Myoelectric Activity and Sequencing of Selected Trunk Muscles During Isokinetic Lifting

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Trained weight lifters lift heavy loads without a concomitant degree of acute low-back injuries. To study the process by which large loads are lifted with minimal injury, integrated electromyographic signals were recorded from four large muscle groups: gluteus maximus, quadriceps, latissimus dorsi, and erector spinae in 4 weight lifters and 11 asymptomatic control subjects. These signals were recorded during a floor-to-knuckle–height isokinetic lift (dead lift) at 30.5 and 45.7 cm/sec. The signals were normalized for the height of the lift and the maximal isokinetic integrated electromyographic activity. The weight lifters achieved maximal force at 50% of maximal lift height, whereas the control subjects achieved it at 67%. Although not statistically significant, the weight lifters used the gluteus maximus more during the early stages of the lift, perhaps contributing to earlier development of force. This process would stabilize the pelvis and permit the erector spinae to extend the trunk more efficiently. The weight lifter then completed the lift with prolonged and increasing activity in the quadriceps. This technique may minimize the required force in the erector spinae and the forces on the low-back structures. Clinical implications include more effective strength training of lifting muscle groups other than spinal extensors and the teaching of lifting strategies employed by weight lifters in low-back rehabilitation and work-hardening programs. [Key words: electromyography, trunk loading, low back]

MUSCLE ACTIVATION STRATEGIES used during lifting result not only in muscle tensions, but also in forces in the ligaments and on the bony structures of the lumbar spine. These forces play major roles in the injuries to these structures that occur during industrial lifting tasks. Observation of weight lifters, who repeatedly lift very heavy loads without a high incidence of acute trauma, suggests that strategies can be adopted to accomplish even severe lifting tasks with minimal risk. Weight lifters attempt to minimize the distance of the burden from the body and employ their legs while lifting, but the question remains whether muscle activation levels and sequences also play roles in the weight lifter's strategy. The purpose of this study was to compare the activation of the major muscles involved in lifting seen in trained weight lifters with that seen in asymptomatic control subjects during an isokinetic floor-to-knuckle–height lift.

METHODS

Four competitive weight lifters and 11 asymptomatic control subjects participated voluntarily in this study after completing an Institutional Review Board-approved informed-consent procedure. Demographic data on these subjects are shown in Table 1. None of the subjects had suffered a previous back injury.

Each subject had bipolar silver/silver chloride surface-type electrodes (NDM Plia-cell diagnostic electrodes, Baxter Healthcare Corp., Deerfield, IL), with the recording sites set 3 cm apart, installed at the following locations: 1) latissimus dorsi—immediately lateral to the lateral scapular border; 2) erector spinae—1 cm superior to the multifidus and lateral to the spinous process of L3; 3) gluteus maximus—midway between the posterosuperior iliac spine and the ischeal tuberosity; and 4) quadriceps—midway between the top of the patella and the bottom of the iliac crest along the anterior thigh.

The preamplifier for each electrode pair was secured to the subject's body by an elastic wrap. Each preamplifier was connected to an electromyograph (EMG) (TEAC model TE4, Teac Corp., White Plains, NY). The EMG provided amplification and real-time graphic display of the EMG signals received from the four electrode sites. The four channels of amplified EMG signals were passed through a band-pass filter with cutoffs at 100 Hz and 700 Hz and a cutoff slope of −40 dB/decade. Each filtered EMG signal was then digitized at 2000 Hz (A/D converter model 200, Infotek, Anaheim, CA) in a microcomputer (HP model 9816, Hewlett Packard, Cupertino, CA) which allowed its display and inspection on a monitor. If the signal and its data were satisfactory, the digitized signal was stored on disc for later analysis.

Electromyographic signal data were collected for 3 seconds during maximal isometric contractions of each of the instrumented muscles. The subjects executed these isometric contractions in a position and/or with a technique that was intended to isolate the muscle and maximize its EMG activity. For the latissimus dorsi, the standing subject was asked to flare the latissimus dorsi (shoulders slightly elevated, humeri flexed) and then maximally contract the latissimus dorsi isometrically, depressing the scapulae while adducting and extending the humeri. For the erector spinae, the subject bent forward to approximately 45° of trunk flexion and was then asked to lift isometrically in a straight leg position against a fixed object with maximal effort. For the quadriceps effort, the subject was asked to perform a maximal isometric lift against a fixed object in a squat position with the thighs at 30° angles to the horizontal and the arms straight and vertical. The load axis was the intersection of the midplane of the body and the vertical plane across the toes. For the gluteus maximus, the subject was asked to perform a maximal contraction of the gluteus maximus in the form of a buttock pinch in a partially forward bent position.

Isokinetic lifting tests were carried out on a prototype linear lift-task machine (Cybex, a Division of Lumex, Ronkonkoma, New York). Each subject performed several warmup lifts with the isokinetic mechanism of the test machine governed at 64 cm/sec. During this warmup, each subject received instruction on the initial body position and lifting technique to be employed, which included keeping the head up and the buttocks down during the lift. Following practice of this technique, the

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Table 1. Demographic Data of the Two Groups

Group	n	*Height* (cm)* *[Range]*	*Weight* (kg)* *[Range]*
Weight lifters	4	174.0 ± 5.3 [167.6-180.3]	93.1 ± 16.8 [78.6-112.7]
Normal asymptomatics	11	177.6 ± 6.9 [162.6-188]	81.1 ± 13 [65.5-97.7]

*Mean ± SD.

isokinetic mechanism of the test machine was set at one of two test speeds: 30.5 cm/sec or 45.7 cm/sec. The choice of the initial test speed was alternated for each subject to minimize learning effects. When the subject was performing repeatable lifts, as assessed by observation of the technique and of the force generated during the lift, the subject was asked to exert maximal effort in a test lift during which the force generated, lift height, and EMG signals were recorded as a function of time. Lifts were repeated at 1-minute intervals until data from three properly performed, repeatable lifts were obtained. After a 5-minute rest period, the practice and test sequence was repeated with the isokinetic mechanism governed at the second test speed.

The digitized EMG signals were full wave rectified and smoothed with a 20-Hz low-pass filter to create IEMG data. To compare the EMG signals collected from the weight lifters with those of the asymptomatic controls, the IEMG data were normalized. Two normalization methods were used. In the first, the maximum value of the IEMG signal, obtained in the isometric tests, was used as the normalization constant. In the second method of normalization, the maximum IEMG value recorded during any of the six isokinetic lifts (three lifts at two speeds) was adopted as the normalization constant. The force and height of lift data were also normalized by their maximum values. Mean values and standard deviations were determined for the normalized IEMG and the normalized force data as functions of the normalized lift height for each of the two test groups.

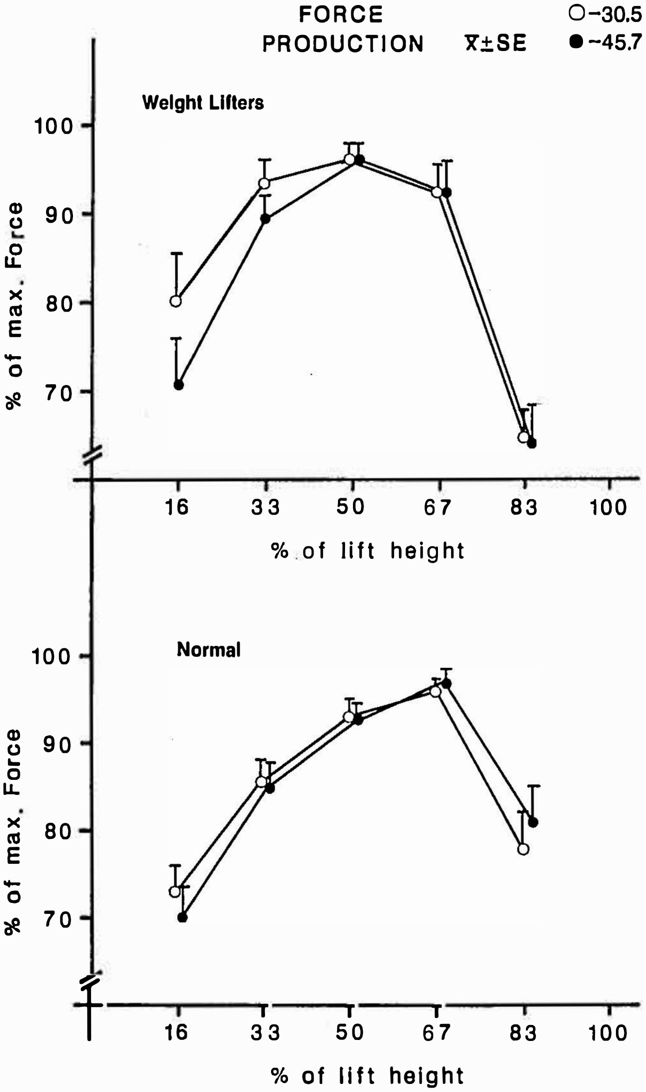

Fig 1. Percentage of maximal force vs. percentage of lift height.

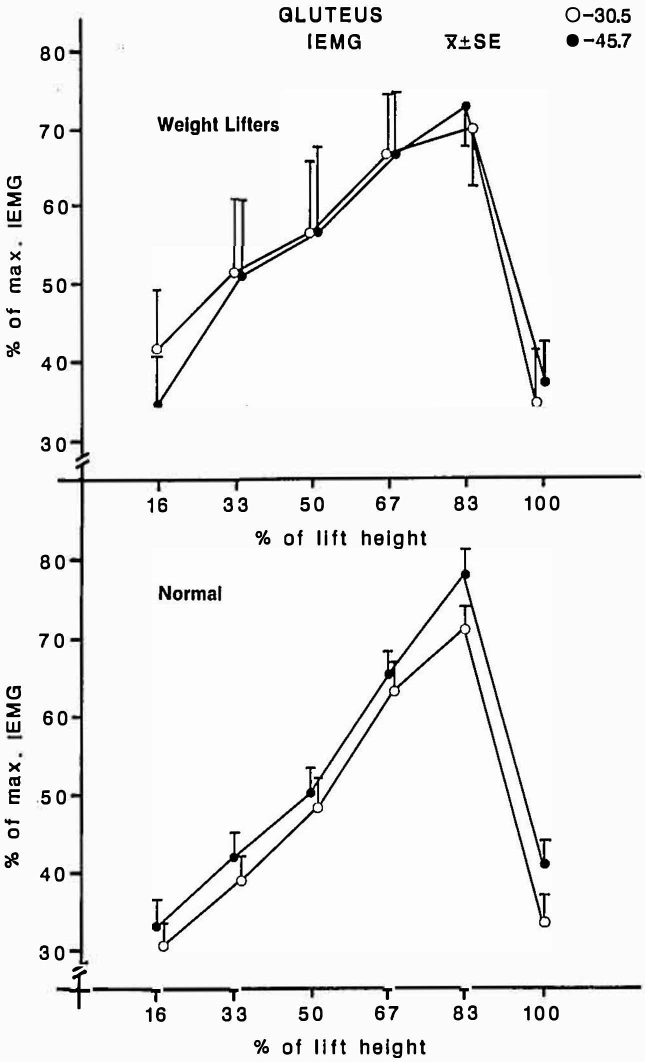

Fig 2. Percentage of maximal gluteus maximus isokinetic IEMG activity vs. percentage of lift height.

RESULTS

Figures 1–5 display the mean values for the normalized IEMG and normalized force data as functions of the normalized lift height for the two test groups and the two lifting speeds. The normalized IEMG data are those resulting from the second normalization technique using the maximum IEMG value recorded during any of the isokinetic tests as the normalization constant.

The force curves show that the weight lifters were able to achieve maximum force at 50% of their maximum lift height. The asymptomatic control subjects did not achieve maximum force until 67% of their maximum lift height. The rise to maximum force was quite abrupt for

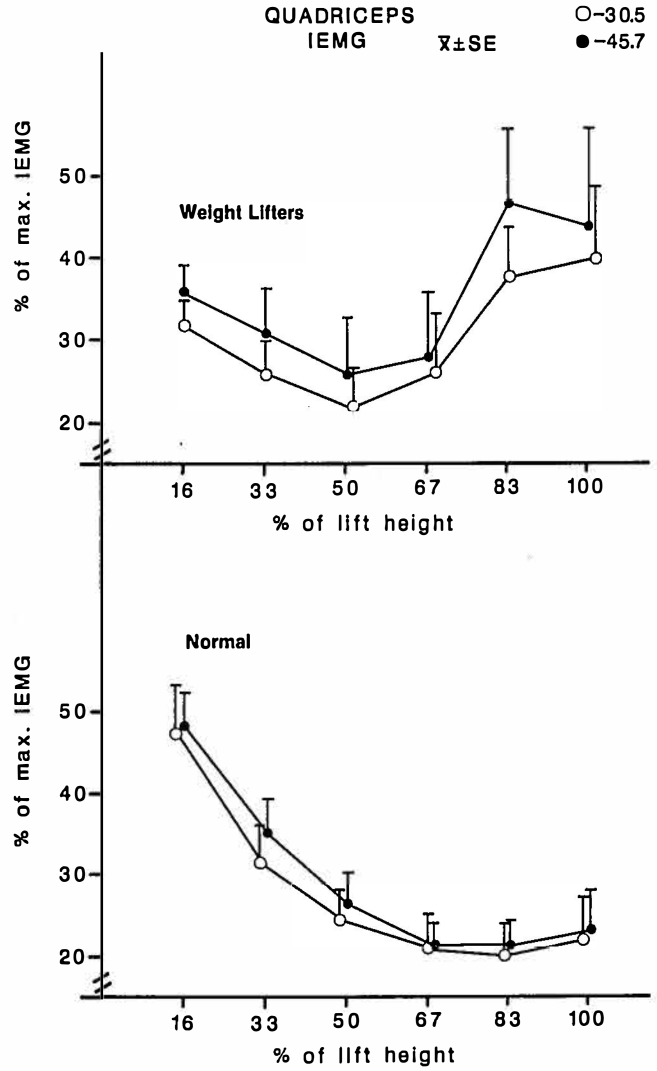

Fig 3. Percentage of maximal quadriceps isokinetic IEMG activity vs. percentage of lift height.

the weight lifters, whereas the asymptomatic control subjects developed force more slowly. The normalized force values at 33% of lift height were, however, the only values that showed significant differences ($P < .05$).

The shape of the normalized IEMG curves for the latissimus dorsi closely followed that of the normalized force curves for both the weight lifters and the asymptomatic control subjects. The normalized IEMG curves for the gluteus maximus and erector spinae muscles were quite similar to each other and did not significantly differ between the two test groups. Maximum normalized IEMG activity was achieved at about 83% of normalized lift height in all cases. The normalized IEMG activity in the quadriceps, however, differed significantly between the two groups. For the asymptomatic control group, the quadriceps activity was maximum at the beginning of the lift and decreased throughout the lift. The quadriceps activity also decreased through the first half of the lift for the weight lifters, but then increased in the second half of the lift, reaching a maximum at about 83% of the lift height. The differences at 83% of lift height were statistically significant ($P < .05$).

The two lift speeds did not produce much variation within or between groups; there were no statistically significant differences. It did take the weight lifters more time to achieve maximum force during the 45.7 cm/sec lifts than in the 30.5 cm/sec lifts.

DISCUSSION

The large trunk and leg muscles monitored in this study were chosen because of their role in the lifting process. Other studies have looked at the activity of trunk and abdominal muscle groups,[4,5] but no previous studies have analyzed the synergistic action of the large trunk and leg muscle groups during a floor-to-knuckle–height lift.

Normalization of EMG data is necessary to allow comparison between subjects and between groups of subjects. A common procedure used in many EMG studies to accomplish this is normalization by the EMG signal from a maximal voluntary isometric contraction. Such a maximal contraction implies that all motor units are firing at their maximal level, which has been confirmed by other investigators.[1,6] There are problems, however, with the techniques that have been discussed previously.[8,9] Further, the ability to perform a maximal isometric contraction of a muscle is somewhat dependent on physical conditioning, posture, body awareness, and previous muscle training.

This latter difficulty presented itself in the current study. In the original study design, unopposed resistant isometric contractions were

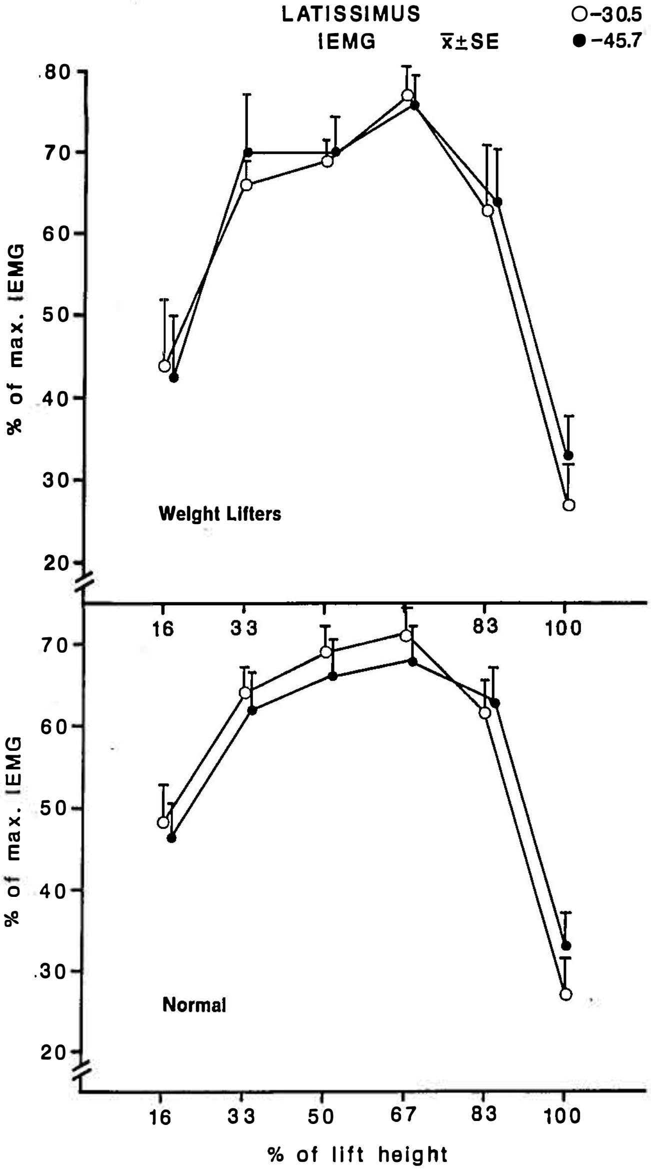

Fig 4. Percentage of maximal latissimus dorsi isokinetic IEMG activity vs. percentage of lift height.

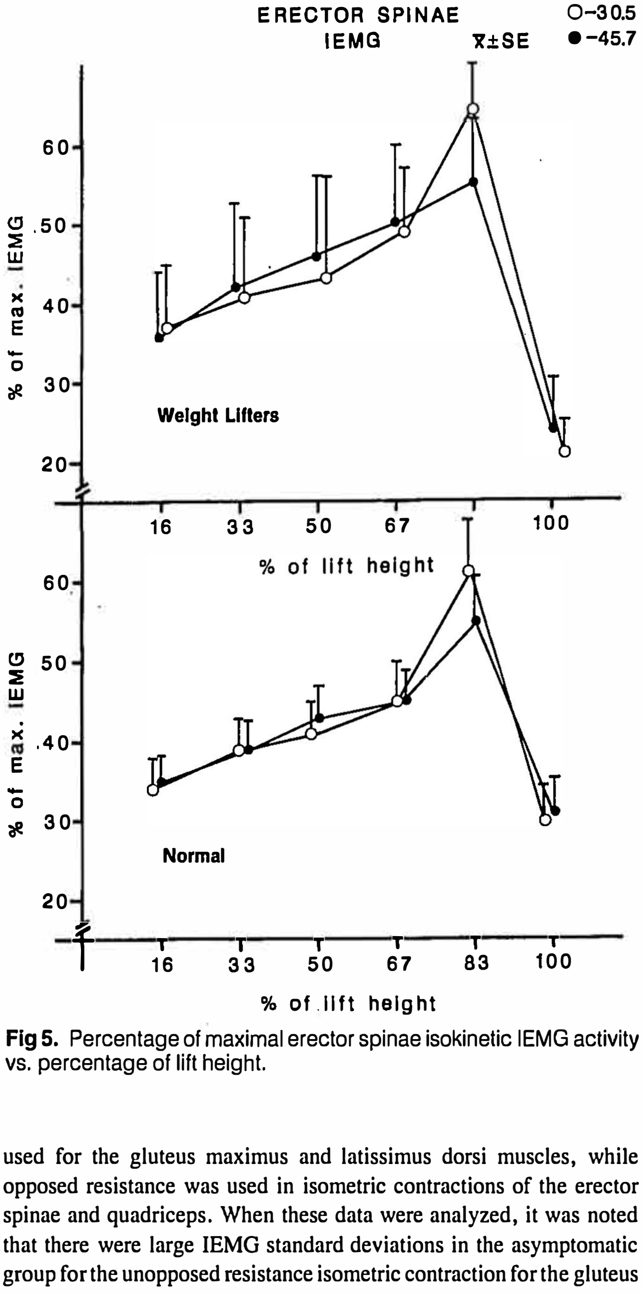

Fig 5. Percentage of maximal erector spinae isokinetic IEMG activity vs. percentage of lift height.

used for the gluteus maximus and latissimus dorsi muscles, while opposed resistance was used in isometric contractions of the erector spinae and quadriceps. When these data were analyzed, it was noted that there were large IEMG standard deviations in the asymptomatic group for the unopposed resistance isometric contraction for the gluteus maximus and latissimus dorsi; for the weight lifter, the IEMG standard deviations were smaller. It was deduced from this that the weight lifters were familiar with these isometric maneuvers as a part of the weight-lifting muscular display and were able to produce an efficient muscular contraction. Untrained asymptomatic control subjects were unable to activate these muscles effectively in this unopposed-resistance method. To overcome this, an alternative method of normalization was used, involving the maximum IEMG magnitude seen for each individual muscle during any of the isokinetic lifts. This technique produced reduced standard deviations that were similar for both test groups.

The problems associated with normalizing EMG data are not unique to this study. Intersubject variability has been shown to be large,[2,3,7] and a variety of normalizing techniques have been used. These include 1) the EMG at 100% maximal voluntary contraction; 2) the EMG at 50% of maximal voluntary contraction; 3) EMG magnitude per unit of isometric moment; 4) peak of the within-subject ensemble average; and 5) mean of the within-subject ensemble average. Yang and Winter evaluated several of these techniques in a comparative study and found that the peak within-subject ensemble average was most effective in reducing intersubject variability.[8] This technique is similar to the method used in this study, except that the absolute peak value was used for normalizing rather than the peak ensemble average.

In examining the force curves, it is clear that the weight lifters achieved maximum force very early in the lift and maintained it for a longer period of time. The more rapid initial rise of force by the weight lifter compared to the asymptomatic control subject is most likely due to a training effect, both neural and mechanical, that allows them to optimally sequence the synergistic action of their musculature. How this is accomplished will be addressed by examining the role of each of the muscles individually.

The gluteus maximus initially creates torque to extend the hips against the resistance of the weight of the trunk and of the object lifted; it then acts in terminal extension to rotate the pelvis posteriorly over the hips. The activity of the gluteus maximus steadily increases, peaking at 83% of the lift height. The posterior pelvic rotation brings the burden closer to the midline of the body, improving the mechanical advantage of the other muscle groups. Although not statistically significant, the weight lifters showed a greater amount of normalized IEMG in the earlier stages of the lift than did the asymptomatic controls.

The gluteus maximus acts to provide a stable pelvis against which the erector spinae can act to produce extension of the trunk. The erector spinae muscle is seen to increase its EMG activity gradually in both the weight lifters and controls in a fashion similar to that seen in the gluteus maximus, peaking at 83% of the lift height. The delay in maximal contraction relative to the maximum force may be explained by an initially poor length–tension relationship, and by the need for a properly positioned and stabilized pelvis to allow the erector spinae to act effectively. As the lift proceeds, the erector spinae becomes optimally positioned with an improved length–tension relationship.

Although normalized erector spinae activity is about the same for both test groups, there is a major difference in how the force is generated (Figure 1), suggesting a difference in the load transfer mechanism by the actions of the quadriceps, gluteus maximus, and latissimus dorsi. There is more normalized latissimus dorsi activity during early and mid lift for the weight lifters than that seen in the asymptomatic control group. This muscle acts initially to move the load closer to the body, reducing the torque required to complete the lift. The initially rapid rise in IEMG activity of the latissimus dorsi in both the weight lifters and controls points to the importance of this function. The latissimus dorsi continue to be very active in the lift up to 67–83% of the lift height; then their activity drops off rapidly as the lift is completed. Because of the extensive attachment of the latissimus dorsi to the posterior layer of the thoracolumbar fascia, the initial contraction of this muscle not only affects the humeral extension in adduction, but applies a tensile force to the posterior layer of the fascia that surrounds the erector spinae muscle. This may lead to an improvement in the ability of the erector spinae to contract.

The quadriceps contraction acts to extend the lower extremity at the knee joint and to stabilize the pelvis (rectus femoris). The asymptomatic control subjects are seen to strongly activate the quadriceps initially, extending the knees. The quadriceps activity then declines to a steady state at 67–83% of the lift height. The responsibility for completing the lift is passed to the erector spinae and the gluteus maximus; however, the weight lifter initiates the lift with combined activity in the quadriceps and the gluteus maximus. The simultaneous extension of both the hips and the knees results in significant early force production, stabilization of the trunk and pelvis, and improvement of the mechanical advantage of the other muscle groups, particularly the erector spinae. The lift is then completed by knee extension driven by increased activity in the quadriceps, peaking between 67% and 83% of the lift height, and by continued activity of the erector spinae and gluteus maximus in extending and stabilizing the hips and spine.

The information from this study may be useful in the rehabilitation setting. First, it is clear that there are a number of muscle groups in addition to the trunk extensors involved in the lifting process, including—as specifically observed in this study—the latissimus dorsi, gluteus maximus, and quadriceps. The rehabilitation of these muscles and muscle groups are just as essential as the rehabilitation of trunk flexors and extenders because these muscles provide significant contributions to the total lift effort. As seen in the weight lifters, the quadriceps are a major contributor in the lifting process; however, we do not believe that quadriceps strengthening alone should be emphasized during back rehabilitation, but that all the lifting muscle groups should be trained for strength equally. It is not only the strength of these muscles that is important during the lift, but when and how they are used. Second, the lifting strategies used by weight lifters could be incorporated in work-hardening and rehabilitative processes to minimize the load on the erector spinae while distributing it to other trunk muscle components. This could be done by teaching the patient how to maintain quadriceps activity throughout the lift, thus reducing the burden placed on the erector spinae.

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