The Influence of Variable Range of Motion Training on Neuromuscular Performance and Control of External Loads

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Abstract

Clark, RA, Humphries, B, Hohmann, E, and Bryant, AL. The influence of variable range of motion training on neuromuscular performance and control of external loads. J Strength Cond Res 25(3): 704–711, 2011—Resistance training programs that emphasize high force production in different regions of the range of motion (ROM) may provide performance benefits. This study examined whether variable ROM (VROM) training, which consists of partial ROM training with countermovements performed in a different phase of the ROM for each set, results in improved functional performance. Twenty-two athletes (age 22.7 ± 2.4 years, height 1.81 ± 0.07 m, and body mass 94.6 ± 14.5 kg) with extensive resistance training backgrounds performed either a VROM or full ROM control (CON) 5-week, concentric work-matched training program. The participants were assigned to a group based on stratified randomization incorporating their strength levels and performance gains in preceding training microcycles. Testing consisted of assessing the force–ROM relationship during isokinetic and isometric bench press and ballistic bench throws, with normalized electromyography amplitude assessed during the isometric tests. Repeated-measure analyses of variance revealed that the VROM intervention significantly (p < 0.05) increased both full ROM bench throw displacement (+15.5%) and half ROM bench throw peak force (+15.7%), in addition to isokinetic peak force in the terminal ROM (13.5% increase). No significant differences were observed in the CON group or between groups for any other outcome measures. Analysis of the force–ROM relationship revealed that the VROM intervention enhanced performance at shorter muscle lengths. These findings suggest that VROM training improves terminal and midrange performance gains, resulting in the athlete possessing an improved ability to control external loading and produce dynamic force.

Key Words specificity, biomechanics, reactive strength, power, periodization

Introduction

Traditional resistance training increases strength and power (11); however, exercises that use the entire range of motion (ROM) may not provide the optimal stimulus for enhancing sports performance. Full ROM exercises typically consist of a large deceleration phase (6,12), resulting in a substantial proportion of the movement being performed at force levels far below maximal (3). This is particularly evident toward the terminal range of movement—a phase critical for athletic performance (19).

This large deceleration phase occurs because the sticking region, which is the position at which the movement is most likely to fail, often occurs at long muscle lengths close to the countermovement position (6,19). By performing countermovements in the same position for each repetition of an exercise, the mechanisms that govern the efficiency of the changeover from eccentric load braking to concentric force production are being ignored throughout the remainder of the ROM. This may attenuate the reactive strength adaptations from resistance exercise if a countermovement is required in the midrange of the movement, resulting in a suboptimal ability to control external loading in this region and a consequent increased risk of injury.

To overcome these limitations, a resistance training program that requires near-maximal countermovement performance, and subsequently near peak force production, in different regions of the ROM may provide a beneficial stimulus for enhancing functional performance gains. Variable ROM (VROM) training, which consists of partial ROM training with the countermovement performed in a different position for each set of an exercise (4), is one such method.
This form of training allows the athlete to lift loads far in excess of their full ROM 1RM through a reduced ROM, which results in substantially greater force production during the partial ROM repetitions (4). However, whether this results in improved longitudinal performance gains is presently unknown. Therefore, the aim of this experiment was to determine the effect of a 5-week VROM training intervention on performance and neuromuscular activation throughout the ROM in well-trained athletes. We hypothesized that VROM training would result in superior performance gains in the terminal phase of the concentric ROM (hypothesis 1), provide similar strength gains to full ROM training at long muscle lengths (hypothesis 2) and improve mid-ROM reactive strength by means of increasing countermovement force production (hypothesis 3).

**METHODS**

**Experimental Approach to the Problem**

This study consisted of a 5-week, concentric work-matched VROM or full ROM training intervention performed by athletes with extensive resistance training backgrounds assigned to a condition based on stratified randomization. Pre and postintervention assessment of bench throw force and displacement, isokinetic bench press strength in distinct segments of the ROM and neuromuscular activation during isometric contractions was performed to assess functional adaptations. This combination of testing protocols allowed for the assessment of functional performance outcomes that ranged from strongly replicative of the training intervention (e.g., ½ ROM ballistic bench throws are specific to ½ ROM bench press) to only modestly replicative (e.g., the static ½ ROM isometric strength has only modest specificity to the dynamic ½ ROM bench press). Statistical analysis consisted of repeated-measures analyses of variance (ANOVAs) with an alpha level set at \( p = 0.05 \).

**Subjects**

Twenty-two male, semiprofessional rugby league players (mean \( \pm SD \), age 22.7 ± 2.4 years, height 1.81 ± 0.07 m, and body mass 94.6 ± 14.5 kg) with a minimum 1 year of continuous resistance training experience volunteered to participate in the present study. These participants possessed bench press strength levels (preintervention 6RM bench press: 107.7 ± 18.1 kg) on par with other studies assessing professional athletes in contact sports (1,16). This number of participants allowed for a high level of statistical power (>80%) based on sample size calculations using the results of previous training studies implementing either partial ROM (8) or functional isometric (7) training. All participants completed an informed consent form outlining any risks involved in the study, along with a preactivity readiness questionnaire. The experiment was approved by the Central Queensland University Ethical Review Board.

The subjects were split into 2 strength-matched groups using stratified randomization, with these groups then randomly assigned to either a control (CON) or VROM training intervention. Stratified randomization of the participant groups was performed based on the individual participant’s 6RM bench press strength and performance gains assessed during the preintervention training cycles. This was performed by ranking each subject based on their strength and performance gains, then using custom-written spreadsheet software to examine the possible combinations of subjects in each group to ensure between group homogeneity.

The participants were all members of the same training squad and had been performing 12 weeks of examiner-prescribed continuous, periodized resistance and plyometric training before the study as part of their off- and preseason training macrocycles. The participant’s 6RM bench press strength was tested before, at the midpoint, and after the 12-week preintervention training program, with these results provided in Figure 1.

A repeated-measure ANOVA was performed on the preintervention strength gain data (2 group \( \times 2 \) training cycles), with no significant (\( p < 0.05 \)) effects or interactions observed. A trend (\( p = 0.060 \)) for training cycle was observed, with strength gains between weeks 6–12 less than during weeks 1–6. This would be expected because of the return to training from an off-season rest period, hence the relatively large increase in strength in the first 6 weeks despite the participants’ extensive training history (11). In addition to ensuring homogeneity for strength and improvement potential, the division of participants also created groups with similar descriptive statistics, which are provided in Table 1. Independent samples \( t \)-test comparisons of the results for the 2 groups revealed no significant preintervention differences in age (\( p = 0.180 \)), height (\( p = 0.891 \)), or body mass (\( p = 0.287 \)).

**Experimental Procedures**

**Training Intervention.** The experimental training intervention was performed in conjunction with the participants’ skill and fitness drills, and therefore, any attempt to assess the effect of a lower body VROM intervention would have been compromised by the magnitude of lower body endurance work being performed. Although this concurrent training presented a confounding variable in the study, it did provide a real-world examination of the benefits of VROM training in an athletic population. As a result of this concomitant training, this experiment limited the training intervention to the upper-body pressing movement, with all other components of the training programs for both the CON and VROM groups remaining identical.

The CON group performed 4 sets of traditional full ROM bench press, plus a participant-determined full ROM warm-up set. The VROM group performed 5 sets per training session, one each of full, three-quarter (¾), one-half (½), one-quarter (¼), and full ROM in that order, plus a participant-determined full ROM warm-up set. This order was reversed for the second training day each week, which was performed between 3 and 4 days after the first session, to ensure that the...
same VROM sets were not performed under fatigue each session. Based on the results of a previous study (4), this allowed for equalization of the concentric workload between the 2 groups.

Each of the VROM sets is named after the countermovement position from terminal extension. For example, the ¼ ROM set required the participant to lower the barbell one-quarter of the ROM from full elbow extension, perform the countermovement and then lift the barbell back to the starting position. As the ROM is reduced, peak force significantly increases because of a greater load being lifted with a similar acceleration profile (17). This results in a training program that invokes the peak force at different positions in the ROM for each set (4). An example of this training method is provided in Figure 2.

Both groups attended 2 training sessions per week, with the bench press exercise performed during each session. This resulted in each group performing the same concentric workload per week upon commencement of the intervention, in addition to an identical workload increase from the prior training program. This was essential to ensure that both training groups had an equal opportunity to improve performance during the intervention. The repetitions for the bench press section of the training program for the CON and VROM groups are provided in Table 2.

The participants performed pre and postintervention testing sessions assessing upper-body performance and neuromuscular activation related to the training intervention. The participants did not perform any upper-body resistance training in the 48 hours before either session, and the postintervention session was performed between 2 and 5 days after the final training session in the intervention.

**Equipment**

This testing session consisted of isokinetic bench press, ballistic bench throws, and isometric bench press performed throughout different phases of the ROM. The reliability of every outcome measure used in this study was examined in a pilot study, with all possessing intraclass correlation coefficient (ICC) values in excess of 0.75.

All force data were recorded using an above ground force plate (Advanced Mechanical Technology Inc., Watertown, MA, USA) sampling at 1,000 Hz and recorded using a data collection computer running custom-written Labview software (National Instruments, Austin, TX, USA). A custom-made bench press with no padding was designed and mounted on the force plate to ensure optimal transference of force to the acquisition system, a system similar to the one used in previous research (20). An explanation of each experimental protocol, listed in testing order, is provided in the following sections.

**Isokinetic Bench Press.** The participant performed 2 sets, separated by a 1-minute rest interval, of 5 consecutive repetitions of concentric-only isokinetic bench press. These tests were performed using a custom-made bench press attachment fastened to an isokinetic dynamometer (Biodex System 3, Shirley, NY, USA). The dynamometer was used to record position data, which was synchronized with the force plate data and sampled at 1,000 Hz. The dynamometer was also used to control the velocity of the movement, which was set at 45°·sec⁻¹ to replicate a heavy bench press lift (12). The participant was instructed to lift the bar with maximal force...
during the tests. Assessing eccentric strength during the downward trajectory would have provided additional important information; however, the potential for injury and the poor repeatability observed in our pilot research precluded this assessment. Consequently, once the bar reached full elbow extension, the participant was then required to lightly pull the bar back down to their chest.

Data analysis consisted of the assessment of the mean peak force values during the 3 repetitions in the testing set with the highest peak force production. The data were split into quarters based on ROM from the chest, resulting in a peak force value for each quarter of the ROM. The data for the first quarter of the ROM were discarded due to inconsistent results between trials, potentially a result of impact spikes and acceleration of the bar before reaching constant velocity. The remaining data epochs were labeled the second quarter (from one-quarter to half ROM), third quarter (from half to three-quarter ROM), and terminal quarter (from three-quarter to terminal ROM). This segmentation of the data allowed for a comparison of force production in 3 distinct regions of the ROM.

Ballistic Bench Throws. For this test, the participant was required to perform 3 repetitions each of 2 different forms of countermovement ballistic bench throws: full ROM and half ROM. All throws were performed using a Smith Machine (Calgym, Ashmore, Australia) barbell loaded with 60 kg, a load within the range of peak power based on the mean preintervention strength levels (2). Each repetition was separated by a 15-second rest interval.

The participant performed the full ROM throws by holding the barbell at full elbow extension, then lowering the barbell to the chest and throwing upward for maximal height. The half ROM countermovement throws were performed using the same protocol as the full ROM countermovement throws; however, an audible signal was produced when the barbell had descended to the midpoint of the ROM. At this point, the participant was required to perform the countermovement and throw the barbell for maximal height. The half ROM position was determined by measuring the displacement during each individual participant’s full ROM bench press using the digital position transducer (IDM Instruments, Melbourne, Australia), then locating the midpoint and using the custom-written Labview software (National Instruments, USA) to automatically provide an audible alert.

For the full ROM throws, both the mean bench throw displacement (deemed the displacement of the barbell during the throw minus the bench press ROM displacement, and measured using the position transducer sampling at 1,000 Hz) and the peak force occurring during the countermovement (assessed using the aforementioned force plate system) were recorded and analyzed. For the half ROM throws, only the peak force was examined, providing an important measure of mid-ROM reactive strength. Barbell displacement was not assessed as an outcome variable during the half ROM throws because of the inability to precisely control the countermovement position, and therefore the functional ROM, between trials.

Isometric Bench Press and Electromyography. Isometric tests were performed with the barbell at the chest and at ¼ of the ROM from terminal elbow extension. These tests were performed using the Smith Machine (Calgym, Australia), which was modified to include a custom-made isometric bench press attachment that restricted vertical movement of the barbell beyond the desired testing position. A 5-second ramp protocol (2-second ramp, 3-second maximal voluntary contraction [MVC]) was performed for the isometric tests.
given that rapid contraction against a fixed load may lead to shoulder injury—a common injury amongst the athletic population used in this study (10). A 1-minute rest interval was allocated between trials. Because of the ramp protocol removing the potential for assessment of rate of force development and force decay, data analysis focussed on the peak force value at each position.

During the isometric tests, electromyography (EMG) of the long head of the triceps brachii and the pectoralis major muscles was performed using bipolar surface electrodes with an interelectrode distance of 10 mm and a gain of 1,000 (Delsys, Boston, MA, USA). This raw signal was sampled at 1,000 Hz. The electrode placement site for the pectoralis major was located directly superior to the nipple and directed along a line halfway between the most superior aspect of the axillary fold and the attachment of the xiphoid process to the sternum. The electrode placement site for the long head of the triceps brachii was determined using a combination of anthropometry and palpation, and is outlined in Figure 3.

A 1,024-ms interval was extracted from EMG data corresponding to the midpoint of the MVC. The raw data were full-wave rectified and processed using a root mean square 10-point moving average algorithm after application of an 8-pole Butterworth filter with a passband of 10–400 Hz. The mean value for the ¼ ROM tests over this epoch was normalized to the value recorded during the isometric test performed on the chest. This resulted in a percentage amplitude value for the ¼ ROM test, allowing for an assessment of changes in neuromuscular activation in the terminal region of the ROM.

**Statistical Analyses**

All statistical analysis was performed using SPSS Version 14 (SPSS, USA). After confirmation of data sphericity and equal variance, statistical analysis consisted of multiple repeated-measure ANOVAs (2 groups x 2 testing sessions) for each measurement, with a significance level set at $p \leq 0.05$. This was performed to detect any differences between or within groups or testing sessions. Fisher’s least significant difference (LSD) post hoc tests were performed on the means of the data in the event of a significant main effect or interaction.

**RESULTS**

The pre and postintervention results for isokinetic peak force in each distinct region of the movement are provided in graphical form in Figure 4. The results for the bench throw and isometric tests, including EMG, are provided in Table 3. The $SEM$ values for each test, based on ICC statistics determined during a prior reliability study (intrarater, intertrial) performed by the investigators, are presented for each outcome measure.
Regarding anthropometry and EMG, a significant decrease in body mass ($p = 0.004$) was observed between testing sessions. The participants in both groups decreased their total body mass by a similar amount. No significant findings were observed for EMG.

**DISCUSSION**

The results of this study suggest that VROM resistance training provides beneficial functional performance adaptations in resistance trained athletes. Potentially, the most important findings were related to the peak force levels produced in the different phases of ROM. For the isokinetic tests, the VROM intervention skewed the force curve toward the terminal phase of the ROM, with the VROM group producing significantly higher peak force values during the terminal phase of the ROM as a result of the training intervention. This increase in performance at shorter muscle lengths after the VROM intervention provides support for hypothesis 1. In contrast, there was no significant difference between groups or testing sessions at longer muscle lengths, providing support for hypothesis 2. The half ROM countermovement throws also resulted in a large increase in peak force production as a result of the VROM intervention, indicative of an improvement in mid-ROM reactive strength and supportive of hypothesis 3. When compared with the minimal changes in peak force observed during the full ROM bench throw, despite the increase in full ROM bench throw displacement, this finding supports the theory that the VROM training method produces midrange functional adaptations with no negative effect on full ROM countermovement performance. In contrast to the adaptations observed in the isometric test performed at the chest.

![](https://www.nsca-jscr.org/)

**TABLE 3. Results for the performance and electromyographic tests (mean ± SD).**

<table>
<thead>
<tr>
<th>Test</th>
<th>ICC R</th>
<th>SEM units</th>
<th>VROM Pre</th>
<th>VROM Post</th>
<th>CON Pre</th>
<th>CON Post</th>
<th>Testing session p value</th>
<th>Group × testing session p value</th>
</tr>
</thead>
</table>
| Bench throw
CM height (cm) | 0.95 | 0.9 | 14.3 ± 3.4 | 16.5 ± 3.5 | 13.6 ± 4.6 | 13.1 ± 3.4 | 0.047† | 0.004‡ |
| CM force (N) | 0.83 | 0.7 | 1,697 ± 290 | 1,724 ± 253 | 1,555 ± 260 | 1,565 ± 321 | 0.681 | 0.841 |
| ½ ROM force (N) | 0.93 | 0.66 | 1,275 ± 165 | 1,475 ± 302 | 1,188 ± 160 | 1,167 ± 131 | 0.081 | 0.003‡ |
| Normalized EMG
Pectoralis (%) | 0.83 | 0.22 | 131 ± 30 | 132 ± 31 | 141 ± 63 | 136 ± 73 | 0.398 | 0.694 |
| Triceps (%) | 0.83 | 0.33 | 140 ± 45 | 175 ± 80 | 170 ± 72 | 147 ± 43 | 0.581 | 0.424 |
| Isometric force
Chest (N) | 0.83 | 0.79 | 1,269 ± 242 | 1,281 ± 182 | 1,299 ± 184 | 1,296 ± 218 | 0.603 | 0.841 |
| 1/4 ROM (N) | 0.77 | 0.197 | 1,884 ± 309 | 2,037 ± 194 | 1,731 ± 183 | 1,953 ± 136 | 0.018† | 0.168 |

*CM = countermovement; EMG = electromyography; ICC = intraclass correlation coefficient; ROM = range of motion; SEM = standard error of measurement; VROM = variable range of motion.

†Significant main effect for Testing Session.
‡Significant interaction between Group and Testing Session.

The results provided in Figure 4 revealed a significant ($p = 0.027$) interaction between testing session and group for terminal quarter isokinetic peak force. Post hoc analysis revealed that the VROM group significantly ($p = 0.003$) enhanced their peak force values in the postintervention testing session (13.5% increase). Only negligible, nonsignificant changes in performance were observed for the CON group (0.1% increase). No significant differences were observed between groups for second or third quarter peak force.

A significant interaction between testing session and group was observed for the measures of full ROM displacement ($p = 0.004$) and half ROM peak force ($p = 0.003$). Post hoc analysis revealed that the VROM group significantly ($p = 0.002$) improved bench throw displacement by 15.5% under the full ROM testing condition postintervention, despite there being no significant increase in peak force during the full ROM countermovement (1.6% increase). In contrast to the full ROM peak force finding, the VROM group produced significantly ($p = 0.033$) higher peak force (15.7% increase) in the half ROM countermovement throws postintervention. No significant adaptations were observed in any measures of bench throw performance in the CON group as a result of the intervention (full ROM bench throw displacement: 3.7% decrease, full ROM bench throw peak force: 1.8% decrease, half ROM bench throw peak force: 3.5% decrease).

No significant differences were observed between groups for either of the isometric tests. A significant effect for testing session ($p = 0.018$) was observed during the ½ ROM isometric tests, with both groups increasing peak force in the second testing session. No significant differences were observed in the isometric test performed at the chest.
observed in the VROM group, the performance of the CON group in all of the tests was only marginally affected. This would be expected based on the participants’ extensive resistance training experience (11).

The dramatic increase in dynamic peak force near terminal extension may explain why previous studies examining partial ROM training have reported only marginal benefits. The previous studies by Massey et al. (14,15) found that partial ROM training produced, at best, similar gains in full ROM strength levels. The results of the present study suggest that the benefits of VROM training are more pronounced at shorter muscle lengths. Due to the ‘sticking region’ of the full ROM bench press occurring at long muscle lengths (6,19), it would appear that a full ROM 1RM strength test would therefore be severely limited in its ability to detect changes as a result of a partial or VROM training intervention. Furthermore, the studies performed previously by Graves et al. (8,9) included isometric strength tests as their criterion performance measures. The results of the present study suggest that isometric strength is not significantly altered as a result of VROM resistance training. This is likely because of the dynamic nature of the exercise regime, which has only minimal specificity to the relatively long duration and static isometric strength tests. This is supported by previous research, which suggests only a limited relationship between isometric strength and dynamic performance (18). The one significant finding in regard to isometric strength was the increase in 1/4 ROM strength for both groups. Given that this increase was of a similar magnitude for both groups, and the novelty of the test, this may have been because of a familiarization effect.

The results of the present study provide evidence of the benefits of VROM training; however, the mechanisms behind the enhanced performance gains are unknown. Statistical analysis revealed no significant differences between groups for neural activation (normalized EMG amplitude), however when examining these results the known limitations of this testing modality must be considered (5). The adaptation in the dynamic force–ROM relationship observed in the VROM group, in the absence of changes to neuromuscular activation or strength during the isometric contractions, provides support for the argument that this form of training may result in alterations to dynamic contractile and elastic mechanics. These adaptations, among others, would result in optimal performance for the given movement and enhanced functional performance. While being beneficial if all subsequent movements occur with kinetic patterns identical to the training stimulus, this response may dampen the performance gains during functional tasks that do not occur with similar ROM-specific movement patterns and force production schemes. Based on this theory, performing all resistance training throughout the full ROM would therefore provide suboptimal functional enhancement if efficient countermovements and maximal force production are required throughout a wide variety of positions within the operational ROM of the muscle. The results of the present study support the above statements, with the finding that performing a resistance training program where near-maximal intensity countermovements occur in different phases of the ROM enhanced full ROM function by augmenting performance at shorter muscle lengths while maintaining performance at longer lengths.

Whether any of these proposed mechanistic adaptations take place in response to VROM training was beyond the scope of this study, and is very difficult to examine accurately in vivo (13). It must also be noted that the neural activation assessment was restricted to the isometric test, because pilot testing revealed poor (ICC < 0.70) intraday reliability for dynamic EMG. This also limits the potential deduction of the true cause for the performance gains observed in the VROM group.

**Practical Applications**

The inclusion of a VROM resistance training microcycle into an athlete’s training program provides superior reactive strength and dynamic force improvements in comparison with performing strictly full ROM training. This method of training appears to be a beneficial component in an athlete’s attempt to achieve optimal sporting performance while reducing their risk of injury. However, the heavy loads used in this method of training indicate that it may be appropriate for preseason strength enhancement training microcycles, and that it should be restricted to athletes with sufficient resistance training backgrounds.

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