Academy of PHYSICAL MEDICINE

Research Paper Review

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

Journal of Electromyography and Kinesiology 2014; 24(5): 652-665

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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.

BACKGROUND INFORMATION

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Pulling movements are a common functional activity of daily living. As such, pulling exercises are inherently present in any well rounded training program. There have been several studies investigating technique during pulling exercises (1-3) and only one study that has addressed joint load based on muscle activation levels (4). However, there are no studies evaluating the ability of technique coaching to influence muscle activity and spine load during pulling exercises. A conjunct study, by these same authors, evaluated the effects of pushing exercises on muscle activity and spine load (5). It is clear thus far that torso muscles generate force to both initiate and prevent motion. 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 (6).

When performing isometric contractions, muscles contribute stiffness to stabilize the torso and spine. Stiffness and stability of the spine promotes resilience to buckling, allowing it to safely bear more load.

Also, stiffness proximal to the joint fixates the proximal attachment of any muscle crossing the joint so that the mechanical effect is focused on the distal attachment, creating faster more powerful limb movements (7). Pulling exercises have been shown to qualify as a justifiable torso training exercise to meet these objectives (4).

Labile (movable) surfaces underneath the subject for stability training are becoming increasingly popular. The use of suspension straps, such as TRX suspension training®, are frequently used in many training facilities. The objective of this study was to investigate mechanisms associated with various pulling exercises by quantifying muscle activation patterns and calculating the resultant spine load using both stable (fixed) and labile (movable) contact surfaces.

Constraint-induced movement therapy has been used in injury rehabilitation, most notably in stroke therapy. The concept involves forcing the use of the injured limb by restraining the uninjured limb when completing a task (9). The authors coin the term *ghost row*, which is a concept similar to constraint-induced movement, where the subject only uses one arm to perform the pull while the contralateral arm mimics the motion pattern of a two-handed row. The authors also intended to investigate the motion pattern differences between the two variations of exercises.

Three hypotheses were investigated in this study:

1. Via comparison of demands resulting from stable (fixed) vs. labile (using a suspension strap training system) surfaces 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 muscle activation and spine position was evaluated. It was hypothesized that technique coaching of exercises would result in participants adopting a neutral spine posture throughout the movements.
3. Via comparison of one-armed rows vs. ghost rows, it was hypothesized that the ghost row would result in a more neutral spine posture than the one-armed row.

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: Stable vs. Labile

Spinal Load:
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). The inverted row (2294 N), TRX pull [angle 2] (2288 N) and stable shoulder retraction [coached] (2221 N) were next. The pull up elicited the most spinal shear of all the pull exercises and a significant effect of exercise on shear forces was found ($p = 0.01$). The most statistically significant differences among pull exercises analyzed were between TRX reverse fly (which had the lowest spinal compression) and the chin up ($p = 0.04$) and pull up ($p = 0.02$). 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 increased during the peak [P]-phase. The chin up, pull up and TRX pull up decreased shear as the participant lowered himself toward the ground [M2] before increasing to the rested position at the bottom of the pull [E]. TRX pull angles 1 and 2, however, increased almost linearly from the point halfway through the movement [M1] to the resting position at the end of the exercise [E]. All pulling exercises induced a shear load less than 500 N.

Muscle Activation:
Of the pull exercises, the chin up and the pull up resulted in the highest activity in the upper back, chest and anterior core musculature (most notably in rectus abdominis). The inverted row resulted in the

highest activity in the low back extensors. The TRX reverse fly elicited little torso muscle activity (< 20% on average). Hypothesis 1 that the use of labile surfaces would increase muscle activation was refuted.

Hypothesis 2: Coaching

Shoulder Retraction from a stable surface placed participants in slight lumbar spine extension with very little L4/5 flexion between the base comparison inverted row exercise and coached and non-coached shoulder retraction tasks. TRX retraction exercises, however, produced different patterns in spine flexion. The TRX pull from angle 1 remained consistent in spine angle throughout the movement (between 6 and 11 degrees of extension); non-coached shoulder retraction moved participants from over 6 degrees flexion at the bottom of the exercise [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 differences in the angle change between the bottom and top of movement for each exercise was not significant ($p > 0.05$).

Spine flexion and lateral bend were similar between coaching and non-coaching variations of the *powerpull*. Twist angles at L4/5, however, were substantially closer to neutral at the peak phase during coached compared to non-coached conditions for both left ($p = 0.01$) and right ($p = 0.03$) sides. Muscle activation of the torso was very similar between the two variations (i.e., the muscular demand of the tasks can be accomplished while reducing exposure of twisting movements to the lumbar spine).

Hypothesis 3: TRX One-Arm Row vs. Ghost Row

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. The results are interesting in that the two exercises may present different challenges in terms of motor patterns and spine position. Contrary to hypothesis 3, ghost rows elicited greater change in spine flexion, however, the hypothesis was verified with respect to spinal twist.

CLINICAL APPLICATION & CONCLUSIONS

- Investigation of the biomechanical demands of stable and labile pulling exercises have shown that different gradations of muscle activity and spine load characteristics are present with every task. The chin up and pull up exercises resulted in highest activity in the back, chest and anterior core, while the inverted row resulted in the highest activity in the low-back extensors. The stable retraction exercises elicited greater muscle activation throughout the back than did the TRX retraction exercises. Hypothesis 1 (i.e., that labile surfaces would increase muscle activation) was, therefore, refuted.
- Coaching setting of the shoulder for stiffness and control achieved more neutral postures (verifying hypothesis 2) and this appears to substantially alter the cost of spinal compression with the associated muscle contraction.
- Ghost rows elicited greater change in *spinal flexion* (i.e., less neutral spine) than expected throughout the movement than one-arm rows (refuting part of hypothesis 3). However, ghost rows allowed the spine to remain more neutral in terms of *spinal twist* compared to one-arm rows (verifying part of hypothesis 3).
- The EMG muscle activation and spine compression data assists in the cost-benefit analysis and decision making process that clinicians can consider when prescribing exercise programs for amateur/elite athletes and individuals recovering from injury.
- Individuals recovering from 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) which may improve recovery time but future studies need to investigate this further.
- The TRX training system (labile/movable surface) is growing increasingly popular and assists in creating a variety in load sharing between legs and the arms/straps as well as in spine load and muscle activation.

STUDY METHODS

Participants

Fourteen male participants were recruited from a university population as a convenience sample for the study. To be included, participants had to be healthy with no previous history of disabling back pain or musculoskeletal pain, as well as being familiar with resistance training techniques.

Instrumentation

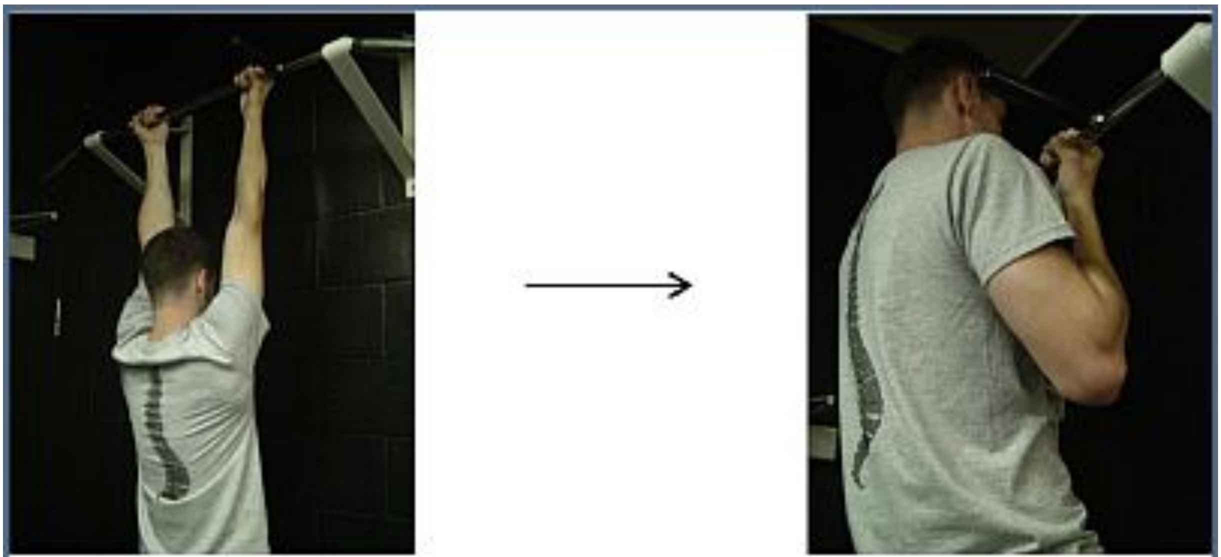
Electromyography (EMG):
Each participant was instrumented with electromyography (EMG) electrodes (in pairs, one on each side of the body) oriented in series, parallel to the muscle fibers to monitor muscle activity. The following muscles were monitored: rectus abdominus, internal oblique, latissimus dorsi, upper thoracic erector spinae, lumbar erector spinae, rectus femoris, gluteus maximus, gluteus medius, biceps brachii, triceps brachii, anterior deltoid, upper trapezius, pectoralis major and serratus anterior. Multiple muscles were collected, however, not all were incorporated into the modeling analysis. Forces at the hands (measured using a force transducer) and feet (measured using a force plate) were also measured. Each participant performed a maximal voluntary isometric contraction (MVC) of each muscle for normalization. Dynamic contractions (i.e., resisted muscle tests) create higher levels of motor unit activity and the values for each muscle were incorporated into the modeling approach to estimate muscle force.

Body Segment Kinematics:
Eighteen reflective markers for tracking linked segment kinematics were adhered to the skin over the following bony landmarks: 1st metatarsal head, 5th metatarsal head, medial malleoli, medial femoral condyles, lateral femoral condyles, greater trochanters, lateral iliac crests and acromia. Ten rigid bodies (made up of 4 or 6 marker clusters) were adhered to the skin over the left and right feet, left and right shins, left and right thighs, the sacrum, inferior to the right ASIS, inferior to the left scapula at the level of T12, and the sternum in order to capture motion 3-dimensionally.

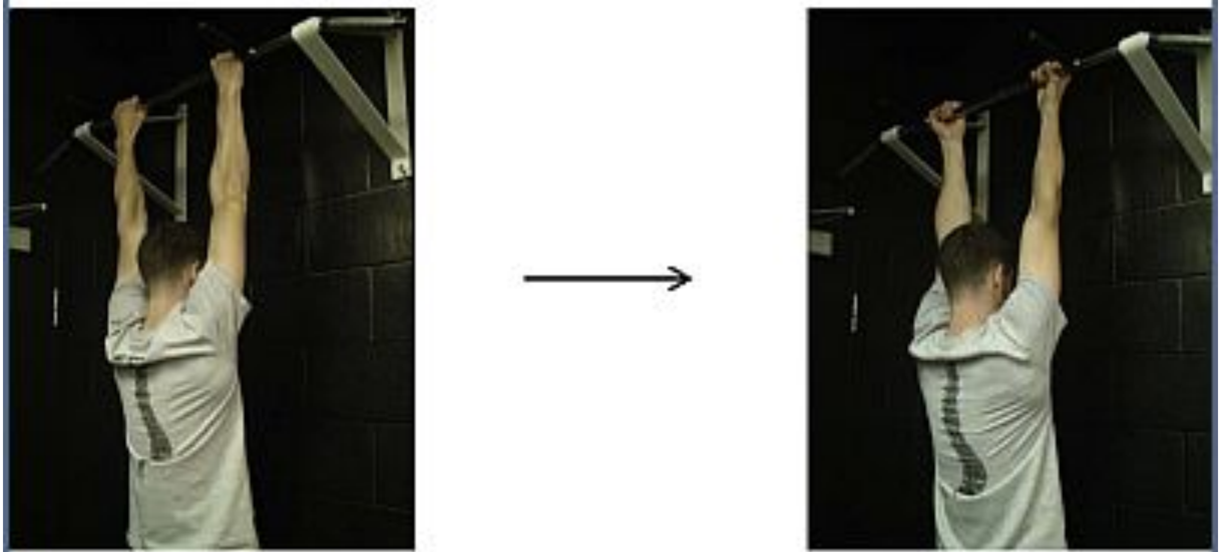
Exercise Descriptions:
Participants performed pulling exercises set to a metronome at 1Hz to maintain consistent movements throughout all exercises. Three repetitions of all exercises were performed. The exercises include:

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 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 10cm 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 was the same as the inverted row. This exercise was done with no instruction (no coaching) and then repeated with cues (coaching) to pull the scapulae down with the erectors of the spine, preventing movement of the scapulae and isolating the retraction to the arms.
5. *TRX shoulder retraction* – the retraction exercises not coached and coached were repeated with the TRX straps at angle 2.

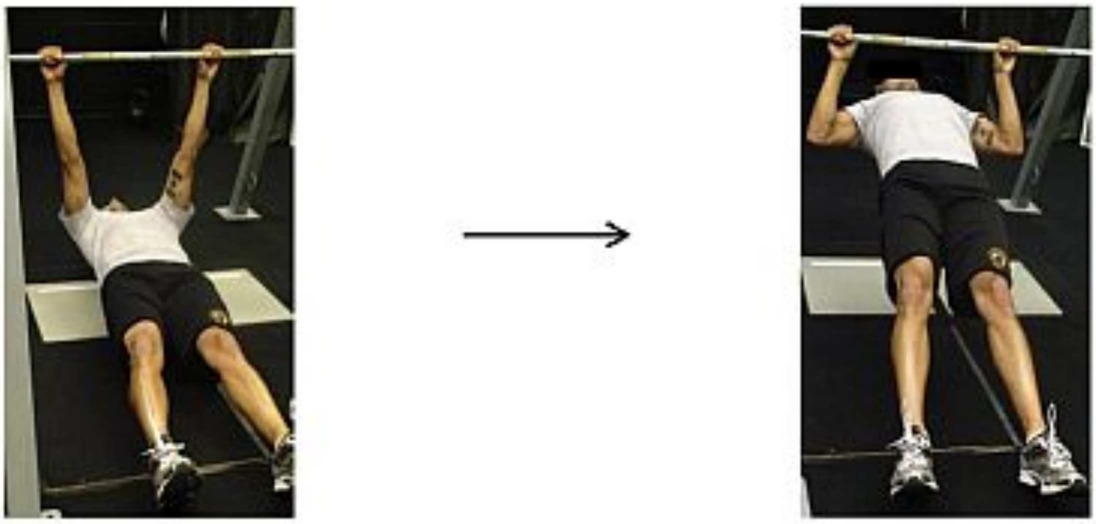
6. *TRX pulls* – with a TRX handle in either hand, participants performed an inverted standing row at 2 different strap lengths (angle 1 [shorter] and angle 2 [longer]) to the same pace as the inverted row. Since the feet were always placed at the same position on the force plates, the body angle and 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* – beginning in the "up" position, with one hand holding the TRX strap at angle 1 and the other reaching to the top of the straps, participants extended their arms 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 their 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 as 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.



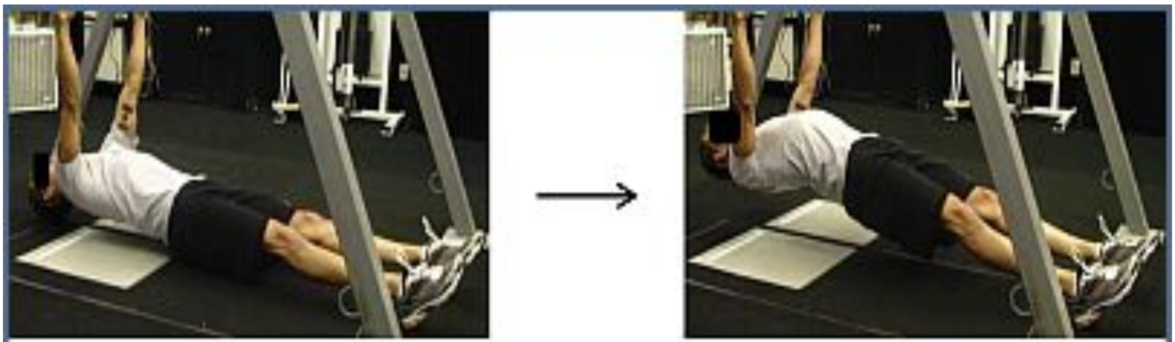
Chin Up



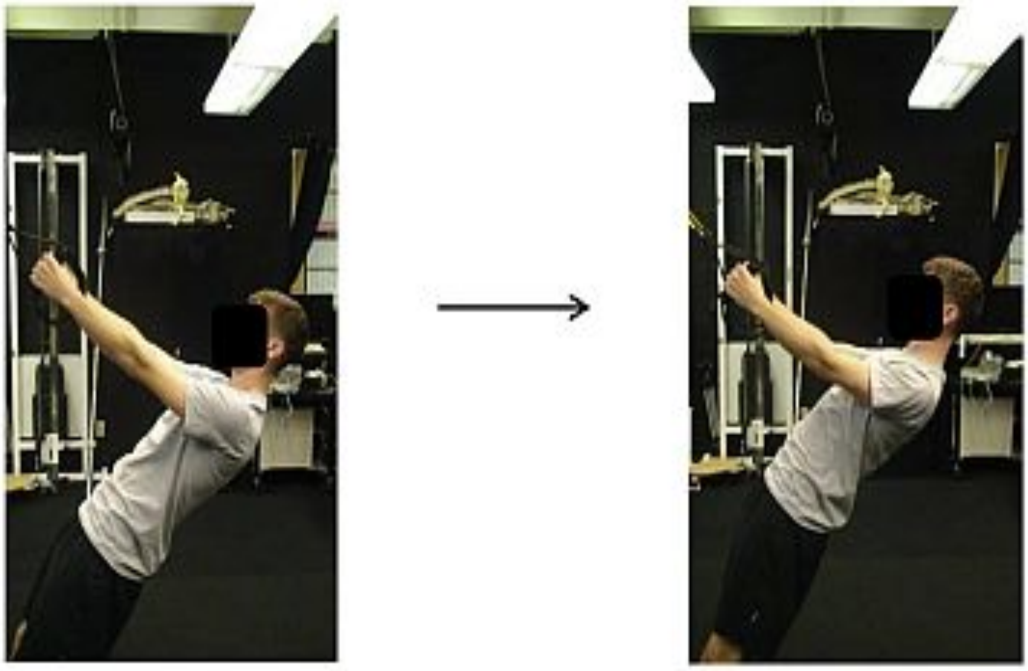
Pull Up



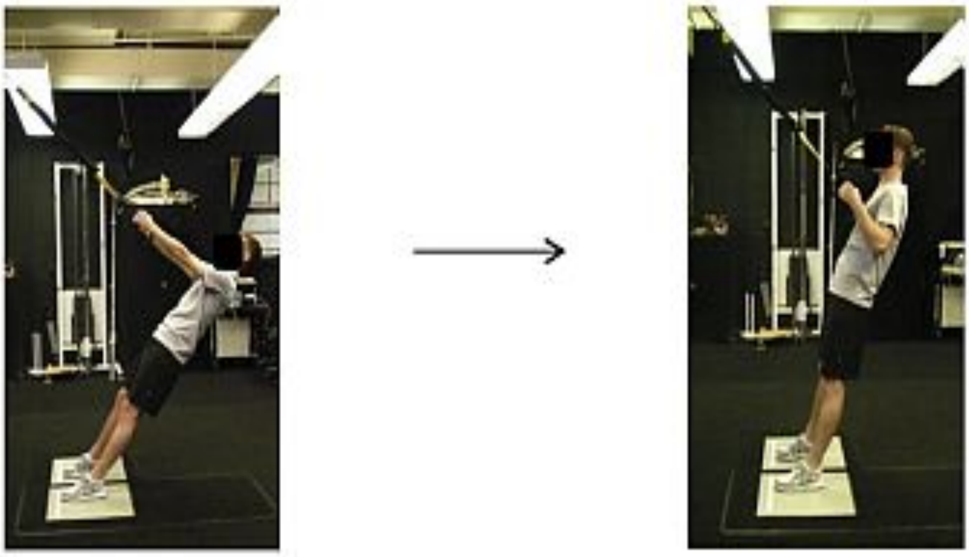
Inverted Row



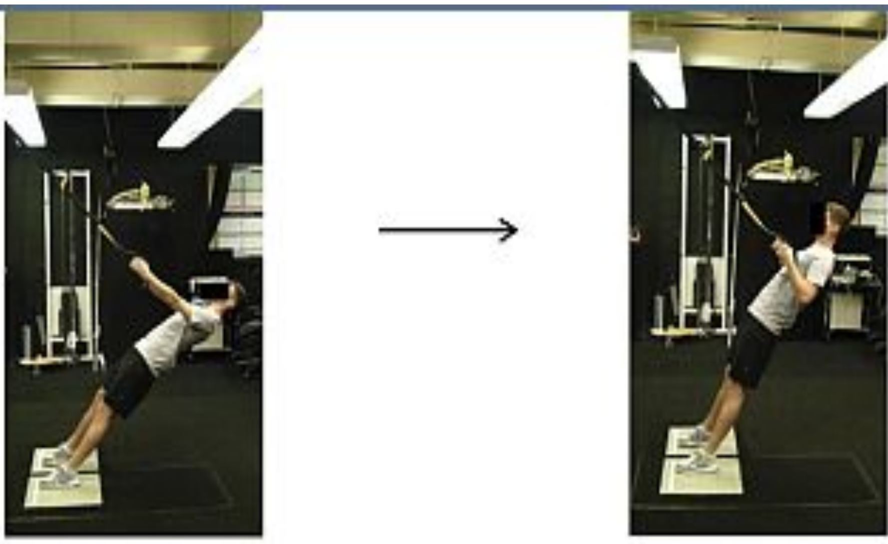
Stable Shoulder Retraction



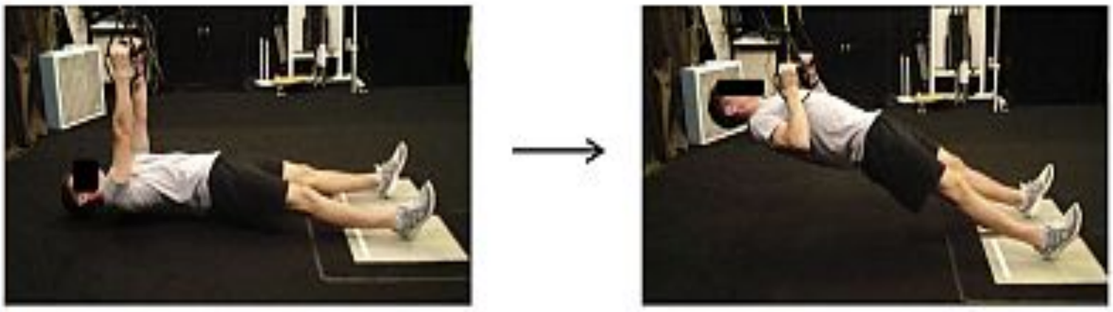
TRX Shoulder Retraction



TRX Pull Angle 1

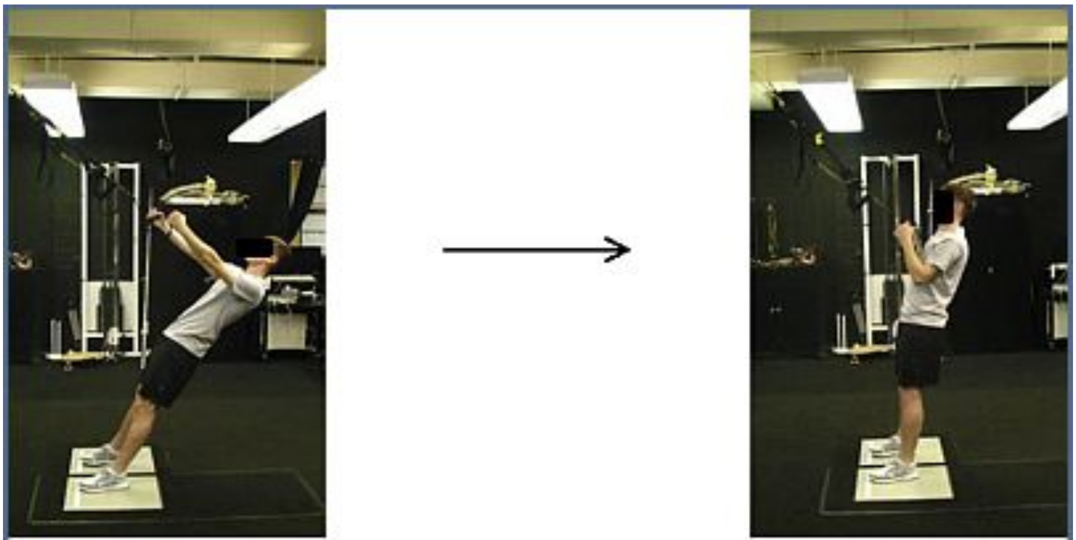


TRX Pull Angle 2

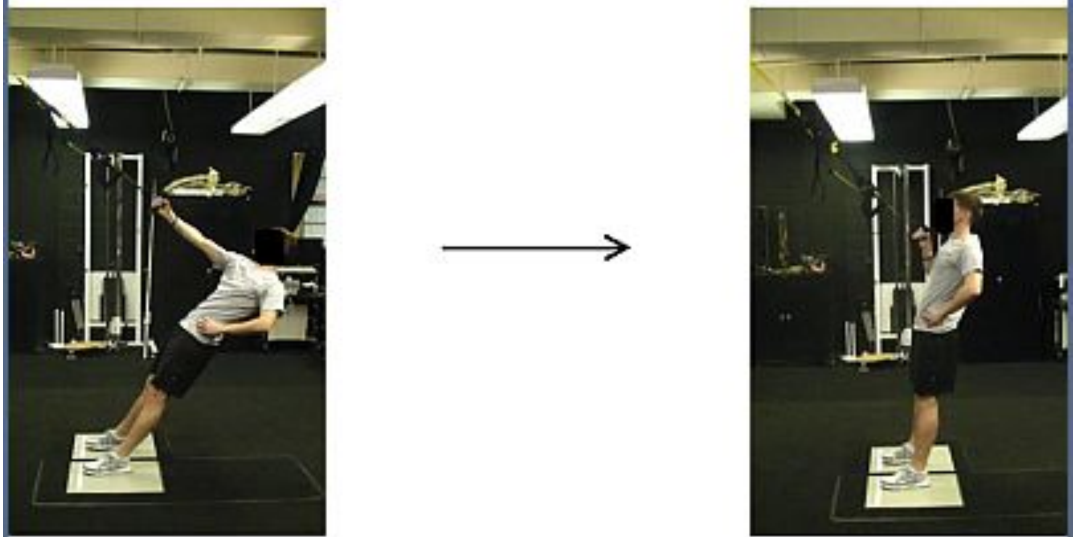


TRX Pull Up

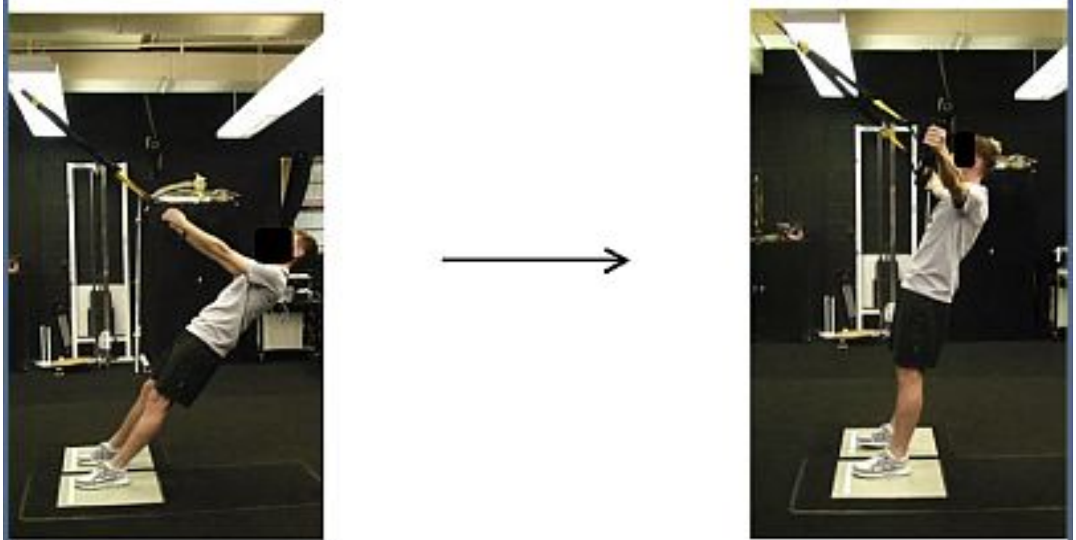
Powerpull



TRX Ghost Row



TRX One Arm Row



TRX Reverse Fly

Participants were taken through a familiarization process before data collection began. The order of the exercises was randomized with exception that the "coached" trials followed the "not coached" trials.

Data Analysis
EMG captured muscle activation for the spine model to enable physiological interpretation. Kinetic and kinematic data were used to predict back loads which calculated the spine curvature angles as well as the reaction moments and forces about the lumbar spine. In this way, the model was sensitive to the different muscle activation strategies and movement patterns of each participant. Averages of EMG muscle activation, spine angles and L4/5 compression forces (spine load) were calculated at 4 phases for 3 repetitions of each exercise:

- *M1* – midway between rest and peak of the exercise (i.e., as the participant was pulling himself up and to the point where they were halfway through the movement for torso exercises).
- *P* – at the peak of the exercise (i.e., at the top of the pull) and the average was taken over the time the participant held this position.
- *M2* – midway between the peak and returning to resting position, as the participant lowered himself toward the ground.
- *E* – rested position at the end of each exercise (i.e., the bottom of a pull) and the average was taken over the time the participant held this position.

Two separate ANOVAs were used to determine the influence, and their sources, of exercise on spine compression and shear force for all exercises except stable and TRX shoulder retractions, powerpull, TRX ghost row and TRX one-arm row. Compression data for pull exercises that were analyzed in this study were not normally distributed, as a result the data was transformed using the natural logarithm and were then found to be normally distributed and was used in data analyses. Two separate t-tests were used to determine the differences during peak exercise phase spinal twist between coached and not coached variations of the powerpull exercise for both left and right sides. Mann-Whitney U test was used to determine the differences in torso EMG muscles during the peak exercise phase between coached and not coached variations for the left and right sides because the data was not normally distributed.

A one-way ANOVA was used to determine differences in changes of spine angles from rested position at the end of each exercise (E) to the peak of the exercise (P) for 3 exercises performed at the same strap length (i.e., TRX pull at angle 2 and TRX shoulder retraction coached and not coached).

STUDY STRENGTHS / WEAKNESSES

Limitations

- A convenience sample of participants with resistance training exercise background was utilized, therefore, it is difficult to generalize findings outside of this specific, self-selected population.
- The sample included only males, so we are also unable to make gender comparisons.
- 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.
- The level/skill of the participants was variable (i.e. the sample included varsity swimmers, distance runners, sprinters and recreational athletes.)

Strengths

- A ranked "atlas of spine compression" for pulling exercises was provided, which assists individual choice of exercises based on spine load tolerance.
- An EMG database used in conjunction with the atlas of spine compression assists in the cost-benefit analysis of clinicians prescribing exercise programs.
- This study 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; "ghost" exercise versus one-limb exercise as an alternative form of rehabilitation when one limb is injured).

Additional References

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