Electromyographic Activity of the Lumbar and Hip Extensors During Dynamic Trunk Extension Exercise

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ABSTRACT. Clark BC, Manini TM, Mayer JM, Ploutz-Snyder LL, Graves JE. Electromyographic activity of the lumbar and hip extensors during dynamic trunk extension exercise. Arch Phys Med Rehabil 2002;83:1547-52.

Objective: To evaluate the effects of exercise intensity and multiple sets on muscle activation patterns during trunk extension exercise.

Design: Descriptive, repeated measures.

Setting: University-based musculoskeletal research laboratory.

Participants: Twenty volunteers recruited from a university setting.

Intervention: Not applicable.

Main Outcome Measures: Electromyographic activity was recorded from the L3–4 paraspinal region, gluteus maximus, and biceps femoris muscles during multiple sets of trunk extension exercise at intensities representing 40%, 50%, and 70% of peak isometric force.

Results: As exercise intensity increased, the electromyographic activity of the gluteus maximus increased to a greater extent than the activity of the paraspinal region. At the 50% intensity level, biceps femoris electromyographic activity was significantly greater than the paraspinal region electromyographic activity, whereas at the 70% intensity no differences were found between muscles. During multiple sets of exercise at the same intensity a muscle by set interaction was observed. This interaction revealed that with respect to other muscle groups, the electromyographic activity of the gluteus maximus increased between sets 1 and 2, whereas electromyographic decrements occurred in the paraspinal region. During exercise at the 40% intensity level, biceps femoris electromyographic activity increased to a greater extent between sets 1 and 2 when compared with the paraspinal region.

Conclusion: Exercise intensity and multiple sets result in alterations in muscle recruitment patterns of the lumbar and hip extensor muscles. These findings raise questions as to the efficacy of added loading and multiple sets during trunk extension exercise.

Key Words: Electromyography; Exercise; Lumbrosacral region; Muscles; Rehabilitation; Spine.

WEAK AND HIGHLY FATIGABLE back musculature has been consistently reported in populations with low back pain (LBP), and numerous researchers have suggested that trunk musculature endurance is associated in the etiology of LBP.[1-4] In 1994, the US Agency for Health Care and Policy Research[5] (now the Agency for Healthcare Research and Policy) concluded that back extensor muscle conditioning exercises were helpful in the management of acute LBP. Additionally, it has been suggested that lumbar muscle conditioning exercises aid in increasing pelvic and spinal stability.[6]

Activation patterns of the lumbar musculature and the hip extensor muscles during dynamic trunk extension exercise have not been extensively studied.[7] The difficulty in fully understanding the neuromuscular characteristics of the lumbar musculature is because of the complex anatomic structure of the sacroiliac joint that creates a hip-spine interaction during movement.[8,9] The gluteus maximus, a strong hip extensor muscle, is tightly coupled with the lumbar paraspinal muscles via the thoracolumbar fascia and with the biceps femoris muscle via the ligamentum sacrotuberale.[8,10] Therefore, if dynamic exercise is to effectively recruit the lumbar paraspinal musculature, the hip-spine interaction must be minimized. This will allow greater lumbar paraspinal activation so that the lumbar muscles are responsible for the work, as opposed to the more powerful gluteal musculature.[9]

Various mechanisms and exercises have been developed to effectively activate the lumbar paraspinal muscles. One such device is a variable angle Roman chair[a] (VARC) that can be adjusted from 75° to 0° relative to horizontal in 15° increments (fig 1). Dynamic trunk extension exercise has been shown to activate the lumbar paraspinal musculature.[11-13]

Hand-held weights are often used with Roman chair exercise to add progressive loads. By using muscle functional magnetic resonance imaging and quantifying the exercise-induced transverse relaxation (T2) contrast shifts that occur in exercised skeletal muscle, Ploutz-Snyder et al[14] observed a nonlinear relation between lumbar extensor T2 increase and relative exercise intensity during dynamic trunk extension exercise. They suggested that trunk extensor muscles other than the lumbar muscles generate the additional force required at higher loads.

It has been suggested that a training protocol involving 1 set of 8 to 12 repetitions to muscular failure is an efficient method of training the lumbar musculature.[15] Additionally, electromyographic decrements associated with fatigue have been reported in the trunk muscles with continuous concentric and eccentric muscular contractions.[16] Taken together, this evidence suggests that 1 set of trunk extension exercise is as efficient as multiple set training because of a decreased neural activation pattern that occurs in the lumbar musculature, when it is fatigued.

The purpose of this study was to evaluate the effect of an added external load and multiple sets on electromyographic activity of the lumbar extensors, gluteus maximus, and biceps femoris during dynamic trunk extension exercise. The results provide an indication of the efficacy of additional loading and

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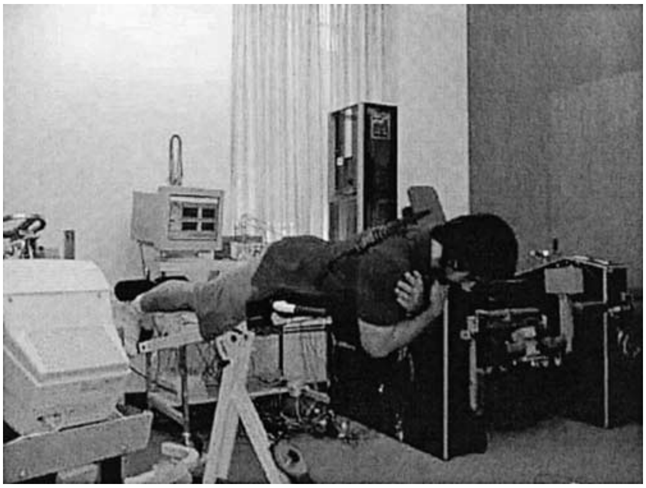

Fig 1. Dynamic extension exercise on the VARC.

training volume requirements during dynamic trunk extension exercise.

METHODS

Participants

Twenty apparently healthy volunteers (13 men, 7 women; mean age ± standard deviation [SD], 23.1±3.9y) were recruited from a university setting. Their descriptive statistics are listed in table 1. Subjects were recreationally active individuals but were not currently engaged in a systematic exercise program (>1d/wk) designed to condition the lumbar or hip extensor muscles. The experimental protocol was reviewed and approved by the Syracuse University institutional review board; before testing, all subjects provided written informed consent. Potential subjects were excluded if they had a history of chronic LBP, current back pain, or orthopedic or cardiovascular contraindications to resistance exercise.

Sample size was determined by a power analysis designed to detect differences in lumbar muscle activity between exercise at 40% and 50% of peak force (power=.80, 2-sided α level=.05). The assumptions on which this calculation was performed were based on the means and SDs obtained from pilot testing, as well as from the first few subjects to complete the study.

Testing

Determination of upper-body mass. To assess the load that an individual lifts during dynamic exercise on a Roman chair, upper-body mass (UBM) must be determined.[17] To do this, each of our subjects was placed in a prone position on the VARC at 15° above horizontal so that their anterior iliac spines were centered on the pelvic pad, with their feet secured under the footpad. Next, the subjects flexed at the waist, placing the torso parallel to the ground with the upper body resting on a bedside scale.[b] The arms were held in a comfortable position over their heads. Subjects were instructed to relax and remain motionless while their UBM was recorded to the nearest .01kg. This procedure was performed 3 times, with the mean considered to represent the UBM. The same investigator performed the procedure with all subjects to ensure uniformity. The UBM measurement protocol has been previously described and found to be reliable.[18] Additionally, subjects' total body weight (clothed) was recorded on the bedside scale.

Electromyography. Before exercise, 2 square (4cm) Ag-AgCl surface electromyography electrodes were placed bilaterally on the subjects' paraspinal region, 1cm above and below the L3–4 interspinous space. Additionally, electrodes were placed over the right gluteus maximus and right biceps femoris muscle. The gluteus maximus electrodes were placed at the midpoint of a line running from the inferior lateral angle of the sacrum to the greater trochanter. Biceps femoris muscle electrodes were placed in midway between the gluteal fold and popliteal joint. Electrode placement was chosen based on Cram and Kasman's standardized electrode placement atlas.[19] A bipolar electrode configuration was used, with an interelectrode distance of 25mm. A reference electrode was placed with respect to the differential electrodes. Before the electrodes were placed, the skin was shaved, abraded, and then cleaned with alcohol to ensure that skin impedance was minimal.

The electromyographic signal was preamplified 100 times with a BioAmp 100.[c] Next, the signal was amplified 10 times with the use of a Cyber Amp 380[c] (total amplification: 1000×) and digitized with an analog-to-digital board via a LabView data acquisition card.[d] All signals passed through a band-pass filter (low pass: 10Hz; high pass: 600Hz), and all data were processed by using LabView.[d] The raw electromyographic signal was recorded at the sampling rate of 1000Hz. The LabView system was used to determine the full-wave rectified electromyographic signal. The operation may be expressed as:

$$\text{Rectified electromyogram} = \left(\sum x^2\right)^{1/2}$$

where x is the individual mV value obtained from the neural energy at 1000Hz.

Determination of maximum voluntary isometric contraction. On completion of the UBM measurement, subjects were fitted with a nylon torso harness equipped with a ring at the midsternal region to which a chain could be attached. At a VARC angle of 15°, relative to horizontal, each subject was attached to a tensiometer[e] by the harness and chain. Appropriate fitting resulted in subjects being parallel to the ground during their full extension phase in the maximal voluntary isometric contraction (MVIC) testing.

Subjects were instructed to cross their hands on the opposite shoulders and to perform a maximal voluntary contraction for 4 seconds while exhaling and keeping their pelvis on the pelvic pad. Verbal encouragement was provided. Electromyographic activity was recorded for the middle 2 seconds during the MVIC. The exerted isometric strength was recorded in kilograms. This procedure was performed 3 times, with a 5-minute recovery period between each trial. The trial resulting in the highest force was considered the subject's MVIC, and electromyographic activity recorded during this contraction was used

Table 1: Descriptive Statistics of the 20 Study Subjects

Gender (n)	Age (y)	Weight (kg)	Torso UBM (kg)*	Lumbar Extension Strength (kg)†
F (7)	22.9±2.4	58.6±10.4	24.0±2.7	38.7±6.7
M (13)	23.2±3.8	71.2±10.6	37.5±15.2	59.8±6.1
Total (20)	23.1±3.3	66.8±11.9	32.8±13.9	52.4±12.3

NOTE. Values are mean ± SD.
Abbreviations: F, female; M, male.
* Torso UBM recorded on the VARC at 15°.
† Peak isometric trunk extension strength recorded on the VARC at 15°.

for normalization. The lumbar extension strength measurement protocol has been previously described and found reliable.[18]

Determination of the Load at 40%, 50%, and 70% of MVIC

To determine the load necessary to represent 40%, 50%, and 70% of each subject's lumbar strength, the following calculation was performed.[18]

$$\text{Torso UBM (kg)} + \text{harness and chain weight (0.7kg)} + \text{MVIC (kg)} = \text{Total lumbar strength (TLS)}$$

$$\text{Y Intensity: (TLS [kg]} \times \text{Y)} - \text{torso UBM (kg)} = \text{Y load (kg)}$$

where Y is the desired workload (ie, 40%).

Three subjects whose torso UBM was greater than 40% of their TLS were excluded from the study.

Dynamic exercise of varying intensity on the VARC. After a 15-minute rest from the lumbar strength testing, subjects performed dynamic trunk extension exercise on the VARC, using a load equal to either 40%, 50%, or 70% of peak isometric adjusted strength. These intensities were chosen because 40% is approximately equal to an individual's UBM, whereas exercise at the 70% intensity level generally results in muscular failure between 4 and 6 repetitions.

For each intensity, 3 sets of 10 repetitions with a 1-minute rest period between each set were performed. A 45-minute recovery was allotted between each exercise intensity. Five subjects completed the protocol in a randomized order. No differences were found between performing the protocols in a randomized order or in a sequential order at 40%, 50%, and 70% intensity. Therefore, the remaining 15 subjects completed the exercises in sequential order, from lowest to highest intensity, because the sequence was more comfortable.

Subjects were instructed to begin each set with the trunk fully flexed and to extend their trunks in a smooth, controlled fashion, completing the concentric phase of the dynamic exercise in 2 seconds. Next, the subjects were instructed to lower their torsos during the eccentric phase in 2 seconds to return to a fully flexed position. A metronome, along with investigator feedback, was used to ensure appropriate timing. The experimental setup is shown in figure 1.

During dynamic exercise at the 40% and 50% intensity levels, electromyograms (EMGs) were recorded for 10 seconds during the ninth and tenth repetitions throughout the entire range of motion for each repetition. The electromyographic activity was averaged over the eccentric and concentric components of each repetition and reported in millivolts per second. During dynamic exercise at 70% intensity, electromyographic activity, was recorded during the ninth and tenth repetitions or during the 2 full repetitions that the subject could complete before muscular failure (11 subjects could not complete 3 sets of 10 repetitions).

Treatment of the Data and Statistical Analysis

Electromyographic data were recorded (mV/s) and were normalized to MVIC and to the 40% intensity level. A *t* test was performed to evaluate the differences in right and left lumbar extensor EMGs. Because no differences were found ($P \leq .05$), the right and left lumbar extensor electromyographic data were averaged and reported. The normalized electromyographic data were analyzed by using a 3-way factorial analysis of variance for repeated measures. Main effects for this statistical model were intensity (40%, 50%, 70%), set (3 levels), and muscle group (bicep femoris, gluteus maximus, combined lumbar extensors).

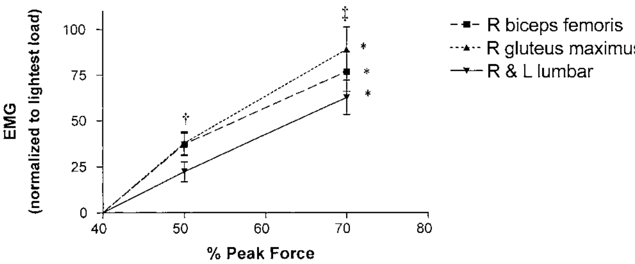

Fig 2. Muscle electromyographic activity normalized to the 40% intensity level and plotted as a function of exercise intensity. Abbreviations: R, right; L, left. * 40%<50%<70%, 40%<70%.† Gluteus maximus, biceps femoris > lumbar extensors. ‡ Gluteus maximus > lumbar extensors ($P \leq .05$).

Data were normalized in the traditional manner to an MVIC and also to the 40% intensity level because of uncertainties in the isometric contraction maximally activate the hip extensor muscles. Because muscles other than the lumbar extensors (ie, gluteals, biceps femoris) are primarily responsible for the initiation of trunk extension from the fully flexed position,[20] it was hypothesized that these muscles would not be maximally activated during the MVIC test because of the biomechanical position required during VARC exercise. Thus, data were additionally analyzed when values were normalized to the lowest intensity level to show alterations in recruitment patterns with an increased load when dynamic trunk extension exercise is normalized to dynamic (vs isometric) trunk extension of a lighter load.

A Scheffé post hoc test was performed when required. Statistical significance was accepted at $P \leq .05$. The Stata software package[f] was used for all statistical analyses. All data are reported as means ± standard errors, unless otherwise noted.

RESULTS

Muscle Recruitment Patterns With Varying Exercise Intensity

When data were normalized to the lightest load, an intensity main effect and muscle by intensity interaction were found ($P \leq .05$). Further analysis revealed that the lumbar extensors increased to a lesser extent at the 50% intensity than did the gluteus maximus and the biceps femoris ($P \leq .05$) (22.1%±5.3%, 37.7%±6.0%, 36.9%±6.0%, respectively). At the 70% intensity level, the increase in lumbar extensor electromyographic activity was significantly less than the increase in gluteus maximus electromyographic activity ($P \leq .05$) (62.7%±9.2%, 88.9%±12.1%, respectively) (fig 2). At the 70% intensity, there was no difference between lumbar extensor and bicep femoris electromyographic activity when normalized to the lightest load (62.7%±9.2%, 76.7%±10.9%, respectively) ($P \leq .05$). All muscle groups exhibited an increase in muscle activation from 40% to 50% to 70% of exercise intensity (fig 2).

When data were normalized to an MVIC, an intensity main effect and muscle by intensity interaction were observed ($P \leq .05$). Electromyographic activity increased significantly from 40% to 50% to 70% for the gluteus maximus and biceps femoris ($P \leq .05$) (gluteus maximus: 34.1%±2.5%, 44.6%±3.1%, 61.3%±4.0%; biceps femoris: 38.3%±2.5%, 51.0%±3.3%, 64.7%±4.0%, respectively). There was no dif-

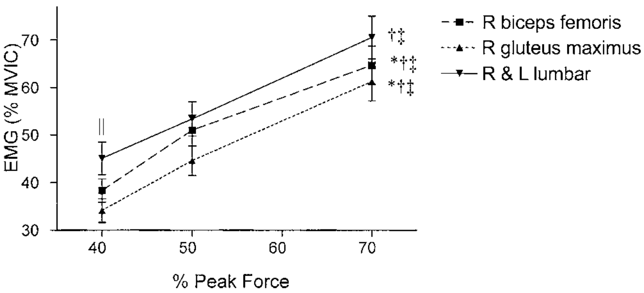

Fig 3. Muscle electromyographic activity normalized to an MVIC and plotted as a function of exercise intensity. * 0%>40%. † 0%>40%. ‡ 0%>40%. ‖ Lumbar extensors > gluteus maximus ($P \leq .05$).

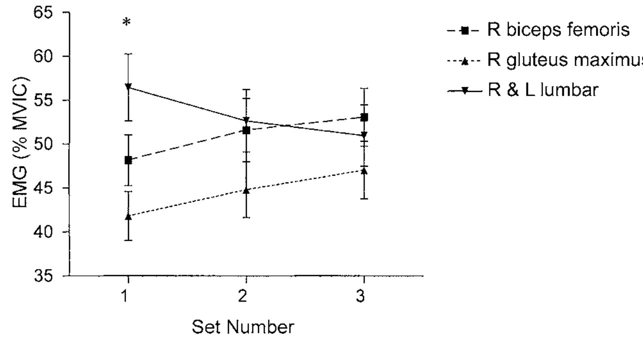

Fig 5. Muscle electromyographic activity at the 50% intensity level normalized to an MVIC plotted as a function of repeated sets. * Lumbar extensors > gluteus maximus ($P \leq .05$).

ference in the electromyographic activity of the lumbar extensors between 40% and 50% of peak isometric force, whereas there was a significant increase between the 50% and 70% intensity levels ($P \leq .05$) (40%: 45.1%±3.0%; 50%: 53.3%±3.4%; 70%: 70.5%±4.0%) (fig 3). At the 40% intensity level, the electromyographic activity of the lumbar extensors was significantly greater than the gluteus maximus ($P \leq .05$) (45.1%±3.0% vs 31.1%±2.5%, respectively). For all other intensities, there were no differences in electromyographic activity among the muscle groups ($P \leq .05$) (fig 3).

Muscle Recruitment Patterns With Increasing Sets

When data were normalized to the lightest load, no significant interactions or main effects were observed ($P \leq .05$). Additionally, when data were normalized to MVIC, there was no change in electromyographic activity with respect to set number for any muscle group ($P \leq .05$). However, a muscle by set interaction was observed. For the 40% intensity level, the lumbar extensor electromyographic activity was greater than the biceps femoris and gluteus maximus during set 1 ($P \leq .05$) (46.0%±3.2%, 36.0%±2.5%, 31.5%±1.9%, respectively). During set 2, the lumbar extensors were greater than the right gluteus maximus ($P \leq .05$) (45.9%±3.2%, 34.4%±2.8%, respectively); there was no difference between the lumbar extensors and the bicep femoris. For set 3, no differences existed among muscle groups ($P \leq .05$) (fig 4).

For the 50% intensity level, the lumbar extensor electromyographic activity was greater than the gluteus maximus during set 1 ($P \leq .05$) (56.3%±3.6%, 41.8%±2.8%, respectively); there was no difference between the lumbar extensor and biceps femoris ($P \leq .05$). For sets 2 and 3, no differences existed among muscle groups ($P \leq .05$) (fig 5).

At the 70% intensity level, the lumbar extensor electromyographic activity was greater than the gluteus maximus during set 1 ($P \leq .05$) (73.2%±4.0%, 59.1%±3.8%, respectively); there was no difference between the lumbar extensors and the biceps femoris ($P \leq .05$). For sets 2 and 3, no differences existed between muscle groups ($P \leq .05$) (fig 6).

DISCUSSION

Our results indicate that the muscle activation patterns of the lumbar extensors, gluteus maximus, and biceps femoris musculature change with varying loads and multiple sets during dynamic Roman chair exercise. During dynamic trunk extension exercise, lumbar extensor electromyographic activity increased to a lesser extent than the gluteal and biceps femoris muscles as load was increased. The most plausible explanation for the differences in muscle recruitment patterns with varying loads is that the lumbar musculature becomes less responsible for producing the compound movement, and the stronger and more powerful gluteal and biceps femoris muscles are activated to accommodate an increased load. Numerous researchers[9,21-23] have suggested that to effectively isolate the lumbar paraspinal musculature, the pelvis must be restrained. Therefore, it appears that during Roman chair exercise at 15°, the pelvis is free to rotate, thus allowing the strong hip extensors to contribute to force production to a greater extent at higher loads.

It has been suggested that, because the high relative percentage of type I muscle fibers in the lumbar musculature,[24,25] the

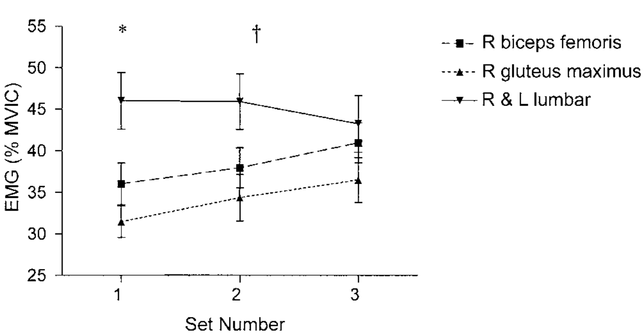

Fig 4. Muscle electromyographic activity at the 40% intensity level normalized to an MVIC plotted as a function of repeated sets. * Lumbar extensors > biceps femoris, gluteus maximus. † Lumbar extensors > gluteus maximus ($P \leq .05$).

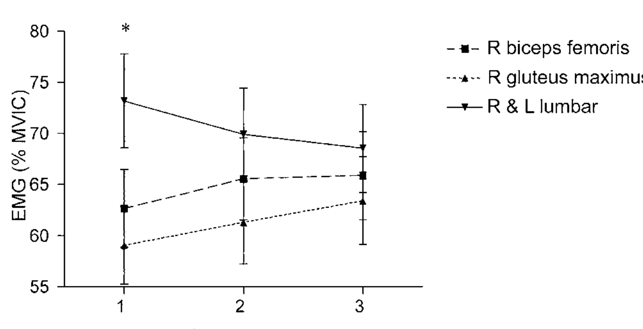

Fig 6. Muscle electromyographic activity at the 70% intensity level normalized to an MVIC plotted as a function of repeated sets. * Lumbar extensors > gluteus maximus ($P \leq .05$).

muscles of the back are adapted for spinal stability.[26] Therefore, because of their stability role, in comparison with providing global movement, the lumbar musculature plays a lesser role with an increased exercise intensity during Roman chair exercise. It is hypothesized that because of the nature of the lumbar extensors, they are not designed for higher loads, and the gluteal and biceps femoris muscles are activated to prevent an excessive load from being placed on the lumbar region.

Arokoski et al[11] showed that the paraspinal muscles exhibit higher relative activity than the gluteus maximus during trunk extension exercise. Our study results also indicate that the paraspinal muscle activation is high. However, our results also suggest that, as load is increased, the relative contribution of the gluteus maximus increases to a greater extent than that of the lumbar paraspinal musculature. This finding supports the hypothesis of Ploutz-Snyder et al.[14] By using muscle functional magnetic resonance imaging T2-weighted images, Ploutz-Snyder found no difference between exercise intensities representing 50% and 70% of peak isometric force. These findings suggest that trunk extensor muscles other than the lumbar extensors are responsible for the accommodation of an increased load. Our study supports such findings, indicating that the gluteus maximus is highly responsible for accommodating additional external loading.

Because the electromyographic activity of the lumbar extensor musculature is not increasing at the same rate as other muscles with an increasing work rate, the use of additional external loading during Roman chair exercise should be questioned. Increased loading could result in increased compressive loads on the intervertebral disks, which could exacerbate existing structural weaknesses and place an individual at risk of injury.[6] Therefore, when designing an exercise prescription to actively stimulate the lumbar muscles, the cost to benefit ratio of additional loading during trunk extension exercise must be calculated.

This study also showed that alterations in muscle activation occur with multiple sets of dynamic trunk extension exercise. Between sets 1 and 2, the lumbar extensor electromyographic activity decreased in relation to the gluteus maximus at all exercise intensities. Moreover, at the 40% intensity level, lumbar activity decreased with respect to the biceps femoris. These data suggest that, with repeated sets, the lumbar extensor musculature becomes fatigued and thus slightly less responsible for accommodating the load, whereas the gluteal and biceps femoris muscles are activated. These findings support those of Smidt et al,[16] who found that electromyographic decrements associated with fatigue occurred in the paraspinal lumbar musculature with 10 continuous cycles of maximal concentric and eccentric contractions. More recently, however, Hermann and Barnes[27] showed that no change in lumbar paraspinal muscle activity occurred over 50 concentric or 50 eccentric maximal voluntary contractions. Although our study did not find a significant set by lumbar extensor electromyographic main effect, as discussed in the aforementioned studies, this result is probably a result of statistical power. As stated previously, the sample size selected for this study was determined by a power analysis designed to detect a muscle group by exercise intensity main effect. To detect a set by lumbar extensor main effect based on the values obtained in this study, it is estimated that a sample size of approximately 65 subjects would be required (power=.80, 2-sided α level=.05).

The decrements observed in muscle activity in relation to the hip extensors with an increasing number of sets raise questions as to the efficacy of multiple sets of trunk extension exercise. Our results suggest that if the goal of a clinical prescription is to achieve optimal lumbar extensor muscle activity in relation to other trunk extensors, only 1 set of dynamic exercise is needed.

To our knowledge, changes in electromyographic activity of the lumbar extensor musculature in relation to other muscles have never been reported for dynamic Roman chair trunk extension exercise of varying loads. It must be noted that these results came from a cohort of young, healthy subjects and may not be generalizable to LBP populations.

CONCLUSION

This study found that specific muscle recruitment patterns occurred in relation to exercise intensity and number of sets performed during dynamic Roman chair exercise. An increased external load results in the gluteus maximus and biceps femoris muscle activity increasing to a greater extent than the lumbar extensors. This suggests that the gluteal and biceps femoris musculature are more responsible than the lumbar musculature for accommodating an increased load. Additionally, a similar trend occurs as multiple sets are performed, and the contribution of the gluteal and biceps femoris muscles increases whereas that of the lumbar extensors does not, thus allowing for continuation of the exercise. These findings raise questions about the efficacy of an additional loading and multiple sets during dynamic trunk extension exercise.

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Suppliers

a. BackStrong International LLC, 203 N Brea Blvd, Ste 110, Brea, CA 92821.
b. Model 2515; Acme Scale Co, 1801 Adams Ave, San Leandro, CA 94577.
c. Axon Instruments Inc, 1101 Chess Dr, Foster City, CA 94404.
d. National Instruments, 6504 Bridge Point Pkwy, Austin, TX 78730.
e. Takei Scientific Instruments, Back-A, No. 6-18, Hatandai I-chome, Shinagawa-ku, Tokyo 142, Japan.
f. Stata Corp, 702 University Dr E, College Station, TX 77840.