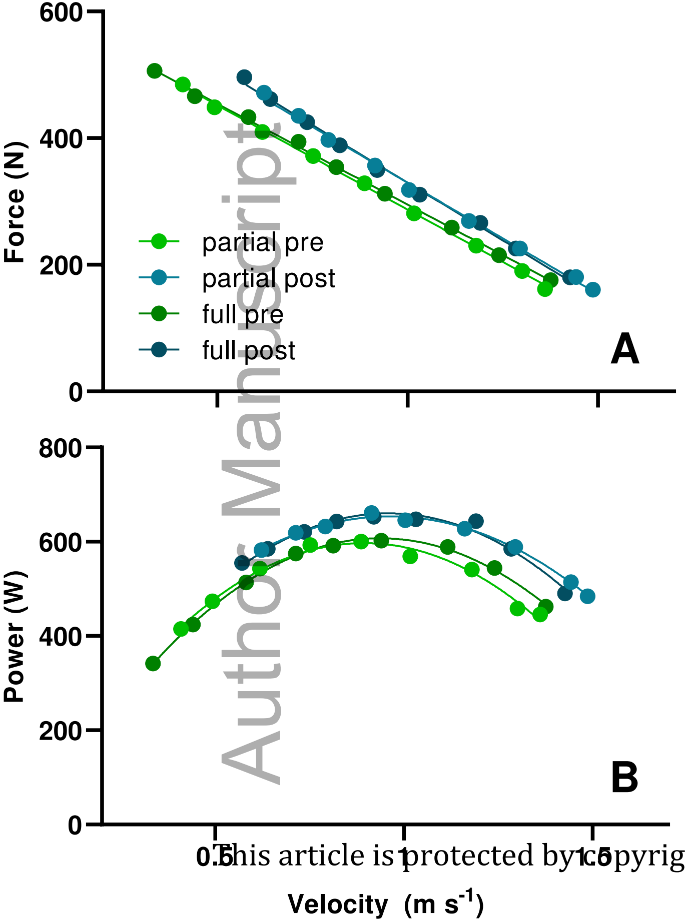
30
training effect mean difference and 90% CI
(full ROM – partial ROM, %)


600
400
200
0
Force (N)
partial pre
partial post
full pre
full post
A
800
600
400
200
0
Power (W)
B
0.5
1
1.5
Velocity (m s-1)

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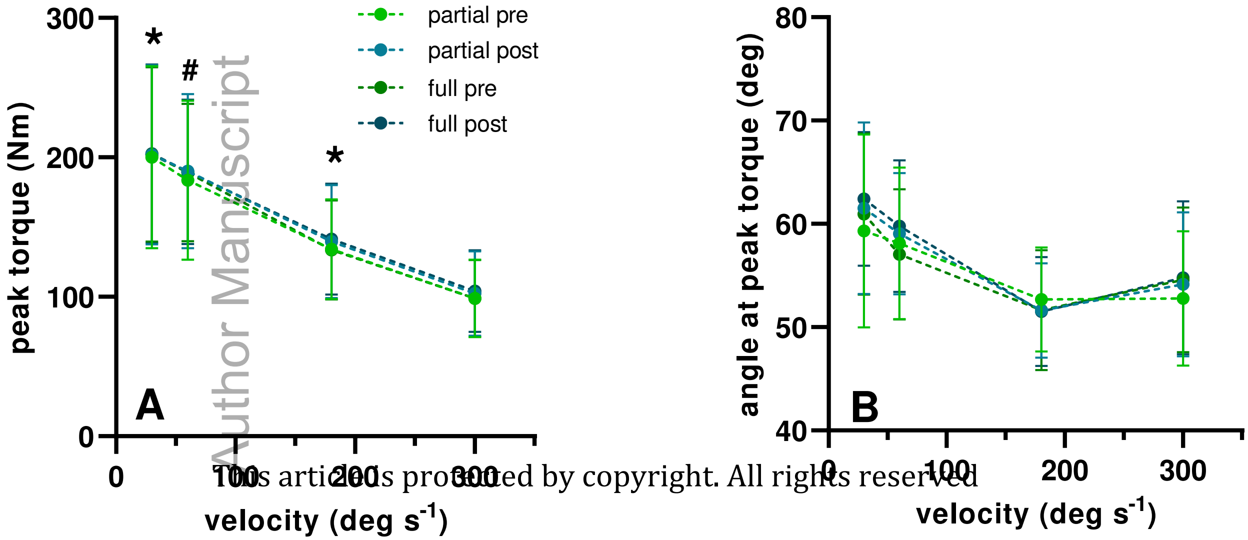

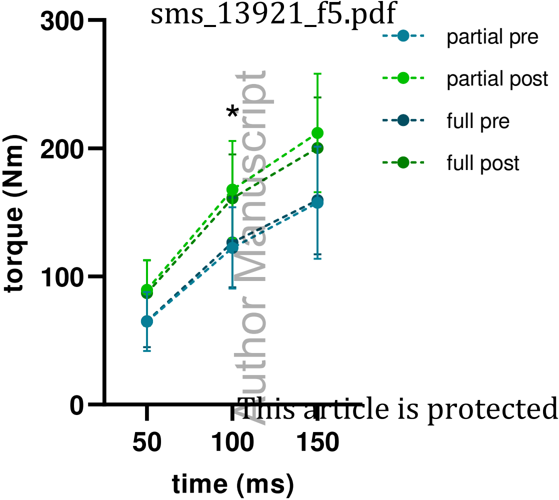
300
200
100
0
torque (Nm)
50
100
150
time (ms)
*
partial pre
partial post
full pre
full post

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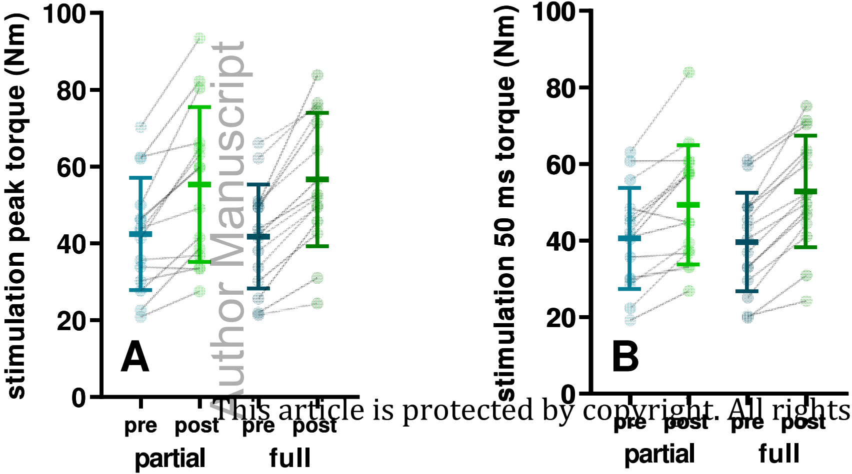

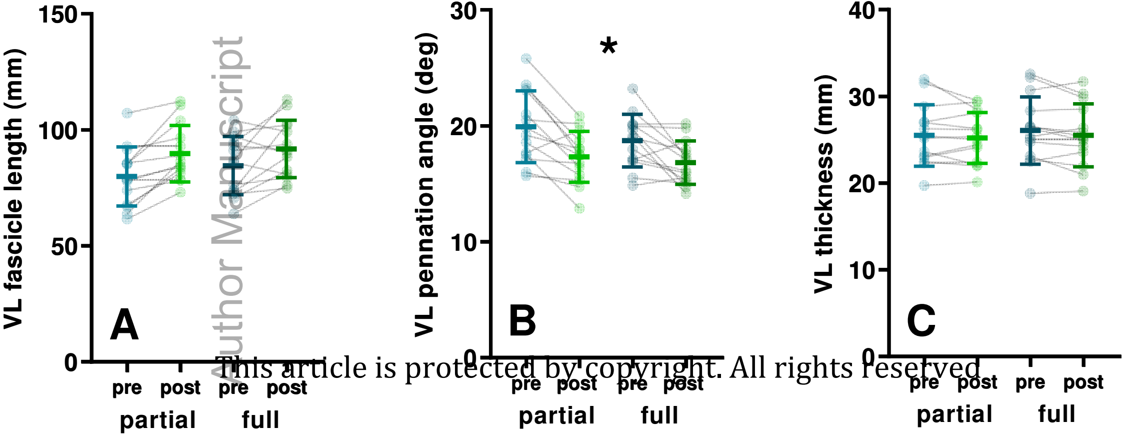
A
VL fascicle length (mm)
0
50
100
150
pre
post
pre
post
partial
full
B
VL pennation angle (deg)
0
10
20
30
*
pre
post
pre
post
partial
full
C
VL thickness (mm)
0
10
20
30
40
pre
post
pre
post
partial
full