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ORIGINAL RESEARCH

MUSCLE ACTIVATION PATTERNS DURING SUSPENSION TRAINING EXERCISES

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ABSTRACT

Background: Suspension training (ST) has been utilized over exercises performed on a stable surface to train multiple muscle groups simultaneously to increase muscle activation and joint stability.

Hypothesis/Purpose: The purpose of this study was to determine whether ST augments muscle activation compared to similar exercises performed on a stable surface.

Study Design: Cross-sectional study

Methods: Twenty-five healthy adults (male: 16; women: 9; BMI: 23.50 $\pm$ 2.48 kg/m^2) had 16 pre-amplified wireless surface EMG electrodes placed bilaterally on: the pectoralis major (PM), middle deltoid (MD), serratus anterior (SA), obliques (OB), rectus abdominis (RA), gluteus maximus (GM), erector spinae (ES), and middle trapezius/rhomboids (MT). Each participant performed reference isometric exercises (Sorensen test, push-up, sit-up, and inverted row) to establish a baseline muscle contraction. Muscle activation was assessed during the following exercises: ST bridge, ST push-up, ST inverted row, ST plank, floor bridge, floor push-up, floor row, and floor plank. The root mean square (RMS) of each side for every muscle was averaged for data analysis. Multivariate analyses of variance (MANOVA) for each exercise with post-hoc comparisons were performed to compare muscle activation between each ST exercise and its stable surface counterpart.

Results: MANOVAs for all exercise comparisons showed statistically significant greater muscle activation in at least one muscle group during the ST condition. Post-hoc analyses revealed a statistically significant increase in muscle activation for the following muscles during the plank: OB ($p = 0.021$); Push-up: PM ($p = 0.002$), RA ($p < 0.0001$), OB ($p = 0.019$), MT ($p < 0.0001$), and ES ($p = 0.006$); Row: MD ($p = 0.016$), RA ($p = 0.059$), and OB ($p = 0.027$); and Bridge: RA ($p = 0.013$) and ES ($p < 0.0001$).

Conclusions: Performing ST exercises increases muscle activation of selected muscles when compared to exercises performed on a stable surface.

Level of Evidence: 1b

Key words: Electromyography, muscle activation, stable surface exercise, suspension training exercise

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INTRODUCTION

Suspension training (ST) is defined as having one or more straps connected to one or more anchor point(s) as the user is suspended from the handles of the straps by either their hands or feet, while the non-suspended pair of extremities are in contact with the ground. This type of training changes how the muscles are recruited due to the unstable base of support (BOS).[1] The unstable BOS affects the human body via three routes: gravity, muscular force, and a "third factor", which was described by Pastucha et al[2] as "the force of physiological impact and deformation forces.".[2] The cumulative effect of these forces is focused on a single point, the body's center of mass (COM). It is the position of the body's COM over its base of support that determines the stability of the body, and therefore the body's ability to perform any given action. STs are advertised as requiring additional muscle contraction to perform any given movement while utilizing the straps. This is purportedly achieved by forcing the primary (main agonist), secondary (assisting agonist), and stabilization (abdominal, lower back, and bracing) musculature to maintain the body's COM throughout a desired range of motion (ROM). The free-hanging straps allows for an unstable base of support during exercise, and result in a less stable base of support. Although there are a variety of studies that report the utility for STs for rehabilitation, physical fitness and wellness,[3] few have comprehensively assessed the activation patterns of multiple muscle groups during functional exercises.

Suspension training was originally developed for use in the military in the 1990s, and has since been adapted for use by the general public. In theory, performing exercises with the suspension trainer should require greater muscle activation than the equivalent exercises performed without it, thereby potentially having a greater impact on strength, functional stability, and athletic performance.[4] Battendorf et al[5] propose that STs require increased muscle activation to perform any given task based on its ability to alter three mechanical properties:[5] 1) size and location of the base of support; changing the size and location of the base of support (BOS) relative to the user's COM creates an unstable exercise platform requiring varied amplitudes of muscle activation to keep the user's center of mass (COM) over the BOS, 2) direction of the vector forces placed on the muscle groups; as the base of support changes in direction, the angles of the vector forces imparted to the muscle groups due to gravity are also changed which may change the pattern of motor recruitment, 3) the horizontal position of the COM relative to the anchor point determines the resistance/load of the exercise; STs are utilized by placing either the feet or hands into cradles attached to straps that are anchored to a fixed point that is above the cradles. The cradles, acting as bases of support may shift horizontally creating a pendulum effect that can alter the COM relative to the BOS horizontally which in turn, alters the gravitational vector and the loads placed on the working muscle groups. These principles have been theorized to be responsible for muscular loading/unloading during ST suspension training, but little evidence is available to fully support the efficacy of this claim.

Though there are a variety of claims regarding the utility of the ST to increase muscle activation, the evidence in the current literature is lacking. Recent studies by Snarr et al[6,7] found increased muscle activation in pectoralis major and anterior deltoid when performing pushups in a ST when compared to pushups on the floor. Similar studies found that pushups performed in a ST elicited greater muscle activation of the rectus abdominis[7] and latissimus dorsi.[8] Limited scientific data is available on primary agonist, secondary agonist, and stabilization muscle activity measured simultaneously over several different exercise types. Therefore, the purpose of this study was to determine whether ST augments muscle activation compared to similar exercises performed on a stable surface.

METHODS

Study Design

A repeated measures design was utilized in a university laboratory setting equipped with a surface EMG, and a suspension trainer attached to a stable anchor point. The subjects performed a total of eight exercises during a single session: four using the TRX® suspension training system (Fitness Anywhere LLC, San Francisco, CA) and four equivalent exercises performed without the ST. The exercises were: push-

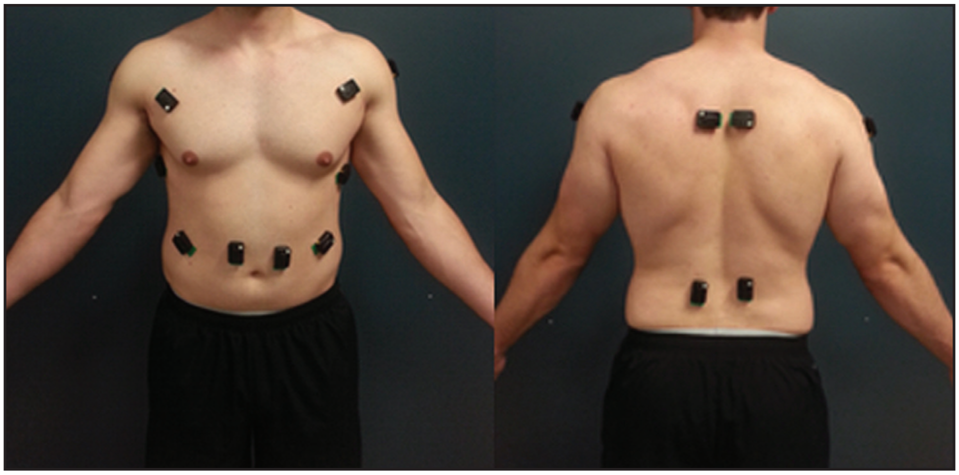

Figure 1. *Electrode placement for muscles of interest.*

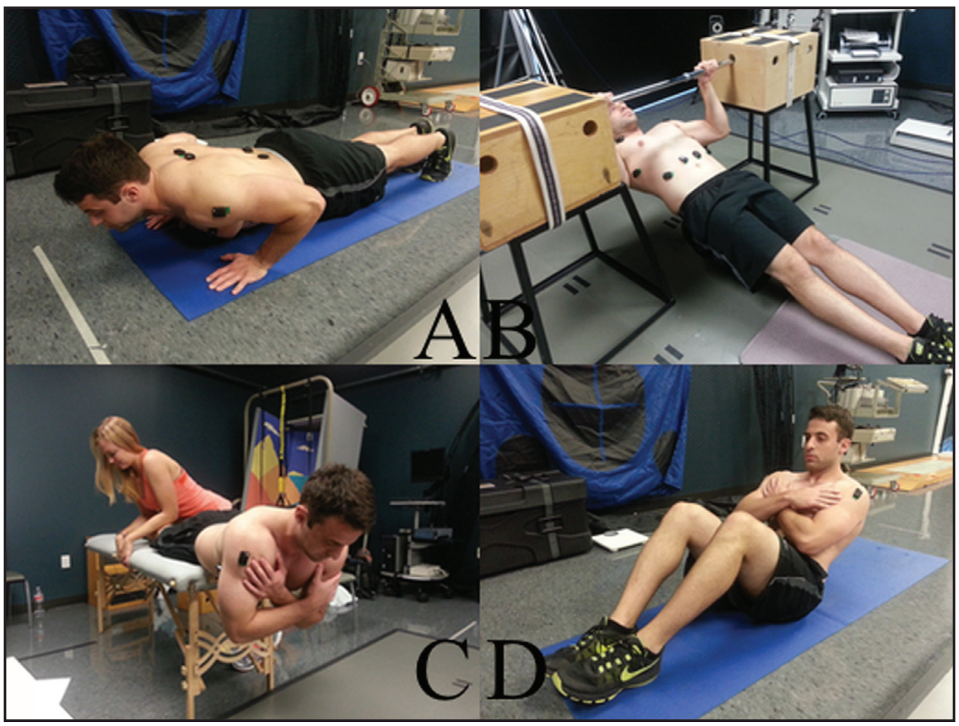

Figure 2. *Isometric exercises chosen for reference isometric contraction (RIC).*

ups, inverted row, bilateral bridge, and a prone plank. After written consent was given, anthropometric measurements such as height, weight and abdomen skinfold thickness were taken with a stadiometer, standard bodyweight scale, and Lange skin-fold caliper (Beta Technology, Inc., Cambridge, MD), respectively. Each subject was equipped with a total of 16 wireless EMG electrodes (Mini Trigno; Delsys, Inc,, Boston, MA). The electrodes were placed bilaterally (Figure 1) over the pectoralis major (PM), middle deltoid (MD), serratus anterior (SA), rectus abdominis (RA), obliques (OB), gluteus maximus (GM), erector spinae (ES), and middle trapezius (MT). The subjects performed the following exercises (Figure 2) in a random order, holding for five seconds each: isometric push-up, isometric sit-up, prone isometric trunk extension, and isometric inverted row to serve as a reference isometric contraction (RIC). After completion of the reference exercises, each subject performed the eight exercises in a randomized order.

The EMG signal was recorded throughout the entire performance of each exercise to compare muscle activation by means of normalized root mean square (RMS) between the ST and the counterpart non-ST exercise.

Subjects

Twenty-five subjects (16 men, 9 women; age: 27.24 ± 4.02 years; BMI: 23.50 ± 2.48) participated in this study after reading and signing an informed consent approved by the Texas Woman University's Institutional Review Board. Inclusion criteria for study participation were: 1) 18-35 years of age, 2) ability to read, speak, and write in English language, 3) no history of spinal, upper or lower extremity injury or surgery within the previous six months, and 4) abdominal skinfold measurement less than 34 mm to prevent impedance affecting EMG reading of abdominal muscles. This skinfold measure was selected arbitrarily to ensure subjects were below 24% body fat as percentages greater than this cut-off increase impedance of the EMG signal.[9]

Procedures

After written consent was obtained, each subject completed the anthropometric measures and a total of 16 pre-amplified Ag wireless electrodes (Trigno, Delsys Inc., Boston, MA; Bandwidth: 450 ± 50 Hz > 80 dB/dec; overall channel noise: < 0.75uV) were placed over muscles of interest. The electrodes were placed bilaterally on the pectoralis major, middle deltoid, serratus anterior, rectus abdominis, external/internal obliques, gluteus maximus, erector spinae, and middle trapezius as described by Criswell (Figure 1).[10] For the male subjects, skin hair was removed with an electric razor as necessary. To establish a reference isometric contraction (RIC) for the muscle groups of interest, each subject performed a 5-second reference body weighted isometric contraction without the ST in the following positions: push-up, inverted row, prone isometric trunk extension, and supine trunk flexion (Figure 2). It was decided to use an isometric reference contraction instead of a maximal isometric voluntary contraction due to the overestimation provided by the latter during typical muscle contractions performed during functional exercises.[11] In addition, the authors wanted to replicate the positions, vector forces of exercises that are commonly done in the clinical environment. The push-up was used as reference for the pectoralis major, middle deltoid and serratus anterior. The inverted row was used for the middle trapezius while the prone isometric trunk extension test was used to assess the erector spinae and gluteal muscles. Lastly, the supine trunk flexion (sit-ups) was used to serve as reference for the rectus and oblique abdominis muscle groups. During the five-second reference contraction, the EMG data were collected with EMG Works® (Delsys Inc., Boston, MA) at a sampling rate of 2000 Hz and filtered through a Butterworth 2nd order band pass filter (cut-off frequency: 100-400 Hz, 160 dB/Dec.). The signal from each muscle of each side was averaged into one value to represent the muscle group bilaterally. The middle three seconds of each five-second epoch were considered for the reference isometric contraction (RIC). The order of performance of reference exercises was randomized for each subject with a one-minute rest break between each exercise.

Upon completion of the reference exercises, the eight exercises (four ST and four non-ST) were randomized and performed in succession with a rest period of three minutes between each. The TRX suspension training system was anchored to a metal frame and adjusted for each subject as follows: pushup (ST handles three inches above floor), inverted row (suspended user's upper body three inches above the ground), bridge (ST foot cradles three inches above the floor), plank (ST foot cradles three inches above floor) (Figure 3). The push-up and the inverted row were performed for five repetitions while the bridge and front plank were performed once with a 30-second isometric hold in an elevated position. For the female subjects, the ST push-up was modified as shown in Figure 4 which is a position commonly utilized for physical fitness tests administered in educational, military and various civil service settings. The data of interest used for statistical comparisons between groups were the third repetition for the push-up and inverted row, and the middle ten seconds for the bridge and front plank. The purpose for selecting the third repetition out of five for the push-up and inverted row was based on the assumption that the third contraction would be the one providing the most stable EMG signal. In this manner any

Figure 3. *Suspension training and floor exercises comparisons.*

possible acceleration at the beginning of the exercise and deceleration and fatigue towards the last two repetitions was eliminated. The sampling rate and filtering processes were identical to those used to obtain the RIC. Once the data was trimmed to the time epoch of interest, the RMS signal for each muscle was normalized to its corresponding RIC.

Statistical Analyses

Data were analyzed using SPSS® version 23 for Windows® (IBM Corp: Armonk, NY). Data were inspected to ensure normality and equality of variances between conditions was met. Means, confidence intervals and standard deviations for the RMS and RIC (%) were obtained for each muscle group. Given that the corre-

Figure 4. *Push-up modification for women.*

Table 1. *Comparisons of mean Root Mean Square (RMS) percent values for Suspension Trainer (ST) and floor plank exercises.*

Muscle Group	ST Mean ± SD 95% CI	Floor Mean ± SD 95% CI	p-value
Pectoralis major	36.53 ± 14.99 30.20 – 42.86	33.15 ± 12.85 27.72 – 38.57	.18
Middle Deltoid	113.99 ± 44.66 95.13 – 132.85	109.70 ± 36.70 94.20 – 125.20	.42
Serratus Anterior	71.47 ± 24.60 61.08 – 81.86	74.57 ± 22.19 65.20 – 83.94	.24
Rectus Abdominis	121.09 ± 118.98 70.85 – 171.33	74.94 ± 30.26 62.16 – 87.72	.07
Obliques	66.79 ± 24.12 56.60 – 76.98	54.63 ± 23.25 44.82 – 64.45	0.02*
Rhomboids/Middle Trapezius	42.53 ± 38.44 26.30 – 58.77	34.56 ± 10.87 29.97 – 39.15	.24
Erector Spinae	40.67 ± 16.45 33.73 – 47.62	41.28 ± 23.33 31.43 – 51.14	.85
Gluteus Maximus	46.10 ± 16.33 39.20 – 52.99	46.28 ± 18.82 38.33 – 54.23	.93

* Statistically significant increase in muscle activation after the post hoc analysis.

lation between variables for each exercise was greater than 0.70 a repeated measures multivariate analysis of variance (MANOVA) for each exercise was used to compare differences between muscle activation between conditions (ST vs Non-ST). Post-hoc analyses for each muscle using Bonferroni adjustments were performed when MANOVA was statistically significant ($p \leq 0.05$).

RESULTS

The MANOVAs were statistically significant for each exercise; push-up ($p = 0.01$; η_p: 0.64), inverted row ($p = 0.04$; η_p: 0.43), bilateral bridge ($p < 0.01$; η_p: 0.70), and prone plank ($p = 0.01$; η_p: 0.66). Post hoc testing revealed that the ST version of the exercise increased the activation of the following muscle groups as compared to its counterpart exercise performed without the ST for the following exercises: plank: obliques ($p = 0.021$); pushup: pectoralis ($p = 0.002$), rectus abdominis ($p < 0.0001$), obliques ($p = 0.019$), rhomboids ($p < 0.0001$), erector spinae ($p = 0.006$); row: deltoid ($p = 0.016$), obliques ($p = 0.027$); bridge: rectus abdominis ($p = 0.013$), erector spinae ($p < 0.0001$). The differences found for the rectus abdominis with the row performed with the ST approached significance with $p = 0.059$. Tables 1.A to 1.D depict the results for each exercise.

Table 2. *Comparisons of mean Root Mean Square (RMS) percent values for Suspension Trainer (ST) and floor push-up.*

Muscle Group	ST Mean ± SD 95% CI	Floor Mean ± SD 95% CI	p-value
Pectoralis major	115.07 ± 36.05 99.85 – 130.29	83.38 ± 30.03 70.70 – 96.07	< 0.01*
Middle Deltoid	245.34 ± 112.98 232.39 – 721.06	84.37 ± 18.18 76.70 – 92.04	.32
Serratus Anterior	91.81 ± 59.57 66.65 – 116.96	72.24 ± 21.99 62.96 – 81.53	.11
Rectus Abdominis	93.90 ± 36.70 78.41 – 109.40	67.47 ± 25.26 56.80 – 78.13	<0.01*
Obliques	81.04 ± 60.14 55.65 – 106.44	52.80 ± 26.74 41.50 – 64.09	0.02*
Rhomboids/Middle Trapezius	67.01 ± 23.50 57.10 – 76.94	46.53 ± 16.60 39.52 – 53.54	<0.01*
Erector Spinae	54.52 ± 21.96 45.34 – 63.90	41.10 ± 15.96 34.37 – 47.84	0.01*

* Statistically significant increase in muscle activation after the post hoc analysis.

Table 3. *Comparisons of mean Root Mean Square (RMS) percent values for Suspension Trainer (ST) and floor row exercises.*

Muscle Group	ST Mean ± SD 95% CI	Floor Mean ± SD 95% CI	p-value
Middle Deltoid	168.98 ± 78.15 135.98 – 201.98	145.69 ± 65.00 118. 24– 173.13	0.02*
Serratus Anterior	47.14 ± 20.11 38.65 – 55.64	54.64 ± 29.82 42.05 – 67.23	.18
Rectus Abdominis	67.41 ± 21.27 58.43 – 76.40	63.43 ± 18.94 55.44 – 71.43	0.05*
Obliques	40.56 ± 24.74 30.11 – 51.00	37.44 ± 20.39 28.83 – 46.05	0.03*
Rhomboids/Middle Trapezius	77.35 ± 23.05 67.62 – 87.09	82.86 ± 21.50 73.78 – 91.94	.20

* Statistically significant increase in muscle activation after the post hoc analysis.

DISCUSSION

The objective of this study was to compare muscle activation between stable surface exercises and similar exercises performed using the ST. The main finding was that each ST exercise had at least one muscle group that showed a statistically significant increase in activation when compared to its equivalent exercise on the ground. Although surface EMG readings can be affected by body movements and other factors,[12] this study's use of a RIC and standardization of joint angles/motions performed allows for the comparisons of muscle activation between conditions. The results of this study appear to indicate that the use of a ST will increase activation of several muscle groups when compared to similar exercises performed on a stable surface.

Table 4. *Root Mean Square (RMS) percent values for Suspension Trainer (ST) and floor bridge exercises.*

Muscle Group	ST Mean ± SD 95% CI	Floor Mean ± SD 95% CI	P-value
Middle Deltoid	78.23 ± 45.92 55.28 – 101.19	62.59 ± 17.20 53.99 – 71.19	.13
Rectus Abdominis	60.83 ± 15.60 53.03 – 68.70	57.73 ± 15.77 49.85 – 65.62	0.01*
Obliques	41.44 ± 28.01 27.44 – 55.45	33.11 ± 12.09 27.06 – 39.15	.12
Erector Spinae	61.51 ± 13.85 54.58 – 68.44	45.50 ± 9.47 40.76 – 50.23	< 0.01*
Gluteus Maximus	58.75 ± 24.41 46.55 – 70.95	54.12 ± 20.02 44.11 – 64.13	.15

*Statistically significant increase in muscle activation after the post hoc analysis.

The ST pushup was the only exercise that demonstrated a statistically significant increase in muscle activation for nearly all muscle groups tested. Snarr et al[6] had similar findings, when they reported increased activation of pectoralis major, anterior deltoid, and triceps brachii while performing ST pushup.[6] One plausible hypothesis for this is that the ST pushup was the only exercise performed where the COM was directly over the unstable base of support (and farther away from the stable base), which may enhance activation of the tested muscle groups.[2] STs are unique in that there are two BOS (one unstable and one stable), so as the COM gets closer over the unstable surface it is also getting further away from the stable surface, and vice versa.[13]

Use of the ST increased the muscle recruitment of the pectoralis, rectus abdominis, obliques, rhomboids and erector spinae possibly due to a combination of decreased angular velocity and unstable BOS. Previous studies have shown that when a novel movement is introduced, the angular velocities required to perform the task are decreased which will allow for increased motor unit recruitment, particularly with concentric contractions.[13] The EMG activity was assessed during the concentric phase of the ST push-up, which requires increased motor recruitment to perform the movement at a reduced angular velocity. Although the angular velocity was not the focus of this study, the subjects that were utilized had no previous exposure to ST and thus demonstrated reduced speed when performing these movements on the ST as compared to without it. The variations in point of stability as previously discussed requires altered magnitudes of motor recruitment based on the need to maintain the center of mass over a base of support that can shift directions based on the forces applied to it.[13,14]

For the bridge exercise, there was a statistically significant increase in muscle activation for the rectus abdominis and erector spinae when using the ST. As previously discussed, distance of COM from the unstable arm will influence muscle activation for a given task. In the bridge exercise, the unstable surface (feet in straps) was further away from the user's COM, thereby decreasing the difficulty of the exercise.[15] The bridge is a commonly used exercise to increase muscle endurance, strength and motor recruitment of the gluteal, hamstring, abdominal and trunk extensor muscle groups.[16,17] The subjects reported increased levels of hamstring activity as compared to the gluteal muscle groups when the bridge was performed in the ST. This may be due to the necessity to control the anterior to posterior swing of the ST straps by activating the hamstrings during the bridge movement.

When performing the plank exercise with feet in the ST straps, all muscles tested in this study demonstrated an increase in activation compared to floor exercises, but only the obliques showed a statistically significantly greater RMS. While no studies to date have studied muscle activation in planks on a

ST, specifically with the feet in the unstable surface, core activation has been shown to increase when using a variety of unstable surfaces. Lehman et. al[14] demonstrated a 20% increase in core activation with push-ups performed with hands on a Swiss ball and Calatayud et al[18] found a statistically significant increase in muscle activation of the triceps, upper trapezius, lumbar erector spinae, rectus femoris and rectus abdominis, with the greatest change in the rectus abdominis when the push-up was performed on a ST. Despite limited research, one consideration for the practitioner would be holding the ST straps in the hands in a high plank position instead of performing the plank with feet in the straps. As mentioned above with the push-up, maintaining the center of mass directly over or closer to the ST straps tends to further increase muscle activation in all surrounding musculature. Thus, a practitioner can apply the strategy of altering body positioning to either assist the user or challenge them further.

With the inverted row, increased muscle activation was statistically significantly greater in the middle deltoid, obliques, and rectus abdominis. This again supports the hypothesis that providing an unstable BOS during an exercise may facilitate increased muscle activation, particularly at the spinal stabilizers. The inverted row has not previously been studied in regards to STs, but there are extensive published reports that discuss muscle activation patterns in the exercise on a stable surface. Mok et al[19] found abdominal musculature generally operated at $<20\%$ of the MVIC during an inverted row performed at 45° angle. While the angle of incline could certainly be manipulated to increase muscle activation, the present study provides another alternative by using a ST. Additionally, further research could be conducted to determine if there is a difference in muscle activation between pushing exercises and pulling exercises on the ST. Calatayud et al[18] determined triceps brachii, pectoralis, and rectus abdominis muscle activation for a pushup on the floor is also less than 20% MVIC. However, the addition of a ST could alter the demands on the muscle due to both the instability component and considering the pushup demands an eccentric contraction of the pectoralis major at the beginning of the exercise while the inverted row requires a concentric contraction of the middle trapezius.

Although an abundance of research has been conducted examining EMG activity of selected muscles during various exercises performed on unstable surfaces, few studies have examined the relative difference of similar exercises performed utilizing a ST. Furthermore, there is no literature currently available that looks at primary, secondary, and stabilization musculature over such a broad spectrum of muscle/exercise combinations simultaneously. Results from this study are consistent with findings from those found in Anderson et al,[20] where there was an increase in stabilization musculature EMG activity during body weight exercise when stability is challenged. Additionally, this study suggests that utilization of a ST alters the pattern of muscle recruitment. Thus, it appears that the muscles of the limbs must be activated to a greater extent to prevent unnecessary horizontal and diagonal movements.[20] Surrounding musculature are then required to help stabilize the moving joint, in addition to performing the desired motion.[13]

Due to the ability to load/unload the user, ST applications are extremely varied.[3] The results of this study suggest that when body positioning is similar, a ST exercise will elicit greater stabilization muscle activation than its stable counterpart as found with the use of sEMG. While traditional unstable surface training is normally utilized to increase exercise difficulty, the TRX® and other similar STs can be used to either increase or decrease muscular demand. This ability to gradually load/unload the user helps to progress the difficulty of the exercise at a selected degree of angulation each time, thus increasing specificity of training. STs also show great potential when applied to strength training. Typical strength training exercises, with the exception of Olympic lifts, are applied primarily in a single plane.[21] Functionally, this is not very applicable as most physical activities are performed in multiple planes during any given movement.[4] For athletes this is especially true, as there are often unexpected, high-load multidirectional vectors throughout the game of play. Given the inherent instability of STs, they can be utilized to train stabilization musculature, and more effectively mimic multidirectional loads that these athletes experience.

Although these results showed that suspension training elicits greater muscle activation than floor exercises in some muscles, these results should be interpreted with caution. It has been documented that the EMG signal is not directly related to the number of muscle fibers activated limiting a direct measurement of neural drive.[12] This is more evident during dynamic contractions where muscles are changing in length and there is a possibility of fatigue like in this investigation.[12] However, EMG amplitude analyses are useful for approximating muscle activation when normalized to a reference contraction.[22] Extrapolation of the results of this study to patients who are symptomatic or have other pathologies should be done with caution. It cannot be concluded that symptomatic individuals will demonstrate the same patterns of muscle activation as the asymptomatic individuals in this study. Additionally the results of this study only allow for speculation as to what underlying biomechanical principles are responsible for the increased muscle activation found using the ST. Results from this study can, however, be extrapolated for future research endeavors to potentially further isolate causal factors responsible for increased muscle activation when using STs. For example, exercises in future studies should be selected that minimize the available base of support and distance between COM and unstable hand straps; as these factors have been found to potentially contribute to increased muscle activation.

CONCLUSIONS

The results of this investigation showed an increased in muscle activation of several upper extremity and core muscles when exercises are performed using a suspension trainer. Such increases in muscle activation during ST were particular to each specific exercise based on positioning and loading of the straps. Future work is necessary to determine the effectiveness of ST in those suffering from upper extremity and lumbo-pelvic musculoskeletal disorders that could benefit from muscle stabilization interventions.

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