# Analysis of Pushing Exercises: Muscle Activity and Spine Load While Contrasting Techniques on Stable Surfaces With a Labile Suspension Strap Training System

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## Abstract

McGill, SM, Cannon, J, and Andersen, JT. Analysis of pushing exercises: Muscle activity and spine load while contrasting techniques on stable surfaces with a labile suspension strap training system. *J Strength Cond Res* 28(1): 105–116, 2014—Labile surfaces in the form of suspension straps are increasingly being used as a tool in resistance training programs. Pushing is a common functional activity of daily living and inherently part of a well-rounded training program. This study examined pushing exercises performed on stable surfaces and unstable suspension straps, specifically muscle activation levels and spine loads were quantified together with the influence of employing technique coaching. There were several main questions that this study sought to answer: Which exercises challenged particular muscles? What was the magnitude of the resulting spine load? How did stable and unstable surfaces differ? Did coaching influence the results? Fourteen men were recruited as part of a convenience sample (mean age, 21.1 ± 2.0 years; height, 1.77 ± 0.06 m; mean weight, 74.6 ± 7.8 kg). 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 the individuals choice of motor control for each task; muscle forces and linked segment joint loads were used to calculate spine loads. Exercises were performed using stable surfaces for hand/feet contact and repeated where possible with labile suspension straps. Speed of movement was standardized across participants with the use of a metronome for each exercise. There were gradations of muscle activity and spine load characteristics to every task. In general, the instability associated with the labile exercises required greater torso muscle activity than when performed on stable surfaces. Throughout the duration of an exercise, there

was a range of compression; the TRX push-up ranged from 1,653 to 2,128.14 N, whereas the standard push-up had a range from 1,233.75 to 1,530.06 N. There was no significant effect of exercise on spine compression ($F_{(4,60)}$ = 0.86, $p$ = 0.495). Interestingly, a standard push-up showed significantly greater shear than TRX angle 1 ($p$ = 0.02), angle 2 ($p$ = 0.01), and angle 3 ($p$ = 0.02). As with any training program for the elite or recreational athlete alike, specific exercises and programs should reflect one's injury history, capabilities, limitations, and training goals. Although none of the exercises examined here breached the NIOSH action limit for compression, those exercises that produced higher loads should be used relative to the individual. Thus, the atlas of muscle activation, compression, and shear forces provided can be used to create an appropriate program. Those individuals not able to tolerate certain loads may refer to the atlas and choose exercises that minimize load and still provide sufficient muscle activation. Conversely, an individual with a resilient back that requires an increased muscular challenge may choose exercises with higher muscle activation and spine load. This helps the individual, trainer, or coach in program design respecting individual differences and training goals.

**KEY WORDS** push exercises on serratus anterior activation, stable vs. labile push exercises, coaching and muscle activation

## Introduction

Locomotion, level changes of one's center of mass, pushing and pulling, and rotation were noted as 4 major categories of human movement (14). Pushing, the focus of this study, is a common functional daily activity, together with being inherent in any well-rounded training program. Given the need to provide guidance to those who must prepare pushing ability, we were motivated to investigate some basic mechanics of pushing.

The muscles of the torso generate force to create three-dimensional (3D) moments that both initiate and prevent motion and contribute stiffness to stabilize the spine. Stiffness and hence stability enhances 2 elements: (a) a stiffer
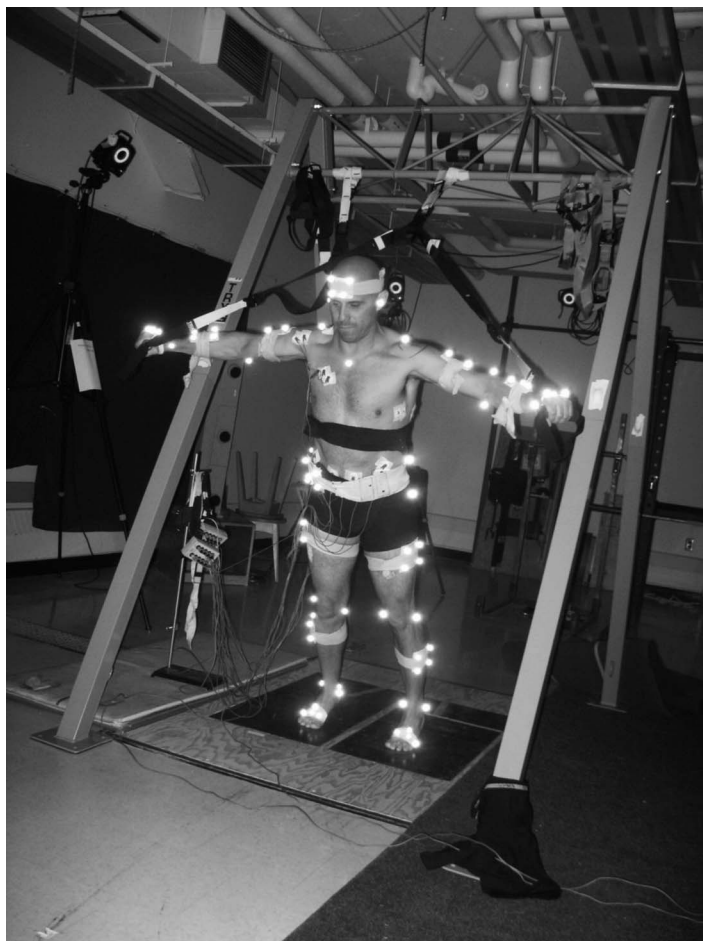
**Figure 1.** Experimental setup with instrumentation of electromyography electrodes to obtain muscle activation values, force plate to obtain force input to the linkage through the feet, and reflective markers used to obtain 3 dimensional body segment kinematics.

lower-body power movements from suspension training warrant an investigation into the demands of such exercises. The objective of this study was to investigate some mechanisms associated with various pushing exercises by quantifying muscle activation patterns and calculating the resultant spine load using both stable and labile contact surfaces. In this primarily descriptive study, 3 specific issues were investigated:

1. The influence of different push exercises on serratus anterior activation, where it was hypothesized that suspension strap exercises would elicit higher activation than stable surface exercises.

2. Comparison of muscle and joint load demands resulting from stable (i.e., from a fixed surface) vs. labile (i.e., using a suspension strap training system) for pushing exercises; it was hypothesized that labile straps would increase muscle activity and spine load.

3. The influence of coaching on the outcome measure of muscle activation; it was hypothesized that coaching would result in more neutral spine postures and thus lower tissue stress.

spine is more resilient to buckling allowing it to safely bear more load and (b) proximal stiffness, i.e., stiffness proximal to the shoulder and hip, fixates the proximal attachment of muscles, so their mechanical effect is focused on the distal attachment creating faster limb movements with more power in the arms and legs. Pushing exercises have been shown to qualify as a justifiable torso training exercise to meet these objectives (7).

The use of labile (movable) surfaces contacting the feet or hands of the subject is becoming more popular (1,13). In particular, suspension straps are used in training centers and adapted to create resistance training in a wide variety of challenges. Closed chain exercises (in which the terminal segments are fixed) in a suspension strap have been postulated to improve specific areas of athletic performance without any detriment to strength, compared with traditional open chain exercises (13). Improvements in upper- and

## METHODS

### Experimental Approach to the Problem

An overview of the methods is as follows: 14 men performed several pushing tasks while muscle activity, external force, and 3D body segment motion including spine posture were recorded. Forces at the hands (through a force transducer) and feet (through 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–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; pushing exercises were performed using stable surfaces for hand/feet contact and repeated where possible
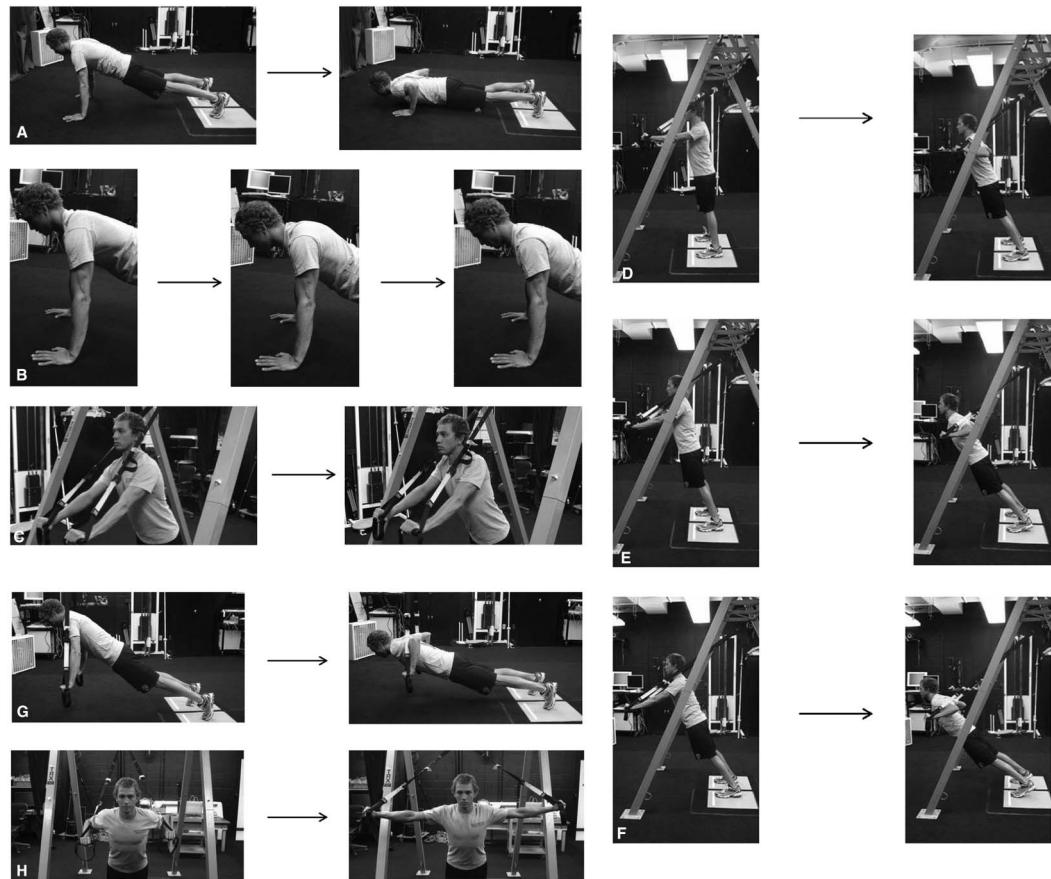
**Figure 2.** A) Standard push-up. B) Stable shoulder protraction. C) TRX shoulder protraction. D, E, F) TRX pushes at angles 1, 2, and 3. G) TRX scapula push-up. H) Reverse fly.

with labile surface contact (TRX suspension straps; TRX Fitness Anywhere, San Francisco, CA, USA).

### Subjects

Fourteen male subjects, mean (*SD*) age, 21.1 years (2.0); height, 1.77 m (0.06); weight, 74.6 kg (7.8), recruited from the university population comprised a convenience sample for this study (range from 18 - 24 years old). They were healthy with no previous history of disabling back pain. All were familiar with resistance training techniques. Participants completed a written informed consent document approved by the University Office for Research Ethics.

### Instrumentation

Each subject was instrumented with electromyography (EMG) electrodes monitoring muscle activity together with markers for 3D body segment movement tracking.

*Muscle Activation Through Electromyography.* 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 (ASIS) 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 ASIS 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°, 2/3 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 the BIC; anterior deltoid (ANTDELT)–with the shoulder flexed to 90°, approximately 3 cm inferior to the acromion process; upper
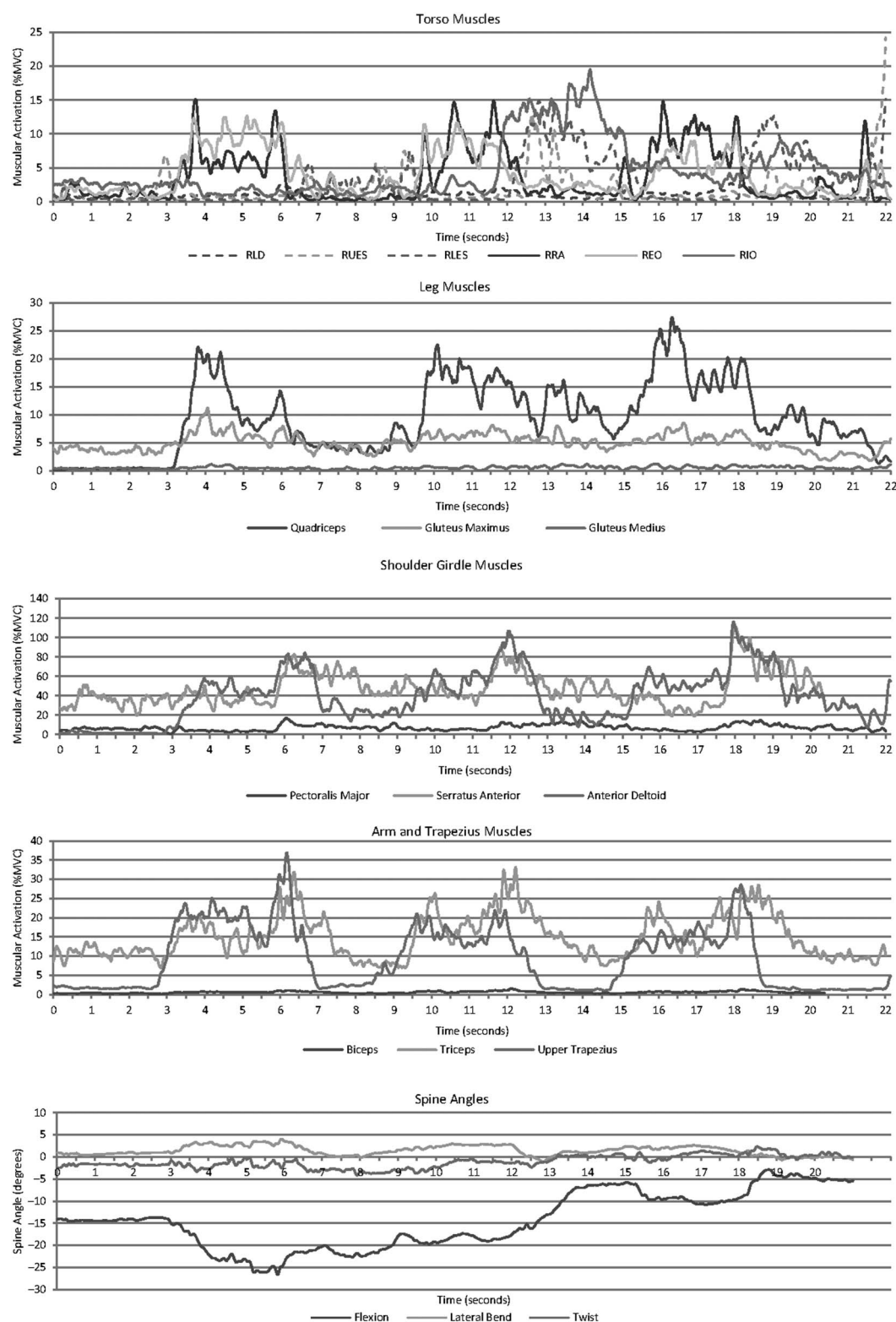
**Figure 3.** Typical time history tracing of a TRX push (3 cycles) at angle 2 from a sample subject.

**TABLE 1.** Serratus anterior activation during different push exercises.*

|  | Standard push-up | Stable shoulder protraction (coached) | Stable shoulder protraction (not coached) | TRX shoulder protraction (coached) | TRX shoulder protraction (not coach) | TRX push–angle 2 | TRX scapula push-up |
|---|---|---|---|---|---|---|---|
| M1 | 72.1 | 21.9 | 47.6 | 17.6 | 4.1 | 16.3 | 23.1 |
| SD | 60.2 | 18.2 | 36.9 | 18.9 | 3.3 | 14.1 | 20.5 |
| P | 72.7 | 25.1 | 49.8 | 13.6 | 3.1 | 18.4 | 16.9 |
| SD | 58.2 | 19.3 | 48.6 | 9.3 | 3.4 | 12.2 | 13.5 |
| M2 | 161.0 | 41.6 | 94.6 | 13.6 | 12.9 | 44.6 | 40.1 |
| SD | 146.8 | 45.6 | 62.4 | 10.0 | 6.7 | 31.7 | 28.6 |
| E | 109.5 | 38.5 | 82.1 | 21.7 | 14.2 | 20.2 | 39.8 |
| SD | 84.4 | 51.9 | 53.6 | 27.5 | 12.6 | 16.9 | 25.4 |

*Expressed as a percent of that obtained during the statically performed calibration task.

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 seventh rib. Before the electrodes were adhered to the skin, the skin was shaved and cleansed with Nuprep abrasive skin prepping gel (Weaver and Company, Aurora, CO, USA). Ag-AgCl surface electrode pairs were positioned with an interelectrode 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 2,160 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 Kinetic and Kinematic Data to Predict Back Loads below).

Each participant performed a maximal voluntary isometric contraction (MVC) of each muscle for normalization (4). These normalization techniques have been developed over 30 years in our laboratory 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 (11)–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 moments and a right and left lateral bending moments. Right latissimus dorsi was normalized to maximum activation achieved during the static phase at the top of a pull-up. For the spine extensors (RLES, RUES) and RGMAX, a resisted maximal extension in the Biering-Sorensen position was performed for normalization. The RGMAX was cued to aid in extension at the hip. Maximal voluntary isometric contraction 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. The 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). Biceps brachii MVCs were taken from a standing bilateral elbow

**TABLE 2.** Rank of mean spine compression at the P-phase of each exercise.

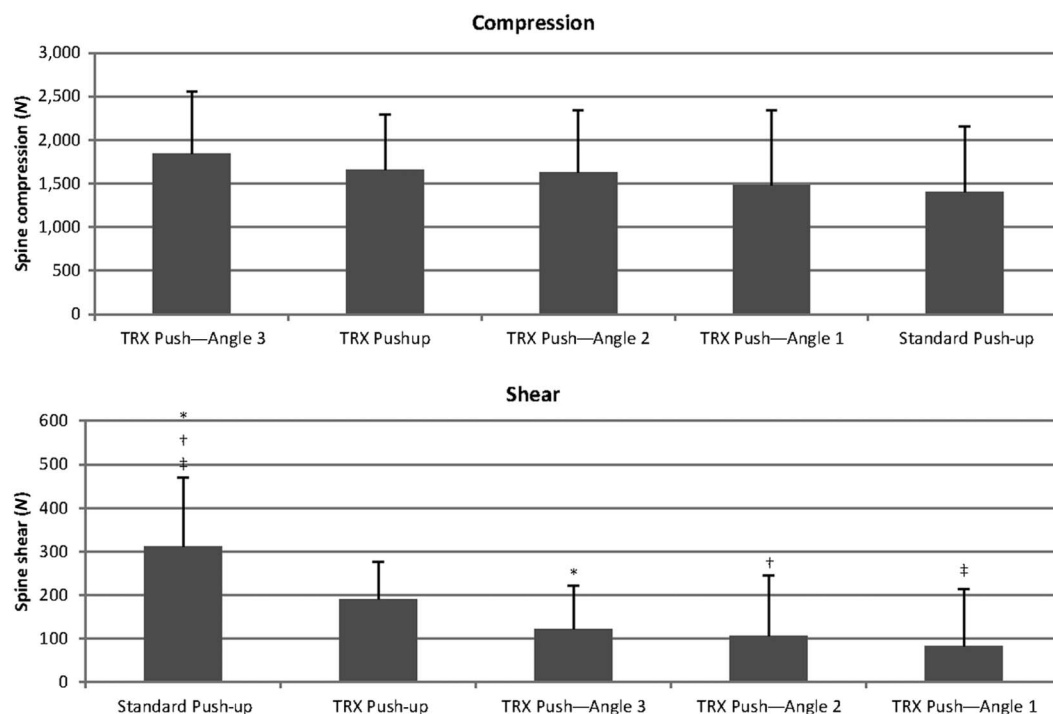| Exercise | Rank | Mean spine compression (N) | SD |
|---|---|---|---|
| TRX push–angle 3 | 1 | 1,838.9 | 852.9 |
| TRX push-up | 2 | 1,653.4 | 759.8 |
| TRX push–angle 2 | 3 | 1,631.1 | 712.0 |
| Stable shoulder protraction (coached) | 4 | 1,582.7 | 717.3 |
| TRX scapula push-up | 5 | 1,581.0 | 505.6 |
| TRX shoulder protraction (coached) | 6 | 1,528.2 | 707.7 |
| TRX push–angle 1 | 7 | 1,484.9 | 638.3 |
| TRX shoulder protraction (not coached) | 8 | 1,449.5 | 566.8 |
| Standard push-up | 9 | 1,399.2 | 716.7 |
| Stable shoulder protraction (not coached) | 10 | 1,381.0 | 515.3 |

**Figure 4.** Absolute spine load for push exercises during the P-phase. *, †, and ‡ denote significant differences ($p \leq 0.05$).

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 accomplished 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.

*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: first metatarsal head, fifth 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 comprised 6 markers; Figure 1). The VICON Nexus motion capture system tracked the 3D coordinates of the reflective markers during the various trials at a sample rate of 60 Hz.

*Force Plates for External Force Measurement and Kinetic Analysis.* Force plate (AMTI, Watertown, MA, USA) data were also collected using the VICON Nexus motion capture system and were sampled at a rate of 2,160 Hz. Where possible, participants placed either foot at a fixed position on separate force plates during the exercises.

**Exercise Description**
Participants were asked to perform exercises with a metronome set to 1 Hz (1 beat per second) that was used to maintain consistent movements throughout all exercises except for 2 (namely, the walkout and lever progression). A research assistant counted out loud to help participants maintain a steady pace. Three repetitions of all exercises were performed, except for 1 (the lever progression given its extreme demand). All exercises are shown in Figure 2.
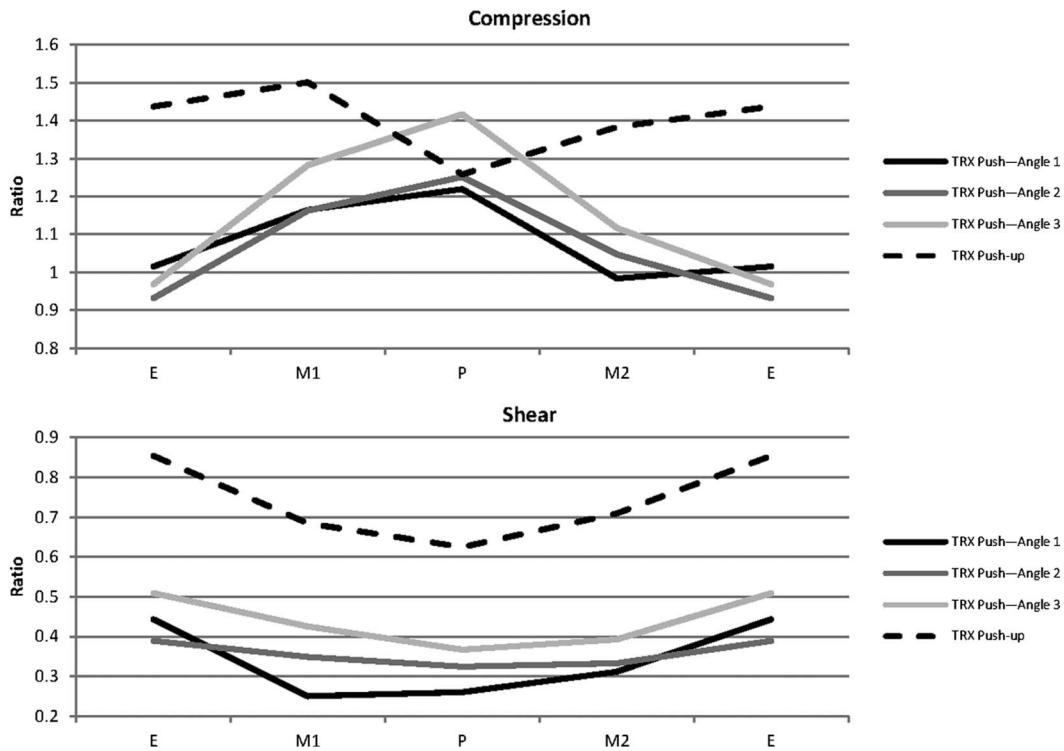
**Figure 5.** Ratio of spine load for push exercises with the standard push-up as base.

*Description of the Push Exercises.*

1. Standard push-up–from a push-up position, participants took 1 beat to lower their chest to the ground, held at the bottom for 2 beats, took 1 beat to push back up, and held at the top for 2 beats.

2. Stable shoulder protraction–from a push-up position, participants protracted their shoulders after the same pace as the standard push-up. This exercise was performed with no instructions (not coached) and then repeated with the same cues as the shoulder retraction exercise (coached).

3. TRX shoulder protraction–the protraction exercises (not coached and coached) were repeated with the TRX straps at angle 2 (see TRX pushes).
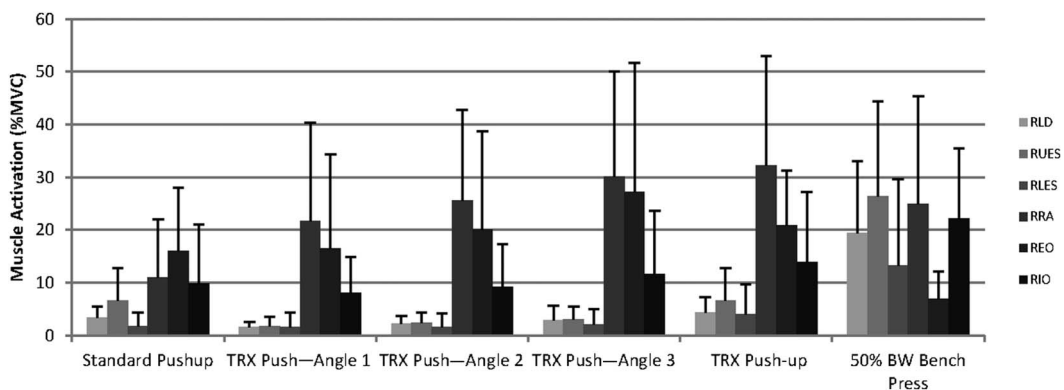


**Figure 6.** Muscle activation of push exercises at P-phase.

4. TRX pushes–standing with the TRX handles in either hand; participants performed a push-up at 3 different strap lengths (from shortest to longest: angles 1, 2, and 3), all performed at the same pace as the standard push-up. The body angle and difficulty of the exercises were controlled by strap length (angle 3, the most difficult and angle 1, the least) with the position of the feet at a fixed location on the force plates.

5. TRX push-up–with the TRX straps hanging vertically, the participants adopted a push-up position with a handle in either hand. They performed a push-up in the same manner and at the same pace as the standard push-up.

6. TRX scapula push-up–standing at TRX push at angle 2, participants began with the handles close to their chest. Over 1 beat, they pushed out on a 45° angle while maintaining their body in the same position. They held the position with their arms fully extended for 2 beats before bringing their arms back in over 1 beat and holding for 2 beats.

7. Bench press–lying on a standard exercise bench, participants bench pressed 50% of their own body weight for 3 repetitions. These trials were performed at the beginning of the collection as a warm-up and at the participants' own pace. Because of the nature of the exercise being performed in a supine lying position, only EMG that was collected as motion capture markers would be crushed and not remain in position.

Participants were familiarized with the data collection process and with exercise technique before data collection. They were instructed on how to generally position themselves for each task and were provided the opportunity to practice the exercises. Each exercise was thoroughly explained and demonstrated immediately before it was performed. However, because coaching effectiveness was an independent variable, specific technique coaching was not performed at this stage. The order of exercises was randomized with the exception of those that had specific instructions that might affect performance on another task (i.e., "coached" trials followed the "not coached" trials).

### Data Processing and Model Development

*Electromyography to Capture Muscle Activation for the Spine Model.* The EMG data were band-pass filtered between 20 and 500 Hz, 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 (3)), normalized to the MVC of each muscle to enable physiological interpretation, and down sampled to 60 Hz using custom LabVIEW software (National Instruments, Austin, TX, USA).

*Kinetic and Kinematic Data to Predict Back Loads.* The 3D coordinates of the markers were entered into a software package (Visual3D; C-Motion, Inc., Germantown, MD, USA) that calculated the spine curvature angles and 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 3D coordinates of the joint markers drove a linked segment model of the arms, legs, and torso constructed with Visual3D (C-Motion, Inc.). This package output the lumbar spine postures described as 3 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 (Figure 3).

2. The reaction forces from the link segment model above were input into a "Lumbar Spine model" that consists of an anatomically detailed, 3D ribcage, pelvis/sacrum, and 5 intervening vertebrae (6). 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 proportional rotation to each of the lumbar vertebral segments (after values obtained by White and Panjabi (15)). 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 subject. 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. Recent updates to the model include a much improved representation of some muscles (8).

3. The third model, termed the "distribution-moment model" (9), 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 to create a moment about the intervertebral joint that matches those calculated by the link segment model to achieve mathematical validity (5). 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 subject while maintaining mathematical validity by satisfying the predicted moments to equal the measured moments.

**TABLE 3.** Muscle activation at the peak phase of push exercises.*

| | RLD | RUES | RLES | Biceps | Triceps | Anterior deltoid | Upper trapezius | Pectoralis major | RRA | REO | RIO | Quadriceps | Gluteus maximus | Gluteus medius | Serratus anterior |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Standard push-up | 3.12 | 6.22 | 1.68 | 3.53 | 22.99 | 71.19 | 9.36 | 46.61 | 10.26 | 14.88 | 9.23 | 14.97 | 2.21 | 1.95 | 117.28 |
| | 2.24 | 6.15 | 2.44 | 3.45 | 22.72 | 51.51 | 6.37 | 40.56 | 10.93 | 12.14 | 10.99 | 9.33 | 4.01 | 1.80 | 140.17 |
| Stable shoulder protraction (coached) | 4.69 | 9.80 | 4.08 | 1.89 | 26.86 | 63.78 | 6.16 | 33.23 | 18.80 | 22.26 | 11.78 | 17.97 | 1.42 | 2.55 | 59.10 |
| | 3.35 | 10.68 | 9.66 | 1.29 | 16.11 | 66.38 | 4.08 | 59.79 | 13.51 | 23.85 | 12.06 | 9.38 | 2.87 | 3.08 | 112.35 |
| Stable shoulder protraction (not coached) | 3.32 | 6.88 | 3.53 | 2.28 | 26.35 | 75.64 | 9.63 | 17.87 | 19.39 | 24.87 | 5.36 | 14.45 | 1.33 | 1.79 | 72.66 |
| | 2.02 | 6.90 | 8.43 | 2.21 | 15.50 | 67.50 | 11.33 | 19.04 | 11.59 | 24.08 | 3.99 | 8.43 | 2.56 | 1.56 | 120.61 |
| TRX shoulder protraction (coached) | 5.45 | 11.56 | 3.00 | 1.25 | 21.89 | 19.82 | 6.56 | 6.82 | 5.41 | 10.40 | 10.43 | 5.00 | 1.30 | 2.02 | 19.33 |
| | 7.34 | 11.20 | 5.06 | 1.00 | 12.36 | 17.06 | 6.54 | 6.39 | 6.74 | 13.06 | 13.11 | 4.44 | 2.91 | 1.96 | 25.04 |
| TRX shoulder protraction (not coached) | 3.75 | 7.00 | 1.96 | 1.51 | 25.27 | 27.93 | 10.00 | 18.41 | 11.01 | 7.77 | 5.91 | 5.86 | 1.26 | 1.93 | 23.30 |
| | 3.81 | 8.87 | 3.83 | 1.33 | 14.01 | 29.34 | 9.96 | 50.75 | 9.85 | 8.98 | 5.90 | 5.11 | 2.61 | 1.89 | 43.95 |
| TRX push–angle 1 | 1.34 | 1.52 | 1.33 | 1.51 | 17.59 | 14.37 | 11.38 | 3.87 | 18.30 | 13.82 | 6.97 | 6.90 | 1.82 | 1.90 | 19.26 |
| | 1.05 | 1.75 | 2.61 | 1.44 | 12.65 | 16.94 | 15.75 | 4.11 | 19.13 | 17.37 | 7.40 | 6.06 | 3.62 | 2.79 | 35.04 |
| TRX push–angle 2 | 2.05 | 2.28 | 1.47 | 2.41 | 21.44 | 34.63 | 16.02 | 8.86 | 23.68 | 18.58 | 8.57 | 10.16 | 2.84 | 2.46 | 36.23 |
| | 1.80 | 2.37 | 2.54 | 2.40 | 14.08 | 29.98 | 18.02 | 7.12 | 19.86 | 18.86 | 8.36 | 5.64 | 5.62 | 2.76 | 47.10 |
| TRX push–angle 3 | 2.91 | 3.07 | 2.04 | 4.28 | 32.14 | 54.00 | 24.71 | 15.39 | 30.12 | 27.22 | 11.61 | 11.84 | 2.36 | 4.07 | 78.51 |
| | 2.78 | 2.40 | 3.11 | 3.01 | 18.74 | 31.42 | 27.39 | 10.16 | 20.05 | 24.34 | 12.41 | 6.87 | 4.94 | 4.56 | 88.86 |
| TRX push-up | 3.86 | 5.97 | 3.74 | 6.14 | 29.61 | 77.76 | 22.23 | 42.34 | 36.70 | 19.12 | 12.67 | 18.35 | 3.56 | 3.28 | 55.55 |
| | 3.11 | 6.36 | 5.80 | 4.88 | 19.35 | 70.49 | 25.79 | 32.80 | 35.38 | 11.89 | 13.51 | 11.21 | 8.83 | 3.12 | 60.25 |
| TRX scapula push-up | 4.27 | 3.35 | 2.76 | 20.24 | 12.27 | 45.72 | 7.14 | 48.11 | 19.69 | 15.42 | 9.09 | 7.44 | 2.14 | 2.43 | 93.54 |
| | 7.44 | 2.62 | 4.90 | 17.06 | 8.07 | 41.65 | 10.10 | 37.61 | 15.07 | 11.24 | 6.97 | 4.42 | 4.49 | 2.93 | 115.98 |
| Bench press | 19.41 | 26.44 | 25.69 | 18.73 | 66.79 | 208.10 | 17.03 | 141.44 | 24.95 | 6.99 | 22.09 | 2.28 | 10.27 | 10.71 | 305.13 |
| | 13.56 | 17.91 | 49.34 | 12.93 | 27.46 | 180.11 | 13.86 | 87.17 | 20.44 | 5.20 | 13.39 | 2.62 | 23.89 | 15.17 | 224.86 |

*RLD = right latissimus dorsi; RUES = right upper erector spinae; RLES = right lower erector spinae; RRA = right rectus abdominis; REO = right external oblique; RIO = right internal oblique.

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: for pushes, this occurred as the participant was moving toward the ground.
2. P–At the peak of the exercise: this occurred at the bottom of a push. 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: for pushes, this was as the participant moved away from the ground.
4. E–Rested position at the end of each exercise: top of a push. An average was taken over the time that the participant held this position.

### Statistical Analysis

Two separate 1-way analyses of variance (ANOVAs) with Tukey's post hoc procedures were used to determine the influence of exercise on spine compression and shear for selected push exercises (i.e., standard push-up; TRX push at angles 1, 2, and 3; and the TRX push-up). An ANOVA was used to test the hypotheses together with Tukey's post hoc procedures–specifically, the effect of stable/labile surfa-

ces for those exercises where this was appropriate, and the effect of coaching on these exercises where coaching was performed.

### RESULTS

The results are organized to address the specific questions and hypotheses posed in the Introduction.

#### Serratus Anterior Activation

The issue addressed here is whether TRX protocols selectively and preferentially target serratus anterior. Table 1 shows SERRANT activation at all phases for the following push exercises: standard push-up, stable shoulder protraction (coached and not coached), TRX shoulder protraction (coached and not coached), TRX push (angle 2), and TRX scapula push-up. The standard push-up stimulated the greatest magnitude of serratus activation among these exercises (161%; note that this is expressed as a percentage of maximum isometric effort as previously described; dynamic effort causes higher neural drive than isometric effort). Conscious effort to stabilize and centrate the shoulder was effective in activating SERRANT. TRX shoulder protraction exercises resulted in less SERRANT EMG compared with the counterpart stable shoulder protraction for both coached and not
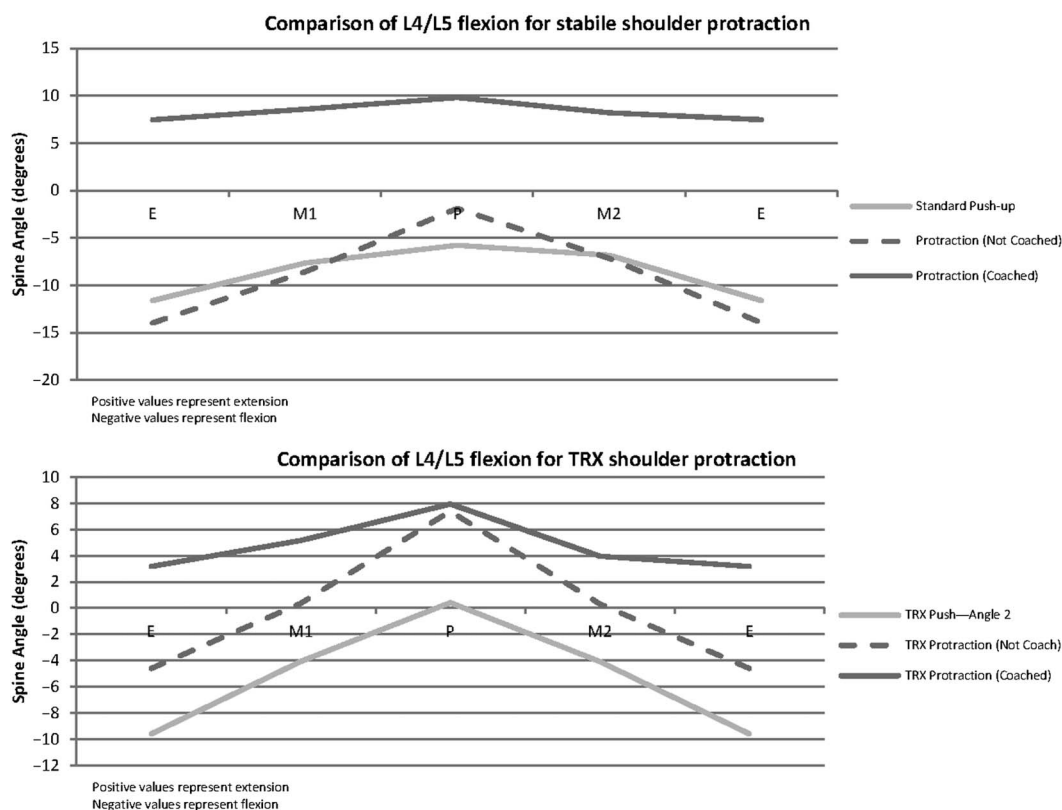


**Figure 7.** The effect of coaching on spine posture during shoulder protraction.

coached conditions at all phases of the movements. Despite claims for abduction movements being superior for serratus activation, SERRANT seems to be challenged most when the arms are pushing in the same direction as gravity. Comparing the TRX push at angle 2 to the TRX scapula push-up with the straps at the same length, the scapula push-up resulted in greater SERRANT activation when the arms were moving towards the body (M1) and when the arms were fully extended away from the body (E).

### Stable vs. Labile

*Pushes.* Time histories were created for all exercises. Figure 3 is a sample that qualitatively displays the phasic nature of muscle activity and spine angle during a TRX push. The push exercise that produced the greatest spine compression (1,840 N) was the TRX push at angle 3 (Table 2); however, there was no significant effect of exercise on compression ($F_{(4,60)} = 0.86$; $p = 0.495$). The standard push-up elicited the greatest shear force even more than the TRX push-up (Figure 4). Although an ANOVA showed a significant effect of exercise on shear forces ($F_{(4,60)} = 4.01$; $p = 0.006$), Tukey's post hoc revealed significantly greater shear forces in the standard push-up compared with TRX angle 1 ($p = 0.02$), angle 2 ($p = 0.01$), and angle 3 ($p = 0.02$) (Figure 4).

Ratios of compression and shear loads from the TRX pushes, throughout the phases of movement, were calculated with the standard push-up as base. Compression increased as the participants reached the P-phase before decreasing to the E-phase, except for the TRX push-up that resulted in a drop in spine compression at the P-phase. Except for the TRX pushes at angles 2 and 3 at E and angle 1 at M2, all 4 variations of the TRX push resulted in greater spine compression than the standard push-up. Spine shear loads showed a different pattern: all 4 conditions produced less shear than the standard push-up. Not surprisingly, the TRX push-up elicited more shear than the other 3 angles (Figure 5).

The TRX pushes and the TRX push-up produced more abdominal muscle activity than the standard push-up, with the exception of RIO activation during TRX push at angles 1 and 2 (Figure 6 for torso muscle activity). Abdominal muscle activity increased with the TRX push exercises as the participants' body position became more horizontal (i.e., angle 1 < angle 2 < angle 3 < TRX push-up). The only exception to this trend was that REO activity was slightly higher during TRX push at angle 3 compared with the TRX push-up. Bench press at 50% of the participants' body weight elicited the highest magnitude of back muscle EMG (RLD, RUES, RLES) (see Table 3 for activity in all muscles).

### Coaching

*Protraction.* Differences in spine flexion were apparent in the protraction exercises. The standard push-up produced a change from approximately 12 degrees of flexion at E to 6 degrees of flexion at P, and stable protraction that was not coached produced 14 degrees of flexion at E and 2 degrees

of flexion at P. Coaching the protraction movement from the ground, however, resulted in 7 degrees of extension at E and 10 degrees of extension at P. The differences in the changes between E and P for these exercises were not significant ($p = 0.46$). The TRX exercises produced greater changes in spine flexion between E and P. The TRX push at angle 2 showed a change from under 10 degrees of flexion to slight extension, and TRX shoulder protraction that was not coached resulted in a change from approximately 5 degrees of flexion to over 7 degrees of extension. Similar to the stable protraction coached trial, coaching with the TRX protraction resulted in the least amount of spine flexion change, with movement from 3 degrees of extension at E to 8 degrees of extension at P (Figure 7).

### DISCUSSION

This report presents the biomechanical demands of stable and labile push exercises in terms of muscle activation levels and the resulting spine load. There are gradations of muscle activity and spine load characteristics to every task. In general, the instability associated with the labile exercises (i.e., TRX training system) required greater torso muscle activity to maintain a straight body position. Though tasks become more challenging with labile hand surfaces, the context and appropriateness of exercise choice by an individual would be guided by injury history, training goals, and current fitness level. The real expert in exercise prescription matches the training demand with the training goal within the special unique realm of injury history. To help with this decision-making process, an atlas of spine compression was provided in Table 2. It is hoped that this will guide the choice of exercises based on spine load tolerance. For example, an individual with compromised spine load tolerance in their back would choose some exercises and avoid others. This table together with the muscle activation data will assist in the cost-benefit analysis involved in expert exercise prescription.

TRX pushes did not activate serratus anterior more than the other push variations with exception of the coached TRX shoulder protraction. This is contrary to other results reported (12), which found that push-ups performed on a labile surface (a wobble board) significantly increased serratus activity compared with push-ups on a stable surface. The differences in findings may be because of the angle of the body. The surface on which the push-up is being performed may have less of an effect than the line of action of the exercise. The current data suggest that serratus anterior is preferentially activated by exercises that place the line of action of the movement in the same direction as gravity; pushing directly against gravity straight away from the chest activates serratus anterior more than pushing at an angle.

Several studies have investigated the effects of training on labile surfaces (1). It was 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 (7) on the effects of different push-up exercises on torso muscle activation and spine loads. These researchers reported similar findings to this investigation that labile push-ups (hands were placed on basketballs) resulted in greater muscle activation but caused more spine load than a standard push-up. It has been demonstrated that a labile surface produces greater abdominal muscle activation during the curl-up than performing the exercise on a stable surface. Labile push-ups (performed in the same position as the TRX push-up) elicit significantly greater muscle activation and, consequently, L4-L5 compression (2). The data set created here adds to this database with using a labile suspension strap system. From the higher perspective, it appears that all pushing exercises are sparing of the spine. No pushing exercise in this study produced more than 2,000 N of spine compression. Interestingly, the aforementioned study (7) did measure higher spine loads but that was for one-armed push-ups that elevated the need to resist twisting torque, which required much higher torso muscle activity.

Coaching movements had the greatest effect on spine motion with the "TRX exercises." In contrast, constrained "stable" exercises such as a standard push-up, there seems to be less chance to change body position compared with using the TRX training system. Thus, it would appear that coaching becomes more important with TRX exercises because users have more opportunity to compensate given the variable base of the support.

The limitations of this study include the sample population; however, though recruiting was constrained to university students, who were healthy and relatively fit, this sample accurately represents the target individuals of the labile suspension strap system tested here. Participants ranged in height from 1.62–1.84 cm, resulting in a slight discrepancy in body angle when performing each exercise, though this difference could also be accounted for by different hand positions. Deep muscles were not monitored, given the invasive nature and special requirements of using intramuscular electrodes. However, previous study that addressed whether the activation of deep muscles could be predicted with surface synergistic muscles during specific controlled activity suggested that muscles, such as the psoas, could be predicted by rectus femoris activity during push exercises (10).

## PRACTICAL APPLICATIONS

In summary, the use of labile surfaces increase muscle activity and the resulting spine load. These data will assist those designing exercise progressions to better match exercise choice to an individual's injury history and training goals, in the effort to enhance performance while sparing joints such as the spine.

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