Research Paper Review

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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

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.

BACKGROUND INFORMATION

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Pushing is a common function of daily activity and is inherent in any well-rounded training program. The purpose of this study was to investigate the basic mechanics of pushing. A conjunct study, by these same authors, evaluated the effects of pulling exercises on muscle activity and spine load. The muscles of the torso contribute to stiffness to stabilize the spine which enhances two elements:

1. a stiffer spine is more resilient to buckling allowing it to safely bear more load and;
2. stiffness proximal to the shoulder and hip fixates the proximal attachment of muscles so their mechanical effect is focused on the distal attachment, creating fasting limb movements with more power in the arms and legs.

Pushing exercises have been shown to qualify as a justifiable torso training stimulus to meet these objectives (1).

The use of labile (movable) surfaces contacting the feet or hands (i.e. suspension straps) is becoming more popular as part of resistance training (2, 3). Improvements in upper- and lower-body 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. Three specific issues were investigated:

1. The influence of different push exercises on serratus anterior (SA) activation. It was hypothesized that labile (suspension strap) exercises would elicit higher activation than stable (fixed) surface exercises.
2. Comparison of muscle and joint demands resulting from stable vs. labile surfaces 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.

PERTINENT RESULTS

This study included fourteen male participants (average age 21.1 ± 2.0 yrs, height 1.77 ± 0.06 m and weight 74.6 ± 7.8 kg).

Hypothesis 1: Serratus Anterior Activation

This hypothesis tested whether TRX protocols selectively and preferentially target serratus anterior. The results were as follows:

- The standard push-up simulated the greatest magnitude of SA activation among the exercises tested.
- TRX shoulder protraction exercises resulted in less SA activation compared with stable shoulder protraction for both coached and not coached conditions at all phases of the movements.
- TRX pushes did not activate SA more than other push variations with the exception of the coached TRX shoulder protraction.
- Conscious effort to stabilize the shoulder was effective in activating SA. SA seems to be challenged most when the arms are pushing in the same direction as gravity.

Hypothesis 2: Stable vs. Labile

- The push exercise that produced the greatest spine compression (1840 N) was the TRX push up at angle 3 (see Table below), however, there was no significant effect of exercise on compression ($p = 0.495$)
- The standard push-up generated the greatest shear force – even more than the TRX push-up.
- Significantly greater shear forces were found in the standard push-up compared with TRX angle 1 ($p = 0.02$), angle 2 ($p = 0.01$) and angle 3 ($p = 0.02$).
- The TRX pushes and the TRX push-up produced more abdominal muscle activity than standard push-up.
- Abdominal muscle activity increased with the TRX push exercise as the participants' body position became more horizontal.
- Bench press at 50% of the participants' body weight elicited the highest magnitude of back muscle activation.

Spinal Compression Values:

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

Overall, there is general consensus among the studies that labile training results in higher torso muscle activation (1). No pushing exercise in this study produced more than 2,000 N of spine compression (i.e. none breached the NIOSH action limit for compression).

Hypothesis 3: Coaching

- Differences in spinal flexion were found in the protraction exercises. The TRX exercise produced greater changes in spine flexion between resting position at the end of each exercise (E) and the peak of the exercise (P) than the stable surface exercises.
- Coaching movements had the greatest effect on spine motion with the TRX exercises. In contrast, with stable exercises such as the standard push-up, there seems to be less chance to change body position compared to using a TRX training system.
- Hence, coaching becomes more important with TRX exercises because users have more opportunity to compensate given the variable base of support.

CLINICAL APPLICATION & CONCLUSIONS

The use of labile surfaces (suspension straps) during pushing exercises increases muscle activity and the resulting spine load. The data from this study can assist in designing program progressions to better match exercise choice to an individual's injury history, training goals and current fitness level, in the effort to enhance performance while sparing joints such as the spine. The atlas of spine compression also provides a decision-making tool to assist both clinicians and athletes in the choice of exercise based on spine tolerance.

STUDY METHODS

Subjects 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. The data was processed and input to a sophisticated and anatomically detailed 3D model that used muscle activity and body segment kinematics to estimate muscle force. Pushing exercises were performed using stable surfaces for hands/feet contact and repeated where possible with labile surface contact.

Participants

Fourteen male subjects aged 18-24 years were recruited from the university population comprised a convenience sample for this study. Subjects were healthy with no previous history of disabling back pain who were familiar with resistance training techniques.

Instrumentation

Each subject was instrumented with electromyography (EMG) electrodes monitoring muscle activity together with 3D body segment markers to track movement. Fifteen channels of EMG were collected by placing pairs of electrodes over the following muscles (not all were incorporated in the modeling analysis):

- rectus abdominis
- external oblique
- internal oblique
- latissimus dorsi
- upper thoracic erector spinae
- lumbar erector spinae
- rectus femoris
- gluteus maximus
- gluteus medius
- biceps brachii
- triceps brachii
- anterior deltoid
- trapezius
- pectoralis major
- serratus anterior

Each participant performed a maximal voluntary isometric contraction of each muscle for normalization (to minimize the risk of back injury and muscle avulsion).

Eighteen reflective markers for tracking kinematics were placed over the following landmarks bilaterally:

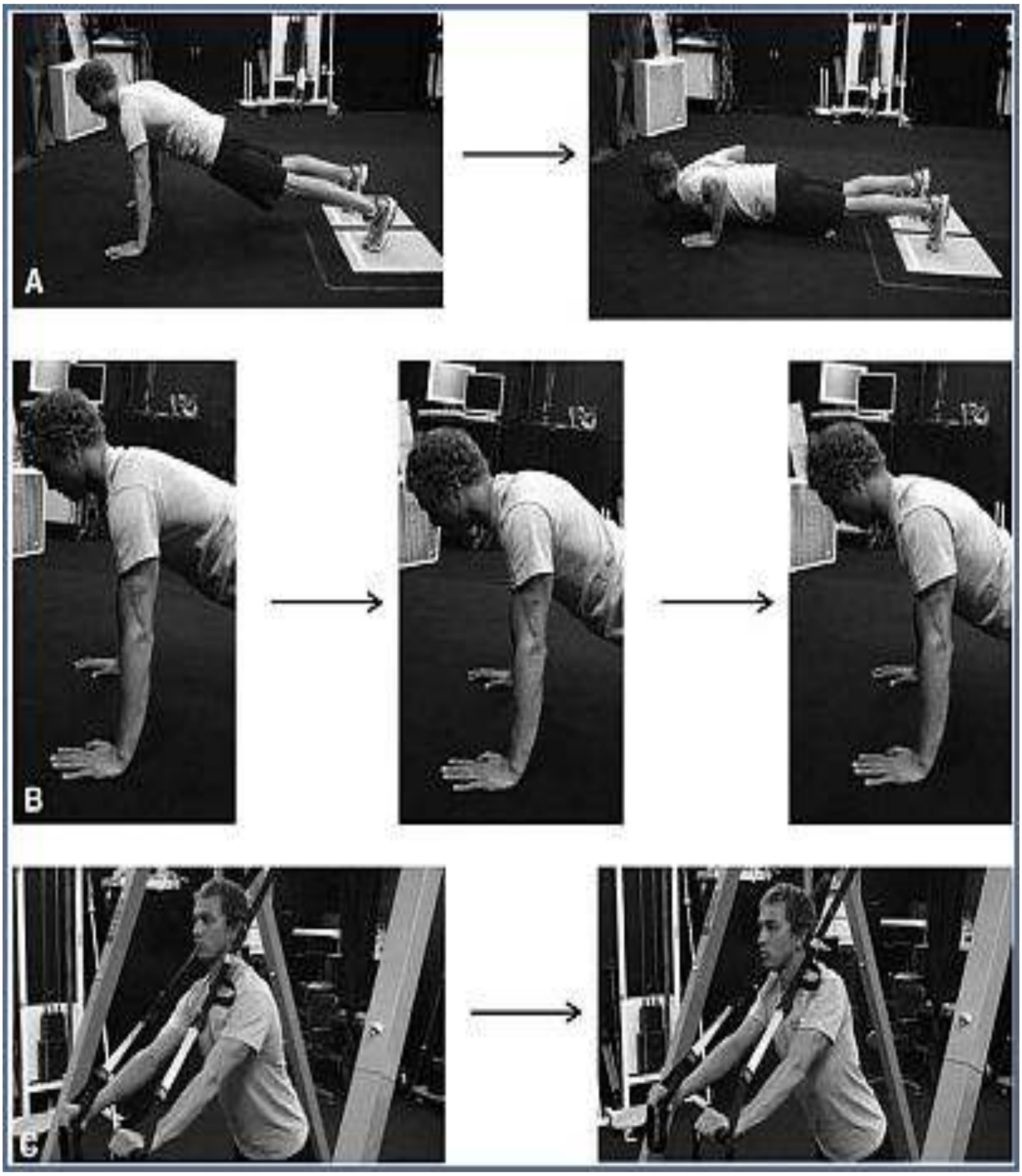
- first metatarsal head
- fifth metatarsal head
- medial malleoli
- lateral malleoli

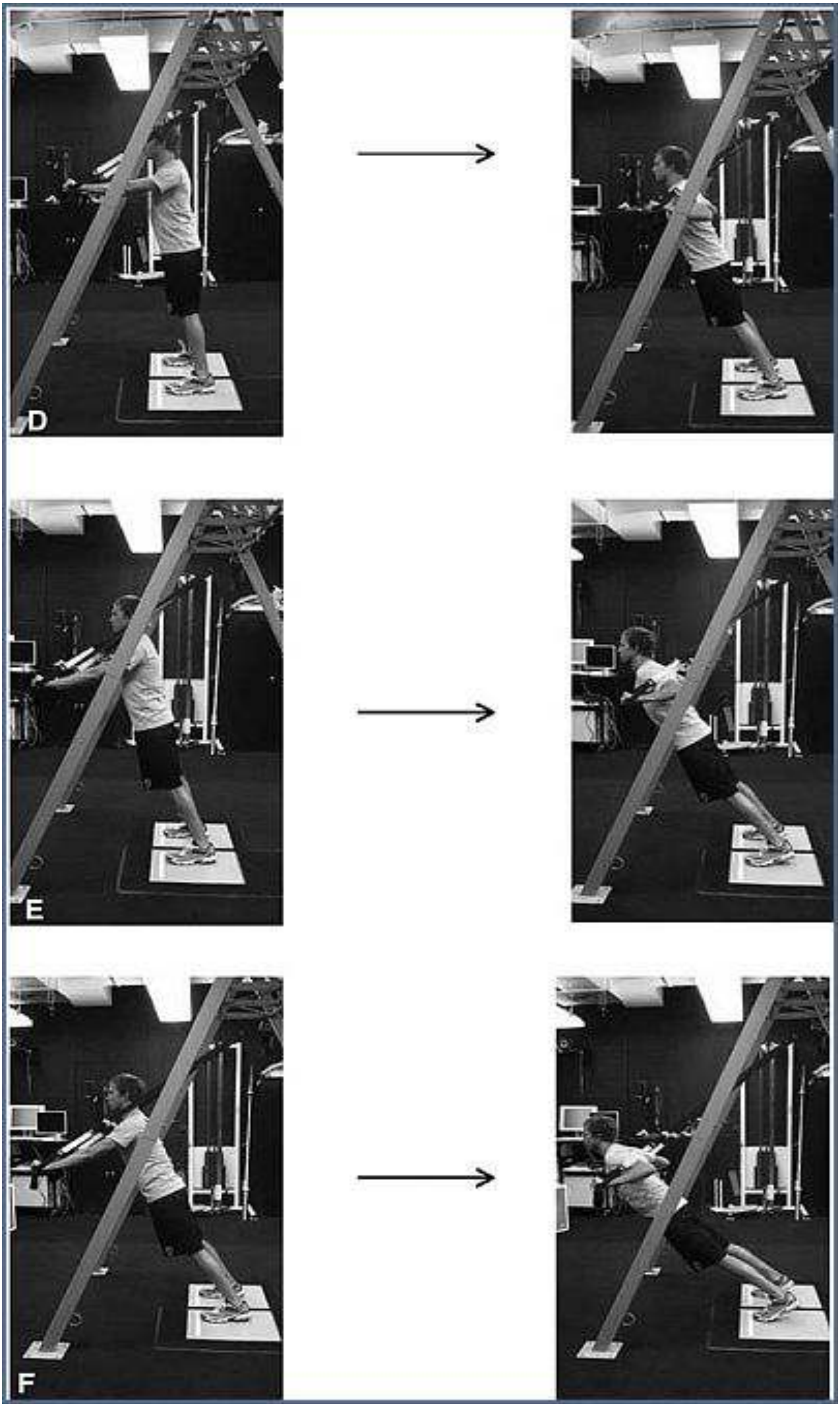
- medial femoral condyles
- lateral femoral condyles
- greater trochanters
- lateral iliac crests
- acromia

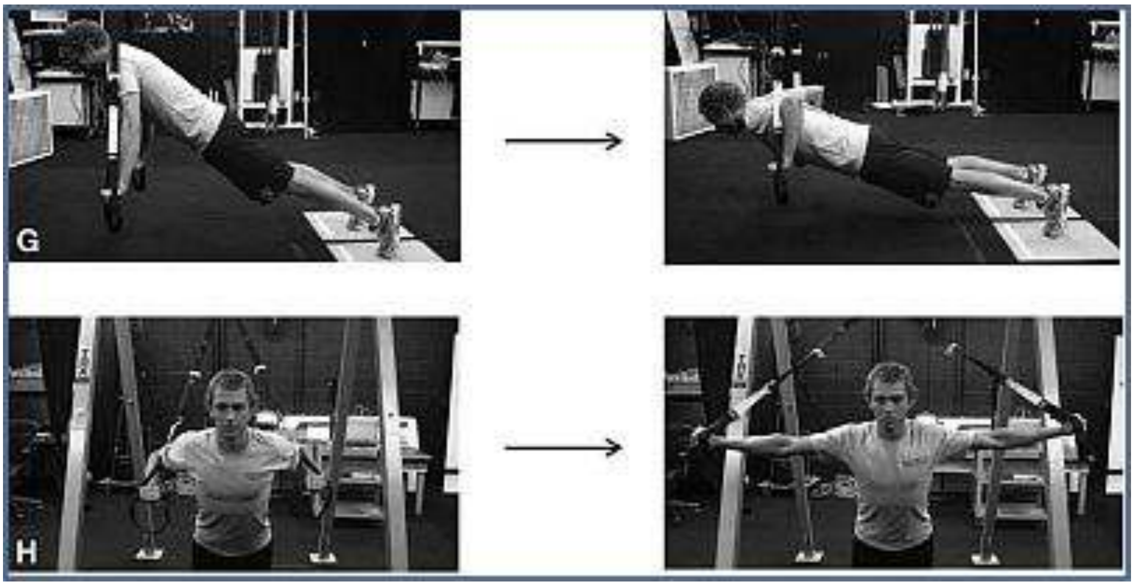
Participants were asked to perform exercises with a metronome set to 1Hz that was used to maintain consistent movements. Three repetitions of all exercises were performed.

Exercise Descriptions

1. *Standard push-up (A in pics below)* – 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 (B in pics below)* – 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 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 [least – D in pic below], 2 (E) and 3 [most difficult – F in pic below]), all performed at the same pace as the standard push-up.
4. *TRX shoulder protraction (C in pics below)* – the protraction exercises (not coached and coached) were repeated with the TRX straps at angle 2 (medium length).
5. *TRX push-up (G in pics below)* – 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 scapular push-up* – standing at TRX push-up angle 2, participants began with the handles close to their chest. Over 1 beat, they pushed out on a 45 degree 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.
8. NOTE: The "reverse fly" exercise (H in pics below) was not included in the list of exercises in this study, despite appearing in the photos.


A
B
C


D
E
F



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 non-coached trials). Each exercise was thoroughly explained and demonstrated immediately before it was performed.

Average of muscle activation (EMG), spine angles, and L4-5 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
2. *P* – at the peak of the exercise. 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.
4. *E* – rested position at the end of each exercise. An average was taken over the time that the participant held this position

Statistical Analysis

- Two separate one-way ANOVAs 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 1-3, and the TRX push-up).
- An ANOVA was used to test the hypotheses together, specifically the effect of stable/labile surfaces on pushing exercises and the effect of coaching on the exercises were coaching on protraction exercises was performed.

STUDY STRENGTHS / WEAKNESSES

Limitations

- A convenience sample of participants with resistance training exercise background was employed, therefore it is difficult to generalize findings outside of this specific population.
- The study sample included only males, so no gender comparisons could be made.
- The participants ranged in height from 1.62 to 1.84 cm, resulting in a slight height discrepancy in body angle when performing the exercises.

Strengths

- A ranked "atlas of spine compression" for pushing exercises was provided, which assists individual choice of exercise based on spine load tolerance.
- The EMG database used in conjunction with the atlas of spine compression assists in the cost-benefit analysis of clinicians prescribing exercise programs.
- Provides useful data on different exercise techniques as options for different training goals (i.e. working out on a stationary surface vs. a movable surface such as the TRX suspension system).

Additional References

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