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Comparison of Tasks to Determine Maximum Voluntary Contraction of Lumbar Muscles in Physically Active Men: Cross-Sectional Study

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Short Communications

Abstract

Introduction: Surface electromyography (sEMG) is commonly used to assess muscle activity; however, accurate interpretation requires normalization. The maximal voluntary contraction (MVC) is the most widely applied approach for this purpose although selecting an appropriate task to achieve MVC, particularly in the posterior muscles of lower back, remains challenging. This study aimed to compare tasks used to apply manual resistance for determining MVC in physically active men with the goal of enhancing the reliability of sEMG normalization in spine-related research.

Materials and Methods: Eight young physically active men participated in this study. The longissimus, iliocostalis, and multifidus muscle activities were assessed using sEMG. Manual resistance for achieving MVC was applied during prone trunk extension, declined trunk extension, and the arch test. One-way analysis of variance (ANOVA), Bonferroni post-hoc test, and Cohen's effect size were used for data analysis.

Results: The ANOVA results revealed significant differences among MVC tasks for the longissimus, iliocostalis, and multifidus muscles ($P < 0.05$). Bonferroni's post-hoc analysis showed that prone trunk extension exhibited significantly different MVCs from other tasks for the longissimus. Additionally, for the multifidus and iliocostalis muscles, MVC during the prone trunk extension task was significantly different from that of the arch task ($P < 0.05$). Cohen's effect size indicated that prone trunk extension, for the longissimus and multifidus, had a much greater effect than other tasks. However, in the iliocostalis muscle, the declined trunk extension and prone trunk extension tasks showed similar results, with no significant difference between them.

Conclusion: Manual resistance against prone trunk extension apparently emerges as the most effective task for achieving MVC in longissimus, iliocostalis, and multifidus muscles in the lumbar spine, highlighting its reliability for normalizing sEMG in physically active men.

Keywords: Surface electromyography; Spine; Muscle contraction; Paraspinal muscles

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Introduction

Surface electromyography (sEMG) is a standard tool in biomechanics, sports, and ergonomics studies for assessing the timing and level of muscle activity, muscle force, and fatigue during athletic or daily activities (1). To prevent misinterpretation of muscle activity levels across different time intervals or between subjects, sEMG data normalization is essential (2). The Maximal Voluntary Contraction (MVC) is one of the most widely applied methods for normalizing muscle activity. In this method, sEMG data are normalized to MVC data, and the results are presented as a percentage or on a scale from 0 to 1 (3).

One of the main challenges in using MVC is

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selecting a task that brings muscle activation close to the target maximal muscle activity (4). MVC results can be influenced by movement characteristics, such as misalignment of muscle orientation and suboptimal muscle length (5), and by participant-dependent factors, such as body fat and skin resistance (4). Furthermore, a participant's skill in activating specific trunk muscles is also expected to be influential (6). If the activity level during the MVC test does not approach the maximum, sEMG signals may exceed the MVC value, incorrectly indicating that the muscle is active beyond its physical capacity. In such conditions, MVC effectively functions as a technique for normalizing submaximal contractions, thereby diminishing its inherent advantage. Understanding these conditions helps researchers more accurately normalize sEMG data, reducing uncertainty in research findings (7).

MVC heavily influences spinal loading research. In sEMG-based methods, MVC is used to determine the contribution of muscles to an activity (8) or to validate musculoskeletal models (9). In musculoskeletal loading models, trunk flexors are often assumed to be inactive (9) and exhibit limited activation in EMG-based methods (8). However, the Longissimus, Iliocostalis, and Multifidus muscles are critical in spine studies. During lifting activities, these spinal extensors play a key role in stability and load control, generating significant compressive and shear forces by creating a lever balance on the vertebrae (10). Therefore, if the goal is to calculate forces on spinal components rather than just net force and torque, the accuracy of normalizing the extensor muscles is critical.

In biomechanical studies, manual resistance is widely used to determine MVC. Despite significant research, there is no consensus on a single task (7, 11). For the MVC of lumbar muscles, prone trunk extension against manual resistance is commonly accepted (12-14). In contrast, spinal loading research has more frequently utilized the declined trunk extension (8, 9, 15). Additionally, the Arch Test has been recommended as a suitable movement in previous studies (11, 16).

There is no standard for the best manual resistance method for the lumbar erector spinae across different tasks. Reports have primarily focused on the highest overall erector spinae activity and often exclude the Multifidus. It is important to note that none of these methods can precisely specify a muscle's activity level relative to its maximal muscle activation capacity (7, 14). Given these limitations and the lack of consensus on a standard method, a detailed comparison of different MVC tasks becomes increasingly important. In spine research, inconsistent methodology and testing protocols make comparisons of results and the selection of an appropriate MVC measurement method challenging. Furthermore, past research on MVC for lumbar muscles has been conducted on healthy (11, 12, 14) and unhealthy (4) populations, whose results may not generalize well to physically active individuals. Therefore, in this study, manual resistance was applied to three everyday tasks - the prone trunk extension, declined trunk extension, and the Arch Test - to compare the contractions of the three muscles (Longissimus, Iliocostalis, and Multifidus) to identify the best method.

Materials and Methods

The present study was a cross-sectional investigation. The participants consisted of eight young, active men recruited through targeted invitations from physical education students. They completed a physical readiness questionnaire and maintained a regular exercise regimen (17). The current study served as a preliminary step toward a larger study of active young men. It was instrumental in selecting an appropriate method for assessing muscle activity in that subsequent research. Therefore, the inclusion and exclusion criteria from the main study were adopted. Accordingly, the inclusion criteria required the ability to perform near-maximal deadlifts, specifically executing at least 85% of a one-repetition maximum (1RM) with a recorded weight exceeding 100 kg.

Furthermore, to ensure high-quality signal acquisition, participants were required to have a total body fat percentage (Fat Mass) of less than 9%. Body composition analysis for this determination was performed using the InBody 720 device (18). Participants had no history of surgery, vertebral fractures, or low back pain in the past year, and a postural examination confirmed the absence of spinal abnormalities. The application of these strict entry criteria limited the pool of eligible individuals, resulting in a small sample size.

Ethical Considerations: Participants voluntarily took part in this research by completing an informed consent form. Prior to the start of the study, the research protocol was approved by the ethics committee of Kharazmi University.

Data Collection: Bipolar sEMG electrodes were placed bilaterally, as shown in Figure 1 (a), on three erector spinae muscles: the Longissimus (3 cm lateral to the midline at the level of the first lumbar vertebra), the Iliocostalis (6 cm lateral to the midline at the level of the third lumbar vertebra), and the Multifidus (2 cm lateral to the midline at the level of the fifth lumbar vertebra) (19). To reduce cross-talk, SF07 adhesive electrodes with a 2 cm diameter were attached to the skin surface. No two electrode pairs were placed within 3 cm of each other (20). To minimize the effects of signal attenuation and cross-talk from subcutaneous adipose tissue and to improve sEMG recording quality, participants for this study were selected from athletes with low body fat percentages (21). Following standard protocols for skin preparation, which included shaving excess hair, cleansing the skin of superficial oils with an alcohol pad, and gently abrading the skin to reduce impedance, the electrodes were applied (20). sEMG signals were recorded using a wireless system (Myon Aktos, Schwarzenberg, Switzerland) with a sampling rate of 1000 Hz and a standard mode rejection ratio (CMRR) of 110 dB at 60 Hz. As the data were normalized, the gain was not reported.

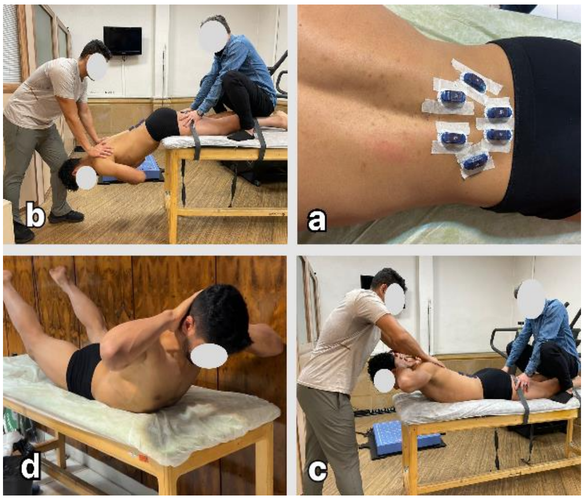

Figure 1. (a) Marker placement for the lumbar region muscles, (b) The declined trunk extension task, (c) The prone trunk extension task, (d) The Arch Test task

Tasks: The tasks included the declined trunk extension, the prone trunk extension, and the Arch Test. In the declined trunk extension (Figure 1, b), participants were positioned prone on an examination table. Their upper body was angled at-30° relative to the horizontal. Their legs and thighs were securely fastened to the table with two straps. Trunk extension was then performed against manual resistance applied at the shoulders for 5 seconds (8). In the prone trunk extension (Figure 1, c), participants were positioned prone on an examination table. Their legs and thighs were securely fastened to the table with two straps. Trunk extension was then performed against manual resistance applied at the shoulders for 5 seconds (12). In the Arch Test (Figure 1, d), participants assumed a prone position and gradually hyperextended their upper bodies and thighs. They held this position for 5 seconds (16). Each test was performed three times. Participants were allowed 1 minute of rest between trials and 2 minutes between tasks. The best record would be reported for analysis.

For sEMG signal processing, MATLAB software (R2023b, The MathWorks® Inc., Natick, MA, USA) and a Butterworth filter (Band-pass, 20-450 Hz, 6th Order) were used to remove electrical noise and reduce motion artifact (14). Although the applied band-pass filter could not eliminate interference from cardiac activity, the EMG signals were recorded from active men with low subcutaneous fat and high muscle strength, resulting in a high signal-to-noise ratio. Motion artifact is primarily below 20 Hz. Furthermore, given the significant anatomical distance between the lumbar muscles and the heart, electrocardiographic (ECG) components did not significantly affect the EMG signals. If electrodes had been placed in areas closer to the heart, the likelihood of this interference would have increased, which was not a concern in the present study (20).

Nevertheless, to remove non-muscular low-frequency components, the signals were processed with a 20-450 Hz filter. Reapplying the processing without a secondary 30 Hz filter did not change the results, indicating no effect from double-filtering. This approach was also consistent with previous studies that used a 10-450 Hz frequency band. The frequency content of the ECG signal is mainly confined to frequencies below 20 Hz, and harmonics from the QRS complex rarely reach 30-40 Hz; therefore, ECG energy at higher frequencies is negligible.

Thereafter, full-wave rectification was applied, and a Butterworth low-pass filter (3 Hz, 6th Order) was used to determine the linear envelope of the signal. Finally, the peak signal values were extracted as the MVC (20). To control for motion artifact from the lower limbs, participants were stabilized using two straps, and the active force applied by an assistant was controlled during the prone and declined trunk extension tests. One assistant applied the manual resistance force (11). The need for a third assistant to provide additional resistance did not arise. To validate the musculoskeletal model in the main study, electrodes were placed symmetrically on both sides of the muscles. The application of an asymmetric force would have resulted in a clear difference between the EMG signals of the left and right sides. The absence of such observation during the present study indicates that the applied forces were approximately symmetric and that the data were reliable for modeling. However, it should be noted that despite screening for spinal health and low back pain history, even minor asymmetries can cause slight side-to-side signal differences, or the force applied by the assistant's two hands may not be perfectly identical. Unlike the present study, most previous research employed unilateral electrode placement. Therefore, a key advantage of this study is the precise monitoring of bilateral muscle outputs.

Data analysis was performed using MATLAB. A one-way ANOVA was used to evaluate the effect of the tasks on the muscles' maximal activation capacities at a significance level of 0.05. The independent variable was task type, and the dependent variables were sEMG values for the Multifidus, Longissimus (erector spinae), and Iliocostalis (erector spinae) muscles. Post hoc Bonferroni tests and Cohen's effect sizes were used to identify the superior method. Cohen's effect size was classified based on a five-stage criterion: trivial (0.01–0.19), small (0.20–0.49), medium (0.50–0.79), large (0.80–1.19), and very large (≥1.20). The statistical significance of differences was examined using a paired t-test and a significance level of 0.05 (22). Instead of calculating post-hoc power, the sufficiency of statistical power was assessed based on the magnitude of observed effect sizes: significant and substantial effect sizes indicate a low probability of Type II error in these comparisons (23). Data collection, processing, and statistical analysis were performed by a PhD student in Physical Education and Sports Sciences, specializing in Sports Biomechanics.

Results

All eligible individuals who entered the study completed all stages without attrition, resulting in a zero dropout rate. The demographic information of the participants is presented in Table 1.

The results of the one-way ANOVA presented in Table 2 showed significant differences in muscle activity across the different tasks for the Longissimus, Iliocostalis, and Multifidus muscles. The effect of the task type on muscle activity was significant.

Table 1. Demographic Information of Participants

Variable	Mean ± Standard deviation
Age (years)	26.00 ± 3.00
Weight (kg)	75.2 ± 20.50
Height (cm)	187.00 ± 5.00
Body Fat (%)	7.00 ± 2.00

The post-hoc Bonferroni analysis for the Longissimus revealed that the prone trunk extension showed a significant difference compared to the Arch Test (P = 0.001) and the declined trunk extension (P = 0.002). In contrast, the difference between the Arch Test and the declined trunk extension was not significant (P > 0.001). For the Iliocostalis, no significant difference was observed between the declined and prone trunk extensions; however, the Arch Test showed a significant difference compared to both the prone trunk extension (P = 0.006) and the declined trunk extension (P = 0.005). For the Multifidus, no significant difference was observed between the declined trunk extension and the prone trunk extension (P = 0.433) or the Arch Test (P = 0.566). However, the Arch Test showed a significant difference compared to the prone trunk extension tasks (P = 0.027). These findings indicate that prone trunk extension elicits the most significant activation in most trunk extensor muscles, whereas the Arch Test has the least effect. The declined trunk extension showed a performance in the Iliocostalis muscle that was similar to the prone trunk extension.

The results of Cohen's effect size analysis, presented in Table 3, revealed distinct patterns of trunk muscle activation across the movement tasks. For the Longissimus muscle, the difference between the prone trunk extension and the declined trunk extension, as well as between the Arch Test and the prone trunk extension, had an enormous effect size and was statistically significant.

Table 2. Results of the One-Way ANOVA

Muscle	Test	Mean ± SD	95% CI	F	η²	P-value
Longissimus	Arch test	0.838 ± 0.095	0.759-0.917	11.04	0.512	0.005
	Declined trunk extension	0.860 ± 0.153	0.732-0.988			
	Prone trunk extension	1.173 ± 0.196	1.009-1.337			
Iliocostalis	Arch test	0.573 ± 0.134	0.461-0.685	8.46	0.446	0.002
	Declined trunk extension	0.766 ± 0.117	0.668-0.864			
	Prone trunk extension	0.760 ± 0.048	0.720-0.800			
Multifidus	Arch test	0.679 ± 0.152	0.552-0.806	4.13	0.282	0.031
	Declined trunk extension	0.847 ± 0.097	0.766-0.928			
	Prone trunk extension	0.759 ± 0.092	0.682-0.835			

SD: Standard deviation; CI: Confidence interval

Table 3. Effect size of manual resistance in different tasks for each muscle

Muscle	Task pair	Effect size	Clinical magnitude	P-value
Longissimus	Prone trunk extension-Declined trunk extension	2.01	Very large	0.004
	Arch test-Prone trunk extension	-2.16	Very large	0.002
	Arch test-Declined trunk extension	-0.16	Trivial	0.733
Iliocostalis	Prone Trunk Extension-Declined trunk extension	-0.05	Trivial	0.872
	Arch test-Prone trunk extension	-1.53	Very large	0.005
	Arch test-Declined trunk extension	-1.86	Very large	0.009
Multifidus	Prone trunk extension-Declined trunk extension	-0.70	Medium	0.132
	Prone trunk extension-Arch test	-1.30	Very large	0.180
	Declined trunk extension-Arch test	-0.60	Medium	0.035

In contrast, the comparison between the Arch Test and the declined trunk extension had a trivial effect size and was not significant. For the Iliocostalis muscle, the differences between the Arch Test and the prone trunk extension, and between the Arch Test and the declined trunk extension, had huge effect sizes and were significant. However, the comparison between prone and declined trunk extensions showed a trivial effect size and was not significant, indicating a similar muscle response between the two tasks. For the Multifidus, the prone trunk extension produced the largest effect size, although its difference compared to the Arch Test was not statistically significant. The comparison between the declined trunk extension and the Arch Test showed a significant medium effect. Therefore, for targeted Multifidus training, prone trunk extension likely induces greater activation, but it should be noted that differences from other tasks are not always detectable. Overall, these results show that prone trunk extension is generally associated with greater trunk muscle activation, but the muscle response pattern varies across muscles. Notably, for the Iliocostalis, prone and declined trunk extension produce relatively similar responses. A negative sign for the effect size indicates that the direction of the difference was such that the muscle activity was greater in the second movement compared to the first.

Discussion

The Maximal Voluntary Contraction is the most widely applied method for normalizing EMG data (3). However, there are concerns about the validity of MVC for normalizing EMG data from posterior lumbar muscles, especially when lumbar spinal loading needs to be investigated in future studies. This is because using MVC is essential for accurately assessing muscle activity and validating the models used in such research (8, 9). The present study, aimed at determining the effect of manual resistance against different tasks in the MVC test, showed that the prone trunk extension is likely more suitable for assessing the MVC of the Longissimus and Multifidus muscles. In contrast, both the prone and declined trunk extension tasks appear suitable for the MVC of the Iliocostalis muscle. The Arch Test was the least preferred task for all three muscles.

Similar studies vary significantly in their execution procedures and participant conditions, and there is no consensus on the MVC task (4, 9, 11, 12, 19, 24). Furthermore, few studies have investigated electromyography during lumbar spinal loading in active young individuals (12). Typically, in lumbar spinal loading studies, the activity of the posterior lumbar muscle group is reported during the declined trunk extension (8, 9, 19). However, MVC studies on posterior spinal muscles have suggested the prone trunk extension and the Arch Test (12, 13, 16, 24). Due to methodological differences among existing studies, it is challenging to compare results and propose a standard method. This study on active young men showed that manual resistance during prone trunk extension was a suitable method for reporting MVC in the Longissimus, Iliocostalis, and Multifidus muscles of the lumbar region, although, for the Iliocostalis, the decline trunk extension showed no significant difference from the prone trunk extension.

The differences in results from these participants compared with past research are likely related to differences in muscle recruitment strategies among active individuals (24). Additionally, an increase in muscle cross-sectional area can lead to fiber pennation, changes in muscle length, changes in muscle lever arms, and changes in muscle orientation. A distinguishing feature of this study compared to similar ones was the inclusion of subcutaneous fat as a control criterion and the low body fat percentage among the active young participants, which improved sEMG data quality. This contrasts with past studies that primarily focused on healthy (11, 12, 14, 24) or patient (4, 9) populations, did not provide information on participants' fitness levels, and limited anthropometric conditions to height and weight.

In the present study, all three lumbar muscles were specifically examined independently, whereas previous research has focused on the aggregate activity level of the erector spinae (11, 12, 16). Participants in this research were homogeneous in terms of fitness level for the strength factor and anthropometrics. Their sEMG data demonstrated consistent quality and similar levels of muscle activity across all tasks, a characteristic less commonly observed in the literature (4, 11, 14, 16). In the present study, men were selected for their availability, lower body fat percentage, and high muscular strength, whereas prior studies predominantly examined women (12, 14). These findings can effectively contribute to validating biomechanical models and to designing targeted training programs for physically active individuals. Given the mean values and the small range of variation, which ensures data stability, the prone trunk extension task is proposed as the recommended method for achieving MVC in active participants.

Limitations

Stronger muscles produce clearer signals, and a lower body fat percentage reduces noise and cross-talk. For these reasons, the age range and fitness level were controlled in the present study. Due to laboratory limitations, female participants were not included. Therefore, the most significant limitations of this research were the number of participants, their gender, age range, and fitness level, which prevent generalizing the results to active women and active individuals in other age groups. Furthermore, this study examined only three tasks involving three lumbar spine muscles, and no conclusions can be drawn about other tests or muscles based on the existing results.

Recommendations

It is recommended that future studies replicate this process across both women and men, across different age groups and fitness levels, and consider muscles in both the thoracic and lumbar regions. Additionally, applying both manual and non-manual resistance in other tests should be considered.

Conclusion

Based on the results of this study, the prone trunk extension produced the most significant activation in the lumbar muscles. Given the control of body fat percentage and fitness level of the participants, the prone trunk extension is proposed as a viable method for determining MVC in active men. It can help validate biomechanical models and design targeted training programs. Selecting appropriate tasks for the target population is essential for obtaining valid and reliable data.

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Authors' Contribution

Project Design and Conceptualization: Amir Sadeghi-Golafzani, Raghad Mimar
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Maintaining the Integrity of the Study Process from the Beginning to the Publication and Responding to the Reviewers' Comments: Amir Sadeghi-Golafzani, Raghad Mimar

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Conflict of Interest

The authors did not have a conflict of interest.

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