ORIGINAL ARTICLE

The Progression of Paraspinal Muscle Recruitment Intensity in Localized and Global Strength Training Exercises Is Not Based on Instability Alone

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ABSTRACT. Colado JC, Pablos C, Chulvi-Medrano I, Garcia-Masso X, Flandez J, Behm DG. The progression of paraspinal muscle recruitment intensity in localized and global strength training exercises is not based on instability alone. Arch Phys Med Rehabil 2011;92:1875-83.

Objective: To evaluate electromyographic activity of several paraspinal muscles during localized stabilizing exercises and multijoint or global stabilizing exercises.

Design: Cross-sectional counterbalanced repeated measures.

Setting: Research laboratory.

Participants: Volunteers (N=25) without low-back pain.

Intervention: Subjects performed (1) localized stabilizing exercises (callisthenic exercises with only body weight as resistance): static lumbar extension, stable (on floor) and unstable static unipedal forward flexion, stable dynamic unipedal forward flexion, and unstable supine bridge; and (2) global stabilizing exercises (70% of maximum voluntary isometric contraction [MVIC]): dead lift and lunge.

Main Outcome Measures: Mean and maximum amplitude of the electromyographic RMS of the lumbar and thoracic multifidus spinae and erector spinae. Electromyographic signals were normalized to the MVIC achieved during a back-extension exercise.

Results: Normalizing to the MVIC, paraspinal muscles were significantly ($P<.05$) most active, with mean and peak amplitudes of 88.1% and 113.4% during the dynamic stable dead lift at 70% of MVIC, respectively. The supine bridge on the unstable surface obtained the significantly lowest values of 29.03% and 30.3%, respectively. The other exercises showed intermediate values that ranged from 35.4% to 61.6%.

Conclusion: Findings from this study may be helpful to strength trainers and physical therapists in their choice of exercises for strengthening paraspinal muscles. Our results suggest that in asymptomatic young experienced subjects, the dead lift at 70% of MVIC provides higher levels of mean and peak electromyographic signals than localized stabilizing exercises and other types of global stabilizing exercises.

Key Words: Postural control; Rehabilitation; Resistance training; Stability; Trunk muscles.

STRENGTHENING CORE MUSCLES has been shown to not only minimize lower-limb injuries,[1] but also to improve conditioning of the lumbar muscles[2,3] to prevent possible pain[4,5] and increase performance.[6,7] Nevertheless, despite the great variety of exercises usually prescribed to strengthen core muscles, definitive scientific evidence does not exist that justifies the appropriate choice of exercises.[8]

Previous research[9,10] has recommended exercise progressions from supine and prone positions and localized stabilizing exercises (eg, bridge on hemispherical ball) toward localized stabilizing exercises in a stance posture (eg, exercises of unipedal stance) to global stabilizing exercises (eg, dead lift and lunge).[9,10] A number of studies have used electromyography[11,12] to compare muscular activity of the paraspinal muscles, providing stratification of efficiency based on muscle activity levels obtained while examining some of these exercises.[13-16] Based on these previous studies, it was suggested that exercises that include an aspect of general instability to increase muscle activity could lead to a low to moderate training stimulus for the asymptomatic active population or athletes.[17,18]

It may not be necessary to use instability devices to obtain functional improvements with trunk-stabilizing exercises. Kavcic et al[19,20] examined muscle activation profiles and stability indexes of 7 stabilization exercises (eg, abdominal curl, side and back bridge, 4-point kneeling with leg extension, seated on a stool or ball), providing a ranking of these exercises in terms of activation and stability. Although exercises such as the side bridge can provide substantial muscle activation with a moderate stability index, all exercises tested in the Kavcic[19,20] studies were performed while positioned on the floor or a stool with an isometric contraction. The Canadian Society for Exercise Physiology position stand recommended dynamic multijoint exercises that provide a moderate degree of

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List of Abbreviations

η^2_p	partial eta-squared
EMG	electromyogram
LE	lumbar erector spinae
LM	lumbar multifidus spinae
MVIC	maximum voluntary isometric contraction
RMS	root mean square
SEMG	surface electromyography
TE	thoracic erector spinae
TM	thoracic multifidus spinae

instability focused on the lumbar spine, using moderate to high loads.[21] Similarly, Yessis[22] suggested that dynamic multijoint or global stabilizing exercises of the lumbar spine, such as the squat and dead lift, allow suitable core strengthening for athletes and fitness practitioners. These traditional exercises significantly activate the core muscles due to the postural alignment relative to the base of support demands needed to ensure a neutral spine position during the full range of motion.[23-26] A number of recent studies showed that such exercises could generate substantial activation of the core muscles versus callisthenic style or localized stabilizing exercises with and without added instability devices.[27-29] Hamlyn et al[28] documented greater muscle activation with resisted squats and dead lifts (80% of 1 repetition maximum) compared with unstable side-bridge and superman callisthenic exercises (ie, localized stabilizing exercises). However, because many recreational fitness enthusiasts may not be comfortable or confident performing traditional ground-based lifts,[21] it is important to compare the extent of paraspinal muscle activation with alternative exercises. Maintaining fitness of the paraspinal muscles is important because they are involved with trunk stability, movement control, and position sense.[16,30]

Whereas the previously cited literature highlighted research comparing global stabilizing exercises with localized stabilizing exercises performed using unstable devices, there are other means of eliciting instability. Challenges to balance and equilibrium also can be achieved by moving body segments outside the base of support, forcing the neuromuscular system to maintain equilibrium by adjusting proper postural alignment. There is very limited research that comprehensively compared stable resisted global stabilizing exercises with a variety of exercises that achieve instability alone or in combination with unstable platforms or by placing body segments outside the base of support. Therefore, applications of this research would expand information regarding exercises that are appropriate and effective in activating paraspinal muscles and thus facilitate a more individualized and appropriate prescription of exercises for muscle strengthening of the core.

Consequently, the purpose of the present investigation was to compare muscular activation of various paraspinal muscles during unstable and stable localized stabilizing exercises and global stabilizing exercises. It was hypothesized that exercises that place a stress on postural alignment with the movement of medium to high resistive loads ahead of the frontal plane (ie, global stabilizing exercises, such as lunges and dead lifts) will obtain the greatest mean and peak levels of paraspinal muscular activation.

METHODS

Study Design

To examine differences in activation between exercises, a within-subject counterbalanced design was used. Surface electromyographic activity of the lumbar multifidus spinae (LM), thoracic multifidus spinae (TM), lumbar erector spinae (LE), and thoracic erector spinae (TE) was recorded during all exercises tested. Surface electromyographic signals were normalized to the maximum voluntary isometric contraction (MVIC)

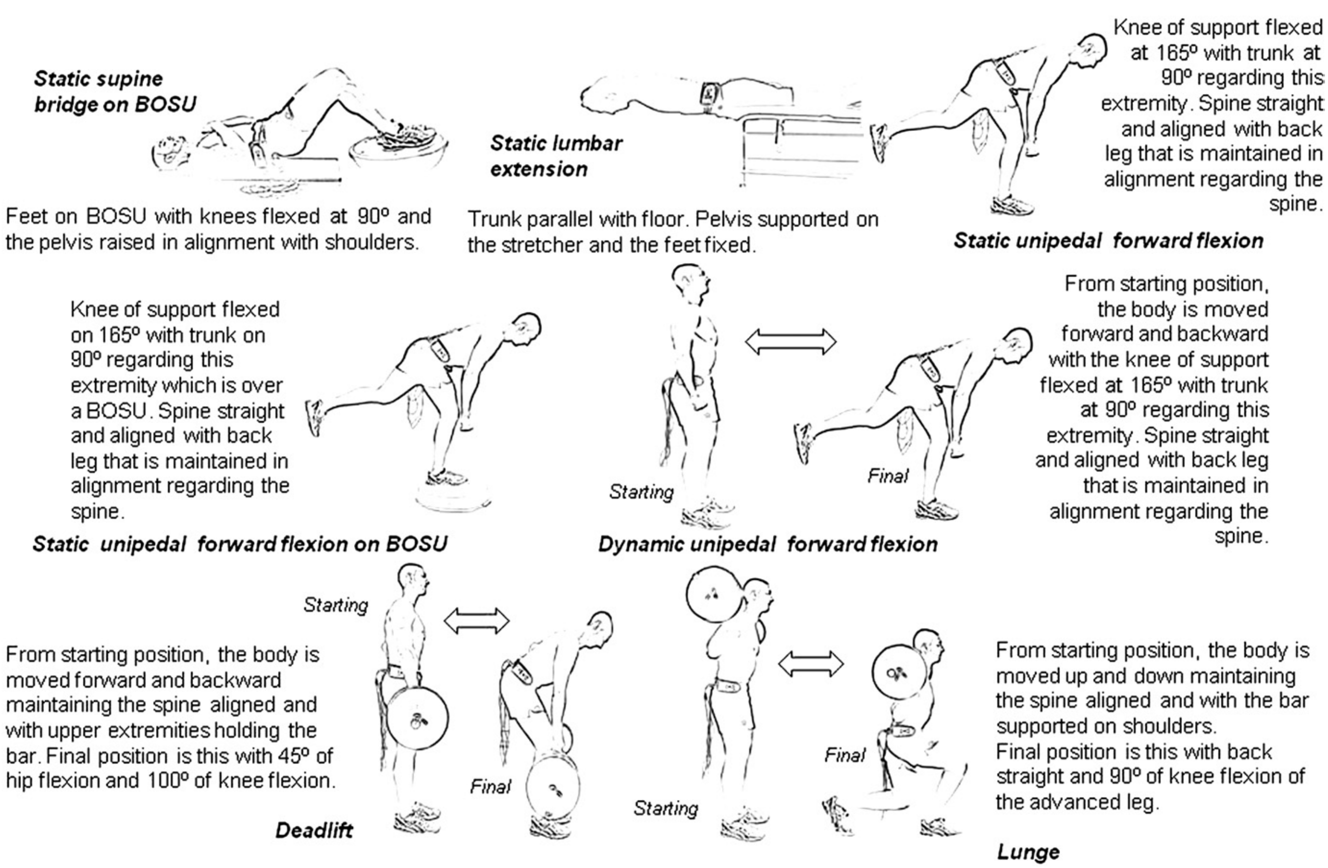

Fig 1. Technique of the exercises used in this study.

achieved during a back-extension exercise that was recorded before data collection. Therefore, dependent variables of this study were maximum and average root mean square (RMS) of the surface electromyography (SEMG) associated with dynamic and isometric (static) contractions.

Participants

University students (N=25; mean ± SD age, 24.3±0.5y; height, 164.8±9.5cm; weight, 78.9±2.2kg; body mass index, 24.8±0.5kg/m) participated voluntarily in this study. Subjects included in the research had a minimum of 1 year of experience in recreational resistance training and were familiar with instability training because they reported having trained regularly on unstable surfaces, such as the BOSU,[a] FitBall,[b] inflatable discs, and T-Bow.[c] No subject included in this study had musculoskeletal pain, neuromuscular disorders, or any form of joint or bone disease. Subjects were not using performance-enhancing medications. All subjects signed an informed consent form before starting the protocol, and the study was approved by the institutions' review boards. All procedures described in this section comply with the requirements listed in the 1975 Declaration of Helsinki and its amendment in 2008.

Procedures

All procedures were performed in 2 sessions in the spring. The first session occurred 72 hours before data collection. After performing a warm-up protocol, each subject performed MVICs, and a load cell (Isocontrol)[d] was used to record the resultant force. A 2-minute rest period was allocated between exercises. The central second of the force signal was selected, and an average value was used as an indicator of MVIC. During each repetition, subjects gradually increased the force production to avoid sudden potentially hazardous jerks. A back extension with maximum isometric effort in the prone position for 5 seconds was used to obtain the MVIC of the back extensor muscles. This value was used as the reference electromyogram (EMG) with which to normalize the intervention exercises' EMG. Also, MVICs were performed for the dead lift and lunge exercises. These MVIC dead lift and lunge values were obtained from the end or final position of the dynamic

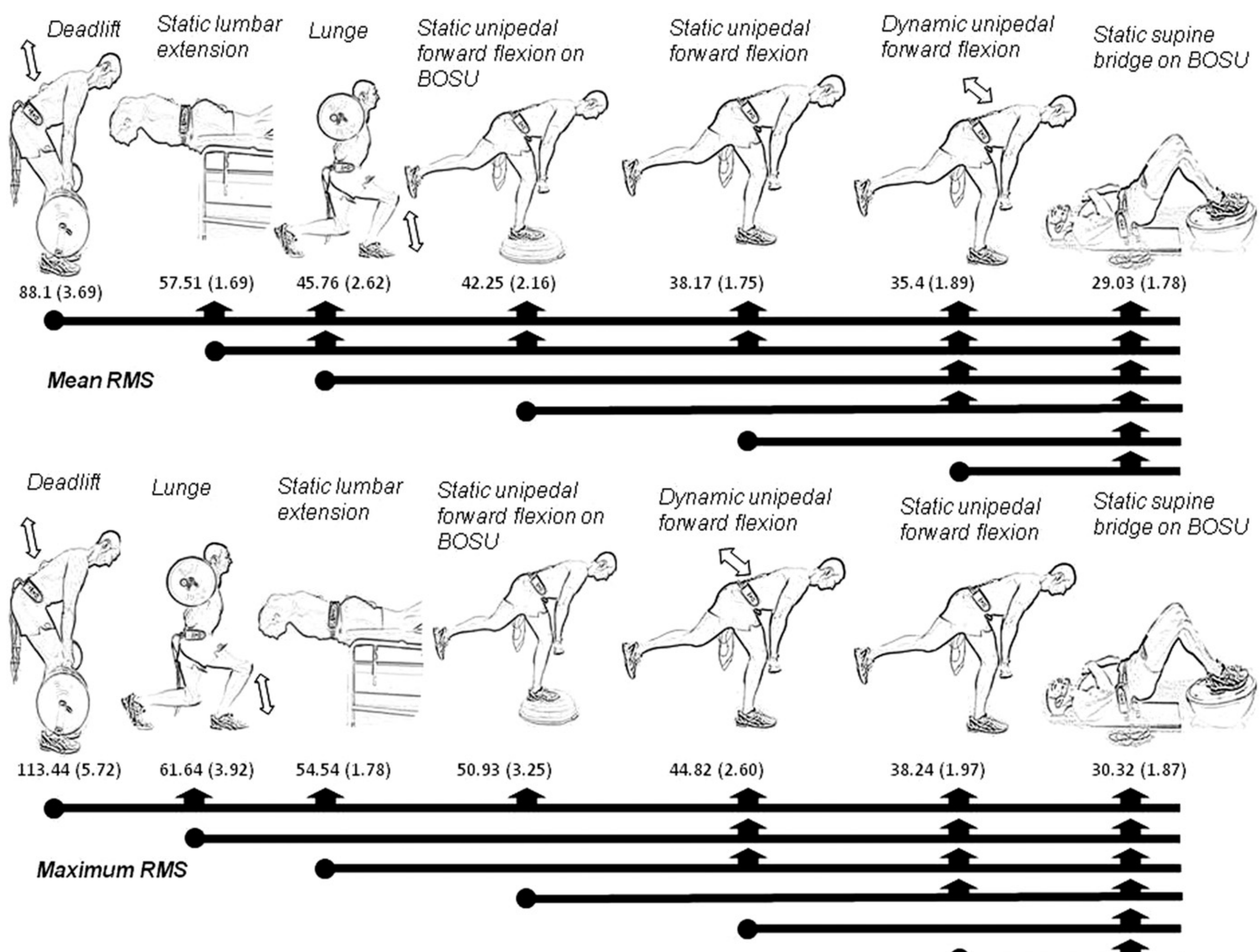

Fig 2. Global SEMG comparisons between exercise conditions. Data expressed as mean (upper figure) and maximum (lower figure) percentage of maximum isometric activation during back extension (n=25). SEM values are in parentheses. Data correspond to a global RMS value of the 4 muscles measured: LM, TM, LE, and TE. Arrows indicate significant differences (*P*<.05) between the exercise condition identified by a circle and exercises corresponding to the arrows. Abbreviation: SEM, standard error of the mean.

exercises (fig 1) to establish the intensity in the data collection session equal to 70% of the MVIC.

Subjects had not performed strength training for 48 hours before data collection and were advised to maintain their nutritional habits and avoid stimulatory substances (eg, caffeine). Measurement protocols were always strictly controlled by the same evaluators. All subjects were familiar with the tests and exercise and therefore no familiarization session was necessary. Before starting the evaluation, height and body mass were measured. Subjects then underwent a standard warm up, directed by the main researcher: 5 cycles of cat-camel, side bridge (10s), and slow jogging (120-s duration combining forward, backward, high knee lifts, heels to buttock) and 10 repetitions of squat using body weight and slow static stretching of the quadriceps and hamstrings (5s each).

In the second experimental session, subjects were required to perform 7 exercises. Localized stabilizing exercises included static (isometric) (1) supine bridge on a BOSU, (2) lumbar extension, (3) forward flexion using a unipedal stance on the floor, (4) forward flexion using a unipedal stance on a BOSU, and (5) dynamic forward flexion using a unipedal stance on the floor (see fig 1). Global stabilizing exercises included traditional resistance exercises, such as the (6) deadlift and (7) lunge (see fig 1). Static exercises were conducted maintaining the effort for 5 seconds, whereas dynamic exercises were executed using 6 repetitions at 70% of MVIC. This relative intensity of dynamic exercise is within the range recommended for strength training programs.[8,31,32] Such comparisons were used previously.[15,27,28] Time between each exercise condition was 5 minutes to ensure complete recovery. All subjects were encouraged verbally throughout all physical tests. Each test was supervised by the same examiner, with 1 reference examiner who attended to monitor strict compliance with protocol.

Electromyography

To acquire the SEMG signals produced during the attempts, an ME6000P4 biosignal conditioner[e] was used. Before placing the electrodes, the skin was prepared by shaving the area and cleaning with alcohol to reduce impedance as much as possible. Pregelled bipolar silver/silver chloride surface electrodes (Blue sensor M-00-S)[f] were placed with an interelectrode distance of 25mm on the following muscle groups: (1) LM (~3cm lateral to the spinous process at L5[14]), (2) TM (~2cm lateral to the T11-12 spinal process[33]), (3) LE (~3cm lateral to the spinal process at L3[14,34]), and (4) TE (~5cm lateral to the spinal process at T9[14,34]). The reference electrode was placed between the active electrodes, approximately 10cm away from each, according to the manufacturer's specifications.

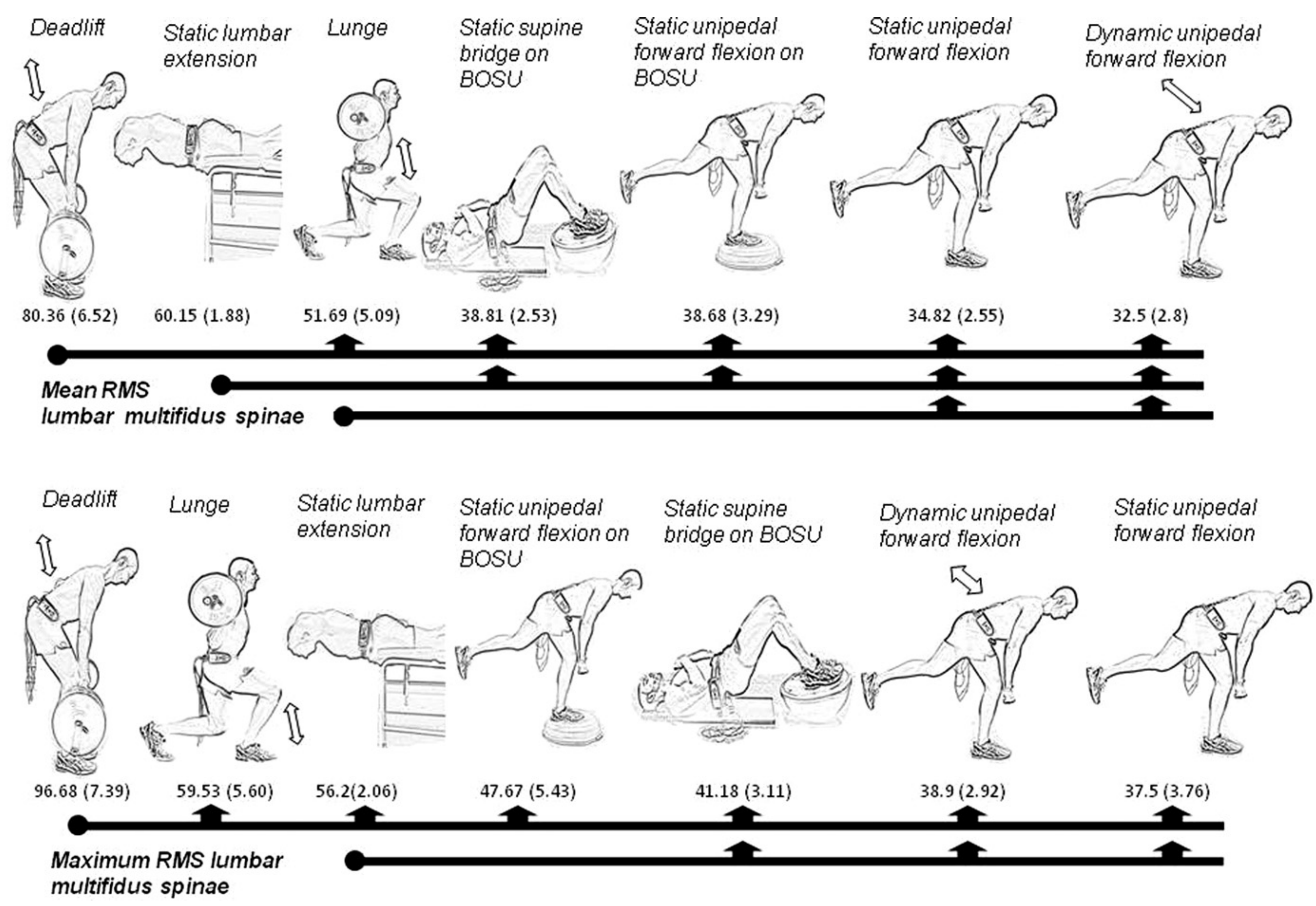

Fig 3. LM SEMG comparisons between conditions. Data expressed as mean (upper figure) and maximum (lower figure) percentage of the maximum isometric activation during back extension (n=25). SEM values are in parentheses. Data correspond to the RMS of the LM. Arrows indicate significant differences (*P*<.05) between the exercise condition identified by a circle and exercises corresponding to the arrows. Abbreviation: SEM, standard error of the mean.

All signals were acquired at a sampling frequency of 1kHz, amplified and converted from analog to digital. All records of myoelectrical activity (in microvolts) were stored on a hard drive for later analysis.

Data Analysis

All surface electromyographic signal analyses were performed using Matlab 7.0.[g] Surface electromyographic signals related to isometric exercises were analyzed by using the 2 middle seconds of the 5-second isometric contraction. Surface electromyographic signals of dynamic exercises were analyzed by using the entire repetition period. Because mean and maximum amplitudes of the EMG RMS signal are unrelated to activity duration, it is a suitable analysis for activities of varying duration.[18,28] All signals were bandpass filtered at a 20- to 400-Hz cutoff frequency with a fourth-order Butterworth filter. Surface electromyographic amplitude in the time domain was quantified by using RMS and processed every 100ms. Maximum and mean RMS values were selected for every trial. The data obtained (ie, mean and maximum RMS) were normalized by using the mean and maximum RMS values achieved during the MVIC back-extension exercise, respectively.

Statistical Analysis

Statistical analysis was carried out using SPSS software, version 17.[h] All variables were checked to ensure that they complied with the assumptions of normality (Kolomogorov-Smirnov normality test) and homocedasticity (Levene test). Standard statistical methods were used to obtain the mean as a measurement of the central trend and SEM as a measurement of dispersion. A mixed-model (muscle group [4: LM, TM, LE, TE] × exercise condition[7]) multiple analysis of variance was applied to establish the effects of the muscle group and exercise condition over the dependent variables related to the SEMG. The 7 exercise conditions included (1) supine bridge on a BOSU, (2) lumbar extension, (3) forward flexion using a unipedal stance on the floor, (4) forward flexion using a unipedal stance on a BOSU, (5) dynamic forward flexion using a unipedal stance on the floor, (6) dead lift, and (7) lunge. Follow-up of the multivariate contrast was performed through univariate contrast. Post hoc analysis with Bonferroni correction was used in the case of significant main or interaction effects. For all statistical analyses, $P=.05$ (α) was accepted as the level of significance.

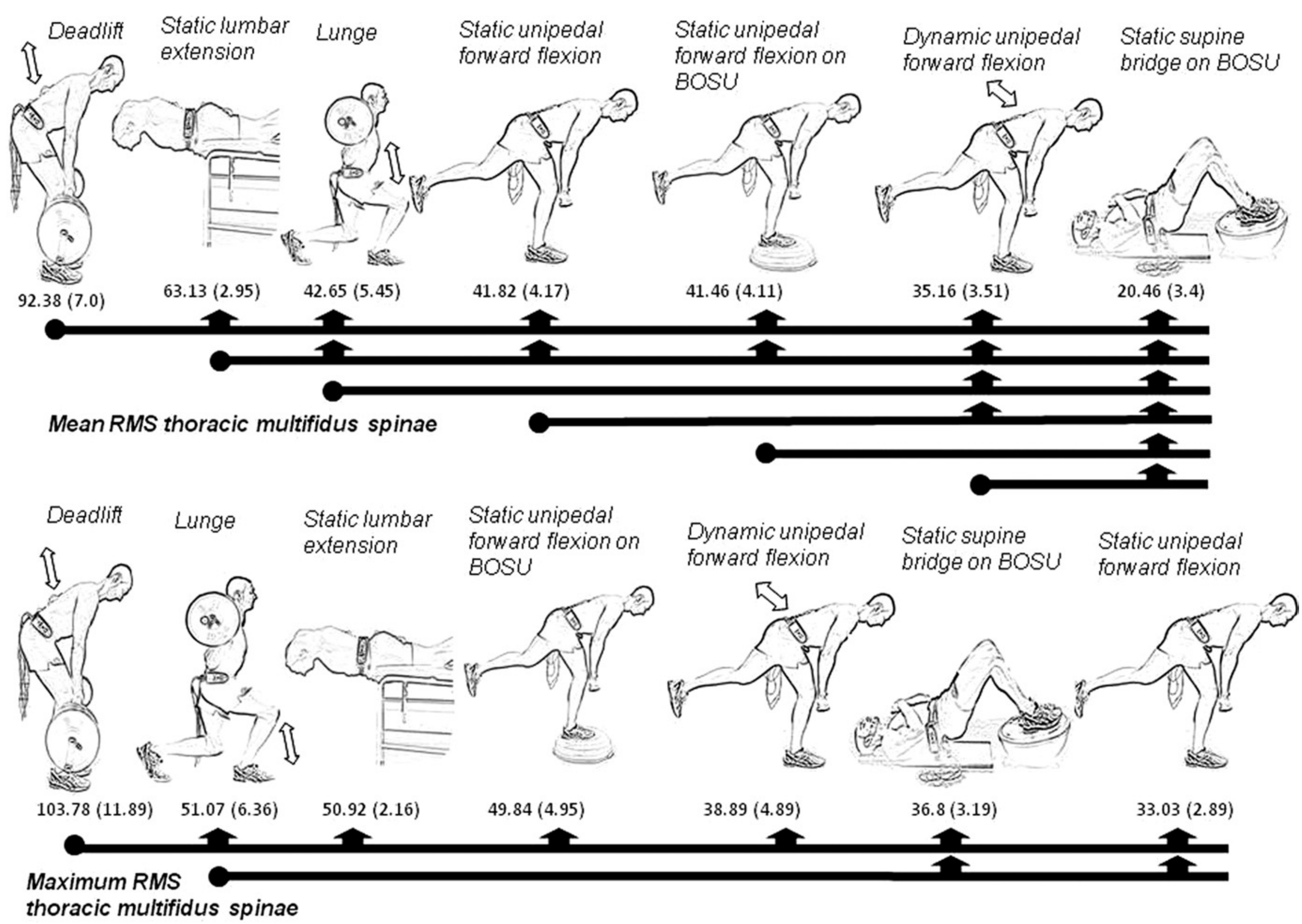

Fig 4. TM SEMG comparisons between conditions. Data expressed as mean (upper figure) and maximum (lower figure) percentage of maximum isometric activation during back extension (n=25). SEM values are in parentheses. Data corresponded to the RMS of the TM. Arrows indicate significant differences (*P*<.05) between the exercise condition identified by a circle and exercises corresponding to the arrows. Abbreviation: SEM, standard error of the mean.

RESULTS

Multivariate contrasts showed a main effect of the exercise condition ($F_{14,1204}$=49.34; $P<.001$; partial η^2 [η^2_p]=.36) on dependent variables. Moreover, there was an exercise condition × muscle group interaction effect ($F_{42,1204}$=3.41; $P<.001$; η^2_p=.11). This means there are differences between exercises and muscle groups on the dependent variables (ie, mean and maximum RMS values). In this sense, the univariate test showed the existence of a main effect of exercise condition on maximum ($F_{3.28,281.87}$=86.66; $P<.001$; η^2_p=.5) and mean RMS EMGs ($F_{3.7,318.14}$=110.21; $P<.001$; η^2_p=.56). After verifying the existence of a main effect of exercise on both dependent variables, pairwise comparisons were checked to establish differences between exercises. Pairwise comparisons (fig 2) showed that maximum and mean RMS values were higher with the dead lift than with the other exercises. This indicates that dead lift is the exercise that produces greater paraspinal muscle activation and therefore is 1 of the most intense exercises for this muscle area. However, supine-bridge exercise showed lower maximum and mean RMS values. Therefore, the intensity of this exercise in paraspinal muscles is low and it would be not effective to improve the strength of these low-back muscles.

Finally, the interaction effect between the different exercise conditions and the muscular group was present on the maximum ($F_{9.8,281.87}$=2.84; P=.002; η^2_p=.09) and mean RMS values ($F_{11.1,318.14}$=2.57; P=.004; η^2_p=.08). Pairwise comparisons related to these effects are shown in figures 3 to 6. Lower-body exercises with high loads in general were more intense (ie, greater muscle activation) than local specific exercises for all low-back muscles tested.

DISCUSSION

Results of the present study agreed with findings of previous studies examining core strengthening exercises. Previous research[9,10] recommended exercise progressions from supine and prone positions and localized stabilizing exercises (eg, bridge on BOSU) toward localized stabilizing exercises in a stance posture (eg, exercises of unipedal stance) to global stabilizing exercises (eg, dead lift and lunge).[9,10] Within these progressions, significant muscle activation can be achieved when using high-resistance localized stabilizing exercises (eg, weight of the trunk) and a large imbalance in the frontal plane of the body (eg, trunk extension from a horizontal plane). In agreement with the hypothesis, a major finding of this study was that maintenance of postural alignment (ie, maintaining a stable

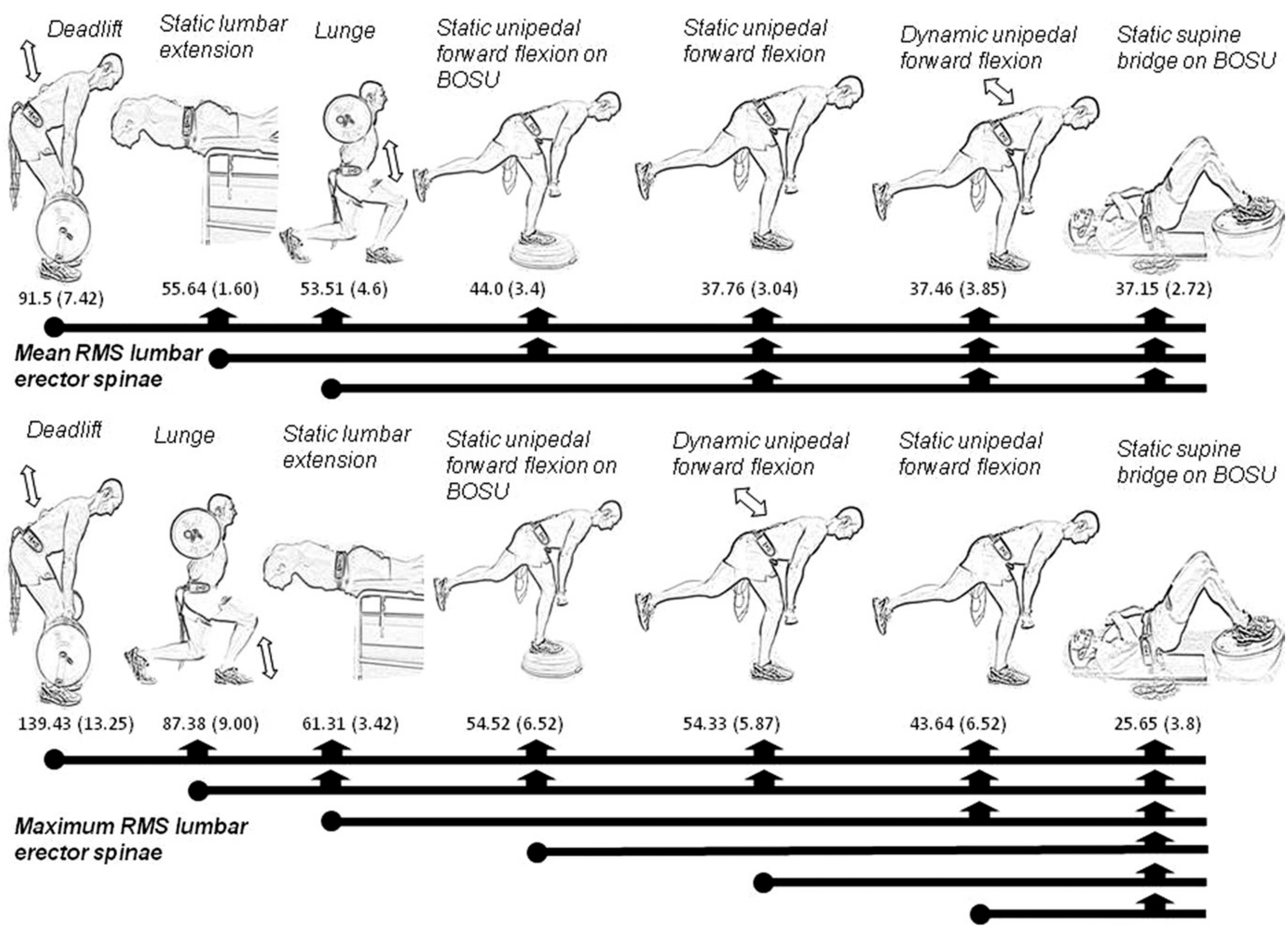

Fig 5. LE SEMG comparisons between conditions. Data expressed as mean (upper figure) and maximum (lower figure) percentage of maximum isometric activation during back extension (n=25). SEM values are in parentheses. Data correspond to the RMS of the LE. Arrows indicate significant differences (*P*<.05) between the exercise condition identified by a circle and exercises corresponding to the arrows. Abbreviation: SEM, standard error of the mean.

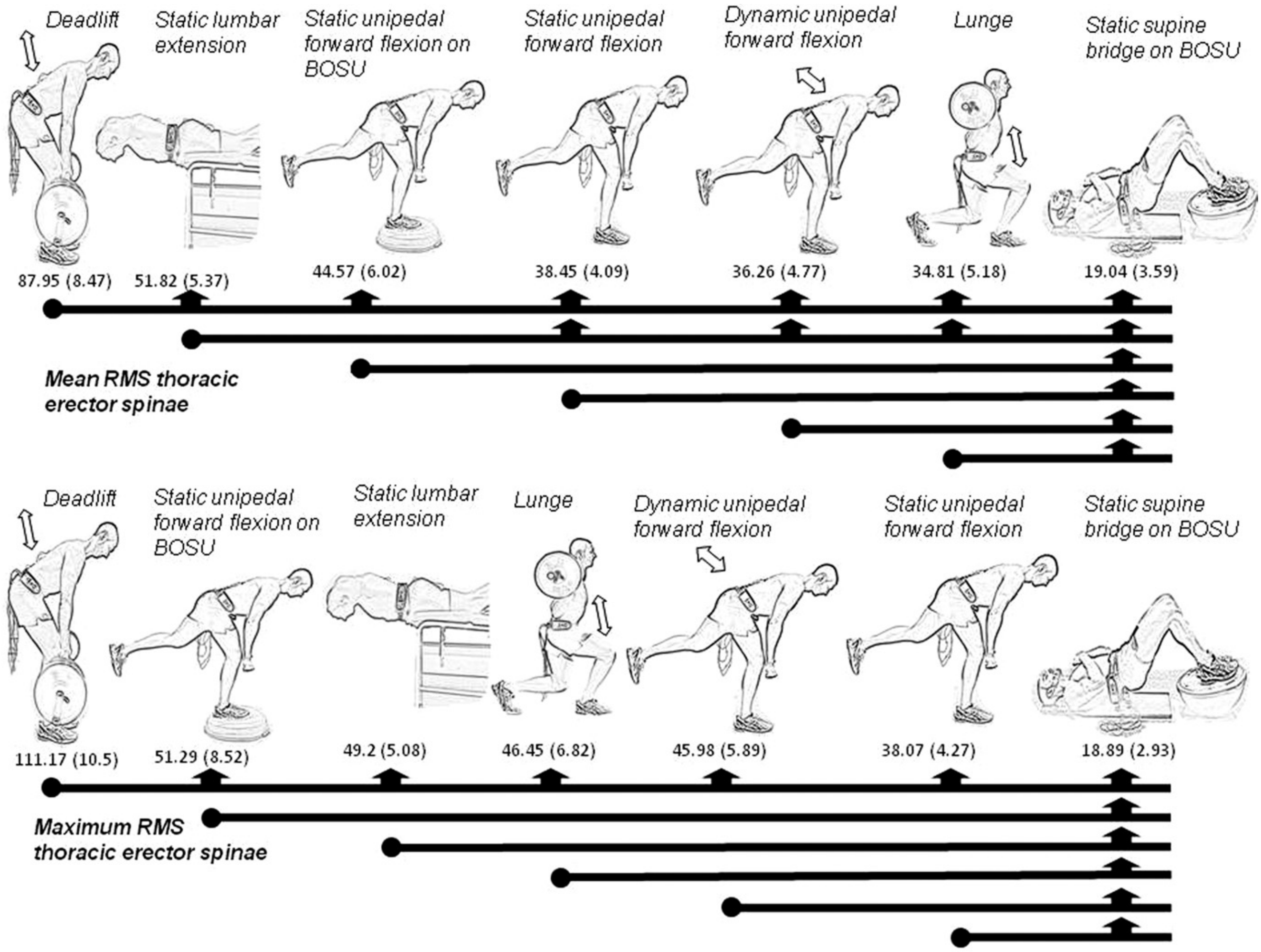

Fig 6. TE SEMG comparisons between conditions. Data expressed as mean (upper figure) and maximum (lower figure) percentage of maximum isometric activation during back extension (n=25). SEM values are in parentheses. Data correspond to the RMS of the TE. Arrows indicate significant differences (*P*<.05) between the exercise condition identified by a circle and exercises corresponding to the arrows. Abbreviation: SEM, standard error of the mean.

neutral zone with body segments outside the base of support) during exercises that stress the lower back can stimulate core-muscle activation as much or more than exercises involving instability devices.[22,35,36]

The present research showed that the supine-bridge exercise on the BOSU overall induced the least mean and peak muscle activation. Our results showing global (all 4 back muscles) mean muscle activity of 29% of MVIC when performing supine bridge on a BOSU agreed with Lehman et al,[38] who found mean erector spinae activity of approximately 30% when the same exercise was performed on a FitBall. These results corroborated the conclusion by Lehman et al[38] that stated that core-muscle activation variations were influenced by the biomechanical demands of the exercise and not exclusively the incorporation of instability devices. In this sense, the unipedal standing exercise on a BOSU performed in our study showed moderate muscle activation. Thus, it strengthens the suggestion that exercises using body weight performed on instability devices may provoke only low to moderate levels of muscle activation (see fig 2).

Similar to previous instability research,[21,35,36] shifting the center of gravity with resistance (external resistance or the resistive torque of a body segment moved outside the base of support) will provide a spectrum of muscle activation ranging from moderate to maximum intensity. Thus, a training stimulus to the core muscles need not involve specialized instability devices. In this line, corroborating previous research using different conditions of instability[29,37] and localized stabilizing exercises,[1,21,27,28] the traditional dead lift provided the highest muscle activation of all exercises analyzed. Consequently, if this exercise is performed using proper technique[31] and appropriate loads,[32] it is an excellent training exercise to increase strength and endurance with the goal of improving musculoskeletal health. The greater core muscle activation with dead lifts may be attributed to the enhanced core muscle stiffness necessary for proper bracing technique during execution of the exercise.[21] The bracing technique ensures stabilization of the lumbar spine.[39]

Paraspinal muscle activity has not been examined previously when performing the lunge. In a recent study, Marshall and Imtiaz[40] measured erector spinae activation of 10.0%±7.3% of MVIC during a single leg squat with the back supported on a Swiss ball or FitBall. However, the lunge in the present study achieved muscle activation levels for the erector spinae of

45.8% of MVIC. This higher muscle activation with the lunge is not surprising because previous studies using traditional high resistance rather than unstable squats with lower resistance have reported higher muscle activation during performance of the stable higher resistance squat,[27,28] which is similar to the lunge exercise. These results can be attributed to characteristics of the motion in which much of the movement is performed with the torso upright, yet during the final phase of this movement, there is a slight anterior pelvic tilt. Similar to a previous study,[41] this forward inclination of the trunk moving the center of gravity toward its anterior limits could help explain the high muscle activation. However, it should be noted that kinematics of the exercise was not examined in the present study.

However, the maximum muscle activation associated with the lunge in this study was not statistically significantly different from that obtained with the prone trunk extension exercises. Meanwhile, these types of prone exercises provoke higher mean amplitude muscle activation than the lunge. Furthermore, the lunge did not provoke higher mean muscle activation compared with the unipedal stance (both stable and unstable), although the lunge induced greater peak muscle activation compared with stable unipedal exercises. As mentioned, this difference could be attributed to performance of the lunge in which the resistance applied caused a substantial anterior imbalance that produced significantly greater peak muscle activation than obtained during the stable unipedal exercises.

Study Limitations

One limitation of the present study was the single intensity (70% of MVIC) of the exercises selected. It is recommended that future research use a progression of resistances to observe the lowest load that could provide a greater stimulus than callisthenic exercises. Second, a neutral spine was not measured directly. Thus, even with investigators watching to ensure proper technique, small changes in joint angle between the different exercises could have affected muscle activity. Finally, our research was carried out on asymptomatic subjects; thus, application of these exercises for individuals with lumbar and dorsal pain may be limited.

CONCLUSIONS

The findings of this study will help trainers and physical therapists provide stratification of exercises oriented to strengthening the paraspinal muscles for lumbar stabilization. A more accurate prescription may be provided depending on the specific characteristics of the practitioner. Results suggest that in asymptomatic young experts, the free-weight multijoint exercises, such as dead lift at 70% of MVIC, generate higher peak and mean levels of muscle activation than other localized exercises of stabilization with and without instability and other global exercises with localized stability.

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Supplier

a. BOSU, 1400 Raff Rd, Canton, OH 44750.
b. Hygenic Corp. 1245 Home Ave, Akron, OH. 44310.
c. Sanpere i Miquel, 13-19, B-At 2. 08032. Barcelona, Spain.
d. ATEmicro, C/Udula 2, San Lorenzo El Ecor, Madrid, Spain.
e. Mega Electronics Ltd, Hakalahdentie 17, Kuopio, Finland.
f. Ambu A/S, Baltorpbakken 13, DK-2750 Ballerup, Denmark.
g. Mathworks Inc, 3 Apple Hill Dr, Natick, MA 01760-2098.
h. SPSS Inc, 233 S Wacker Dr, 11th Fl, Chicago, IL 60606-6307.