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Trunk Muscle Activity During Lumbar Stabilization Exercises on Both a Stable and Unstable Surface

Trunk stability is believed to play an important role for lumbar spine injury prevention and rehabilitation.^{8,9,20,21} Therefore, exercises for improving trunk stability are performed widely in sports and rehabilitation. An especially important function of muscles is their contribution to trunk stability, and it is thought that the coactivation of several trunk muscles is needed to achieve a degree of spinal stability beneficial for both the prevention and the treatment of low back injury.^{3,6,14,22,23}

From a functional anatomy perspective, trunk muscles can be classified as either global or local muscles.⁵ The global muscles, such as the rectus abdominis (RA) and external obliques (EO),

produce torque and transfer the load directly between the thoracic cage and the pelvis. The local muscles, such as the

transverse abdominis (TrA) and lumbar multifidus (MF), have more direct or indirect attachments to the lumbar vertebrae. They are associated with the segmental stability of the lumbar spine during whole-body movements and postural adjustments.^{4,11,12,19} So, the functions of local muscles are necessary to enhance segmental stability of the spine.⁷

Trunk stability has been defined in terms of a coactivation of global and local muscles. So, specific training that promotes the function of these muscles is needed to achieve coactivation.¹⁴ Exercises for this purpose have been termed lumbar stabilization or core stabilization exercises. Although no formal definition of lumbar stabilization exercises exists, this approach is aimed at promoting the neuromuscular control, strength, and endurance of muscles that are central to maintaining dynamic stability of the spine and trunk. One approach for trunk stability training involves the use of unstable surfaces. The purported advantage of these tools is the potential for increased muscular demand required to maintain postural stability.

The authors of a previous study have shown that performing curl-ups on an unstable surface resulted in an increase in activity of the RA and EO.²⁸ Similar findings were observed when the prone bridge exercise was performed on a Swiss

- **STUDY DESIGN:** Controlled laboratory study.
- **OBJECTIVES:** To clarify whether differences in surface stability influence trunk muscle activity.
- **BACKGROUND:** Lumbar stabilization exercises on unstable surfaces are performed widely. One perceived advantage in performing stabilization exercises on unstable surfaces is the potential for increased muscular demand. However, there is little evidence in the literature to help establish whether this assumption is correct.
- **METHODS:** Nine healthy male subjects performed lumbar stabilization exercises. Pairs of intramuscular fine-wire or surface electrodes were used to record the electromyographic signal amplitude of the rectus abdominis, the external obliques, the transversus abdominis, the erector spinae, and lumbar multifidus. Five exercises were performed on the floor and on an unstable surface: elbow-toe, hand-knee, curl-up, side bridge, and back bridge. The EMG data were normalized as the

percentage of the maximum voluntary contraction, and data between doing each exercise on the stable versus unstable surface were compared using a Wilcoxon signed-rank test.

- **RESULTS:** With the elbow-toe exercise, the activity level for all muscles was enhanced when performed on the unstable surface. When performing the hand-knee and side bridge exercises, activity level of the more global muscles was enhanced when performed on an unstable surface. Performing the curl-up exercise on an unstable surface, increased the activity of the external obliques but reduced transversus abdominis activation.

- **CONCLUSION:** This study indicates that lumbar stabilization exercises on an unstable surface enhanced the activities of trunk muscles, except for the back bridge exercise. *J Orthop Sports Phys Ther* 2010;40(6):369-375. doi:10.2519/jospt.2010.3211

- **KEY WORDS:** electromyography, lumbar spine, multifidus, transversus abdominis

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ball. However, there was no change in trunk muscle activity when the back bridge exercise was performed on an unstable surface.¹¹ In a separate study, performing a bench press on an unstable surface was shown to have no effect on electromyographic (EMG) recordings, although, force output was decreased.^{2,13} In contrast, trunk muscle activity increased when performing a squat on an unstable surface.¹

From these findings, the influence of surface stability on muscle activity appears to be muscle and exercise dependent. The exercises increased the perturbation to the trunk when the body's center of mass was over an unstable surface and further away from the stable surface.¹⁷ Additionally, decrease of the contact area between the individual and the unstable surface increased the perturbation of the trunk, as demonstrated by increased muscle activity.^{1,16,17}

However, previous researchers have limited their measurement of muscle activity to the use of surface electrodes. There appears to be no published report describing the activity of local muscles during lumbar stabilization exercises. It is also not clear whether the advantage of performing an exercise on the unstable surface is greater than that of performing the same exercise on the stable surface. Therefore, the purpose of this study was to clarify whether differences in surface stability influence trunk muscle activity, as measured using a combination of surface and intramuscular fine-wire electrodes.

METHODS

Subjects

NINE HEALTHY MALES PARTICIPATED in this study. Their mean \pm SD age, height, and body mass were 24.1 ± 0.8 years, 170.4 ± 4.8 cm, and 62.2 ± 4.6 kg, respectively. None of the subjects had consistently trained with stabilization exercise previously. Exclusion criteria included a history of lumbar spine disorder, neurological disorder, or spine surgery.

The study was approved by the Ethics Committee of the University of Tsukuba, and each subject provided a written informed consent before participation.

Electromyography

EMG recordings were obtained from 5 trunk muscles using a combination of surface and intramuscular fine-wire electrodes.

Intramuscular fine-wire electrodes were fabricated from 2 strands of urethane-coated, stainless steel, 0.5-mm-diameter wire (Unique Medical Co, Ltd, Japan), from which 2 mm of urethane was removed from the end. The electrodes were threaded through a 23-gauge (60-mm) hypodermic needle. The tips of the intramuscular fine-wire electrodes were bent at 1 and 2 mm to form hooks. Electrodes were sterilized by autoclaving (HighClave HVE-50; Hirayama Manufacturing Corp, Kasukabe-shi, Saitama, Japan) at 121°C for 20 minutes. Using ultrasound imaging, the intramuscular electrodes were inserted bilaterally in the TrA, approximately midway between the rib cage and the iliac crest,¹⁸ and in the MF, approximately 2 cm lateral to the L5 spinous process.²⁶ After the electrodes reached the targeted muscles, adequate location was confirmed through electric stimulation observed with ultrasound imaging.

Before attaching the surface electrodes, the skin was rubbed with a skin abrasive and alcohol swabs to reduce the skin impedance to below 2 k Ω . If the measured impedance was greater than 2 k Ω , the surface electrodes were removed and the skin preparation repeated.

Pairs of disposable Ag/AgCl (Vitrode F-150S; Nihon Kohden Co, Ltd, Tokyo, Japan) surface electrodes were attached to the skin in an orientation parallel to the muscle fibers over 3 muscles on both sides of the body: for the RA, 3 cm lateral to the umbilicus; for the EO, midway between the costal margin of the ribs and the iliac crest, approximately 45° to the horizontal; for the erector spinae (ES), 3 cm lateral to the L3 spinous process.

The ground electrode was placed over the body of the sternum.

Exercises Procedures

The subjects performed 5 exercises often used in clinical practice and in previous studies.^{10,15,17,24,25,27} Each exercise was performed on both a stable and an unstable surface. Instructors provided feedback to ensure that a consistent spine and lower limb posture was maintained during the exercises, for which the subjects were requested to hold their posture for 3 seconds.

Elbow-Toe The subject was instructed to maintain a prone plank position on the floor, such that the elbows were beneath the shoulders and the upper arms were perpendicular to the floor. In this position, only the toes and forearms were touching the floor. Subjects performed the elbow-toe on the floor for the stable condition, and with forearms on a Swiss ball and toes on a balance disk for the unstable condition (**FIGURE 1A**).

Back Bridge The subject was supine on the floor, with feet flat on the ground, knees bent at 90°, toes facing forwards, and hands on the floor by the sides, palms facing down. The subject raised the pelvis to achieve and maintain a neutral hip flexion angle. Subjects performed the back bridge on the floor (stable condition) and with feet on a BOSU Balance Trainer (unstable condition) (**FIGURE 1B**).

Hand-Knee The subject assumed a quadruped position and was asked to hold a neutral pelvis position as well as to breathe normally. The subject then lifted the right upper extremity and held it straight, while simultaneously lifting the left lower extremity and holding it straight also. Subjects performed the hand-knee on the floor (stable condition) and with a BOSU (unstable condition) (**FIGURE 1C**).

Side Bridge The subject was positioned in right sidelying, with the right elbow directly beneath the shoulder and upper arm perpendicular to the ground. The subject raised the pelvis so that the spine was straight, thereby achieving a position supported only by the right elbow and the

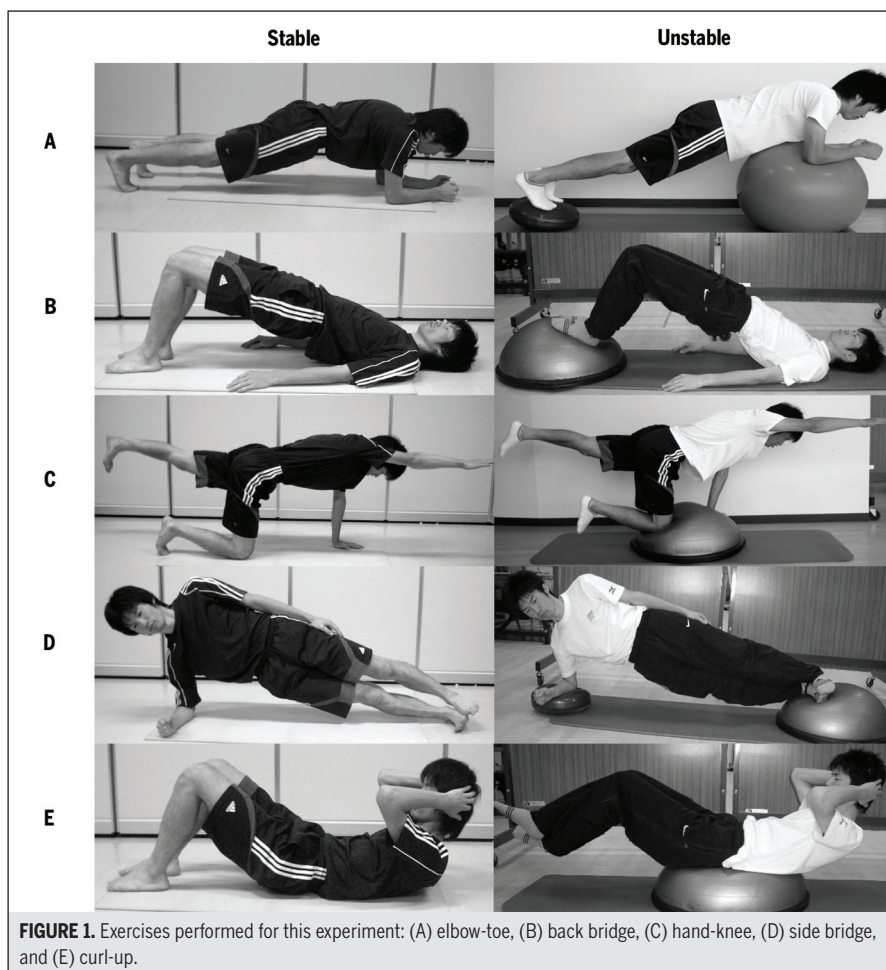


FIGURE 1. Exercises performed for this experiment: (A) elbow-toe, (B) back bridge, (C) hand-knee, (D) side bridge, and (E) curl-up.

side of the right foot. Subjects performed the side bridge on the floor (stable condition) and with the elbow on a balance disk and feet on a BOSU (unstable condition) (**FIGURE 1D**).

Curl-up The subject was supine, with hips at 45° and knees at 90° and hands behind the head. The subject tucked in chin and curled the upper trunk by lifting the thoracic spine off the floor. With the exercise performed optimally, the curl-up was performed so that the scapulae were off the floor. Once in this position, the subject was asked to breathe deeply. The subjects performed the curl-up both on the floor (stable condition) and with a BOSU (unstable condition) (**FIGURE 1E**).

Maximum Voluntary Contraction Trials

For normalization of the EMG data, a maximum voluntary contraction (MVC)

trial was performed with each muscle of interest while the EMG signal amplitude was recorded. The test positions were consistent with those demonstrated in manual muscle testing books commonly used by physical therapists, but in some cases additional manual resistance was applied. Manual resistance was applied gradually, with the maximum amount held for 3 seconds. Correct electrode placement was further confirmed by observing the EMG signal amplitude during the manual muscle tests.

For the RA, MVC was tested using a partial sit-up with knees flexed and hands behind the head, and trunk flexed, with resistance applied to the shoulder in the trunk extension direction. For the EO on the right side, the subject was in a supine position, with knees flexed and hands behind the head,

and trunk flexed and rotated to the left. Resistance was applied at the shoulders in the trunk extension and right rotation directions. For the EO on the left side, the trunk was instead flexed and rotated to the right, with the resistance applied at the shoulders in the trunk extension and left rotation directions. The MVC for the MF and ES was performed with prone trunk extension, with resistance applied to the upper thoracic area in the direction of trunk flexion. MVC for the TrA was recorded when performing a maximal expiratory maneuver with abdominal hollowing in a sitting position. Sixteen subjects were given similar verbal encouragements for each of the MVC trial to help ensure a maximum effort throughout the 3 seconds, and the subjects asked after each MVC if they thought it required maximum effort. If not, the MVC was repeated. MVC trials were performed with a 1-minute rest between each trial.

EMG data were collected for the 3-second period of the isometric phase. The MVC was calculated for the 1-second period that consisted of the highest signal activity.

Data Analysis

EMG data were collected during both the dynamic and isometric phases of exercise performance. The dynamic phase, lifting and lowering of the pelvis and/or the extremities, was performed at the subject's own pace. The isometric phase was maintained for 3 seconds.

Raw EMG signals were sampled at 1000 Hz, amplified (MEG-6116; JB-640J Nihon Koden Co, Ltd, Japan), band-pass filtered (20-500 Hz), and full-wave rectified using analysis software (Vital Recorder¹ and Bimutus-Video; Kissei Comtec Co, Ltd, Japan).

The root-mean-square of EMG amplitude was calculated for a 1-second period of the isometric phase of each exercise. The mean root-mean-square of MVC trials was used for normalizing EMG amplitudes obtained during the experimental exercises (% MVC).

RESULTS

ALL EMG DATA WERE EXPRESSED IN percent MVC and compared between the unstable and stable surface for each muscle.

Muscle activity was significantly greater when the elbow-toe exercise was performed on an unstable surface than when performed on a stable surface bilaterally for the RA, EO, TrA, and ES, and for the left MF ($P < .05$) (FIGURE 2). In contrast, there were no significant differences in muscle activity between the unstable and the stable conditions when performing the back bridge exercise (FIGURE 3). Muscle activity during the hand-knee exercise was significantly greater when performed on the unstable surface compared to the stable surface, bilaterally for the RA and EO, and for the side ipsilateral to the arm lifted for the ES ($P < .05$) (FIGURE 4). With the side bridge exercise, only the activity of the RA was significantly greater with the unstable condition ($P < .05$) (FIGURE 5). During the curl-up exercise, the activity of the EO was significantly higher when performed on the unstable surface; however, activity of the TrA was significantly lower ($P < .05$) (FIGURE 6).

DISCUSSION

THE AIM OF THE INVESTIGATION WAS to determine if differences in surface stability influence trunk muscle activity during performance of a selected set of stabilization exercises.

Compared to a stable surface, performing the elbow-toe on an unstable surface increased activity of all trunk muscles. This differs from the findings of a previous study that used surface electrodes, in which greater activity was observed with the unstable surface only for the RA and EO, with no difference observed for the internal obliques (IOs)/TrA.¹⁵ This difference between studies could be attributed to a difference in the difficulty of the exercise. In the study by Lehman et al,¹⁵ subjects placed their forearms on a Swiss ball, while in the present study we

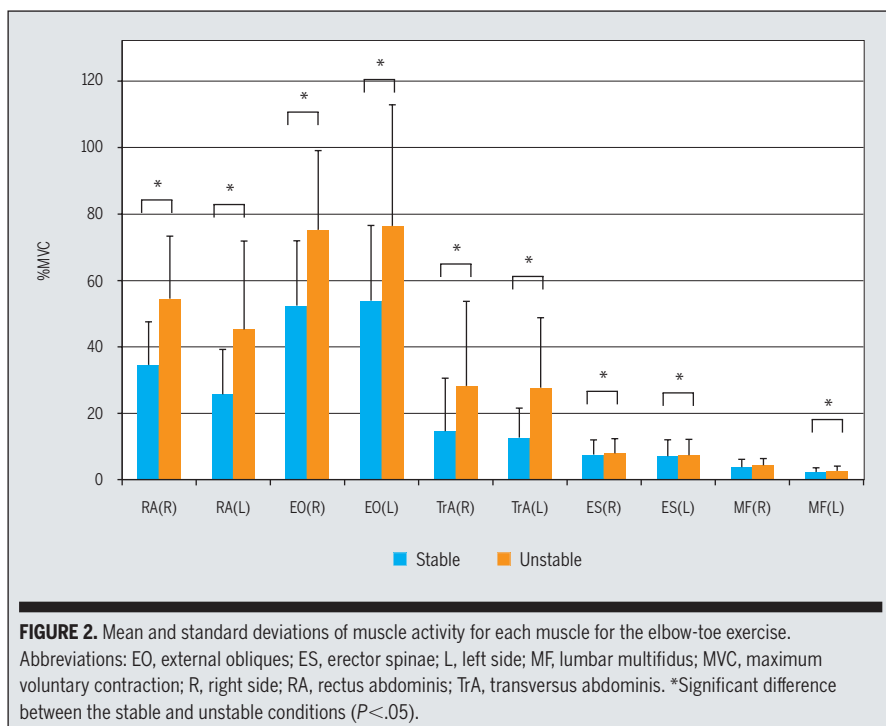


FIGURE 2. Mean and standard deviations of muscle activity for each muscle for the elbow-toe exercise. Abbreviations: EO, external obliques; ES, erector spinae; L, left side; MF, lumbar multifidus; MVC, maximum voluntary contraction; R, right side; RA, rectus abdominis; TrA, transversus abdominis. *Significant difference between the stable and unstable conditions ($P < .05$).

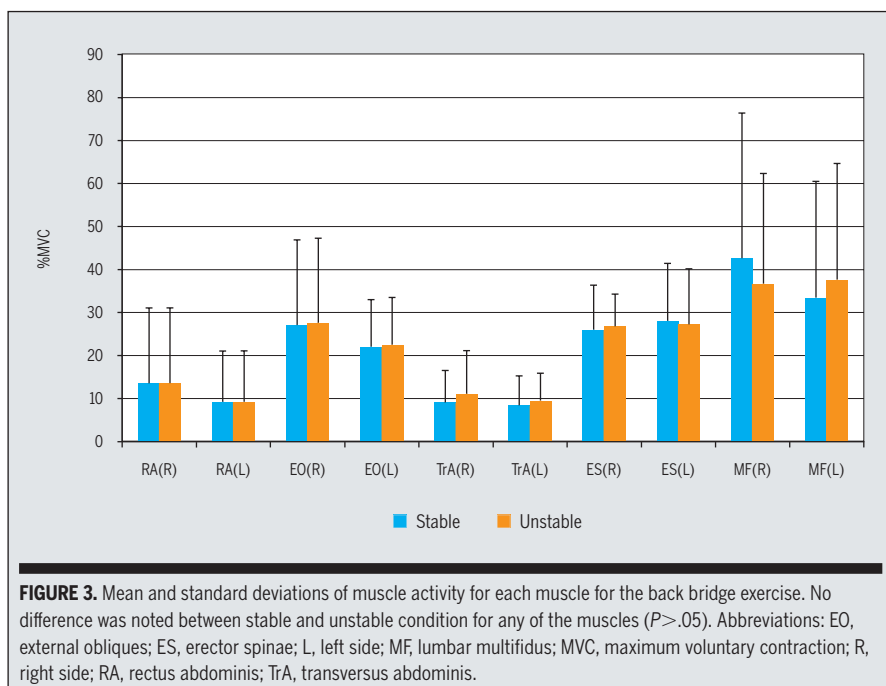


FIGURE 3. Mean and standard deviations of muscle activity for each muscle for the back bridge exercise. No difference was noted between stable and unstable condition for any of the muscles ($P > .05$). Abbreviations: EO, external obliques; ES, erector spinae; L, left side; MF, lumbar multifidus; MVC, maximum voluntary contraction; R, right side; RA, rectus abdominis; TrA, transversus abdominis.

Statistical Analysis

As the data were not normally distributed, nonparametric statistics were used for the analysis. The Wilcoxon signed-rank test was used to compare muscle activity for each exercise between the stable and

unstable conditions. The level for statistical significance was set as $\alpha = .05$. Adjustments for multiple comparisons were not performed. All analyses were performed using Dr SPSS II for Windows (SPSS Japan Inc, Tokyo, Japan).

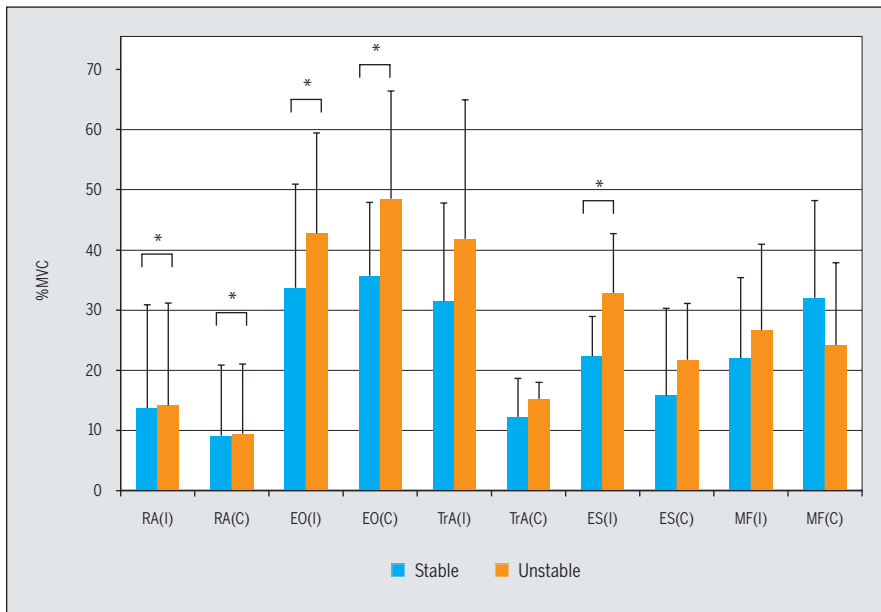


FIGURE 4. Mean and standard deviations of muscle activity for each muscle for the hand-knee exercise when lifting the right arm and left lower extremity. Abbreviations: C, contralateral to arm lifted; EO, external obliques; ES, erector spinae; I, ipsilateral to arm lifted; MF, lumbar multifidus; MVC, maximum voluntary contraction; RA, rectus abdominis; TrA, transversus abdominis. *Significant difference between the stable and unstable conditions ($P < .05$).

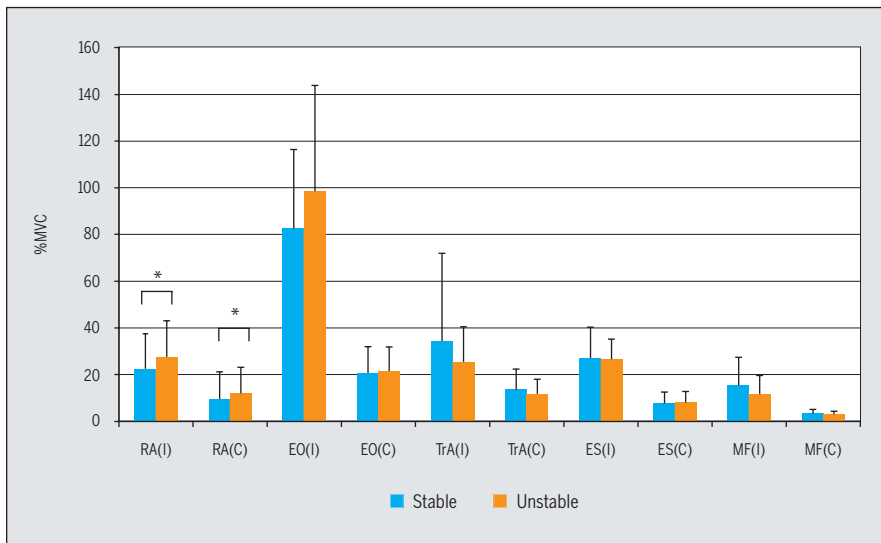


FIGURE 5. Mean and standard deviations of muscle activity for each muscle for the side bridge exercise lying on the right side. Abbreviations: C, contralateral to arm used for support; EO, external obliques; ES, erector spinae; I, ipsilateral to arm used for support; MF, lumbar multifidus; MVC, maximum voluntary contraction; RA, rectus abdominis; TrA, transversus abdominis. *Significant difference between the stable and unstable conditions ($P < .05$).

also had the subjects place their toes on a balance disk. The addition of the balance disk may have increased perturbation of the trunk and thereby promoted coactivation of global and local muscles. Significant differences were found for

the ES and MF, but these were extremely small differences. The lack of influence exerted by the unstable surface for the ES and MF may be due to the fact that those muscles are not considered agonist for this exercise.

The finding that there was no difference in trunk muscle activity between stable and unstable surfaces for the back bridge exercise is consistent with findings of previous studies,^{10,15,24} thereby suggesting that trunk muscle activity is not systematically influenced by surface stability during this exercise.

For the other 3 exercises, there was greater activity of the global muscles when the exercise was performed on an unstable surface. Whereas, the activity of local muscles either did not differ between stable and unstable conditions (hand-knee and side bridge exercises), or was lower with the unstable condition (curl-up exercise).

With the hand-knee exercise performed on an unstable surface, activity of the RA, EO, and ES (ipsilateral to arm lifted) was enhanced. We presume that activity of the EO and RA was enhanced because these muscles serve to control rotation and extension of the trunk.

With the side bridge exercise, activity of the RA was greater when performed on the unstable surface. It is possible that the unstable surface generates greater lateral bending, extension, and rotation torque of the trunk, and that the increased muscle activity is associated with controlling these movements.

Compared to a stable surface, performing the curl-up exercise on an unstable surface resulted in greater activity of the EO but less activity of the TrA. These results differ from those of previous research, in which surface electrodes revealed greater activity of the EO and of the lower portion of the RA when using an unstable surface, but no change in the IO/TrA activity level.²⁸

These differences may stem from the difficulty level of the exercises between studies. In the previous study, subjects had their feet on the floor, as compared to in the air in this study. Because the feet were in the air, the unstable surface generated extension and rotation torque. Therefore the activity of the EO, which acted on rotation and flexion of the trunk, increased.

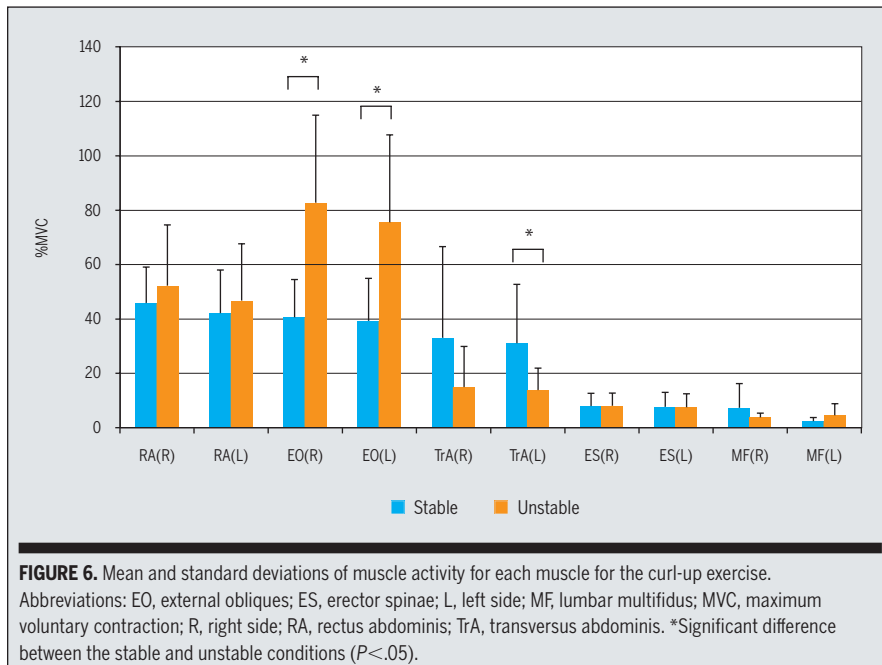


FIGURE 6. Mean and standard deviations of muscle activity for each muscle for the curl-up exercise. Abbreviations: EO, external obliques; ES, erector spinae; L, left side; MF, lumbar multifidus; MVC, maximum voluntary contraction; R, right side; RA, rectus abdominis; TrA, transversus abdominis. *Significant difference between the stable and unstable conditions ($P < .05$).

In this study, we found greater muscle activity for exercises performed on unstable surface compared to a stable surface, especially for the global trunk muscles, RAs, and EOs. This is consistent with the results of previous studies.^{15,28} In our study, the increase in EO activity was most notable, suggesting that an unstable surface increases the need to control trunk rotation. From the results of the present study, there is greater participation of the global muscles for additional trunk control than the local muscles.

CONCLUSION

THE PRESENT STUDY DEMONSTRATED that muscle activity differs, depending on surface stability, except for back bridge exercise. In particular, the activity of the more global trunk muscles, such as the EO, was greater with the unstable surface. ●

KEY POINTS

FINDINGS: Stabilization exercises on unstable surface produced greater activity of global muscles for additional trunk control, except for back bridge exercise. The increase in EO activity was espe-

cially noted.

IMPLICATION: Clinically, these results may have implications for the selection of exercises, indicating that performing the exercises on an unstable surface may preferentially activate muscles such as the EO and RA, as compared to the TrA and MF, which are considered more local stabilizers of the trunk.

CAUTION: Further confirmation of these results is necessary in larger more diverse populations, including females, older individuals, and especially individuals with chronic and acute low back pain.

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