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Muscle activity and spine load during pulling exercises: Influence of stable and labile contact surfaces and technique coaching

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ABSTRACT

This study examined pulling exercises performed on stable surfaces and unstable suspension straps. Specific questions included: which exercises challenged particular muscles, what was the magnitude of resulting spine load, and did technique coaching influence results. Fourteen males performed pulling tasks while muscle activity, external force, and 3D body segment motion were recorded. These data were processed and input to a sophisticated and anatomically detailed 3D model that used muscle activity and body segment kinematics to estimate muscle force, in this way the model was sensitive to each individual's choice of motor control for each task. Muscle forces and linked segment joint loads were used to calculate spine loads. There were gradations of muscle activity and spine load characteristics to every task. It appears that suspension straps alter muscle activity less in pulling exercises, compared to studies reporting on pushing exercises. The chin-up and pull-up exercises created the highest spine load as they required the highest muscle activation, despite the body "hanging" under tractioning gravitational load. Coaching shoulder centration through retraction increased spine loading but undoubtedly adds proximal stiffness. An exercise atlas of spine compression was constructed to help with the decision making process of exercise choice for an individual.

1. Introduction

Pulling movements are recognized as a fundamental category of human movement (Santana, 2000). As a common functional daily activity, they are inherent in any well rounded training program. Given the need to provide guidance to those who must prepare pulling ability, we were motivated to investigate basic mechanics of pulling using both stable and labile hand contact surfaces.

There have been several studies of pulling exercises that have described technique (Graham, 2001, 2004; Pierce, 1998) and only one that has addressed estimates of joint load based on muscle activation levels (Fenwick et al., 2009). However, as far as the authors are aware, there are no studies evaluating the ability of technique coaching to influence muscle activity and spine load; other than a conjunct study evaluating pushing exercises (McGill et al., 2014). It is clear that the muscles of the torso generate force to create three-dimensional moments that work to both initiate and prevent motion. Interestingly, comparisons of the mechanics of pulling and pushing through the shoulder, back, and chest complex, revealed that while the peak force production was slightly lower in pulling than pushing, power output and torso movement velocity was substantially higher in maximal effort pulling (Pearson et al., 2009). When performing isometric contractions these muscle efforts contribute stiffness to stabilize the torso and the spine. Stiffness and hence stability enhances two elements. First, a stiffer spine is more resilient to buckling allowing it to safely bear more load. Second, proximal stiffness (i.e. stiffness proximal to the shoulder and hip) fixates the proximal attachment of any muscle crossing the hips or shoulders so that the mechanical effect is focused on the distal attachment, creating faster limb movements with more power in the arms and legs (McGill, 2014). Pulling exercises have been shown to qualify as a justifiable torso training exercise to meet these objectives (Fenwick et al., 2009).

The use of labile (movable) surfaces underneath the subject for stability training is becoming more popular (Anderson and Behm, 2005). In particular, the use of suspension straps are used in training centers and adapted to create resistance training in a wide variety of challenges. The objective of this study was to investigate mechanisms associated with various pulling exercises by quantifying muscle activation patterns and calculating the resultant spine

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load using both stable and labile contact surfaces. Specifically, several issues were investigated:

(1) Comparison of demands resulting from stable (i.e. from a fixed surface) vs. labile surfaces (i.e. using a suspension strap training system) for pulling exercises. It was hypothesized that the use of labile surfaces would increase muscle activation and spine load.
(2) The influence of coaching on the outcome measure of muscle activation and spine position, the hypothesis being that technique coaching of exercises would result in participants adopting a more neutral spine posture throughout the movement.
(3) One-armed rows vs. "Ghost" rows. The ghost row only uses one arm to perform the pull while the contralateral arm mimics the motion pattern of a two-handed row. Thus, it has the potential to eliminate injurious motion patterns (i.e. axial twist about the lumbar spine) often observed in unilateral exercises (such as the one-arm row). It was hypothesized that the ghost row would result in a more neutral spine posture than the one-arm row.

2. Methods

2.1. Participants

Fourteen male participants, mean (SD) age 21.1 years (2.0), height 1.77 m (0.06) and weight 74.6 kg (7.8), were recruited from the university population as they are readily available for participation, were healthy with no previous history of disabling back or musculoskeletal pain, were all familiar with resistance training techniques, and thus comprised a convenience sample for this study. The study was approved by the Office of Human Ethics at the University, and all participants signed an informed consent form.

2.2. Instrumentation

Each participant was instrumented with electromyography electrodes monitoring muscle activity together with markers for 3D body segment movement tracking. Forces at the hands (via a force transducer) and feet (via force plates) were collected. These data were processed and input to a sophisticated and anatomically detailed 3D model that used muscle activity and body segment kinematics to estimate muscle force (see Fig. 1). In this way the model was sensitive to the individual choice of motor control selected by each person and for each task. Muscle forces and linked segment joint loads were used to calculate spine loads. Pulling exercises involving a labile contact surface were done so with TRX suspension straps (TRX Fitness Anywhere, CA, USA). The force transducer, a series load cell (Transducer Techniques, CA, USA) was attached in series with the TRX suspension straps during exercises utilizing the straps.

2.2.1. Electromyography (EMG)

Fifteen channels of EMG were collected by placing electrode pairs over the following muscles on the right side of the body: rectus abdominis (RRA): 3 cm lateral to the navel; external oblique (REO): approximately 3 cm lateral to the linea semilunaris at the same level as the RRA electrodes; internal oblique (RIO): at the level of the anterior superior iliac spine and medial to the linea semilunaris, but superior to the inguinal ligament; latissimus dorsi (RLD): inferior to the scapula over the muscle belly when the arm was positioned in the shoulder mid-range; upper (thoracic) erector spinae (RUES): 5 cm lateral to the spinous process of T9; lumbar erector spinae (RLES): 3 cm lateral to the spinous process of L3; rectus femoris (RRF): midway between the patella and the anterior superior iliac spine over the belly of the muscle; gluteus maximus (RGMAX): approximately 6 cm lateral to the intergluteal cleft; gluteus medius (RGMED): approximately 5 cm lateral to the posterior inferior iliac spine; biceps brachii (BIC): with the elbow flexed at 90°, ⅔ of the way down the anterior aspect of the upper arm between the acromion process and the cubital fossa; triceps brachii (TRI): posterior aspect of the upper arm at the same level as BIC; anterior deltoid (ANTDELT): with the shoulder flexed to 90°, approximately 3 cm inferior to the acromion process; upper trapezius (TRAP): midway between the acromion and C7; pectoralis major (PECMAJ): with the arm abducted and elbow flexed to 90°, midway between the axilla and the areola; serratus anterior (SERRANT): with the arm abducted and elbow flexed to 90°, over the attachment to the 7th rib. Before the electrodes were adhered to the skin, the skin was shaved and cleansed with Nuprep™ abrasive skin prepping gel. Ag–AgCl surface electrode pairs were positioned with an inter-electrode distance of approximately 2.5 cm and were oriented in series, parallel to the muscle fibers. The EMG signal was amplified and analog to digital converted with a 16-bit converter at a sample rate of 2160 Hz using the VICON Nexus™ (Los Angeles, CA, USA) motion capture system software. Though multiple muscles were collected, not all were incorporated into the modeling analysis (see Section 2.4.2 below).

Each participant performed a maximal voluntary isometric contraction (MVC) of each muscle for normalization (after Brown and McGill (2009)). These normalization techniques have been developed over 30 years in our lab to achieve isometric activation in ways that minimize the risk of back injury and muscle avulsion. Dynamic contractions create higher levels of motor unit activity according to known force–velocity relationships – these are incorporated into the modeling approach to estimate muscle force. Specifically, for the abdominal muscles (RRA, REO, RIO), participants adopted a sit up posture with the torso at approximately 45° to the horizontal with the knees and hips flexed at 90°. Manually braced by a research assistant, the participant was instructed to produce a maximal isometric flexion moment followed sequentially by a right and left twisting moment and a right and left lateral bending moment. RLD was normalized to maximum activation achieved during the static phase at the top of the pullup exercise. For the spine extensors (RLES, RUES) and RGMAX, a resisted maximal extension in the Biering-Sorensen position was performed for normalization. RGMAX was cued to aid in extension at the hip. MVC for RRF involved the participant sitting on a therapy bed with his legs hanging over the edge. The participant grasped the edge of the bench behind him for support and performed a knee extension and hip flexion moment while being resisted by a research assistant. RGMED trials were performed in a side lying position during hip abduction, together with cued hip external rotation and extension (i.e. a lateral straight leg raise). BIC MVCs were taken from a standing bilateral elbow flexion trial, resisted with straps that were secured to the ground at an angle that the participant felt he could elicit maximal muscle activation. The TRAP MVC trial made use of a set of straps similar to the BIC MVC; however, participants were instructed to perform a maximal shoulder elevation effort. The MVC protocol for TRI, ANTDELT, PECMAJ and SERRANT was done from a supine push effort. Straps were secured to the ground at the participant's head and adjusted to a length the participant felt he could achieve maximal activation. With the straps at full length, the elbows were slightly flexed from full extension. The push was done isometrically, with the triceps cued to extend the elbow at the top of the push. The maximal amplitude observed during the normalizing contraction for each muscle was taken as the maximal activation for that particular muscle.

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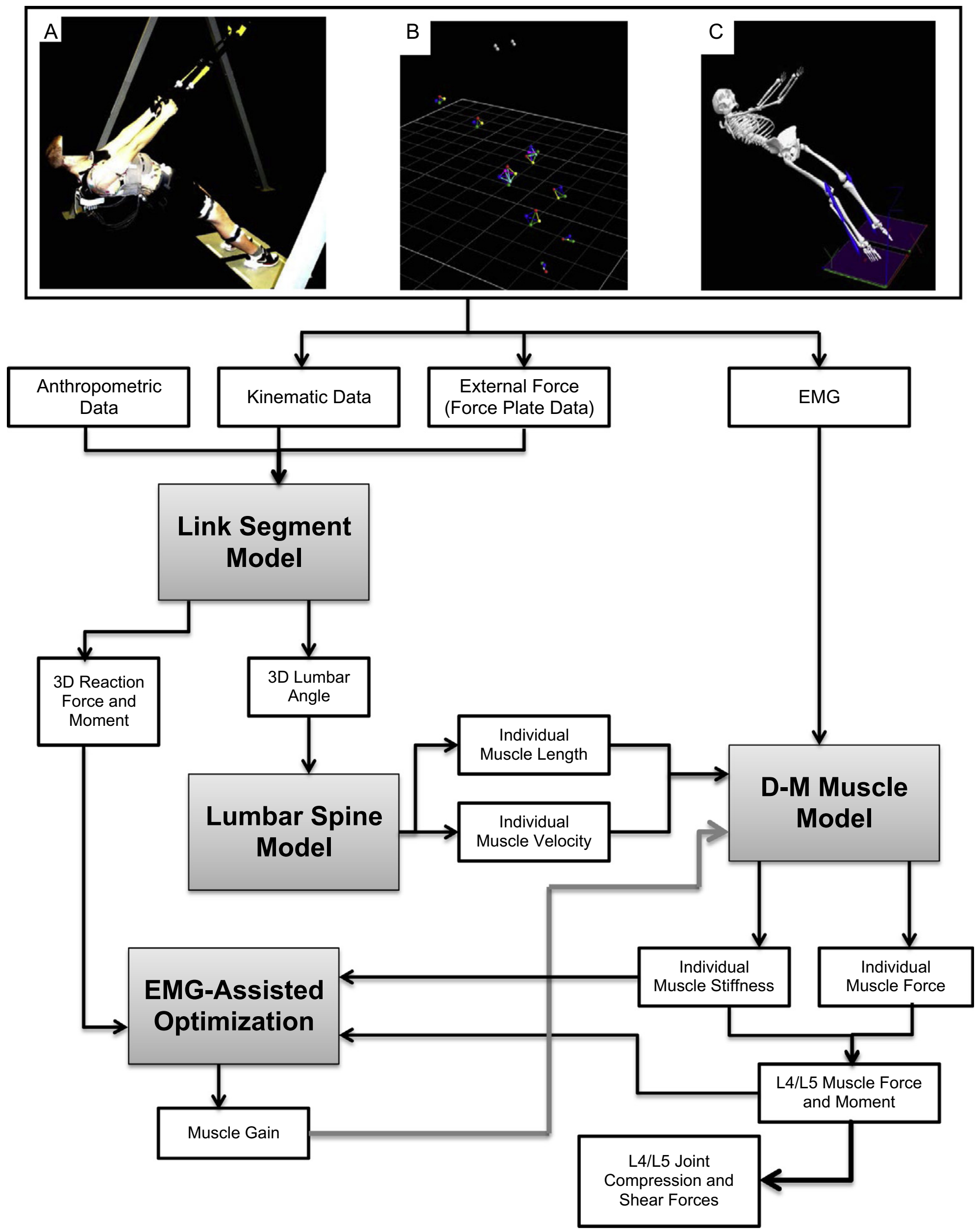

Fig. 1. Visualization of exercises using reflective markers for 3D kinematic analysis during: (A) Collection, (B) Vicon marker recognition, (C) Visual 3D reconstruction. Note the force vectors (arrows) projected from the feet through the body. The flow diagram shows the data collected from the participant and input to the EMG processor and link segment model. The vertebral angles drive the Lumbar Spine model that prepares muscle forces for the EMG optimization processor that balances predicted and measured moments.

2.2.2. Body segment kinematics and marker placement

Eighteen reflective markers for tracking linked segment kinematics were adhered to the skin with hypoallergenic tape over the following landmarks bilaterally: 1st metatarsal head, 5th metatarsal head, medial malleoli, lateral malleoli, medial femoral condyles, lateral femoral condyles, greater trochanters, lateral iliac crests and acromia. Ten rigid bodies molded from splinting material were adhered to the skin with hypoallergenic tape over the following areas: right and left feet, right and left shins, right and left thighs, sacrum, 3 cm medial to the right ASIS, inferior to the left scapula at the level of T12 and sternum. At least 4 reflective markers were adhered with tape to each rigid body (thigh clusters were comprised of 6 markers) (Fig. 1). The VICON Nexus™ (Los Angeles, CA, USA) motion capture system tracked the three-dimensional coordinates of the reflective markers during the various trials at a sample rate of 60 Hz.

2.2.3. Force plates for external force measurement and kinetic analysis

Force plate data were also collected at a rate of 2160 Hz. Where possible, participants placed either foot at a fixed position on separate force plates during the exercises (obviously pull ups did not involve floor mounted force plates).

2.3. Exercise description

Participants were asked to perform pulling exercises. A metronome set to 1 Hz (1 beat per second) was used to maintain consistent movements throughout all exercises. A research assistant counted out loud to help participants maintain a steady pace. Three repetitions of all exercises were performed. All exercises are shown in Fig. 2.

1. Chin up – from a vertical hanging position with an underhand grip, participants pulled themselves up over 2 beats so that their chin was even with the bar. They held that position at the top for 1 beat before descending back to their original position over 2 beats. Participants hung at the bottom for 1 beat.
2. Pull up – adopting an overhand grip, participants performed the same exercise as the chin up at the same pace.
3. Inverted row – hanging from a bar slightly higher than shoulder length from the ground with both feet on either force plate, participants pulled their bodies towards the bar over 1 beat so that their chest was 10 cm from the bar. They held their body position at the top for 2 beats before lowering over 1 beat and pausing at the bottom for 2 beats.
4. Stable shoulder retraction – beginning in the same position as the inverted row, participants were instructed to retract their shoulders and return to a hanging position. The pace this exercise was the same as the inverted row (i.e. 1 beat to move up, 2 beats pause at top, 1 beat to move down, 1 beat pause at bottom). This exercise was done with no instructions (not coached) and then repeated with cues to pull the scapulae down with the erectors of the spine, preventing movement of the scapulae and isolating the retraction to the humeri (coached).
5. TRX shoulder retraction – the retraction exercises (not coached and coached) were repeated with the TRX straps at angle 2 (see TRX pulls below).

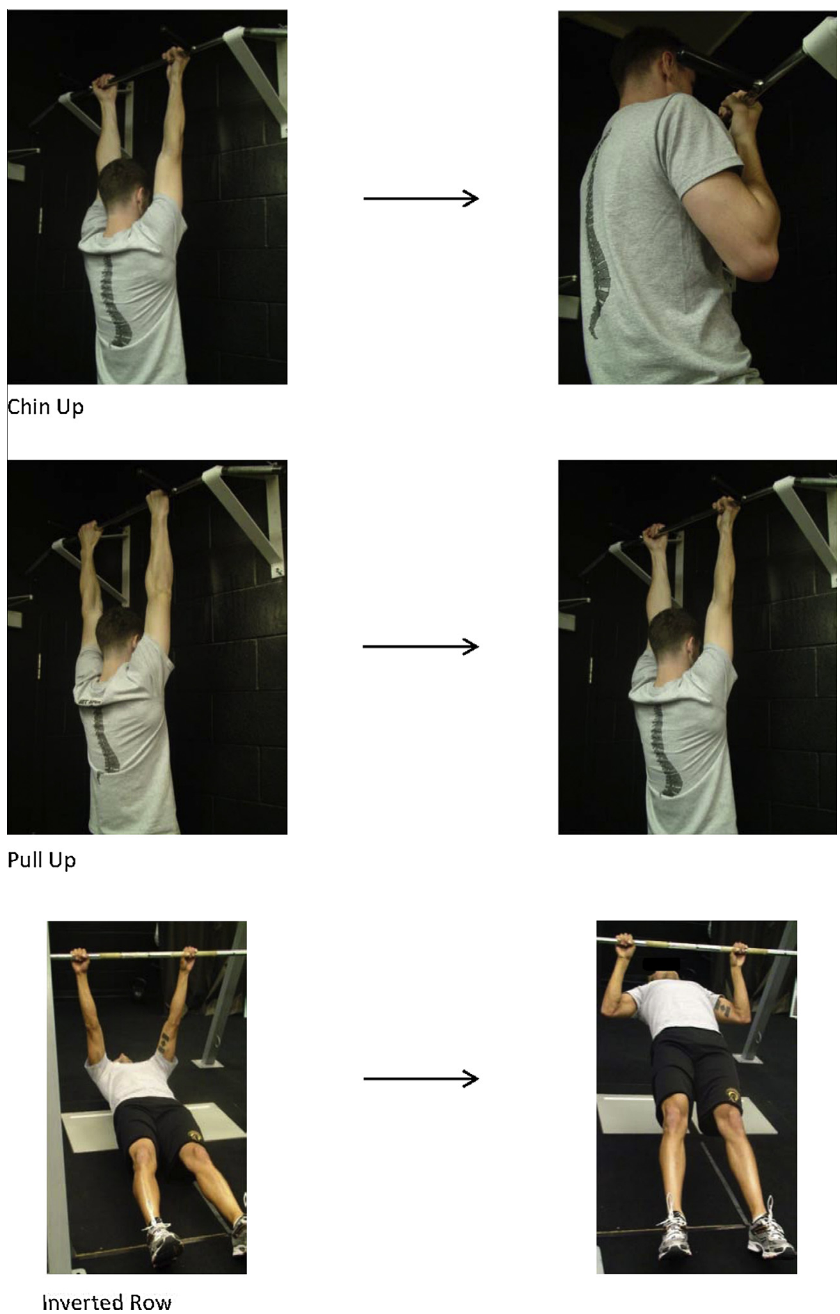

Fig. 2. Photographs of the exercises.

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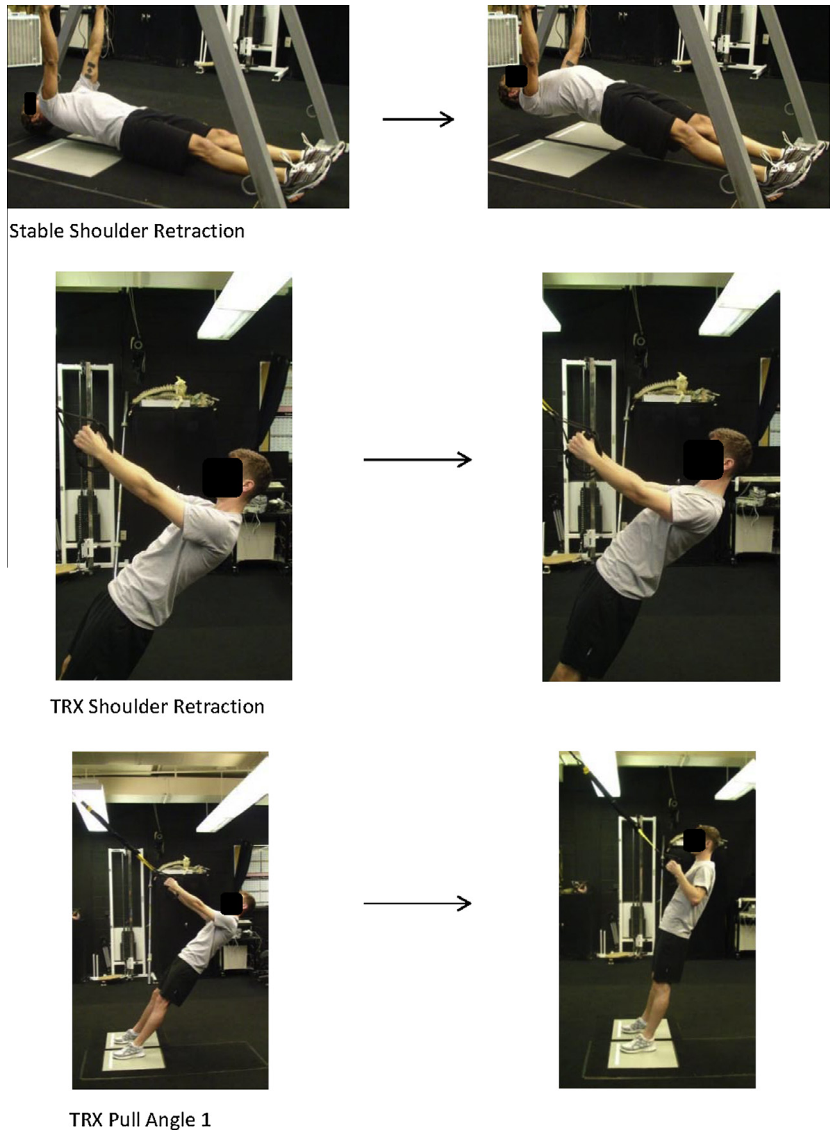

Fig. 2 (*continued*)

6. TRX pulls – with a TRX handle in either hand, participants performed an inverted standing row at 2 different strap lengths (angle 1 [shorter] and angle 2 [longer]) to the same pace as the inverted row. Since the feet were always placed at the same position on the force plates, the body angle and difficulty of the exercises were controlled by strap length.
7. TRX pull up – hanging from the TRX straps in the same position as the inverted row, participants repeated the movement for the inverted row at the same pace.
8. Powerpull – with one hand holding the TRX strap at angle 1 and the other reaching to the top of the straps, participants extended their arm and rotated their body to reach back towards the ground over 1 beat. Holding at the bottom for 2 beats, they then pulled themselves back up over 1 beat and held at the top for 2 beats. This exercise was done without any instruction (not coached) and then repeated with cues to prevent any twisting in the lumbar spine (coached). Participants were told to keep the ribs stationary with respect to the pelvis and rotate the torso using their hips. Both variations of the exercise were done on the left and right sides.
9. TRX ghost row – holding the TRX strap in one hand at angle 1, participants performed a row while mimicking the movement with the other hand. This exercise was done on both sides and performed at the same pace as the inverted row.
10. TRX one-arm row – performing the same movement at the same pace and angle as the TRX ghost row, participants placed their non-pulling arm on their hip for the TRX one-arm row.
11. TRX reverse fly – standing with arms straight hanging at angle 1 of the TRX straps, participants abducted and extended their arms to pull themselves forward to a straight standing position. The pace was the same as the inverted row.

Participants were taken through a familiarization process before data collection began. They were instructed on how to generally position themselves for each task and were provided the opportunity to try some of the exercises. Each exercise was thoroughly explained and demonstrated immediately before it was performed. The order of exercises was randomized with the exception of those that had specific instructions that might affect

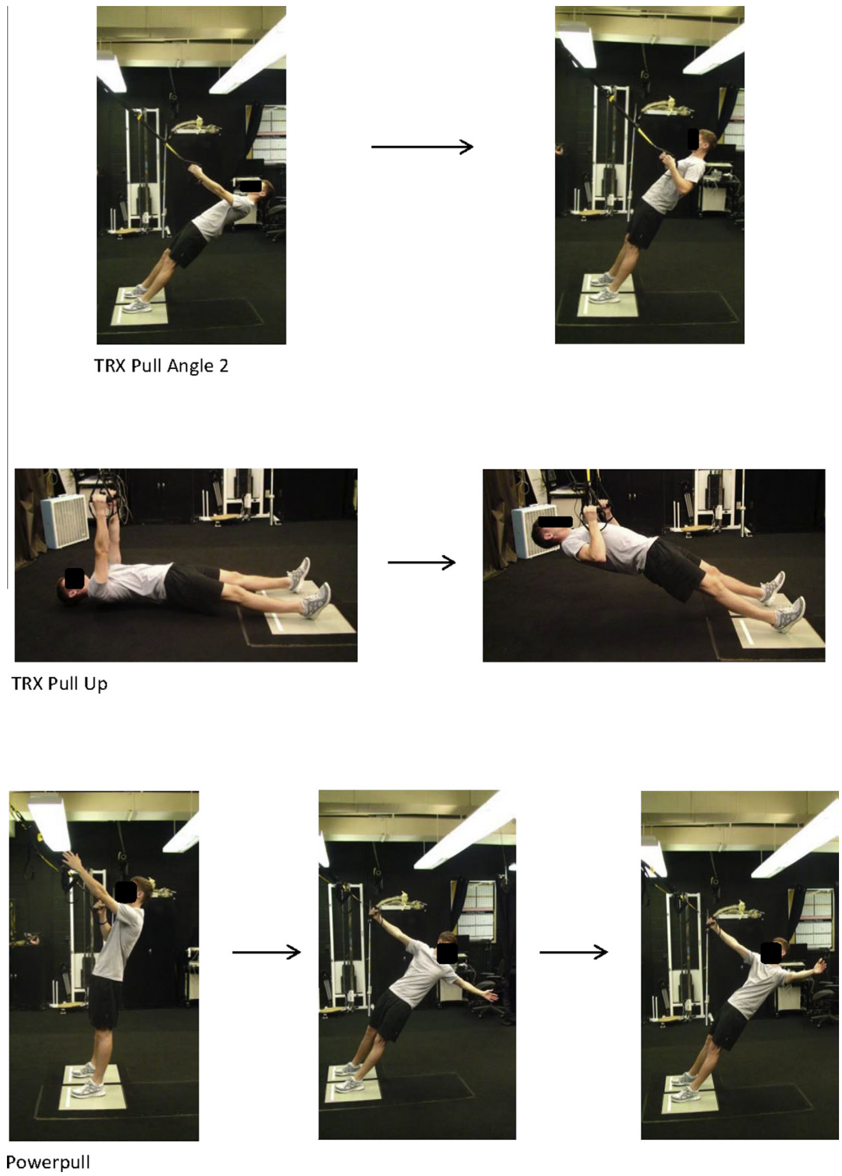

Fig. 2 (*continued*)

performance on another task (i.e. “coached” trials followed “not coached” trials).

2.4. Data analysis

2.4.1. EMG to capture muscle activation for the spine model

The EMG data were band pass filtered between 20 and 500 Hz (to reduce motion and EKG artifact after DeLuca (1997)), full wave rectified, low pass filtered with a second order Butterworth filter at a cut-off frequency of 2.5 Hz (to mimic the frequency response of torso muscle after Brereton and McGill (1998)), normalized to the maximal voluntary contraction of each muscle to enable physiological interpretation, and down sampled to 60 Hz using custom LabVIEW™ software.

2.4.2. Kinetic and Kinematic Data to predict back loads

The three-dimension coordinates of the markers were entered into a software package (Visual3D™, C-Motion, Germantown, MD, USA) which calculated the spine curvature angles as well as the reaction moments and forces about the lumbar spine (represented by the L4/L5 joint). Normalized EMG signals and lumbar spine position data were entered into an anatomically detailed model of the lumbar spine. Specifically, the modeling process proceeded in 4 stages:

1. The three-dimensional coordinates of the joint markers drove a linked segment model of the arms, legs and torso constructed with Visual3D™. This package output the lumbar spine postures described as three angles (flexion/extension, lateral bend and twist), bilateral hip angles and bilateral knee angles together with the reaction moments and forces about the L4–L5 joint.
2. The reaction forces from the link segment model above were input into a “Lumbar Spine model” that consists of an anatomically detailed, three-dimensional ribcage, pelvis/sacrum and 5 intervening vertebrae (Cholewicki and McGill, 1996). Over 100 laminae of muscle, together with passive tissues represented as a torsional lumped parameter stiffness element, were modeled about each axis. This model uses the measured 3D spine motion data and assigns the appropriate rotation to each

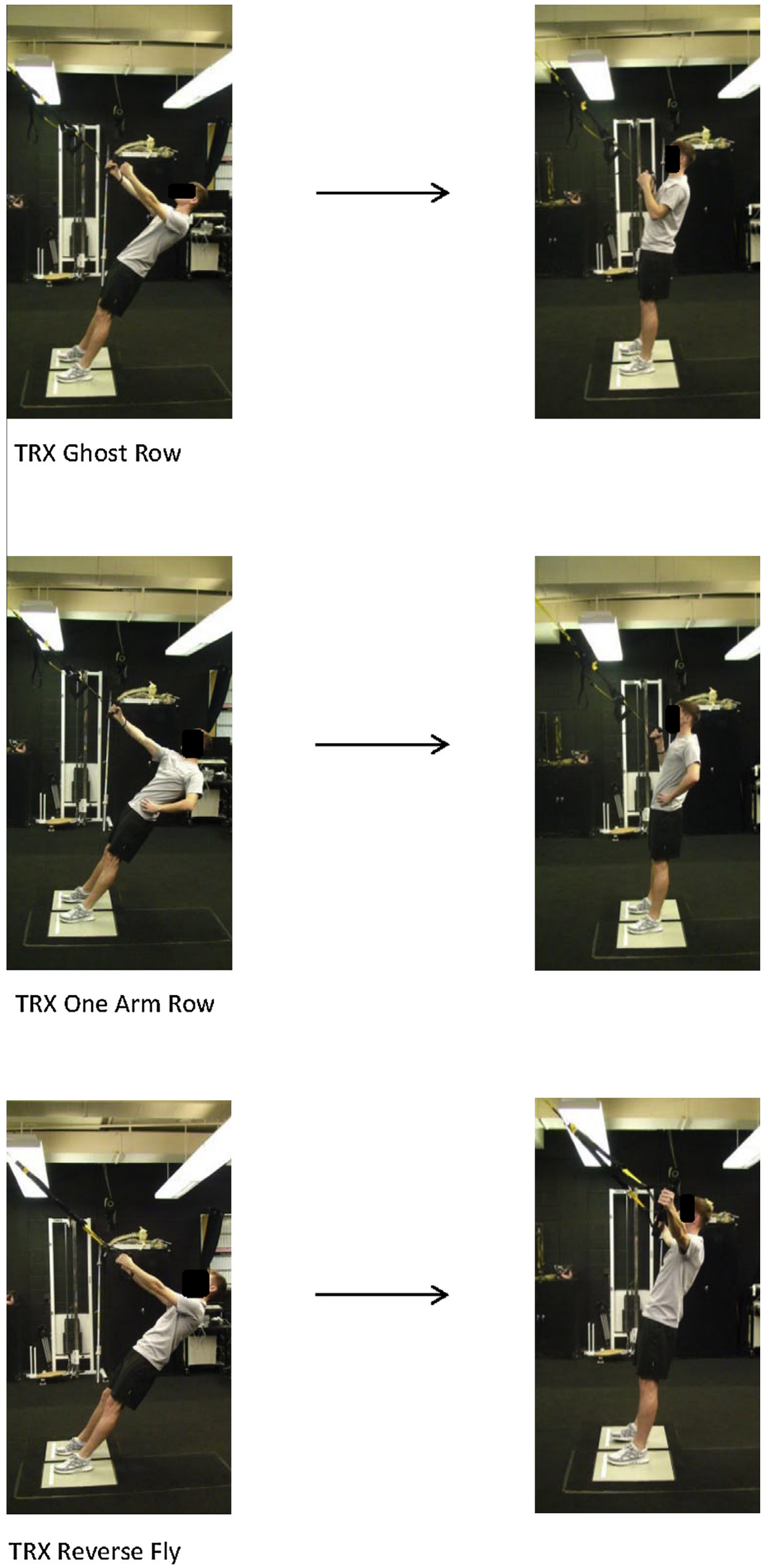

Fig. 2 (*continued*)

of the lumbar vertebral segments (after values obtained by White and Panjabi (1978)). Muscle lengths and velocities are determined from their motions and attachment points on the dynamic skeleton of which the motion is driven from the measured lumbar kinematics obtained from the participant. As well, the orientation of the vertebral segments along with

stress/strain relationships of the passive tissues were used to calculate the restorative moment created by the spinal ligaments and discs. Some recent updates to the model include a much improved representation of some muscles documented by (Grenier and McGill, 2007).
3. The third model, termed the "distribution-moment model" (McGill, 1992; McGill and Norman, 1986), was used to calculate the muscle force and stiffness profiles for each of the muscles. The model uses the normalized EMG profile of each muscle along with the calculated values of muscle length and velocity of contraction to calculate the active muscle force and any passive contribution from the parallel elastic components.
4. When input to the spine model, these muscle forces are used to calculate a moment for each of the 18 degrees of freedom of the 6 lumbar intervertebral joints. The optimization routine assigns an individual gain value to each muscle force in order to create a moment about the intervertebral joint that matches those calculated by the link segment model to achieve mathematical validity (Cholewicki and McGill, 1994). The objective function for the optimization routine is to match the moments with a minimal amount of change to the EMG driven force profiles. The adjusted muscle force and stiffness profiles are then used in the calculations of L4–L5 compression and shear forces.

In this way the model was sensitive to the different muscle activation strategies and movement patterns of each participant.

Averages of muscle activation (EMG), spine angles and L4/L5 compression forces (spine load) were calculated at 4 phases for the 3 repetitions of each exercise:

1. M1 – Midway between rest and the peak of the exercise, as the participant was pulling himself up; for torso exercises, the point where they were halfway through the movement.
2. P – At the peak of the exercise: this occurred at the top of the pull. An average was taken over the time that the participant held this position.
3. M2 – Midway between the peak and returning to a rested position, as the participant lowered himself toward the ground.
4. E – Rested position at the end of each exercise, the bottom of a pull. An average was taken over the time that the participant held this position.

2.5. Statistical analysis

Two separate one-way analyses of variance with Tukey post hoc procedures were used to determine the influence, and their sources, of exercise on spine compression and shear for select pull exercises (i.e. chin up; pull up; inverted row; TRX pull angles 1 and 2; TRX pull up; and TRX reverse fly). Compression data for the pull exercises analyzed, however, were not normally distributed, determined by Levene's test for equality of variance in SPSS Statistics 20.0 (IBM®). Consequently, the data were transformed using the natural logarithm and were then found to be normally distributed. An ANOVA was used to test the transformed data with Tukey post hoc procedures.

A one-way ANOVA with Tukey post hoc was used to determine differences in changes of spine angles from E to P for TRX pull at angle 2 and TRX shoulder retraction coached and not coached. These movements were compared because all three were performed at the same strap length (i.e. TRX pull angle 2).

Participants began the Powerpulls in the "up" position, with the pulling arm flexed at the elbow and the reaching arm touching the top of the straps. Since the coaching cues for these movements were directed towards limiting twist in the spine, 2 separate *t*-tests were used to determine the differences in P twist between coached and not coached variations of this exercise for both the left and right sides. The Mann–Whitney *U* test was used to determine differences in torso EMG (RLD, RUES, RLES, RRA, REO, RIO) during the P-phase between coached and not coached conditions for the left and right sides. This test was used because the data were not normally distributed, as determined by Levene's test in SPSS Statistics 20.0 (IBM®).

3. Results

3.1. Stable vs. labile

The exercise that resulted in the greatest spine compression was the pull up (2852 N), next was the chin up (2680 N) followed closely by the TRX pull up (2626 N) (Table 1). The pull up elicited the most spine shear of all the pull exercises and a significant effect of exercise on shear forces was found ($F(6,81) = 2.98$, $p = 0.01$). The statistically significant differences among the pull exercises analyzed were between the TRX reverse fly and the chin up ($p = 0.04$) and pull up ($p = 0.02$) (Fig. 3).

To reduce the effects of variability between participants when interpreting spine loads, ratios of compression and shear loads from the pull exercises were calculated with the inverted row as base. As shown in Fig. 4, the TRX pull up followed a trend in spine compression similar to that of the chin up and pull up. There was an increase in load as participants pulled themselves up, which peaked at the P-phase with greater load than the inverted row (i.e. the ratio was always greater than 1). Spine compression then decreased through M2 and reached a low value at E that was less than that of the inverted row. The other TRX pull exercises followed unique trends, with TRX angle 1 and the reverse fly never reaching more compression than the inverted row. TRX angle 2 compression was lowest as participants pulled themselves up (M1) and highest as they lowered themselves down (M2). Shear load ratios were more consistent with one another in their trends. All exercises produced the highest shear load at the bottom of the exercise (E) and decreased as the participants pulled themselves up (M1). Shear for every exercise except the TRX reverse fly then increased to the P-phase. The chin up, pull up and TRX pull up decreased in shear through M2 before increasing to E, while TRX pull angles 1 and 2 increased almost linearly from M1 to E.

Muscle activation of the back (RLD, RUES, RLES) during the TRX pull exercises increased as the body moved towards a horizontal position (i.e. angle 1 < angle 2 < TRX pull up). EMG of the back muscles during the TRX pull up was most comparable to the inverted row. Of all the pull exercises, the chin up and the pull up elicited the most abdominal muscle activation, most notably in RRA. The TRX reverse fly elicited little torso muscle activity (<20% on average) (Fig. 5).

3.2. Coaching

3.2.1. Retraction

Shoulder retraction from a stable surface placed participants in slight lumbar spine extension. Very little difference was observed in L4/L5 flexion angles between the inverted row and coached and not coached retraction tasks. TRX retraction exercises, on the other hand, produced different patterns in spine flexion between exercises. While the TRX pull from angle 2 remained consistent in spine angle throughout the movement (between 2 and 6 degrees of extension); shoulder retraction that was not coached moved participants from over 6 degrees of flexion in a hanging position (E) to almost 11 degrees of extension at the top of the movement (P). Coaching cues of setting the scapulae with the erectors of the spine attenuated the change in spine flexion; however, the

Table 1
Rank of mean spine compression at the P-phase of each exercise.

Exercise	Rank	Mean spine compression (*N*)	SD
Pull Up	1	2852	1339
Chin Up	2	2680	1327
TRX Pull Up	3	2627	1182
Inverted Row	4	2294	767
TRX Pull – Angle 2	5	2288	764
Stable Shoulder Retraction, Coached	6	2221	775
TRX Pull – Angle 1	7	2042	715
Stable Shoulder Retraction, Not Coached	8	1997	634
TRX Shoulder Retraction, Coached	9	1707	620
TRX Shoulder Retraction, Not Coached	10	1599	656
TRX Reverse Fly	11	1596	531

differences in the change of spine angle between E and P for each exercise were not significant ($p = 0.12$) (Fig. 6).

3.2.2. The Powerpull and the influence of coaching

Spine flexion and lateral bend were similar between the coached and not coached variations of the Powerpull (data not shown); however, twist angles at L4/L5 were substantially closer to neutral at the P-phase during the coached conditions compared to the not coached conditions for both the left ($t(18) = 2.87$, $p = 0.01$) and right ($t(18) = 3.45$, $p = 0.003$) sides. Muscle activation of the torso (RLD, RUES, RLES, RRA, REO and RIO) was very similar between the two variations. This shows that the muscular demand of the task can be accomplished while reducing exposure of twisting movements to the lumbar spine (Fig. 7).

3.3. TRX one-arm vs. ghost rows

Similar torso EMG profiles were observed between the TRX one-arm row and ghost row for both the left and right sides. The one-arm row exercises resulted in less change in spine flexion than the ghost rows; however, there was more change in spine twist with the one-arm rows. Lateral bend angles were similar between the two exercises and, as expected, were biased away from the side the participants were pulling (Fig. 8).

3.4. Exercise atlas

The sophisticated modeling approach facilitated the creation of an atlas listing exercises by rank. All exercises, where L4/L5 compression could be calculated, were ranked for spine load at the P-phase (see Table 1). The TRX pull at angle 2 produced almost identical load on the spine as the inverted row, with the pull at angle 1 (a more upright position) resulting in less load than these

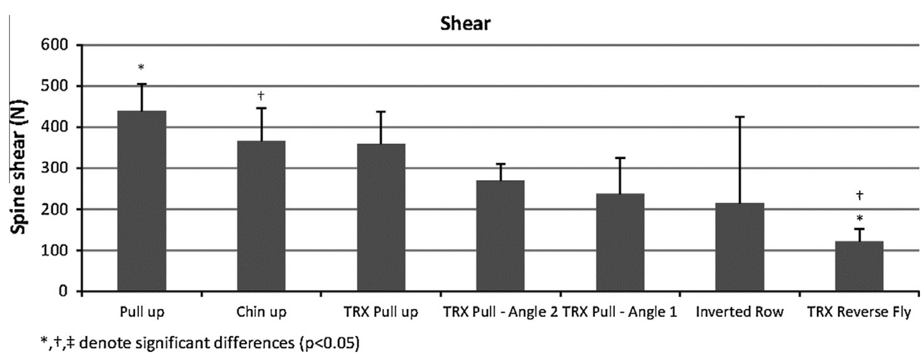

Fig. 3. Shear load of the spine during the P-phase of the pulling exercises.

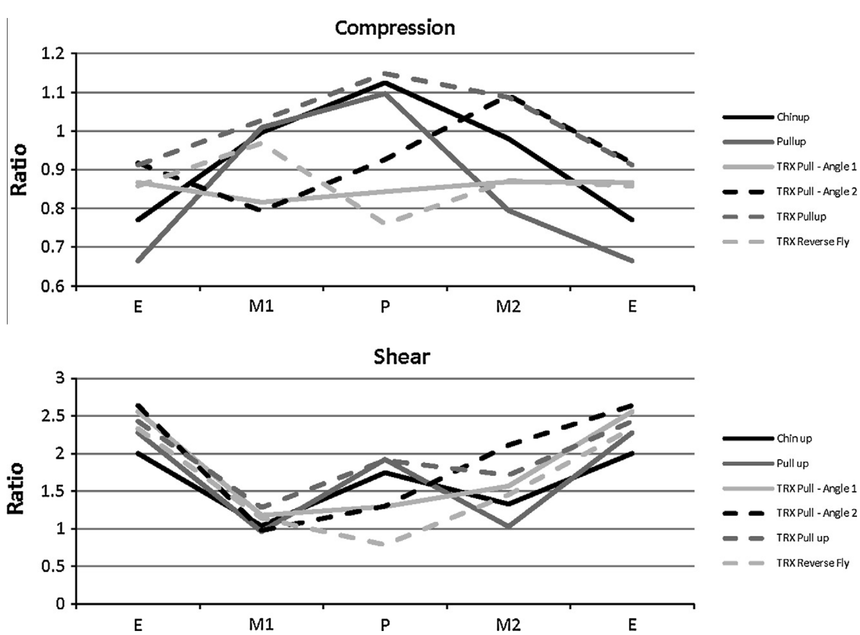

Fig. 4. Ratios of spine compression and shear were calculated using the inverted row as a base, for the comparison of pull exercises.

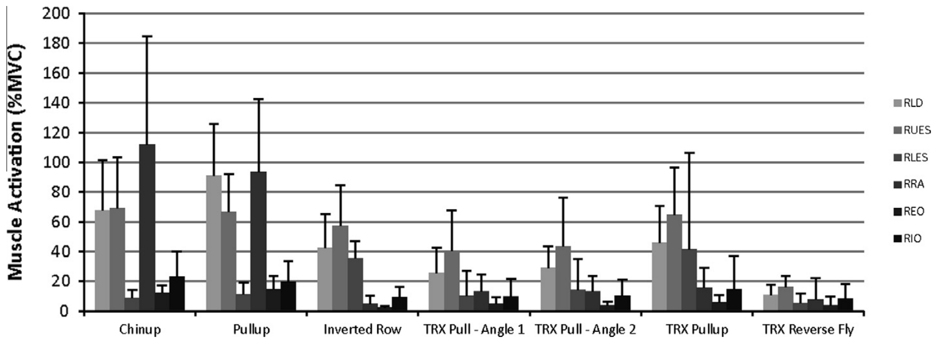

Fig. 5. Muscle activation profiles during the P-phase of pull exercises.

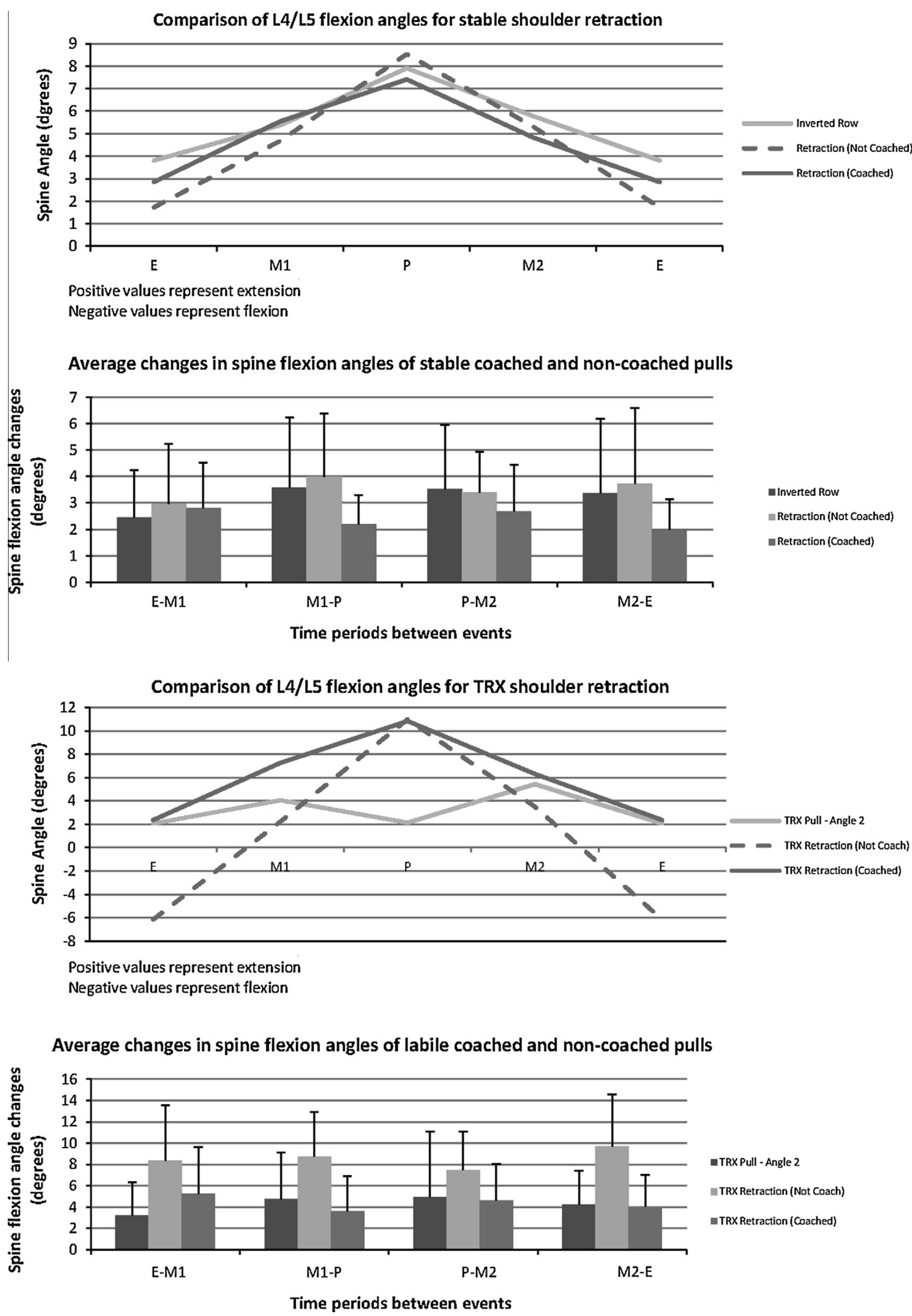

Fig. 6. L4/L5 angles and spine flexion angle changes during coached and non-coached conditions are compared for both stable and labile shoulder retraction exercises.

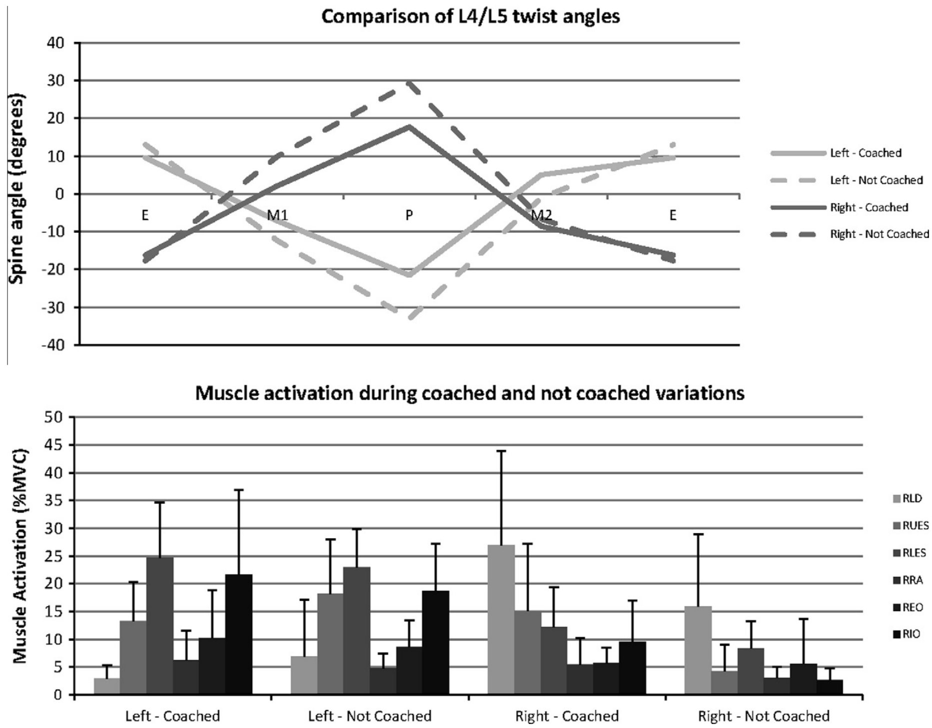

Fig. 7. The spine twist angles and muscle activation for the Powerpull exercise during coached and non-coached conditions.

two exercises. The pull exercise with the most compressive load was the pull up (still below 3000 N), followed by the chin up and TRX pull up. The latter 2 produced almost identical load on the spine. Table 2 lists EMG levels for the peak phase of each exercise.

4. Discussion

In this description of the biomechanical demands of stable and labile pulling exercises, the different gradations of muscle activity and spine load characteristics with every task are clear. The chin up and pull up exercises resulted in the highest activity in the upper back, chest and anterior core musculature, while the inverted row resulted in the highest activity in the low back extensors. Additionally, the stable retraction exercises elicited greater muscle activation throughout the back than did the TRX retraction exercises. Thus, the muscle activation portion of Hypothesis 1 was refuted. It may come as a surprise to observe that the highest compressive load was experienced during the two "hanging pulls" (pull up and chin up) which traction the spine under gravitational forces. However the source of the compression was the elevated core and back muscle activity needed to pull up which, because they span the length of the torso, impose substantial compressive load to the spinal joints. Although there were significant differences between the pull up and chin up to the TRX reverse fly, all pulling exercises induced a shear load less than 500 N (A limit suggested by McGill, 2007). None of the exercises breached the upper limit for either compression or shear; however the exercises that elicited higher loads should be matched appropriately to only the capable individual.

The data of this study suggest that labile surfaces in pulling exercises are not as influential as with pushing exercises. For example, Anderson and Behm (2005) commented in their review of stable vs. labile exercises that the general consensus is that labile training results in higher torso muscle activation. Specific examples include a study by Freeman et al. (2006) of the effects of different pushup exercises on torso muscle activation and spine loads. These researchers reported similar findings to this investigation that labile pushups (hands were placed on basketballs) resulted in greater muscle activation but caused more spine load than a standard pushup. Beach et al. (2008) reported similar findings that labile pushups (performed using straps) elicit significantly greater muscle activation and, consequently, L4/L5 compression. The data set created here adds to this database.

Coaching shoulder centration for stiffness, and thus control, achieved more neutral postures (verifying Hypothesis 2) and appear to substantially alter the cost with the associated muscle contraction (Table 1). Our analysis of the TRX one-arm rows and TRX ghost rows were interesting but inconclusive in that the two exercises may present different challenges in terms of motor patterns and spine position. Contrary to Hypothesis 3 the ghost rows elicited greater change in spine flexion, revealing that it was less neutral throughout the movement than the one-arm rows. However, the hypothesis was verified with respect to spine twist, in which the ghost rows allowed the spine to remain more neutral compared to the one-arm rows. Individuals recovering from an arm or shoulder injury may find benefit in performing ghost rows because they can move their recuperating limb through the same movements as their healthy arm in an un-weighted exertion. Consistent with constraint-induced therapy (Taub et al., 1999), ghost rows may improve recovery time for some individuals, although this remains a topic for future investigation.

In general, the TRX training system assisted in creating variety in the load sharing between the legs and the arms/straps. The exercises tested here provided some opportunity for variety in spine load and muscle activation. Thus, the context and appropriateness for program selection could be guided by the individual in terms of injury history, training goals and current fitness level. The real expert in exercise prescription matches the training demand with the training goal while considering any special variables such as specific injury history. To help with this decision making process, an atlas of spine compression was provided in Table 1. It is hoped

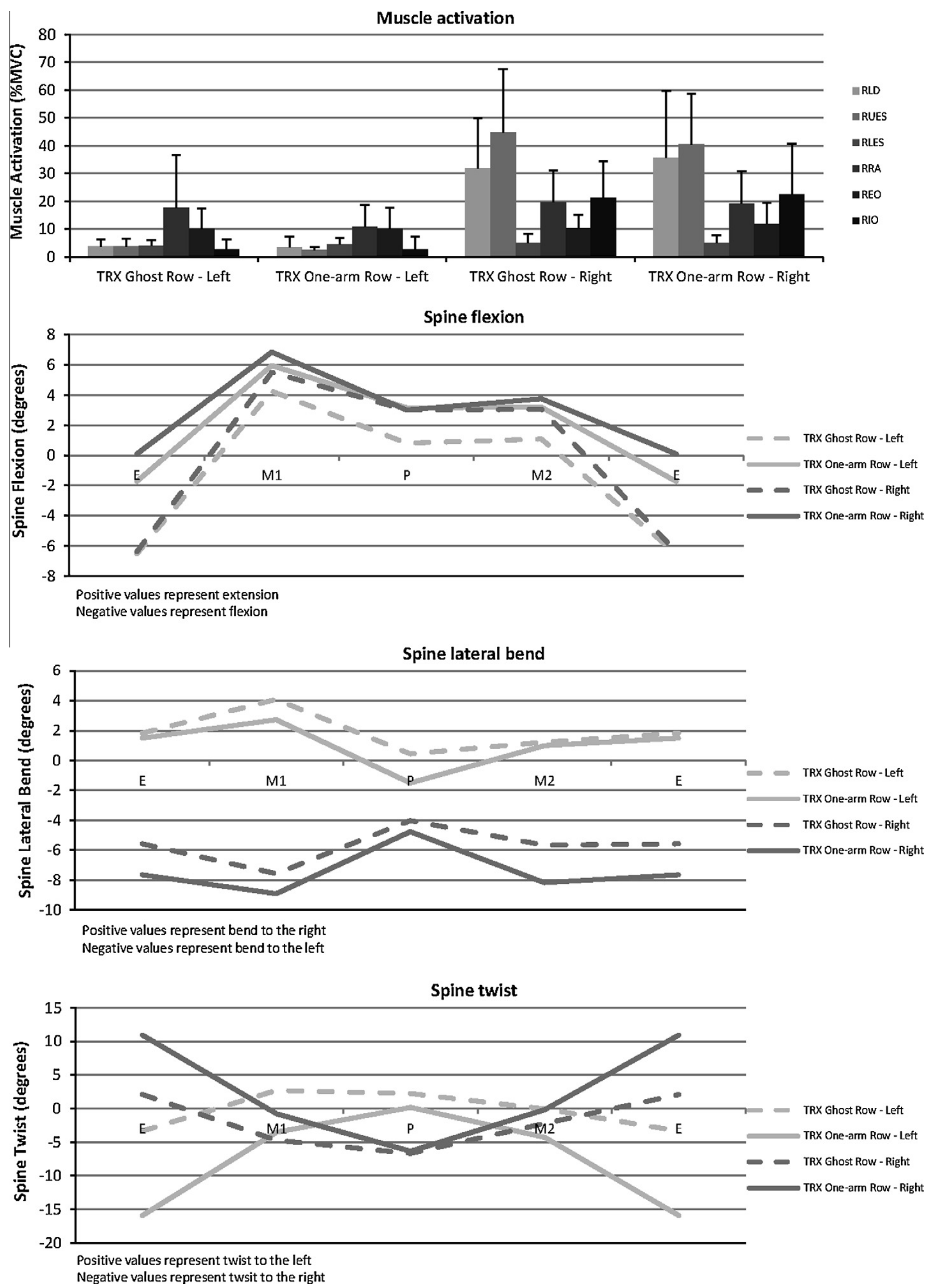

Fig. 8. Patterns of muscle activation, spine flexion, spine lateral bend and spine twist are compared between one-arm rows and ghost rows.

that this will assist the choice of exercises based on spine load tolerance. This table together with the EMG data will assist in the cost-benefit analysis involved in expert exercise prescription.

The relevance and limitations of this study include the sample population, who were healthy and relatively fit. Participants ranged in height from 1.62 cm to 1.84 cm, resulting in a slight discrepancy in body angle when performing each exercise, though this difference could also be accommodated by different hand positions. Thus, interpretation of variance via the standard deviation values needs to be considered in terms of subject non-homogeneity together with exercise specific variables. Nonetheless, subjects spanned a spectrum from varsity level swimmers, distance runners and sprinters who may not regularly weight train to recreational athletes who do train regularly in a gym. The spine model has been developed over the past 30 years; in terms of content validity the various individual components have been subject to internal validity checks and sensitivity analyses. This component validation approach is built on the premise that models built of well validated components will probably be valid (Lewandowski, 1982). While a direct comparison of spine load and measured surrogates such as interdiscal pressure (e.g. Schultz et al., 1982) appear to be very comparable, the models ability to begin with direct measurement of biological signals of kinematics and muscle activation patterns enable the prediction of measured moments in a wide variety of dynamic multiplanar activities (see for example: Cholewicki et al., 1995; McGill, 1992; McGill and Norman, 1986). This demonstrates predictive validity. The anatomical representation of the spine tissues are set to the 50th percentile male. Errors in predicted moments guide the adjusting of muscle gain (error term) to act as a scaling variable for individuals larger or smaller than the 50th percentile male. In this way the model is sensitive to variations in every individual's motor control scheme. Specifically, a great asset

Table 2
Muscle activation as % MVC (mean and standard deviation) at the peak phase of pull exercises.

	RLD	RUES	RLES	Biceps	Triceps	Anterior Deltoid	Upper Trapezius	Pectoralis Major	RRA	REO	RIO	Serratus Anterior
Chin up	66	66	8	29	18	7	8	57	108	12	22	48
	36	34	6	33	11	5	3	65	75	7	17	44
Pull up	85	62	10	31	22	9	10	79	87	14	18	50
	48	33	9	25	15	9	8	97	58	11	16	57
Inverted Row	30	39	44	25	7	10	29	7	4	2	7	10
	28	35	74	22	6	9	32	10	5	2	8	14
Stable Shoulder Retraction, Coached	24	43	33	2	10	8	31	5	4	3	11	21
	15	20	36	3	10	12	49	5	3	2	16	31
Stable Shoulder Retraction, Not Coached	28	46	43	2	12	5	39	4	3	2	6	14
	17	21	53	3	16	7	43	5	2	2	5	18
TRX Shoulder Retraction, Coached	17	33	12	4	9	6	10	5	3	4	7	17
	11	15	10	4	9	8	9	6	3	4	9	22
TRX Shoulder Retraction, Not Coached	16	27	13	3	6	3	23	3	2	1	5	10
	14	18	18	2	6	4	21	4	2	2	10	14
TRX Pull, Angle 1	22	35	9	22	5	6	13	7	12	4	8	14
	18	28	16	17	3	6	11	8	13	5	12	15
TRX Pull, Angle 2	27	40	13	28	7	11	27	8	12	3	9	14
	17	34	21	18	4	10	27	11	13	3	11	14
TRX Pull Up	41	58	37	41	8	9	23	12	14	5	13	28
	29	37	63	25	5	8	21	16	14	6	23	33
Powerpull, Coached (left)	2	10	37	2	10	16	15	5	5	8	16	34
	3	9	68	2	10	21	16	5	5	9	18	42
Powerpull, Not Coached (left)	4	12	32	1	10	5	16	2	3	6	11	7
	9	12	66	2	10	7	20	3	3	6	12	10
Powerpull, Coached (right)	19	11	14	20	5	5	11	23	4	8	6	28
	20	12	26	20	5	5	11	22	5	16	8	42
Powerpull, Not Coached (right)	11	3	7	8	4	6	20	14	2	4	2	21
	15	7	7	11	5	11	24	22	3	7	3	31
TRX Ghost Row (left)	2	3	8	4	1	1	6	7	15	9	2	31
	3	3	16	3	1	3	6	9	20	8	4	39
TRX Ghost Row (right)	29	40	12	25	6	8	13	8	17	9	19	18
	20	26	28	22	4	9	12	10	12	6	14	17
TRX One-Arm Row (right)	33	37	14	19	6	7	12	9	17	11	20	20
	26	22	36	13	5	6	11	11	13	8	19	20
TRX Reverse Fly	11	16	5	4	31	25	22	5	8	4	8	9
	7	8	7	4	11	19	13	6	15	6	10	10

The rows of data highlighted in grey represent the standard deviation.

of this approach is that muscle co-contraction patterns create the necessary controlling stiffness of a flexible lumbar spine to bear load without buckling. No other approach has been successful in capturing this behavior.

These data provide insight into these pulling exercises to assist those who develop exercise progressions.

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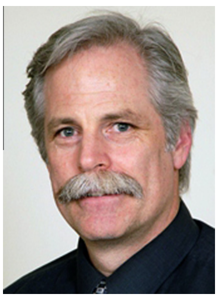

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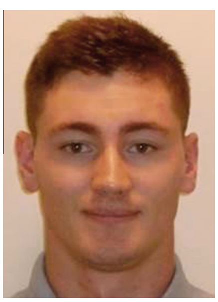

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