ABSTRACT

Background: The stabilizing action of the serratus anterior (SA) muscle is vital in maintaining normal scapulothoracic rhythm. This warrants investigation of exercises to discern which are best to activate the SA muscle. Recruitment of the muscles in the trunk and lower extremity kinetic chain during exercises has demonstrated increased SA activation due to the myofascial connections between various segments of the body. Variation of surfaces during an exercise has also been shown to alter the muscle recruitment patterns.

Purpose: The primary purpose was to determine the effects of trunk and lower extremity kinetic chain muscle recruitment on the SA muscle activity while on an unstable surface. The secondary purpose was to determine if the SA muscle activity would change when the surface stability during the exercises was reduced.

Study Design: Descriptive, within-subject repeated measures.

Methods: Surface electromyographic activity of the SA, latissimus dorsi (LD), external oblique (EO) on the dominant, and femoral adductor (FA) muscles on the non-dominant side and gluteus maximus bilaterally was analyzed during forward punch plus (FPP) and two of its' variations: FPP with closed chain serape (CS), FPP with open chain serape (OS) on stable and unstable surface in twenty-one healthy males. A two-way repeated measure ANOVA was used to determine the difference in the muscle activation between exercises, surfaces, and interaction between these two variables. A separate one-way repeated measures ANOVA with Sidak post hoc test was used for comparisons between stable and unstable surfaces. (p≤0.05).

Results: Muscle activity was statistically significantly higher for the CS and the OS exercises compared to the FPP for all the muscles except for the LD within the same surface. There was no significant difference in muscle activity for any of the muscles when compared between stable and unstable surfaces.

Conclusions: Incorporating the trunk and lower extremity kinetic chain during the FPP exercise increased the SA activation on both stable and unstable surfaces. However, the type of surface did not influence the activation of any muscle across exercises. The results of this study further strengthen the benefit of the kinetic chain exercises but also caution that adding an unstable surface to an exercise does not always imply higher muscle activation.

Level of Evidence: 2b

Key Words: Kinetic chain, serratus anterior, movement system, myofascial chains
INTRODUCTION

Normal scapulothoracic kinetics and kinematics are essential for proper function of the upper extremity. Due to its anatomical location, the scapula acts as a connecting link between the upper extremity and the trunk. Abnormal scapular kinematics such as decreased scapular upward rotation, posterior tilting, and external rotation have been related to various mechanical dysfunctions at the shoulder such as subacromial impingement. Chronic and repetitive shoulder impingement could lead to rotator cuff pathologies such as tendinopathies or tears. Abnormal scapular kinematics could represent a dysfunctional link in the chain that connects the upper extremity to the rest of the body. In the absence of a normal scapular kinematics, all of the muscles that attach to the scapula cannot function efficiently. This muscular imbalance may contribute to scapular dyskinesis.

Although several muscles attach to the scapula and are responsible for the normal three-dimensional scapulothoracic motion, the serratus anterior (SA) has been shown to be one of the primary muscles responsible for normal rhythm. The SA commonly presents as weak in patients with shoulder dysfunction. Reduced SA muscle activation could lead to abnormal scapular motion during all the motions of the shoulder complex. Therefore, the SA plays a key role in regulating the normal scapulothoracic rhythm by stabilizing the scapula over the thoracic cage. Hence, motor control and/or strengthening of the SA is an important intervention in patients with various shoulder dysfunctions.

Researchers have suggested several exercises to strengthen the SA muscle. Since the shoulder complex depends on the synchronous movement of multiple segments in the body, kinetic chain recruitment during various exercises has shown to increase the SA muscle activation. The use of the kinetic chain model during rehabilitation of patients with shoulder dysfunctions has been suggested to be more effective than traditional exercises that include upper extremity muscles alone. Kinetic chain model exercises engage multiple segments and muscles of the body simultaneously. This treatment approach also takes into consideration the entire neuromuscular system rather than isolating the different segments of the body while treating common shoulder and upper extremity (UE) dysfunctions.

One explanation why incorporating the kinetic chain during various UE exercises may result in higher SA muscle activation is due to various myofascial connections between the trunk and the limbs. The SA muscle is part of what has been described as "the serape effect" which highlights the myofascial connections between the SA, ipsilateral rhomboids, external oblique (EO), and contralateral internal oblique, and femoral adductor (FA) muscles. Additionally, SA has myofascial connections to the ipsilateral latissimus dorsi (LD) near the inferior scapular border. Due to its myofascial connection with the LD, the SA muscle has indirect connections with bilateral gluteus maximus (GM) muscles via thoracolumbar fascia. Increased activation of the SA has been achieved when all the other muscles in a kinetic chain have been activated along with the SA during various exercises.

With an intent to increase the muscle activation and improve proprioception, use of different surfaces has been advocated. For this reason, unstable surfaces such as balance boards, inflatable discs, and exercise balls are commonly used during rehabilitation exercises. Although there is evidence supporting an increase or decrease in the muscle activation when the exercise was performed on unstable rather than a stable surface, no change in the muscle activation by addition of the unstable surface has also been documented.

Hence, researchers have not reached a consensus regarding the benefits of adding unstable surfaces during the performance of various exercises. Various electromyographic studies have been conducted to investigate the best exercises for the activation of the SA. Forward punch plus (FPP) has been one of the previously documented exercises to best activate the SA muscle in an open chain. Kaur et al found that the extremities and trunk kinetic chain recruitment increased the SA muscle activation on a stable surface during the FPP exercise. Previous studies have reported increased SA activation with the extremities and trunk kinetic chain recruitment on an unstable surface during a closed
chain exercise. There are no studies that have examined the effects of the kinetic chain on the SA activation on an unstable surface during an open chain exercise. Thus, the primary purpose was to determine the effects of trunk and lower extremity kinetic chain muscle recruitment on the SA muscle activity while on an unstable surface. The secondary purpose was to determine if the SA muscle activity would change when the surface stability during the exercises was reduced.

METHODS

Subjects
Twenty-one healthy males with fair to very lean body composition (low percentage body fat), as reported in ACSM's Guidelines for Exercise Testing and Prescription completed the study. The body composition of the participants was assessed to achieve most accurate surface electromyography (EMG) signal by reducing the effects of body fat on the EMG signal.29 The subjects mean age was 26.7 ± 2.6 years, mean height, 177.2 ± 5.6cm, mean weight, 79.5 ± 7.8 kg, and mean percentage body fat, 12 ± 3.6%. The study was approved by the Institutional Review Board of the University of St. Augustine for Health Sciences, Austin, TX. Sample size of 19 subjects was needed using conventional values for a medium effect size (f= 0.25); degrees of freedom = 6, power = 0.80; alpha = 0.05. Twenty-one subjects completed the study.

Procedures
The subjects provided informed consent and then were screened regarding inclusion and exclusion criteria (Table 1). Skin fold measurements were taken using the guidelines provided in the ACSM's Guidelines for Exercise Testing and Prescription.28 Lange* skin fold calipers (model # 68902, Fitness Mart*, division of Country Technology, Inc., Gays Mills, Wisconsin) and the three site formula regression equations for men (chest, abdomen, and thigh) were used to assess the body composition. Leg length was measured by the principal investigator to standardize the step length during exercises to allow for the accurate comparisons of performance among participants.28 The leg length was measured from the anterior superior iliac spine (ASIS) to the end of the medial malleolus with the subject lying supine while not wearing shoes.

The Trigno wireless EMG system (Delsys Inc. Boston, MA, USA) was used to collect all the EMG data. Wireless electrodes (37mm x 26mm x 15 mm) and a four bar (99.9% silver) contact area, with an inter-electrode distance of 10 mm (Delsys Inc. Boston, MA, USA) were used in conjunction with a hard-wired single differential amplifier. The skin was prepared before the electrode placement using vigorous cleaning of the area with an alcohol pad. The subjects shaved the area if body hair was present. EMG electrodes were applied using the double sided hypoallergenic adhesive tape to the lower muscle fibers of

| Table 1. Inclusion/Exclusion Criteria |
|--------------------------------------|
| **Inclusion Criteria**                             | **Exclusion Criteria**                                    |
| • Males                                          | • Currently experiencing pain anywhere in the body.       |
| • Age 18-40 years                               | • Any neuromuscular disorder, joint or bone disease.      |
| • Age-related body composition (% body fat)     | • Upper extremity (UE) motion limitation (visual inspection). |
| between fair to very lean, as reported in ACSM’s Guidelines for Exercise Testing and Prescription | • Upper or lower extremity (LE) injury within prior six months. |
|                                                     | • History of any neck, back, UE, or LE surgery.           |
|                                                     | • Performed upper limb strength training for more than five hours/week |
|                                                     | • History of chronic ankle instability of the stance leg (determined using Ankle Instability Instrument) |

ACSM= American College of Sports Medicine
the SA, LD, and EO muscles on the dominant side, GM bilaterally, and FA of the contralateral side of the subjects according to the procedure described by Cram et al.\textsuperscript{31} The electrode placement for each muscle was as follows: for the SA the electrodes were placed below the axillary area, at the level of the inferior tip of the scapula, and just medial to fibers of the latissimus dorsi; for the LD, the electrodes were placed approximately 4 cm below the inferior tip of the scapula, half the distance between the spinous processes and the lateral edge of the torso; for the EO, the electrodes were placed lateral to the rectus abdominis and directly above the anterior superior iliac spine, halfway between the crest and the ribs at a slightly oblique angle so that they were parallel to the muscle fibers; for the GM, the electrodes were placed half the distance between the greater trochanter and the sacral vertebrae in the middle of the muscle at an oblique downward angle at the level of the trochanter or slightly above; and for the FA muscle, the electrodes were placed on the medial aspect of the thigh in an oblique direction 4 cm from the pubis. After placing the electrodes, subjects performed light jumping jacks for 30 seconds to warm up.\textsuperscript{32}

For normalization of the EMG data, maximum voluntary isometric contractions (MVICs) were established for each muscle. Test positions were consistent with those described by Kendall\textsuperscript{33} and previous research.\textsuperscript{30,34} For the SA muscle, participant was asked to sit at the edge of the bed with feet touching the floor. The arm of the testing side was elevated to 125°. The investigator placed one hand on the upper arm and the other hand was placed on the lateral border of the scapula. The participant was asked to resist downwardly directed force. For the LD muscle, the participant was asked to lie prone. The arm was positioned in adduction, extension and internal rotation. The investigator provided resistance just below the elbow in the combined direction of shoulder abduction and flexion. For the FA muscles, the participant was placed in the side lying position with testing side down. The top leg was cradled by the investigator while providing resistance to the lower thigh, just above the knee. While the participant was instructed to lift the leg towards the ceiling. For the GM muscle, participant was in prone position with hip extended and knee flexed beyond 90°. The resistance was applied in the downward direction on the posterior thigh just above the knee. For the EO muscle, the participant while in hook lying was asked to perform an oblique sit up to move the resisted shoulder towards the opposite knee.

The MVICs were performed over a five-second period using a metronome involving a gradual build up to maximum muscle activity. Each muscle test was repeated three times, with a 15-second rest between contractions.\textsuperscript{9,11} Between MVIC measurements of different muscles, a two minute of rest period was provided. Verbal feedback was provided for each subject for the MVIC procedures.

**Exercises**

The exercises under investigation were either based on the previous recommendations to best activate the SA muscle\textsuperscript{9,13,26} or based on the myofascial connections reported in the literature.\textsuperscript{35-37} The following exercises were performed on the ground (stable surface) and the BOSU® Balance Trainer (Ashland, OH, USA), (unstable surface) with the subject wearing shoes. The order of the exercises was randomized using a computerized random sequence generator.

**Exercises 1 and 4: Forward punch plus (FPP)** (Figure 1 and 4): Subject stood in a parallel stance, and the exercise started with subject’s dominant arm at the side of the body with elbow flexed to 90° and radioulnar joint in the midway between pronation and supination. The subject then flexed the shoulder to 90° and fully extended the elbow, internally rotated the humerus to 45°, and protracted the scapula. The subject then returned to the initial position by extending the shoulder, flexing the elbow in the same forearm position, and standing in a parallel stance.

**Exercises 2 and 5: FPP with closed chain serape effect (CS)** (Figure 2 and 5): Subject performed FPP with the dominant arm as he rotated the trunk to the opposite side with simultaneous contralateral leg flexion and adduction in a closed chain. The subject stepped forward and crossed the midline of the trunk as marked by the white tape on the ground. The subject then returned to the initial position by extending the shoulder, flexing the elbow in a neutral position and standing in a parallel stance. The
length of the forward step was standardized for each subject by placing the tapes on the floor at a distance of 75% of their leg length (± 3 cm on either side of the 75% of the leg length).

Exercises 3 and 6: FPP with open chain serape effect (OS) (Figure 3 and 6). Subject performed FPP with the dominant arm as the trunk was rotated to the opposite side and performed simultaneous contralateral...
leg flexion and adduction in an open chain. The subject swung the contralateral leg in front and crossed the midline of the trunk as he maintained his balance. The subject then returned to the initial position by extending the shoulder, flexing the elbow in neutral position, and standing in a parallel stance.

The subjects were verbally instructed to punch as hard as possible with maximum force to reach a stand with a visual marker placed at the maximum reach distance to ensure adequate protraction of the scapula with the exercises. The subjects were required to bring their fist close to the marker with each exercise trial. The subjects were asked to stand with feet at their hip width apart on both surfaces while maintaining their balance. The positions of the feet were marked to make sure that the subjects returned to their previous foot positions in case they moved between trials. Practice trials were provided to the subjects, and three trials of the exercises were performed with at least five seconds rest between repetitions. The speed of the trials was regulated by a metronome set to 50 beats per minute, where each phase (starting position to maximum reach and maximum reach to the ending position) was performed during one beat.9,11,26 The subjects were given verbal commands to begin and end each exercise trial for proper technique during the training and data collection. A minimum of two minutes of rest was provided between different exercises to prevent the influence of fatigue on muscle activation.9,11

Data processing

The data were collected at a sampling frequency of 1926 Hz, CMRR > 80 dB@60 Hz; signal to noise ratio of > 750 nv, and no gain was applied to the signal. All collected signals were subsequently band pass filtered (between 20 and 450 Hz) with a 2nd order filter on the high-pass, and a 4th order filter on the low-pass then rectified and finally smoothed by using a root-mean-square (RMS) calculation. RMS was calculated using a default window length of 0.125 s with a 0.0625s window overlap. For all subjects, MVIC was averaged across the three intermediate seconds for each muscle to calculate the mean of the peak RMS value of the three trials. The mean RMS EMG activity of each muscle was calculated across the three trials of every exercise, for all the subjects. The mean RMS value of the three trials for each muscle was normalized to its respective MVIC value and represented as

**Figure 5.** Exercise 5-Forward Punch Plus (FPP) with closed chain Serape effect (CS), unstable.

**Figure 6.** Exercise 6-Forward Punch Plus with open chain Serape effect (OS), unstable.
a percentage of MVIC (%MVIC) using the following equation:

\[\%MVIC = \frac{\text{Average RMS value of the three repetitions}}{\text{average peak RMS value}} \times 100\]

**Data Analysis**

A two-way repeated measure analysis of variance (ANOVA) with two repeated factors, surface (two levels) and exercises (three levels), was performed on the %MVIC EMG activity for each of the six muscles (SA, LD, EO, FA, and bilateral GM) to determine significance between surfaces, between exercises, and interaction between surface and exercises. In the event of significant results, a separate one-way repeated measures ANOVAs was performed to compare the normalized EMG values of the same muscle during three exercises for both the stable and the unstable surfaces. Separate ANOVAs were performed on each muscle tested to determine if the change in the SA activation was due to the recruitment of the trunk and LE muscles and if there were any significant differences among the three exercises. In the event of a significant ANOVA, Sidak post hoc test was used for the pairwise comparison of exercises. The level of significance was set at 0.05 for all analyses, and 95% confidence intervals (CIs) were reported around the %MVIC for each exercise. The Statistical Package for the Social Sciences (SPSS Inc, 24.0, Chicago, IL, USA) was used for the analyses.

**Results**

The two-way repeated measures ANOVA was not statistically significant for the surface (F = 0.045, p = 0.835) and for the interaction between surface and exercises (F = 0.237, p = 0.714). This indicates that the change in the surface from stable to unstable did not significantly change the muscle activity for any of the muscles during each exercise.

However, the muscle activity was statistically significantly different between the exercises for all the muscles except for Latissimus Dorsi (F = 12.7, p < 0.001). One-way repeated measures ANOVA was statistically significant for the main effects for both surfaces among the three exercises for the SA (Table 2) (stable: F = 12.2, p < 0.001; unstable: F = 9.3, p = 0.002), EO (Table 3) (stable: F = 20.8, p < 0.001; unstable: F = 13.6, p < 0.001), FA (Table 4) (stable: F = 20.3, p < 0.001; unstable: F = 12.726, p < 0.001), contralateral glutaeus maximus (cGM) (Table 5) (stable: F = 9.5, p < 0.001; unstable: F = 3.4, p = 0.041), and ipsilateral glutaeus maximus (iGM) (Table 6) (stable: F = 17.3, p < 0.001; unstable F = 12.8, p = 0.001).

Results of the pairwise comparisons indicate that the EMG activity (% MVIC) of the SA, EO, FA, and iGM during both the stable and the unstable surfaces for the CS and the OS was significantly higher than the EMG activity of the FPP. However, cGM activity was significantly higher for the CS but not for the OS (Tables 1 - 6). There were no statistically significant differences between CS and OS for any muscle for the either surface (p > 0.05) except for the FA (stable: p = 0.003 and unstable: p = 0.025). There was no statistically significant difference for the activation of the LD (Table 7) (stable: F = 2.1, p = 0.146).

| Exercises | Mean (%MVIC) | SD   | 95% CIs (Lower bound - Upper bound) | p-value |
|-----------|--------------|------|------------------------------------|---------|
| **Stable Surface** | | | | |
| FPP       | 85.50        | 43.17| 65.85 - 105.15                      | 0.034*  |
| CS        | 132.54       | 86.97| 92.95 - 172.13                      | 0.001*  |
| OS        | 160.65       | 100.95| 114.70 - 206.60                    |         |
| **Unstable Surface** | | | | |
| FPP       | 84.98        | 37.70| 67.819 - 102.14                     | 0.03*   |
| CS        | 138.40*      | 94.33| 95.46 - 181.33                      |         |
| OS        | 157.39*      | 110.23| 107.21 - 207.57                    | 0.007*  |

SD = standard deviation; FPP = forward punch plus; CS = FPP with closed chain serum effect; OS = FPP with open chain serum effect.
*p value statistically significant at p ≤ 0.05.
Table 3. Mean EMG activation of the External Oblique for the three exercises.

| Exercises | Mean (%MVIC) | SD  | 95% CIs (Lower bound - Upper bound) | p-value |
|-----------|--------------|-----|------------------------------------|---------|
| Stable Surface |             |     |                                   |         |
| FPP       | 52.08        | 21.81 | 42.15 - 62.01                      | 0.001*  |
| CS        | 78.75        | 32.61 | 63.90 - 93.59                      |         |
| OS        | 92.68        | 34.04 | 77.18 - 108.17                     |         |
| Unstable Surface |     |     |                                   |         |
| FPP       | 53.83        | 25.87 | 42.05 - 65.60                      | 0.001*  |
| CS        | 85.87        | 33.99 | 70.40 - 101.34                     |         |
| OS        | 87.79        | 37.94 | 70.52 - 105.06                     |         |

SD= standard deviation; FPP = forward punch plus; CS = FPP with closed chain serape effect; OS = FPP with open chain serape effect.
*p value statistically significant at p≤0.05.

Table 4. Mean EMG activation of the Adductor muscles for the three exercises.

| Exercises | Mean (%MVIC) | SD  | 95% CIs (Lower bound - Upper bound) | p-value |
|-----------|--------------|-----|------------------------------------|---------|
| Stable Surface |             |     |                                   |         |
| FPP       | 14.87        | 13.11 | 8.90 - 20.834                      | 0.002*  |
| CS        | 67.34        | 67.06 | 36.82 - 97.87                      |         |
| OS        | 111.52       | 101.71 | 65.21 - 157.81                    | 0.001*  |
| Unstable Surface |     |     |                                   |         |
| FPP       | 33.92        | 52.57 | 9.99 - 57.85                       | 0.003*  |
| CS        | 73.00        | 88.76 | 32.60 - 113.41                    |         |
| OS        | 110.82       | 140.68 | 46.78 - 174.86                    | 0.003*  |

SD= standard deviation; FPP = forward punch plus; CS = FPP with closed chain serape effect; OS = FPP with open chain serape effect.
*p value statistically significant at p≤0.05.

Table 5. Mean EMG activation of the contralateral Gluteus Maximus for the three exercises.

| Exercises | Mean (%MVIC) | SD  | 95% CIs (Lower bound - Upper bound) | p-value |
|-----------|--------------|-----|------------------------------------|---------|
| Stable Surface |             |     |                                   |         |
| FPP       | 12.27        | 12.93 | 6.39 - 18.16                      | 0.001*  |
| CS        | 16.27        | 13.38 | 10.18 - 22.36                     |         |
| OS        | 13.41        | 10.07 | 8.82 - 17.99                      | 0.549   |
| Unstable Surface |     |     |                                   |         |
| FPP       | 10.12        | 5.78  | 7.49 - 12.75                      | 0.04*   |
| CS        | 14.07        | 9.02  | 9.97 - 18.18                      |         |
| OS        | 12.53        | 7.34  | 9.19 - 15.87                      | 0.223   |

SD= standard deviation; FPP = forward punch plus; CS = FPP with closed chain serape effect; OS = FPP with open chain serape effect.
*p value statistically significant at p≤0.05.
and unstable: F = 4.8, p = 0.074) among the three exercises across the two surfaces.

**Discussion**

To effectively rehabilitate a patient with shoulder complex dysfunction, it is vital to choose the exercises that are best in recruiting the SA muscle due to its role in the normal scapulothoracic rhythm. In the current study, EMG activation of the SA during the FPP exercise and its two variations, CS and OS, that incorporated the muscles (LD, EO, FA, GM) in the kinetic chain linkages on various surfaces was investigated. The SA muscle activation was significantly increased with the integration of the extremities and trunk kinetic chains on both surfaces, but there was no statistically significant difference in the mean EMG activation of the SA between the stable and the unstable surfaces.

**Comparison of the three Exercises**

This study is not the first to investigate the effects of the kinetic chain recruitment on the activation of the SA muscle. The SA muscle activation was significantly greater during the CS and the OS exercises as compared to the FPP (only) exercise. Therefore, simultaneous recruitment of various trunk and lower extremity muscles during the CS and the OS exercises probably facilitated the SA muscle activation. To authors’ knowledge, no other researchers have compared the effects of the stable and the unstable surfaces on the recruitment of the SA muscle activation in the FPP exercise. This study is in agreement with the previous research that has investigated the effects of kinetic chain recruitment on the activation of the SA muscle.9-11,15 Maenhout et al.11 and Kim et al.10 proposed that kinetic chain recruitment via the ipsilateral leg extension activated the muscles.

| Exercises | Mean (%MVIC) | SD  | 95% CIs (Lower bound - Upper bound) | p-value |
|-----------|--------------|-----|------------------------------------|---------|
| Stable Surface | | | | |
| FPP | 15.91 | 7.00 | 12.72 - 19.09 | |
| CS | 25.16 | 12.63 | 19.41 - 30.91 | 0.002* |
| OS | 33.20 | 19.69 | 24.23 - 42.16 | 0.001* |
| Unstable Surface | | | | |
| FPP | 16.70 | 7.47 | 13.30 - 20.10 | |
| CS | 22.46 | 9.69 | 18.05 - 26.87 | 0.002* |
| OS | 31.18 | 20.50 | 21.85 - 40.51 | 0.001* |

SD = standard deviation; FPP = forward punch plus; CS = FPP with closed chain serape effect; OS = FPP with open chain serape effect.

Table 6. **Mean EMG activation of the ipsilateral Gluteus Maximus for the three exercises.**

| Exercises | Mean (%MVIC) | SD  | 95% CIs (Lower bound - Upper bound) | p-value |
|-----------|--------------|-----|------------------------------------|---------|
| Stable Surface | | | | |
| FPP | 41.63 | 28.03 | 27.69 - 55.57 | |
| CS | 43.8 | 29.3 | 29.24 - 58.39 | 0.957 |
| OS | 57.27 | 42.27 | 36.24 - 78.29 | 0.146 |
| Unstable Surface | | | | |
| FPP | 37.03 | 18.07 | 28.05 - 46.02 | |
| CS | 39.79 | 20.62 | 29.53 - 50.05 | 0.785 |
| OS | 54.32 | 42.56 | 33.15 - 75.79 | 0.074 |

SD = standard deviation; FPP = forward punch plus; CS = FPP with closed chain serape effect; OS = FPP with open chain serape effect.

* p value statistically significant at p≤0.05.

Table 7. **Mean EMG activation of the Latissimus Dorsi muscle for the three exercises.**
in a myofascial chain that connects the SA muscle to the GM muscles via the LD and thoracolumbar fascia, which in turn resulted in higher SA activation during a push-up plus exercise.

The present and the previous investigations supported the hypothesis that by engaging the adjacent muscles in a kinetic chain, there was improved activation of the primary muscle of interest.9-11,15,17 Based on the results, it may be reasonable to choose exercises (exercises 2, 3, 5, and 6) that utilize the muscles incorporated in various myofascial chains (serape effect that connects SA to the EO, FA, and the SA connections to the bilateral GM via thoracolumbar fascia and the LD) connected to the SA if the aim is to achieve higher SA activation than a traditional FPP exercise. Yamauchi et al.15 investigated the effects of trunk rotation on the activation of the scapular muscles and concluded that incorporating diagonal movement patterns could be more beneficial than engaging the scapular muscles in isolation. Similar results were reported by De Mey et al.17 as they investigated the effects of kinetic chain on the muscle recruitment during various scapular retraction exercises and found increased activation of the proximal muscles as they recruited the distal muscles in the chain.

Comparison of the stable versus the unstable surfaces
To compare the effects of different surfaces on the SA muscle activity exercises 1 and 4, 2 and 5, and 3 and 6 were compared with each other. There was no change in the muscle activation between the stable and the unstable surfaces. The amount of muscle activation on an unstable surface has been documented to depend on the extent of instability.21,25 The BOSU® Balance Trainer may not have created enough instability to increase the SA muscle activation. Other types of unstable surfaces such as balance boards and inflatable discs need to be investigated in the future in order to identify their effects on SA activation. Therefore, the current findings cannot be generalized to all types of unstable surfaces. The type of exercises investigated in the present study may be another reason for no statistically significant differences in the activation of the SA muscle between different surfaces. More dynamic exercises than the FPP and its variations may result in higher SA muscle activation on the unstable surface. The authors of the present study chose not to incorporate any other type of unstable surface or other exercises due to the risk of injury to the subjects while performing the exercises. The non-significant differences in the SA muscle activation between the stable and the unstable surfaces are supported by several investigations secondary to various factors such as subject’s characteristics and their response to various types of unstable surfaces used, the nature and intensity of exercises performed, and the type of unstable surface used.17,20,22,24,25,38

No significant change in the muscle activation on the unstable surface could also be attributed to the additional demands placed on the body in maintaining stability in the unstable environment.19,21,39-41 To maintain the balance, antagonists, synergists, and stabilizing muscles may play a bigger role in maintaining posture and stability.19,23,42 In addition, these muscles have been documented to cause either facilitation or inhibition of the agonist muscles. The SA muscle acts more as a prime mover/agonist in performing the FPP exercise used in this study. Therefore, previous researchers support the results of the present study that there was no change in the SA muscle activation with the addition of LE instability. Additionally, a muscle group may show no change in the muscle activation by adding unstable surface because unstable surfaces may result in a lower muscle force output to provide more stabilization. Hence, no change in muscle activation was observed on an unstable surface for the other muscles (LD, EO, FA, and GM) in the present study could be because these muscles are not the prime stabilizers of the body. It may be a possibility that the muscle activation of the prime stabilizers may have increased when the exercises were performed on the unstable surface. The authors of the present study did not measure the force production and the EMG activation of the prime stabilizers of the body during these exercises. Future studies are recommended to investigate these variables when performing these exercises on different surfaces.

A significant decrease in SA activation while performing a push up plus exercise on the unstable surface was found by Lehman et al.,22 Maenhout
et al.,11 and De Mey et al.25 Those authors concluded that the lack of increased muscle activation on the unstable surface could be due to subject variability to the exercise performance and the type of unstable surface used. Lehman et al.43 compared the push-up plus exercise on stable and the unstable surfaces and concluded that the vertical distance between the center of mass of the subject and the unstable surface might have a role to play in the amount of muscle activation. They further stated that greater the distance between the subject’s center of mass and the unstable surface the higher the muscle activation. This study did not measure the position of the center of mass, but the insufficient distance between the subject’s center of mass and the center of the BOSU® Balance Trainer could be another reason why the authors did not find any significant change in the SA muscle activation across two surfaces. However, caution should be exercised when generalizing such phenomenon because research also exists supporting a change in the muscle activation of various muscles with the addition of the unstable surfaces.18-20,42,44 Further investigation on the effects of various surfaces on the muscle activation among different exercises and what factors could lead to increase, decrease, or no change in the muscle activation on the unstable surfaces is warranted. Lastly, since the width of the base of support was standardized for each subject across both surfaces, it would be interesting to see if changing the width of the base of support has any effect on the activation of the SA muscle between the two surfaces.

Limitations and Future Scope

The present study recruited young healthy males which limits the generalization of the results to other populations that are not similar to the subjects in the present investigation such as people with shoulder dysfunction, of a different age group, and females. Use of surface EMG to record motor recruitment of specific muscles during dynamic exercises has limitations such as consistency and security of electrode placement, motor unit recruitment by participants, crosstalk among various muscles in the vicinity, and amount of effort given by the subjects.31 Several testing positions have been recommended for measuring the MVIC activity of the SA muscle across various participants.45 For EMG normalization purpose, MVIC data for the SA muscle was collected with participants shoulder flexed to 125° as recommended by Cram et.al19 and as per another study.8 Caution is warranted in extrapolating the results of our study due to the variability in the MVIC positions for the SA muscle activation. Significant variation in the SA MVIC positions across subjects may also explain why the SA muscle activation was higher than the MVIC with exercises that incorporated the additional muscles in the kinetic chain that have connections with the SA muscle (exercises 2,3,5, and 6). Future studies are warranted to compare the activation of the SA muscle in the kinetic chain exercises with other MVIC positions that could produce maximum EMG amplitudes for various fibers of the SA muscle across subjects. EMG data for all the muscles that have myofascial connections with the SA muscle was not collected due to the limited ability of the surface EMG in evaluating the deeper muscles accurately. It could be interesting to see the role of all the muscles in a kinetic chain that could influence the recruitment of the SA muscle during these dynamic exercises, perhaps using kinesiological needle EMG. Future studies could also look at the kinetic and kinematic data while performing these dynamic exercises. It would be beneficial to compare various rehabilitation exercises that have demonstrated high SA recruitment including the ones in the present study and develop a continuum of exercises from a lower to higher recruitment of the SA that could assist clinicians in rehabilitating the patients with shoulder dysfunctions in progressive training regimes.

CONCLUSION

Given the SA’s pivotal role in controlling scapular rhythm during various shoulder movements, finding the best exercises for higher SA muscle activation is crucial for effective rehabilitation of various shoulder dysfunctions. In light of the current inclination towards utilization of the kinetic chain during rehabilitation due to its clinical efficacy, this study further investigated the effects of various surfaces on the SA muscle activation in a kinetic chain model. Consistent with the previous research, LE and trunk kinetic chain utilization resulted in higher activation of the SA muscle regardless of the surface. Further
research is required to substantiate any additional benefit of adding unstable surfaces to achieve higher muscle activation.

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