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# Effect of Surface Stability on Core Muscle Activity for Dynamic Resistance Exercises

Jeffrey Willardson
*Eastern Illinois University*, jmwillardson@eiu.edu

Fabio E. Fontana
*University of Northern Iowa*

Eadric Bressel
*Utah State University*

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# Effect of Surface Stability on Core Muscle Activity for Dynamic Resistance Exercises

**Jeffrey M. Willardson, Fabio E. Fontana, and Eadric Bressel**

***Purpose:*** To compare core muscle activity during resistance exercises performed on stable ground vs. the BOSU Balance Trainer. ***Methods:*** Twelve trained men performed the back squat, dead lift, overhead press, and curl lifts. The activity of the rectus abdominis, external oblique abdominis, transversus abdominis/internal oblique abdominis, and erector spinae muscles was assessed. Subjects performed each lift under three separate conditions including standing on stable ground with 50% of a 1-RM, standing on a BOSU Balance Trainer with 50% of a 1-RM, and standing on stable ground with 75% of a 1-RM. ***Results:*** Significant differences were noted between the stable 75% of 1-RM and BOSU 50% of 1-RM conditions for the rectus abdominis during the overhead press and transversus abdominis/internal oblique abdominis during the overhead press and curl ($P < .05$). Conversely, there were no significant differences between the stable 75% of 1-RM and BOSU 50% of 1-RM conditions for the external obliques and erector spinae across all lifts examined. Furthermore, there were no significant differences between the BOSU 50% of 1-RM and stable 50% of 1-RM conditions across all muscles and lifts examined. ***Conclusions:*** The current study did not demonstrate any advantage in utilizing the BOSU Balance Trainer. Therefore, fitness trainers should be advised that each of the aforementioned lifts can be performed while standing on stable ground without losing the potential core muscle training benefits.

***Keywords:*** biomechanics, exercise performance, physical performance, resistance training, sport medicine, strength training

During the last ten years, the prescription of exercises designed specifically to emphasize core stability have increased in popularity.[1] The term *core* is used to describe the lumbopelvic and abdominal regions of the body, and stability of the core is thought to be essential to provide a foundation for movement of the upper and lower extremities, to support loads, and to protect the spinal cord and nerve roots.[2,3] Core stability is highly dependent on tension development in muscles that originate on the lumbar vertebrae (eg, erector spinae) and pelvis (eg, rectus abdominis, external oblique abdominis, internal oblique abdominis, and transversus abdominis).[4,5]

Willardson is with the Kinesiology and Sports Studies Department, Eastern Illinois University, Charleston, IL; Fontana is now with the Health, Physical Education, and Leisure Services Department, University of Northern Iowa, Cedar Falls, IA; and Bressel is with the Health, Physical Education, and Recreation Department, Utah State University, Logan UT.

The use of unstable surfaces has increased in popularity when prescribing exercises for core stability training.[6–19] Free weight exercises that were previously performed on stable ground and benches are now commonly performed on unstable surfaces. For example, the squat is now commonly performed while standing on balance discs and the overhead press is now commonly performed while seated on a stability ball.[6,7,9,11,15]

Previous research has demonstrated greater activation in the core muscles when free weight lifts were performed on unstable surfaces.[6,7,16] Anderson and Behm[6] compared core muscle activity (eg, abdominal stabilizers, upper lumbar erector spinae, lumbosacral erector spinae) during three squat lifts with varying levels of instability: (1) an *unstable* squat performed while standing on balance discs, (2) a *stable* squat performed with a free weight bar while standing on stable ground, and (3) a *very stable* squat performed in a Smith machine while standing on stable ground. The authors demonstrated that the activity of all muscles examined increased progressively from the *very stable* to the *unstable* squat.

Similarly, Behm et al[7] demonstrated greater activation in the upper lumbar and lumbosacral portions of the erector spinae when the dumbbell chest press was performed while lying on a stability ball vs. a stable bench. In a related study, Norwood et al[16] compared core muscle activity (eg, latissimus dorsi, rectus abdominis, internal oblique abdominis, and erector spinae) during four bench press lifts with varying levels of instability: (1) *stable* (traditional style), (2) *upper body instability* (lying on a Swiss ball), (3) *lower body instability* (feet on a BOSU Balance Trainer), and (4) *dual instability* (lying on a Swiss ball and with feet on a BOSU Balance Trainer). The authors demonstrated that the activity of all muscles examined was greatest for the dual instability bench press.

In each of the aforementioned studies, greater instability consistently elicited higher levels of core muscle activity.[6,7,16] However, the amount of resistance that could be safely used on the unstable surfaces was limited, and subjects may have been lifting at very low percentages of their maximal strength. Because healthy individuals are capable of lifting at higher intensities when on a stable surface vs. an unstable surface, there is a need for research to compare differences in core muscle activity with loads that are typical and safe for each condition. This may allow for meaningful comparisons that could be applied in practical settings. Therefore, the purpose of this study was to compare core muscle activity during resistance exercises performed on stable ground vs. the BOSU Balance Trainer. Based on previous research showing elevated muscle activity during more unstable conditions, we hypothesized that use of a BOSU Balance Trainer would elicit higher levels of core muscle activity compared with performing lifts on stable ground.

# Methods

## Subjects

Twelve trained men volunteered to participate in this study (see Table 1 for characteristics). All subjects had consistently trained with weights a minimum of 4 years for the purpose of gaining maximal strength and muscle mass. The number

**Table 1 Subjects' Characteristics**

| Variable | Mean | Standard Deviation |
|---|---|---|
| Age (y) | 21.50 | 1.31 |
| Height (m) | 1.79 | 0.06 |
| Body Mass (kg) | 83.17 | 9.25 |
| 1-RM Squat (kg) | 135.58 | 24.94 |
| 1-RM Dead lift (kg) | 156.58 | 10.78 |
| 1-RM Overhead Press (kg) | 69.17 | 10.36 |
| 1-RM Curl (kg) | 56.17 | 5.57 |

of subjects was based on an effect size of 0.25 SD with an alpha level of 0.05 and power at 0.80.[19]

To qualify for inclusion, subjects were initially screened using the Physical Activity Readiness Questionnaire (PAR-Q) and determined to be healthy. None of the subjects had incurred any low back, knee, or ankle injuries during the previous year, and all subjects had consistently performed the lifts used in the study as part of their resistance training programs. Before data collection, this study was approved through the institutional review board and subjects were required to sign a consent form in accordance with human subject regulations. Subjects were permitted to continue with their usual resistance training regimens throughout the study. However, they were restricted from lifting weights the same day before a testing session.

## Experimental Design

A quasi-experimental crossover design was employed whereby subjects performed four lifts (ie, dead lift, back squat, overhead press, and curl) at two intensities (50% 1-RM and 75% 1-RM) and on two surfaces (ie, stable ground and unstable BOSU Balance Trainer). The electromyographic (EMG) activity of various core muscles was analyzed for each condition after a 5-week familiarization period.

## Familiarization Sessions

A 5-week familiarization period was implemented so that each subject received adequate practice for each lift while standing on the BOSU and to assess maximal strength. Subjects attended one training session per week during which each lift was practiced while standing on the BOSU. A BOSU Balance Trainer can be described as half sphere mounted on a stable platform that is designed to make resistance exercises more challenging by increasing balance demands. The BOSU was positioned so that subjects were required to balance with the stable platform side up (see Figure 1). During the first practice session, subjects performed 2 sets of 15 repetitions of each lift while utilizing an unloaded Olympic barbell (ie, 20 kg). The same number of sets and reps were used during subsequent practice sessions but the load was increased to 50% of their maximal resistance. During weeks

**Figure 1 —** Back squat performed while standing on the BOSU Balance Trainer.

2, 3, 4, and 5, maximal strength testing was assessed while standing on stable ground for each lift.

## Maximal Strength Assessment

Because of safety concerns, maximal strength was not assessed while standing on the BOSU Balance Trainer. During the lengthy familiarization period, it was apparent that working with higher loads (75% of a 1-RM) on the BOSU was unsafe for subjects, despite the strenuous safety precautions. Therefore, the intensity of lifts performed on the BOSU Balance Trainer represented a percentage of maximal strength relative to stable ground. Maximal strength was assessed twice for each lift: during weeks 2 and 4 for the back squat and overhead press, and during weeks 3 and 5 for the dead lift and curl. For safety reasons, all testing sessions took place while standing inside a lifting cage, in which catch pins were set at the bottom point in the range of motion for each lift. Two experienced spotters were present for each testing session.[20,21]

Maximal strength testing for all lifts proceeded as follows: for the first warm-up set, 5 to 10 repetitions were performed at 40% to 60% of the perceived maximum. Following a 1-min rest and light stretching, 3 to 5 repetitions were performed at 60% to 80% of the perceived maximum. At this point, the resistance was increased to the same level or a level that was approximately 2 to 5 kg higher

than the perceived maximum, and a maximal repetition was attempted. If that repetition was successful, an additional 2 to 5 was added to the bar, and following a 5-min rest, another maximal repetition was attempted. This process was repeated until a failed attempt occurred. The 1-RM (one-repetition maximum) was recorded as the last successfully completed attempt.[20,21]

## Experimental Data

Following the familiarization period, experimental data were collected during week 6, at which time subjects performed 1 set of 3 repetitions of each lift while standing on stable ground or standing on the BOSU Balance Trainer with 50% of a 1-RM. Each subject also performed 1 set of each lift while standing on stable ground with 75% of a 1-RM. All repetitions were performed at a controlled cadence using a digital timer. To control for order effects, the lifts (ie, back squat, dead lift, overhead press, curl) and conditions (ie, BOSU 50% 1-RM, stable 50% 1-RM, stable 75% 1-RM) were counterbalanced and randomly assigned using the Latin square procedure.

Electromyographic signals were recorded using Delsys DE-2.1 differential surface electrodes, which contained preamplifiers (10×) potted in polycarbonate enclosures (Delsys Inc., Boston, MA, USA). The electrode configuration included two silver bars each 10 mm long × 1 mm in diameter. The interelectrode distance was 10 mm with a typical common-mode rejection ratio of 92 dB, with a minimum at 84 dB. The input impedance was greater than 15 MΩ at 100 Hz and the noise was <1.2 μV. The surface electrodes were positioned on the skin over the rectus abdominis (RA), external oblique abdominis (EO), transversus/internal oblique abdominis (TA/IO), and erector spinae (ES). A common reference electrode was placed on the skin over the anterior superior iliac spine.[14,22]

The aforementioned muscles were selected because they are can be observed with surface EMG and because they are important components of the core muscle group.[1–5] The electrodes were positioned according to previously published procedures.[14,22] Note that the TA/IO location of 2 cm inferior and medial to the anterior superior iliac spine is the point at which the transversus abdominis blends with the internal oblique abdominis muscle; therefore, the activity of these two muscles could not be separated.

Electromyographic activity from the selected muscles for each subject was recorded on the right side only. To ensure high fidelity of the EMG signals, the skin at each site was shaved, cleaned with rubbing alcohol, and lightly abraded with sandpaper before electrode placement. Medical-grade adhesive was used to affix the electrodes to the skin. The collection of EMG activity began on the verbal command "go," at which time subjects began their repetitions and the EMG system was manually triggered to record 10 s of data between a bandwidth of 20 Hz and 450 Hz (Butterworth design with 3-dB points at 20 and 450 Hz and a roll-off = 12 dB/oct). Electromyographic signals were amplified by a factor of 10,000 using a Delsys Bagnoli-4 amplifier (Delsys Inc.). The amplified signals were sampled at 1000 Hz with a 16-bit A/D card (National Instruments E-series) and subsequently used for the analytical procedures.

Collected EMG signals were analyzed by computing the root mean square (RMS) over an 8-s window for each repetition for each lift. The RMS over the

middle 8 seconds of the 10-s window was chosen to correspond with the 8-s lifting cadence per repetition (ie, 4 seconds eccentric and 4 seconds concentric) and to give a global measure of activity. Next, an average RMS over the three repetitions for each condition was computed. The average RMS value of each muscle was then normalized to average reference RMS values computed for each muscle during an EMG reference assessment.

Reference EMG assessments for each muscle were obtained by asking subjects to perform maximal voluntary contractions (MVCs) consistent with previously published procedures.[14,22] Reference muscle actions were obtained after a rest period of 10 minutes following the experimental assessments to allow for sufficient recovery because there were a high number of conditions and lifts.[23] For muscles RA and TA/IO, subjects lay supine on a stable flat surface with hips and knees flexed and feet secured by an assistant. Subjects crossed their arms over their chest and on the command "go" attempted to maximally curl-up against manual resistance. For muscle EO, the same aforementioned procedures were followed, but the curl-up included a twist to the left. For muscle ES, subjects lay prone on stable flat surface with feet secured by an assistant; the hands were positioned behind the head and on the command "go" they attempted to extend at the trunk maximally against manual resistance. Each test was performed twice, and each effort was held for 3 seconds with a 30-s rest between repetitions. Muscle EMG activity were recorded and analyzed for the entire 3 seconds effort using the same collection and analysis parameters described previously. Accordingly, our dependent measure was a normalized EMG (NEMG) value as a percent of the reference contraction.

### Statistical Analysis

The reliability between the maximal strength tests for the back squat, dead lift, overhead press, and curl was assessed using Pearson correlations. The NEMG of the core muscles was compared using a 3 (Conditions) $\times$ 4 (Lifts) $\times$ 4 (Muscles) repeated-measures ANOVA. The lower-bound correction was applied when the Mauchly's test of sphericity was violated. Significance of interactions and main effects was based on an alpha level of $P < .05$. All statistical comparisons were made using SPSS version 14.0 (SPSS Inc., Chicago, IL).

## Results

The Pearson correlations indicated that the results for the maximal strength tests were highly reliable (back squat = .97; dead lift = .89; overhead press = .84; curl = .84). The 3 $\times$ 4 $\times$ 4 repeated ANOVA indicated a significant three-way interaction for condition $\times$ lift $\times$ muscle ($F_{18, 198} = 5.33$; $P < .01$; $\eta_p^2 = .33$). Further analysis on the three-way interaction was conducted using a 3 (Conditions) $\times$ 4 (Lifts) repeated-measures ANOVA for each of the four muscles independently. Post hoc comparisons were calculated as necessary using the Bonferroni correction factor.

## Rectus Abdominis

The 3 × 4 repeated-measures ANOVA for the RA muscle indicated a significant interaction for condition × lift ($F_{6, 66} = 5.56$; $P < .05$; $\eta_p^2 = .34$). Post hoc comparisons indicated that the stable 75% of 1-RM overhead press elicited significantly greater activity vs. all other combinations of conditions and lifts ($P < .05$; see Figure 2). There were no other significant comparisons.

## External Oblique Abdominis

The 3 × 4 repeated-measures ANOVA for the EO muscle indicated that the interaction for condition × lift was not significant. However, the main effects for condition ($F_{2, 22} = 27.57$; $P < .01$; $\eta_p^2 = .72$) and lift ($F_{2, 22} = 10.02$; $P < .01$; $\eta_p^2 = .48$) were significant. Post hoc comparisons for condition indicated that the stable 75% of 1-RM was significantly different from the stable 50% of 1-RM ($P < .01$), but not significantly different from the BOSU 50% of 1-RM ($P = .40$). Furthermore, the BOSU 50% of 1-RM condition was not significantly different from the stable 50% of 1-RM condition ($P = .43$). Post hoc comparisons for lift indicated that the overhead press was significantly different from the back squat ($P < .01$), dead lift ($P < .01$), and curl ($P < .01$; see Figure 3). There were no other significant differences between lifts.

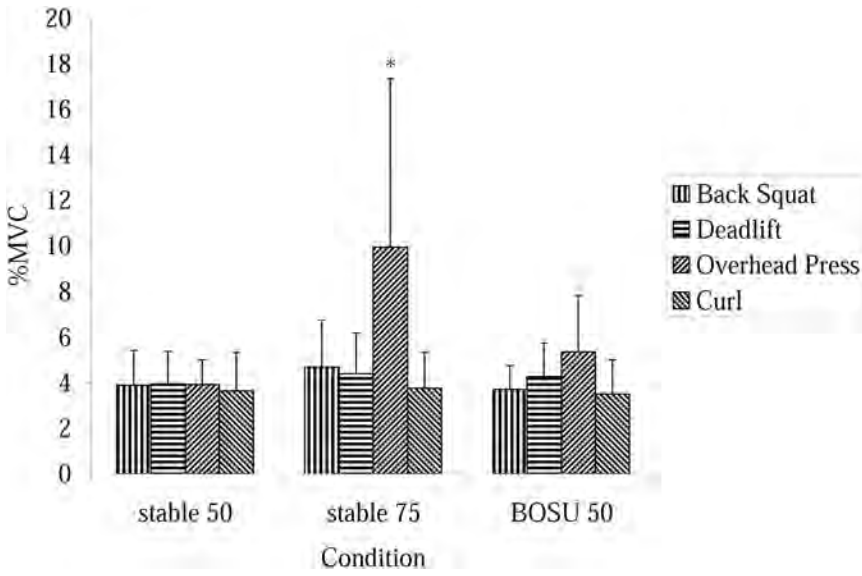


**Figure 2** — Normalized rectus abdominis activity. *Stable 75% 1-RM overhead press significantly greater activity vs. all other combinations of conditions and lifts ($P < .05$).

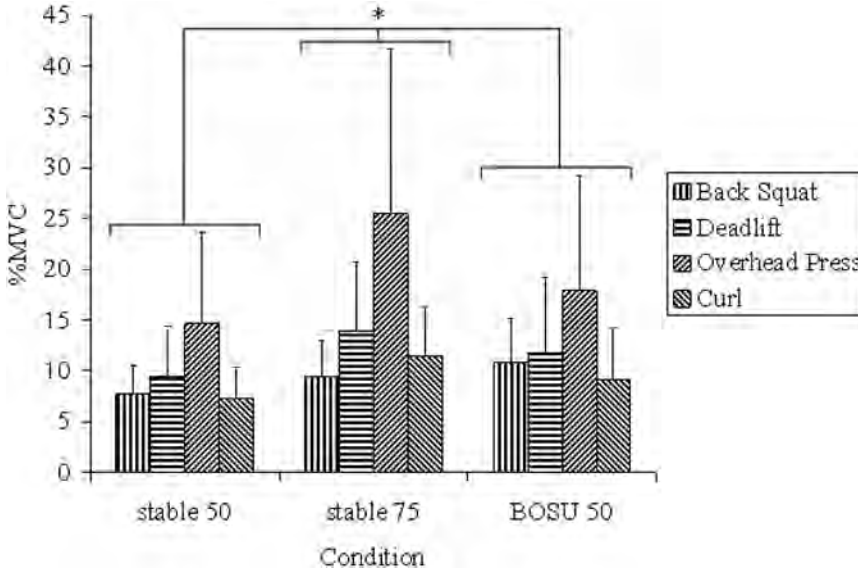


**Figure 3** — Normalized external oblique activity. *Across lifts, stable 75% 1-RM condition significantly different from stable 50% 1-RM condition ($P < .01$), but not significantly different from BOSU 50% 1-RM condition ($P = .40$).

## Transversus Abdominis / Internal Oblique Abdominis

The 3 × 4 repeated-measures ANOVA for the TA/IO muscles indicated a significant interaction for condition × lift ($F_{6, 66} = 10.61$; $P < .01$; $\eta_p^2 = .49$). Post hoc comparisons indicated that the back squat and dead lift were not significantly different across all combinations of conditions and lifts. For the overhead press, the stable 75% of 1-RM elicited significantly greater activity vs. the BOSU 50% of 1-RM ($P < .05$). However, the BOSU 50% of 1-RM overhead press was not significantly different from the stable 50% of 1-RM overhead press ($P = 1.0$). For the curl, the stable 75% of 1-RM elicited significantly greater activity vs. the BOSU 50% of 1-RM ($P < .01$) and the stable 50% of 1-RM ($P < .05$). However, the BOSU 50% of 1-RM curl was not significantly different from the stable 50% of 1-RM curl ($P = 1.0$; see Figure 4).

Post hoc comparisons for the TA/IO muscles also indicated that the stable 75% of 1-RM overhead press and curl elicited significantly greater activity vs. the stable 75% of 1-RM dead lift and back squat ($P < .05$). The stable 50% of 1-RM overhead press elicited significantly greater activity vs. the stable 50% of 1-RM dead lift and back squat ($P < .05$). There were no significant differences across lifts for the BOSU 50% of 1-RM condition (see Figure 4).

## Erector Spinae

The 3 × 4 repeated-measures ANOVA for the ES muscle indicated that the interaction for condition × lift and main effect for condition were not significant.

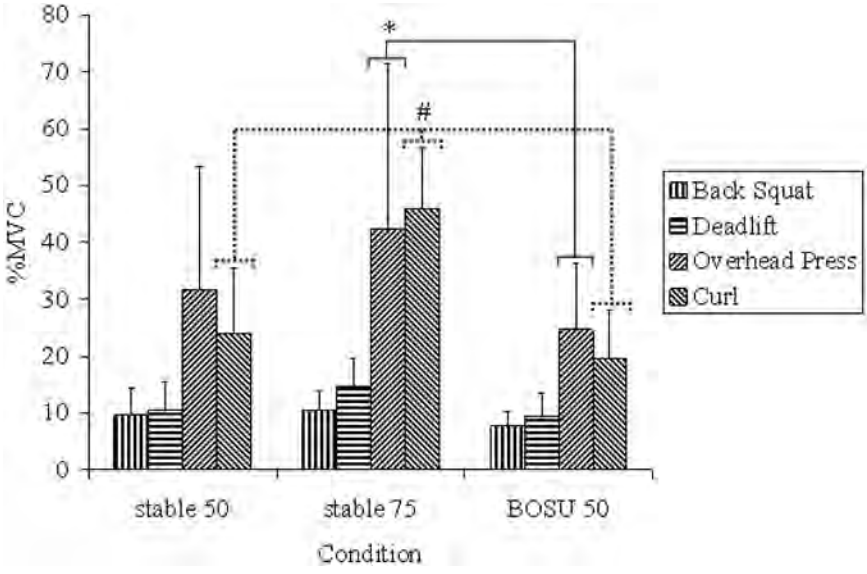


**Figure 4** — Normalized transversus abdominis/internal oblique activity. *Stable 75% 1-RM overhead press significantly greater activity vs. BOSU 50% 1-RM overhead press ($P < .05$). #Stable 75% 1-RM curl significantly greater activity vs. BOSU 50% 1-RM curl ($P < .01$) and stable 50% of 1-RM curl ($P < .05$). The back squat and dead lift were not significantly different across all combinations of conditions and lifts.

However, the main effect for lift was significant ($F_{2, 22} = 45.37$; $P < .01$; $\eta_p^2 = .81$). Post hoc comparisons for lift indicated that the dead lift elicited significantly greater activity vs. the back squat ($P < .01$), overhead press ($P < .01$), and curl ($P < .01$). The back squat elicited significantly greater activity vs. the overhead press ($P < .01$) and curl ($P < .01$). The overhead press and curl were not significantly different ($P = .07$; see Figure 5).

## Discussion

The current study was unique in that previous studies compared callisthenic exercises on stable vs. unstable surfaces[7,14] or compared lifts performed on stable ground vs. callisthenic exercises on unstable surfaces.[10,17] This is one of the few studies to compare relatively stable vs. unstable lifts. The key finding of the current study was that there were no significant increases in core muscle activity when performing the dead lift, back squat, overhead press, and curl on the BOSU. The stable 50% of 1-RM and the BOSU 50% of 1-RM conditions were not significantly different across all muscles and lifts examined.

However, there were some significant differences noted when the load was increased to 75% of 1-RM on stable ground. Unfortunately, subjects were not assessed with higher loads on the BOSU. Therefore, the current study was unable to fully examine the potential interaction between the load and surface stability.

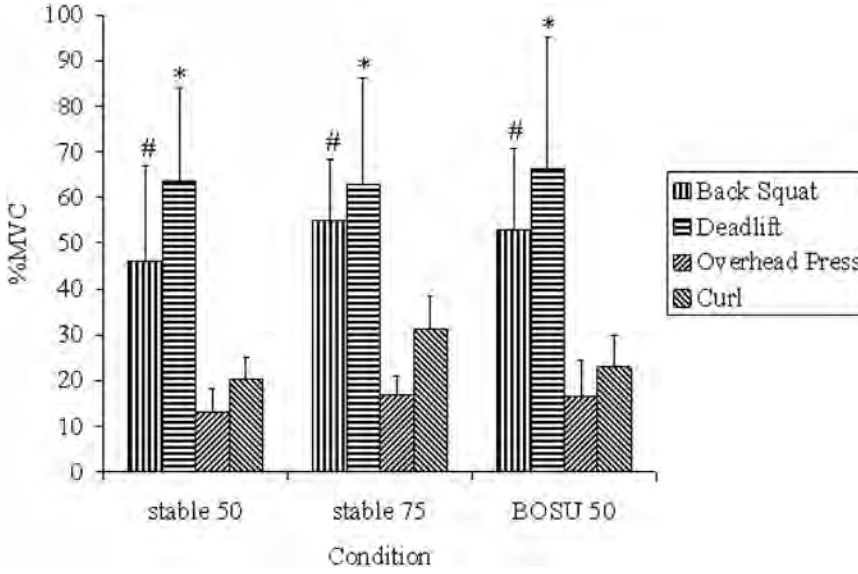


**Figure 5** — Normalized erector spinae activity. *Across conditions, dead lift significantly greater activity vs. back squat ($P < .01$), overhead press ($P < .01$), and curl ($P < .01$). #Across conditions, back squat significantly greater activity vs. overhead press ($P < .01$) and curl ($P < .01$); across conditions, overhead press and curl not significantly different ($P = .07$).

Because standing on the BOSU increased balance demands, the 50% of 1-RM intensity may have been higher in relative terms. However, the findings were unique for each muscle and lift examined, and the stable 75% of 1-RM condition was not always significantly different from the other conditions.

For the RA muscle, the stable 75% of 1-RM overhead press elicited significantly greater activity across all combinations of conditions and lifts. However, the mean activity level was relatively low at approximately 10% MVC (see Figure 2). Norwood et al[16] demonstrated similar results for the barbell bench press when performed with increasing instability. Because the RA functions as a prime mover for lumbar flexion, this muscle may not contribute largely to spinal stability during supine and standing postures in which the trunk is maintained in a statically extended position.

For the EO muscle, the overhead press elicited significantly greater activity vs. all other lifts (see Figure 3). These results were consistent with the function of the EO muscle in maintaining spinal stability in the frontal plane. During performance of the standing overhead press, the body can be likened to an inverted pendulum, which necessitates bilateral activation of the EO muscles to resist disruptive torques associated with postural sway.[10]

For the TA/IO muscles, the overhead press and curl elicited the largest activation levels; during these lifts, significantly greater activity was noted for the stable 75% of 1-RM condition vs. the BOSU 50% of 1-RM condition (see Figure 4). The TA/IO muscles have been emphasized as important contributors to spinal stability.

For example, studies have demonstrated that the TA/IO were among the first muscles activated during unexpected loading of the trunk, and during upper and lower extremity movements, regardless of the direction of limb movement.[24–26] The results of the current study suggest that to effectively train the stabilizing function of the TA/IO muscle, the overhead press and curl lifts can be performed while standing on stable ground. There was no evidence to indicate that standing on the BOSU would provide a superior training stimulus for these muscles.

For the ES muscle, the dead lift and back squat elicited the largest activation levels (approximately 45% to 65% MVC); conversely, the overhead press and curl elicited the smallest activation levels (see Figure 5). The activity of the ES muscle was not significantly different between conditions. This finding may have important relevance in clinical settings; the results of the current study suggest that individuals may achieve a similar training stimulus for this muscle by standing on stable ground or by standing on the BOSU balance trainer. A surprising finding was the nonsignificant differences between the stable 50% of 1-RM and stable 75% of 1-RM across all lifts examined; this may indicate that lifting at higher intensities (ie, >75% of a 1-RM) is required to elicit greater activation levels or the EMG equipment used was not sensitive enough to detect differences.

In contrast, Hamlyn et al[10] reported significantly greater activation in the upper lumbar erector spinae and the lumbosacral erector spinae during the back squat and dead lift performed on stable ground with 80% of 1-RM vs. the superman and side-bridge exercises performed on a stability ball. Similarly, Nuzzo et al[17] reported significantly greater activation in the longissimus and multifidus muscles for the back squat and dead lift performed on stable ground with 50%, 70%, and 90% of 1-RM vs. the quadruped, pelvic thrust, and back extension exercises performed on a stability ball. The conflicting results of the current study vs. Hamlyn et al[10] and Nuzzo et al[17] might be due to the different exercises examined for the unstable condition, and the stability ball exercises being performed without utilizing external resistance.

This study had certain limitations that should be noted. First, maximal strength was not assessed for lifts while standing on the BOSU; therefore, the relative intensity was not equated between the stable and unstable conditions. However, when selecting an appropriate load, a fitness trainer would be well advised to select a lower intensity load relative to stable ground, rather than attempting to measure maximal strength while standing on the BOSU. We believe this strategy might be safer and more time efficient.

Secondly, muscle activity during the concentric and eccentric phases of each lift were not analyzed separately. Previous research has demonstrated different neural recruitment patterns for concentric, eccentric, and isometric muscle actions.[27] However, the core muscles assessed in the current study acted isometrically as stabilizers; therefore, a global measure of activity was selected to represent the average activity over an entire repetition of each lift. We cannot rule out the possibility that differences between conditions may have been more pronounced had the phases of each lift been separated. This should be examined in future research.

Thirdly, reference muscle actions took place postexercise, which may have confounded the normalization procedures owing to the effects of fatigue. However, a recent review cited several studies that demonstrated full recovery of isometric

force production within 2 to 4 minutes following various exercise tasks.[23] In the current study, subjects rested 10 minutes following the experimental assessments; we believe this would have allowed sufficient recovery for maximal force production during the reference muscle actions.

## Practical Applications

Fitness trainers can apply the results of this investigation when programming exercises to improve the stabilizing function of the core muscles. The key finding was that there were no significant increases in core muscle activity when performing the dead lift, back squat, overhead press, and curl on the BOSU. Therefore, fitness trainers should be advised that each of the aforementioned lifts can be performed while standing on stable ground without losing the potential core muscle training benefits. Regardless of the condition, the overhead press and curl elicited greater activation levels in the RA, EO, and TA/IO muscles, whereas the back squat and dead lift elicited greater activation levels in the ES muscle.

## Conclusion

Significant differences were noted between the stable 75% of 1-RM and BOSU 50% of 1-RM conditions for the rectus abdominis during the overhead press and transversus abdominis/internal oblique abdominis during the overhead press and curl ($P < .05$). Conversely, there were no significant differences between the stable 75% of 1-RM and BOSU 50% of 1-RM conditions for the external obliques and erector spinae across all lifts examined. Furthermore, there were no significant differences between the BOSU 50% of 1-RM and stable 50% of 1-RM conditions across all muscles and lifts examined. Overall, the current study did not demonstrate any advantage in utilizing the BOSU Balance Trainer. Future research might examine the possibility of utilizing higher intensity loads while lifting on this device.

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