
COMPARISON OF DIFFERENT ROWING EXERCISES: TRUNK MUSCLE ACTIVATION AND LUMBAR SPINE MOTION, LOAD, AND STIFFNESS

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ABSTRACT

Fenwick, CMJ, Brown, SHM, and McGill, SM. Comparison of different rowing exercises: trunk muscle activation and lumbar spine motion, load, and stiffness. *J Strength Cond Res* 23(2): 350–358, 2009—The objective of this study was to investigate 3 different rowing exercises and quantify the muscle activation of the torso and the hip musculature, together with the corresponding spinal loading and stiffness. Seven healthy men from a university population were instrumented to obtain surface electromyography of selected trunk and hip muscles and to obtain spine position using an electromagnetic spine position sensor, together with video analysis to calculate joint moments. The 3 rowing exercises investigated were the inverted row, standing bent-over row, and standing 1-armed cable row. The inverted row elicited the highest activation of the latissimus dorsi muscles, upper-back, and hip extensor muscles. The lower activation of the lumbar erector spinae muscles during the inverted row corresponded to the lower spine load measured. The standing bent-over row produced large activation symmetrically across the back, but it produced the largest lumbar spine load. The 1-armed cable row challenged the torsional capabilities of the trunk musculature. Some core exercises may be better for rehabilitation (e.g., having the training goals of modest muscle activation with low spine load), whereas other exercises may be better for athletic training (e.g., resulting in higher muscle activation and larger spine load). When prescribing core exercises, those wishing to spare the low back may choose the inverted row, given the lowest spine load exercise. The standing bent-over row elicited large muscle activation symmetrically from the upper to lower back; it

induced larger spine loads but also, not surprisingly, the highest spine stiffness. If torsional endurance or strength is the training goal, the 1-armed cable row might be considered.

KEY WORDS core training, performance, stability, technique

INTRODUCTION

Core training is used in low-back rehabilitation, health, fitness, and athletic training regimes. The objective of these exercises is to challenge the trunk musculature (abdominals and back) in a way that enhances stiffness and stability of the lumbar region of the torso. However, some exercises may be better for rehabilitation (modest muscle activation with low spine load) and others for athletic training (higher muscle activation resulting in larger spine load). Although many studies measure muscle activation, few measure the resulting spine load, which limits the ability to make wise exercise choices and recommendations for those dealing with back trouble or for those simply wishing to avoid high back loading.

Manuals have been written defining the proper technique for performing different rowing exercises (7,8,13), but they have little science-based evidence for their recommendations. To our knowledge, no study has investigated the rowing mechanism and quantified muscle activation, spine loading, and spine stiffness. A simplified definition of stability incorporates the concept of how well a system can maintain or recover its original position after perturbation. With reference to the spine, stability can be thought of as ensuring sufficient stiffness by optimally coordinated muscle contraction and, therefore, stiffness around the spine. When muscle stiffness is increased, a larger perturbation is needed to disrupt the spine and make it unstable (3). Therefore, spine stiffness is a direct predeterminant of spine stability. Cholewicki and McGill (6) showed that individuals with higher muscle activation had a higher “margin of safety” in terms of stability than individuals with lower muscle activation.

The objective of this study was to investigate 3 different rowing exercises to quantify the muscle activation of the spine and the hip extensors, spinal loading, and muscle-generated

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stiffness. Muscle stiffness, specifically stiffness of all muscles acting about a torso axis, was computed because stiffness is the closest quantifiable surrogate of spine stability. The 3 exercises that were investigated were the inverted row (body weight row), the standing bent-over barbell row, and the 1-armed cable row. Our hypothesis was that the inverted row would produce the highest activation of the muscles in the extensor chain with the lowest spine loads, and the standing bent-over row would produce a large lumbar moment and result in the largest spine loads.

METHODS

Experimental Approach to the Problem

This basic science investigation was intended to assess muscle activation during 3 rowing exercises and to evaluate the effects each exercise has on lumbar spine loading and muscle-supported stiffness.

Subjects

Seven healthy men aged 27.1 years (*SD* 3.8), 1.79 m tall (*SD* 0.06), with a mass of 80.9 kg (*SD* 6.8), participated in this study. All subjects were recreationally active; however, the tasks were novel to some of the participants. Participants were given instructions on how to properly complete the exercises, and technique was monitored throughout the experiment. The experimenters did not control for prior training levels, nutritional intake, or any other confounding variables. Thus, the results from this study are limited to the average healthy university student and not the high-level athlete. All subject recruitment and data collection procedures were performed in accordance with the University of Waterloo office of research and ethics guidelines.

Procedure

Sixteen channels of electromyography (EMG) were collected from electrode pairs placed bilaterally over the following muscles: right and left rectus abdominis (RRA and LRA) lateral to the navel, right and left external obliques (REO and LEO) about 3 cm lateral to the linea semi lunaris but on the same level of the RRA and LRA electrodes, right and left internal oblique (RIO and LIO) caudal to the REO and LEO electrodes and the anterior superior iliac spine and still cranial to the inguinal ligament, right and left latissimus dorsi (RLD and LLD) over the muscle belly when the arm was positioned in the shoulder midrange, right and left upper (thoracic) erector spinae (RUES and LUES) approximately 5 cm lateral to the spinous process (actually longissimus thoracis and iliocostalis at T9), right and left lumbar erector spinae (RLES and LLES) approximately 3 cm lateral to the spinous process (actually longissimus and iliocostalis at L3), right gluteus medius (RGMED) at the muscle belly found by placing the thumb on the ASIS and reaching with the fingertips around to the gluteus medius, right gluteus maximus (RGMAX) at the middle of the muscle belly approximately 4 cm lateral to the gluteal fold, right rectus femoris (RRF) approximately 5 cm caudal to the inguinal ligament, and right biceps femoris

(RBF) over the muscle belly midway between the knee and hip. The skin was shaved and cleansed with a 50/50 H₂O and ethanol solution. Ag-AgCl surface electrode pairs were positioned with an interelectrode distance of about 2.5 cm. The EMG signals were amplified and then A/D converted with a 12-bit, 16-channel A/D converter at 2048 Hz. Each subject was required to perform a maximal contraction of each measured muscle for normalization (9). For the abdominal muscles, each subject adopted a sit-up position and was manually braced by a research assistant. They then produced a maximal isometric flexor moment followed sequentially by a right and left lateral bend moment and then a right and left twist moment. Little motion took place. Each participant also performed an isometric reverse curl-up by adopting a supine position in which he attempted to lift his pelvis off the table while a research assistant restrained his knees. Subjects were further instructed to attempt to twist right and left. For the spine extensors and gluteal muscles, a resisted maximum extension in the Biering-Sorensen position was performed (12). A specific RGMED normalizing contraction was also attempted with resisted side-lying abduction (i.e., the clam). Participants laid on their left side with the hips and knees flexed. Keeping their feet together, they abducted their right thigh to parallel, and a research assistant restricted further movement. Normalizing contractions for the RRF were attempted with isometric knee extension performed from a seated position with simultaneous hip flexion on the instrumented side. For the RBF, participants laid supine and were instructed to flex the knee and extend the hip while the researcher manually resisted both movements. The maximal amplitude observed in any normalizing contraction for a specific muscle was taken as the maximum for that particular muscle. The EMG signals were normalized to these maximal contractions after full-wave rectification and low-pass filtering with a second-order Butterworth filter. A cutoff frequency of 2.5 Hz was used to mimic the EMG to force frequency responses of the torso muscles (2). The normalized EMG was downsampled to 32 Hz.

Lumbar spine position was measured about 3 orthogonal axes using a 3 Space IsoTRAK electromagnetic tracking instrument (Polhemus Inc, Colchester, Vt). This instrument consisted of a single transmitter that was strapped to the pelvis over the sacrum and a receiver strapped across the ribcage, over the T12 spinous process. In this way, the position of the ribcage relative to the pelvis was measured (lumbar motion). Spine posture was normalized to that obtained during standing (thus corresponding to 0° of flexion-extension, lateral bend, and twist). The absolute values of the raw lateral bend and twist angles were analyzed because of the symmetry of the spine's ranges of motion in these 2 axes. Therefore, the results refer to individuals as being more or less laterally bent and/or twisted during the performed exercise.

Video was collected at 30 Hz and was upsampled to 32 Hz to sync up with the 3 Space and the EMG.

Spine Load and Stiffness Estimation

Normalized EMG signals and lumbar spine position data were entered into an anatomically detailed model of the lumbar spine. This model represents approximately 90 muscle lines of action spanning 6 lumbar joints (L5–sacrum to T12–L1). The force and stiffness generated by each muscle fascicle were estimated from a distribution-moment (10) approach incorporating the normalized muscle activation, muscle cross-sectional area, stress-generating capability, instantaneous muscle length, and velocity. Muscle compressive and shear forces were computed as sums of the forces of all muscle fascicles acting along the anatomic compressive and shear axes, respectively, of the L4–L5 joint. Lumbar spine stiffness was computed about each of the flexion/extension and axial twist axes as the average sum of the individual muscle stiffness values estimated across each lumbar joint and about each axis (14). A more detailed description of the various components of the modeling techniques can be found elsewhere (5,6). The absolute value of the muscular mediolateral shear was taken; therefore, no direction was assigned to the results.

Description of Exercises

Before instrumentation, participants were asked to stand on an instrumented platform and complete an inverted row, as described below. The largest mass recorded on the platform during the row was subtracted from the subject’s total body weight, and the difference was selected as the load to be lifted during the standing bent-over row. This load was then divided in half to obtain the load to be pulled during the 1-armed cable row. This procedure served to normalize the load lifted during all 3 exercises.

Inverted Row. Two chains with handles were suspended from the ceiling with force transducers connected in series with the handles. The lengths of the chains were set so that when a participant pulled himself up, his upper body was horizontal to the ground. Participants were instructed to grab the handles with a pronated grip and to lower themselves underneath it. Participants were told to keep their knees bent at 90°, to keep

their bodies tight, and pull themselves up while using the knees as the fulcrum (see Figure 1A and 1B).

Standing Bent-Over Row. Using the mass determined from the inverted row, participants lifted the loaded barbell from the ground, flexed the trunk over the hips, and were instructed to keep a neutral spine while they pulled the bar to their chest, bending their arms at the elbows (see Figure 1C and 1D).

One-Armed Cable Row. A cable pulley system was set up with the cable perpendicular to the subject at hand level. A force transducer was connected in series with the cable and recorded the force produced during the row. Standing in a lunge position with the left foot in front of the right, participants took a pronated grip (right hand only) and were instructed to pull the load, bending at the elbow, straight back to their torso, while maintaining a neutral spine. These instructions were to ensure that the cable stayed perpendicular to the body (see Figure 1E and 1F).

Subjects were asked to perform 3 trials of each exercise, with 3 repetitions per trial. Subjects were instructed to complete the exercise at 60 bpm using a metronome, with 1

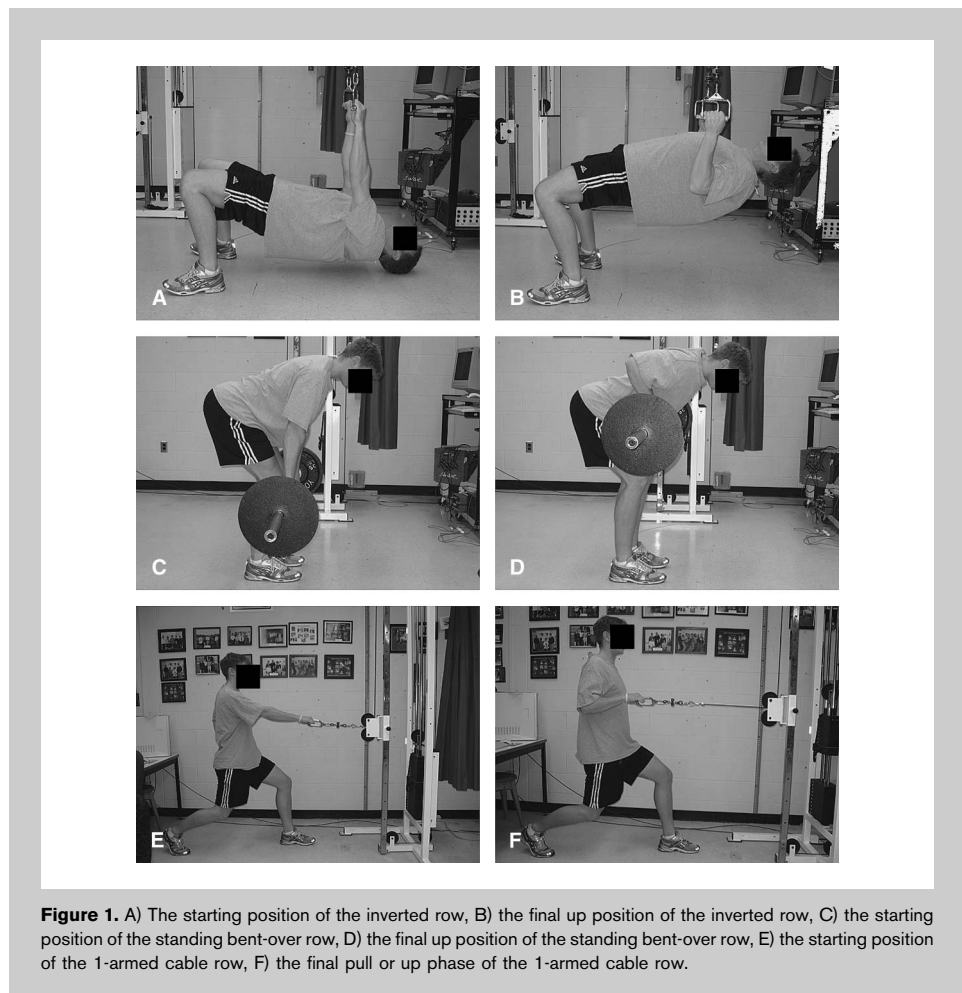


Figure 1. A) The starting position of the inverted row, B) the final up position of the inverted row, C) the starting position of the standing bent-over row, D) the final up position of the standing bent-over row, E) the starting position of the 1-armed cable row, F) the final pull or up phase of the 1-armed cable row.

beat being the pull motion and the next beat being the release motion.

Data Analysis

Only the second repetition of each exercise was analyzed because the first repetition served as a warm-up and enabled each subject to get into a groove; during the last repetition, participants were easing and becoming sloppy. Using the video recorded, each trial (EMG, 3 Space, force, and video) was clipped into the different pulling phases (up phase and down phase). The start of the pull-up phase was defined as the instant in time at which the participant's hand moved toward his body, and the end of the up phase was defined as the point at which the hand stopped moving toward the body; the down phase was defined as the point at which the hand started to move away from the body and back to the original position, and the end of the trial was defined as the point at which the person had returned to his starting position. These phases were then used to clip the EMG and 3-Space data.

The frame at which peak force occurred during the inverted row (summation of both hands), standing bent-over row, and 1-armed cable row was the frame used to calculate the external moments. To determine the force produced at the hands during the standing bent-over row, the video clip for each trial was padded using 15 frames of raw data before and after the up and down phases of each exercise to eliminate filter artifact for the first frame of analysis, and then the load lifted was digitized. The entire trial (including the padded data) was filtered using a second-order Butterworth low-pass filter with a cutoff frequency of 2.5 Hz. Acceleration was calculated using the equation (16),

$$Ay_i = \frac{y_{i+1} - 2y_i + y_{i-1}}{\Delta t^2}$$

where Ay_i is the acceleration in the vertical (y) direction at the i th frame, y is the position of the center of the barbell, i is the frame number, and t is the time interval (i.e., 1/32 of a second).

Statistical Analyses

For EMG, spine position, and spinal/muscular loading, a 2-way repeated-measures analysis of variance was performed independently for each variable (within-factors direction: 2 levels; exercise: 3 levels, $\alpha = 0.05$), followed by a least squared mean post hoc analysis in which a significant main effect and interaction differences were found. Because of camera difficulties, one subject's joint compression and anterior/posterior shear data were left out of the statistical analysis.

RESULTS

Example of a Force Recording

An example of the force measured from both hands during the inverted row is illustrated in Figure 2. The first and fourth vertical line represents the section of the trial analyzed (the second repetition of the performed set). The first vertical line represents the initiation of the person pulling his upper body (using his knees as the fulcrum) toward his hands. The second vertical line represents the point in time at which the participant reached a maximum height for the pull and held the position until the third vertical line, at which the participant initiated the descent back to the bottom with his arms fully extended (represented by the fourth line). Peak force occurred at the initiation of the pull upward and was reduced gradually until the person reached his maximum height; it then increased until the person was back at the bottom (starting) position.

Comparison of Peak Muscle Activation

Neither the exercise completed nor the direction of the pull had a significant effect on the activation of the RRA, LRA, and REO muscles. However, the LEO had significantly higher muscle activation during the 1-armed cable row at 9.3% MVC than both the bent-over row and the inverted row, which were observed to be 4.2 and 3.8% MVC, respectively ($F = 7.29, p = 0.0085$). There were no differences observed between the inverted row and standing bent-over row (see Figure 3 and 4). The LEO had significantly higher activation levels during the up phase of all exercises at 6.3% MVC compared with the down phase at 5.2% MVC ($F = 6.22, p = 0.0469$). There were no significant differences found for the left LIO's level of activation between exercises and within the up-down phases of all exercises. The RIO activation level measured during the 1-armed cable row was 20.8% MVC, which was significantly larger than that produced during the

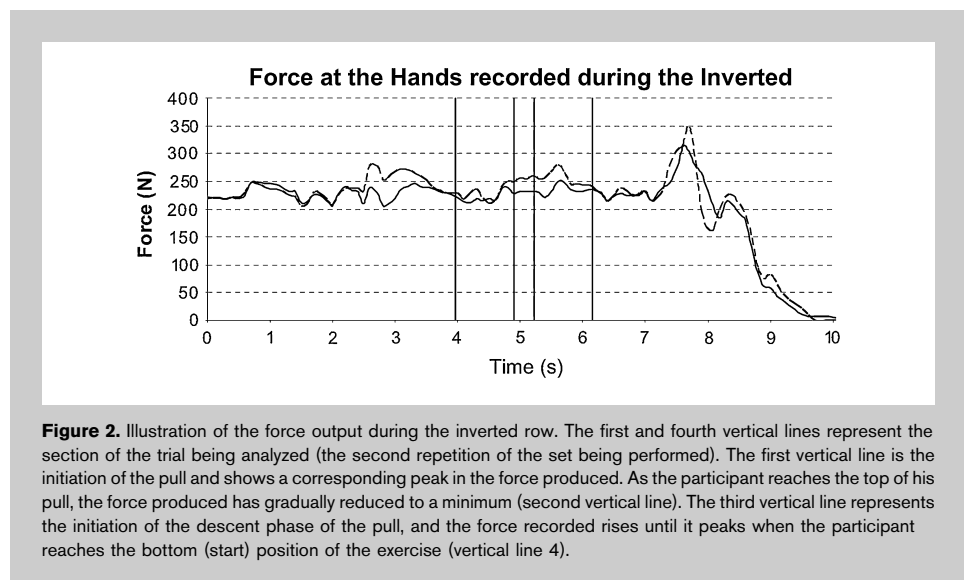


Figure 2. Illustration of the force output during the inverted row. The first and fourth vertical lines represent the section of the trial being analyzed (the second repetition of the set being performed). The first vertical line is the initiation of the pull and shows a corresponding peak in the force produced. As the participant reaches the top of his pull, the force produced has gradually reduced to a minimum (second vertical line). The third vertical line represents the initiation of the descent phase of the pull, and the force recorded rises until it peaks when the participant reaches the bottom (start) position of the exercise (vertical line 4).

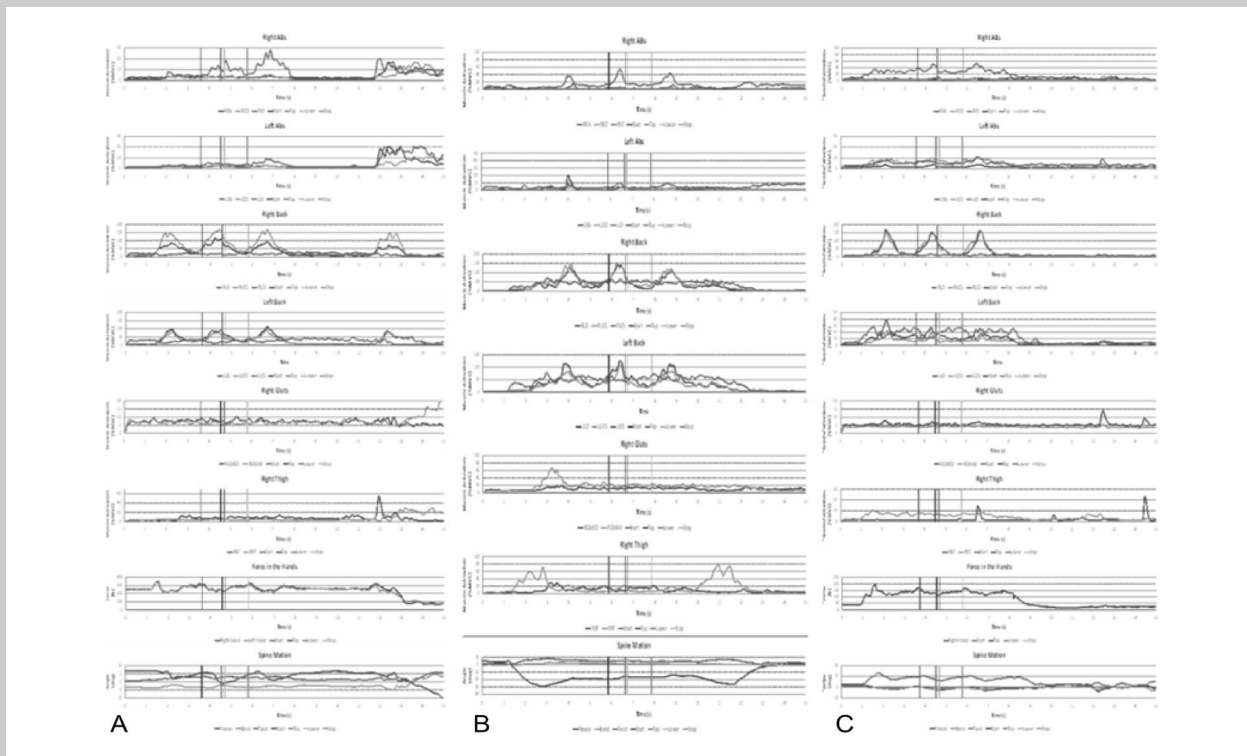


Figure 3. Illustration of a typical time history for the A) inverted row, B) standing bent-over row, and C) 1-armed cable row. The vertical lines represent the section of the time history used for analysis during each event.

inverted row and standing bent-over row at 12.0 and 13.3% MVC, respectively, as shown in Figure 4 ($F = 6.54, p = 0.0120$).

The RLD activation level during the up phases of all 3 exercises was 82.2% MVC, which was significantly larger than the down phase at 53.8% MVC ($F = 7.72, p = 0.0320$). On the left side, there was an interaction between the exercises and the direction of pull (up or down) for the LLD. The up phase of the inverted row produced a muscle activation in the LLD of 64.8% MVC, which was significantly higher than its down phase at 44.1% MVC as well as the up phase for both the standing bent-over row at 53.4% MVC and the 1-armed cable row at 15.4% MVC. The muscle activation during the inverted row's down phase was significantly higher than both of the down phases for the bent-over row and the 1-armed cable row, which were 29.9 and 10.9% MVC, respectively ($F = 5.85, p = 0.0190$). Muscle activation was significantly higher during the up phase of the bent-over row compared with its down phase as well as the up phase for the 1-armed cable row; similarly, the down phase of the standing bent-over row was significantly higher than the down phase of the cable row ($F = 5.85, p = 0.0190$). The muscle activation levels during the up and down phases of the 1-armed cable row were not significantly different.

There were no significant differences found in the muscle activation levels of the RUES. Conversely, muscle activation

for the LUES was affected by the interaction of the exercise performed and the direction of pull. The up phase of the inverted row had significantly higher muscle activation levels at 90.9% MVC than its down phase at 54.2% MVC as well as the up phase for both the standing bent-over row and the 1-armed cable row at 72.8 and 14.8% MVC, respectively. The inverted row's down phase had significantly higher activation than the down phase for the 1-armed cable row at 10.2% MVC, but it was not significantly different than the down phase of the bent-over row at 54.1% MVC ($F = 5.95, p = 0.0160$). Muscle activation was significantly higher during the up phase of the bent-over row compared with its down phase as well as the up phase for the 1-armed cable row; similarly, the down phase of the standing bent-over row was significantly higher than the down phase of the cable row ($F = 5.95, p = 0.0160$). The muscle activation levels during the up and down phases of the 1-armed cable row were not significantly different for the LUES muscle.

During the standing bent-over row, the activation levels of the RLES and LLES muscles were 42.5 and 43.3% MVC, respectively, which was significantly larger than those observed during the inverted row at 29.9 and 28.7% MVC and the 1-armed cable row at 17.3 and 14.7% MVC (right: $F = 15.75, p = 0.0004$; left: $F = 28.81, p < 0.0001$). Also, the inverted row produced significantly higher levels of muscle

activation than the 1-armed cable row, as illustrated in Figure 4 (right: $F = 16.56, p = 0.0004$; left: $F = 28.81, p < 0.0001$).

For the inverted row, the RGMAX activation was 19.2% MVC, which was not significantly different than during the standing bent-over row at 19.0% MVC; however, both exercises produced significantly higher muscle activation levels than did the 1-armed cable row at 8.5% MVC ($F = 4.24, p = 0.0405$). Similarly, the inverted row produced an RGMED activation level of 19.9% MVC, which was not significantly different than that achieved during the standing bent-over row at 13.7% MVC but was significantly larger than that produced by the 1-armed cable row of 10.7% MVC (see Figure 4) ($F = 5.25, p = 0.0231$).

As shown in Figure 3, the activation of the RBF during the inverted row was 25.7% MVC, which was significantly higher than the standing bent-over row and 1-armed cable row at 12.5 and 1.9% MVC, respectively, and the standing bent-over row was significantly larger than that of the 1-armed cable row ($F = 29.14, p < 0.0001$).

The activation level of the RRF (see Figure 4) observed during the 1-armed cable row was 11.5% MVC and was not significantly different than that observed during the standing bent-over row at 8.2% MVC, but it was significantly larger than the activation levels observed during the inverted row at 2.7% MVC ($F = 5.21, p = 0.0235$).

Comparison of Raw and Normalized Spine Position

Spine motion along the flexion/extension axis was affected by what exercise was performed (see Figure 5A). Both the inverted row and 1-armed cable row at angles of 2.8° of extension and 2.8° of flexion were not significantly different than each other, but they were significantly less flexed than

the angle recorded during the standing bent-over row of 22.9° of flexion ($F = 27.20, p < 0.0001$). However, when spine angle was normalized to the participants' maximum range of motion, both the standing bent-over row (42.9%) and the inverted row (34.8%) were closer to their end ranges of flexion and extension motion, respectively, than the 1-armed cable row (8.6%), as illustrated in Figure 5B ($F = 5.10, p = 0.0249$).

Raw and normalized peak spine position along the lateral bend axis was not affected significantly by exercise, direction of pull, or a combination of both.

An interaction between the exercise performed and the direction of pull affected the spine motion about the twist axis. A measured twist angle of 7.6° during the 1-armed cable row while pulling up was significantly larger than its lowering downward twist angle of 6.9° as well as the inverted row and standing bent-over row upward twist angle at 2 and 3.2°, respectively ($F = 4.23, p = 0.0407$). Also, the twist angle of the cable row during the down phase was significantly larger than the twist angles measured for the down phases of the inverted row (2.3°) and the standing bent-over row (3.3°; $F = 4.23, p = 0.0407$). The twist angles measured for the bent-over row during both the up and down phases were significantly larger than those of the respective twist angles measured during the inverted row, but no differences were found within both exercises ($F = 4.23, p = 0.0407$). However, when the spine angles were normalized to their maximum range of motion, the 1-armed cable row produced a twisting motion that was 67.7% of the maximum. As illustrated in Figure 4B, this percentage was significantly larger than the inverted and standing bent-over rows' normalized twist angles of 19.3 and 25.2%, respectively ($F = 14.26, p = 0.0007$).

Comparison of Spinal Loading and Stiffness

The standing bent-over row had significantly higher compressive forces measured at 3576 N than the 1-armed cable row at 2457 N and the inverted row at 2339 N (see Figure 6) ($F = 60.61, p < 0.0001$).

There were no significant differences in the L4/L5 joint's anterior/posterior shear for all exercises.

The muscle contribution to the medial/lateral shear (absolute values) of the L4/L5 joint was affected by an interaction between the exercise performed and the direction of the pulling action. The shear force calculated for the cable row during the up phase at 130 N was

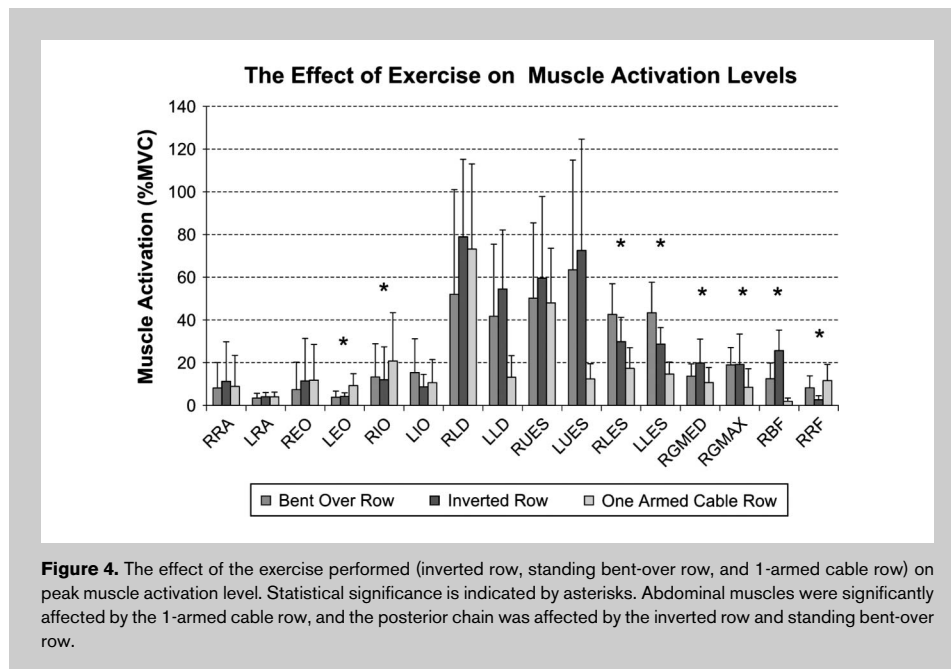


Figure 4. The effect of the exercise performed (inverted row, standing bent-over row, and 1-armed cable row) on peak muscle activation level. Statistical significance is indicated by asterisks. Abdominal muscles were significantly affected by the 1-armed cable row, and the posterior chain was affected by the inverted row and standing bent-over row.

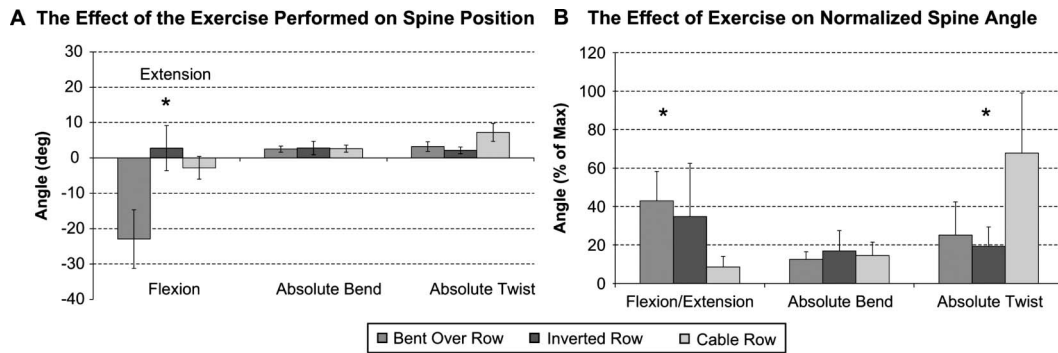


Figure 5. The effect exercise had on A) raw spine angle and B) normalized spine angle. During the standing bent-over row, participants are significantly more flexed than during the inverted and 1-armed cable row. However, the normalized extension during the inverted row and normalized twist during the 1-armed cable row are closer to their end ranges of motion than the raw spine angles would suggest.

significantly larger than its down phase at 103 N as well as the up phases of the standing bent-over row at 87 N and the inverted row at 76 N ($F = 8.33, p = 0.0054$). The 1-armed cable row and the standing bent-over row (94 N) during both down phases are significantly larger than the down phase of the inverted row at 79 N ($F = 8.33, p = 0.0054$).

The flexor muscular stiffness calculated for the standing bent-over row at $3244 \text{ N}\cdot\text{m}\cdot\text{rad}^{-1}$ was significantly larger than that of the inverted row at $2515 \text{ N}\cdot\text{m}\cdot\text{rad}^{-1}$, and both the standing bent-over row and the inverted row were significantly larger than that of the 1-armed cable row at $2077 \text{ N}\cdot\text{m}\cdot\text{rad}^{-1}$ (see Figure 7) ($F = 27.43, p < 0.0001$).

The axial muscular stiffness values for the up phase of all exercises ($1814 \text{ N}\cdot\text{m}\cdot\text{rad}^{-1}$) were significantly larger than those calculated for the down phase ($1556 \text{ N}\cdot\text{m}\cdot\text{rad}^{-1}; F = 9.85, p = 0.0201$).

DISCUSSION

Inverted rows spare the back with more neutral spine angles and may be more appropriate for those who have less tolerance to spine motion and load. The compression and anterior/posterior shear forces measured during the inverted row were similar to those estimated during the leg and contralateral arm extensions (birddog), as reported by Callaghan et al. (4). The inverted row elicited higher activation of the thoracic erector spinae and the latissimus dorsi muscles compared with the birddog, and it also produced high activation of the RBF, RGMED, and RGMAX muscles. However, while performing the inverted row, there is much higher activation in the upper thoracic than the lower lumbar erector spinae. This asymmetry in thoracic and lumbar muscle activation may develop an overpowered upper back relative to the lower back (11). Although this may be beneficial in some people because the lower activation level of the lumbar erector spinae reduces the lumbar spine load, it may be contraindicated for

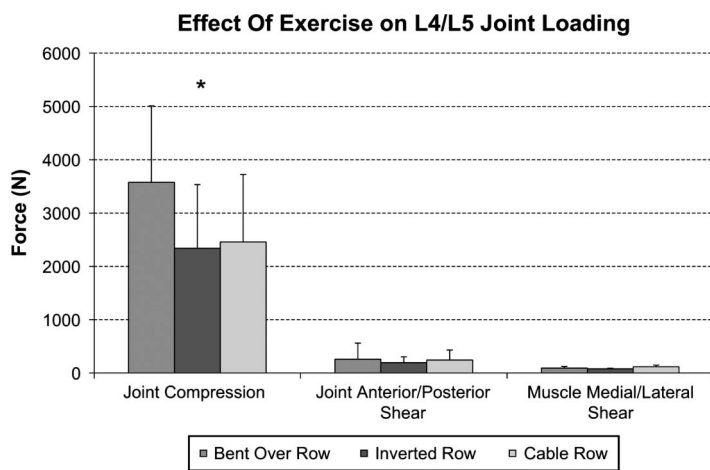
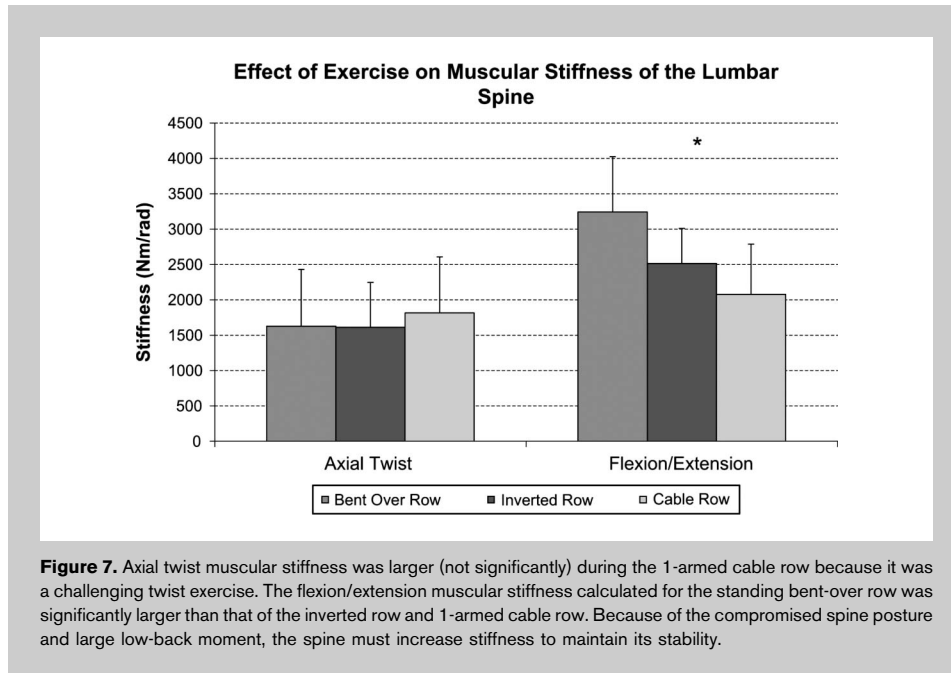


Figure 6. The joint compression measured during the standing bent-over row was significantly larger than that measured during the inverted row and 1-armed cable row. The compromised spine angle and the large moment caused by the load in the hand contributed to the high joint compression.



others. For example, Reeves and Cholewicki (15) found imbalances in activation amplitude between the lumbar and thoracic extensor muscles as markers of those who have a history of low-back injury. This observation suggests that the inverted row may be more appropriate for some individuals, but not all, who require reduced low-back loads. Furthermore, the inverted row did not seem to challenge the anterior musculature, including the abdominals and RRF. Therefore, by having the body suspended with feet on the ground and knees bent at 90°, there is already a considerably large flexor reaction torque created by the mass of the torso, which requires an extensor restorative torque to keep the spine neutral. However, most participants seemed to overcompensate for this torque by hiking their lumbar spines well into the extension range of motion capacity. This observation suggests that by extending the lumbar spine, a better force-length relationship of the erector muscles may be achieved, or that people are able to rest on the passive tissues of the spine, as opposed to the higher energy cost of larger back extensor activation with abdominal bracing during a neutral spine posture. It may be a control strategy by which it is simply easier to drive the spine into an end-range position so that the muscles do not need to control. Adams et al. (1) observed that damage to the lumbar spine occurred in vitro at a small extension angle combined with low spine compression (as low as 500 N). Therefore, to spare the spine, it is critical for a trainer to ensure that proper technique is followed and that posture is impeccable.

The standing bent-over row resulted in the highest spine compression and the largest amount of spine flexion. The standing bent-over row challenged the flexion/extension muscle stiffness capabilities significantly more than the

inverted row and 1-armed cable row. This result is attributable to the compromised spine position in combination with the barbell creating a large external moment on the lumbar spine. Muscle activation was similar to that of the inverted row but did not show asymmetrical activation of the thoracic and lumbar erector spinae. Therefore, the load in the hand created a large flexor torque that the thoracic and lumbar erector spinae muscles had to correct for, resulting in increased muscle stiffness that stabilized the lumbar spine.

The 1-armed cable pull clearly created a torsional challenge and, in turn, produced the largest challenge to the axial twist muscular stiffness. This

torsional challenge is expensive in terms of spine load, given the relatively higher compressive force resulting from the cocontraction of both sides of the trunk musculature to resist the trunk from rotating. However, even though the participants were instructed to maintain neutral spines, the normalized measured twist displacement was significantly larger than in the inverted row or in the standing bent-over row. On average, each person peaked at 70% of his twist motion capacity. This finding strengthens the notion about being relentless on maintaining form, because this twisting was very small from an observational point of view yet very large in terms of the total in vivo capacity for twist.

One limitation of this study is that it did not evaluate participants with low-back pain or athletes who might have been better at activating muscles. However, it is suggested that the inverted row can offer a challenging extensor chain exercise with lumbar spine loading similar to what would occur in exercises prescribed for low-back pain patients in rehabilitation programs.

PRACTICAL APPLICATIONS

The objective of core exercises is to challenge the trunk musculature (abdominals and back) and enhance the stability of the torso and lumbar spine. However, some exercises may be better for rehabilitation (modest muscle activation with low spine load), and others might be better for athletic/performance training (higher muscle activation resulting in larger spine load) in which large spine load is inevitable. When prescribing torso exercises, features such as muscle activation level and spine posture must be matched to the training goals and injury history. The data in this study suggest that if a client or athlete is prone to having low-back trouble,

the inverted row could be considered, given the very modest lumbar spine load. On the other hand, the thoracic and upper-back musculature is more substantially challenged. For those seeking more balance between activation of the thoracic and lumbar erector spinae muscles, other exercises could be used to train the lumbar erector muscles; while maintaining low spine loads, the birddog (4) exercise has been shown to be preferable. The standing bent-over row elicited large muscle activation of both the upper and lower back. Thus, for a client or athlete for whom back loading is not a concern, the standing bent-over row exercise may be preferred (being mindful of maintaining the neutral spine curve, which ensures the spine will maintain the highest tolerance level) (11). When designing a program to train isometric torsional endurance or strength of the trunk musculature, the 1-armed cable row may be considered. Note that the data presented here produced axial twisting torque without any actual torso twisting. The purpose of this exercise was to challenge the torso muscles in their ability to resist twisting the upper body, not to train the twisting motion of the torso.

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