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Electromyographic Analysis of Core Trunk, Hip, and Thigh Muscles During 9 Rehabilitation Exercises

Rehabilitation or performance enhancement training should be based on the principle that specific imposed demands on the musculoskeletal system will produce specific adaptations within the system. Exercises designed to increase strength or endurance should target specific muscle groups that are weak or are important to the activities in which the individual wants to participate. A clinician should be able to establish a specific exercise program that includes optimal exercise positions to target specific identified

muscular performance deficits. Electromyographic (EMG) analysis can provide information as to the relative amount of muscular activity an exercise requires, as well as the optimal positioning for the exercise.

Researchers have recently reported on the importance of specific trunk, hip, and thigh muscle strengthening and endurance/stabilization training for the prevention of athletic injuries.^{6,31,52} Weakness and poor endurance of the lumbar extensor, gluteus maximus, and hip external rotator muscles have also been noted in individuals with lower extremity injuries and low back pain.^{9,28,31,32,36,39} Leetun et al³¹ found that athletes who were not injured had stronger hip abductor and external rotator muscles. It has also been reported that females with patellofemoral joint pain have weaker hip abductors, extensors, and external rotators as compared to age-matched controls.^{26,43} Mascal et al,³⁴ in a case series including 2 patients, reported that strengthening these muscles resulted in a significant improvement in patellofemoral pain, lower extremity kinematics, and return to function.

In addition to injury prevention, studies have demonstrated that specific strengthening of the core hip and trunk muscles may improve athletic performance.^{13,46,51,54} The trunk and hip muscles have been shown to be very important for

- **STUDY DESIGN:** Prospective, single-group, repeated-measures design.
- **OBJECTIVE:** To identify exercises that could be used for strength development and the exercises that would be more appropriate for endurance or stabilization training.
- **BACKGROUND:** The exercises analyzed are often used in rehabilitation programs for the spine, hip, and knee. They are active exercises using body weight for resistance; thus a clinician is unable to determine the amount of resistance being applied to a muscle group. Electromyographic (EMG) analysis can provide a measure of muscle activation so that the clinician can have a better idea about the effect the exercise may have on the muscle for strength, endurance, or stabilization.
- **METHODS AND MEASURES:** Surface EMG analysis was carried out in 19 males and 11 females while performing the following 9 exercises: active hip abduction, bridge, unilateral-bridge, side-bridge, prone-bridge on elbows and toes, quadruped arm/lower extremity lift, lateral step-up, standing lunge, and using the Dynamic Edge. The rectus abdominis, external oblique abdominis, longissimus thoracis, lumbar multifidus, gluteus maximus, gluteus medius, vastus medialis

obliquus, and hamstring muscles were studied.

- **RESULTS:** In healthy subjects, the lateral step-up and the lunge exercises produced EMG levels greater than 45% maximum voluntary isometric contraction (MVIC) in the vastus medialis obliquus, which suggests that they may be beneficial for strengthening that muscle. The side-bridge exercise could be used for strengthening the gluteus medius and the external oblique abdominis muscles, and the quadruped arm/lower extremity lift exercise may help strengthen the gluteus maximus muscle. All the other exercises produced EMG levels less than 45% MVIC, so they may be more beneficial for training endurance or stabilization in healthy subjects.

- **CONCLUSION:** Our results suggest that these exercises could be used for a core rehabilitation or performance enhancement program. Depending on the individual needs of a patient or athlete, some of the exercises may be more beneficial than others for achieving strength. *J Orthop Sports Phys Ther* 2007;37(12):754-762. doi:10.2519/jospt.2007.2471

- **KEY WORDS:** endurance, lower extremity, spine, stabilization, strength

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obtaining maximal power and accuracy of the golf and baseball swing.^{46,51,54}

The purpose of this investigation was to quantify muscle activation with EMG analysis during 9 exercises involving the trunk, hip, and thigh muscles. We hypothesized that in the muscles analyzed, specific exercises would generate significantly greater levels of EMG signal amplitude than other exercises.

METHODS

Subjects

THIRTY HEALTHY SUBJECTS, 19 MALES and 11 females (mean \pm SD height, 176 ± 8 cm; body mass, 74 ± 11 kg), whose ages ranged from 19 to 58 years (mean \pm SD, 27 ± 8 years), participated in the study. The subjects were recruited from the University of South Dakota community and volunteered to participate. Subjects were accepted for the study if they were in good health, with no current or previous lower extremity or back problems. They were excluded if they had low back or lower extremity pain, or any recent surgery. The rights of subjects were protected. Participants signed an informed consent form prior to participation and the protocol for this study was approved by the University of South Dakota Institutional Review Board.

Procedures

Prior to electrode placement, each subject was familiarized to the procedures by being instructed in and practicing the muscle tests and exercises to be performed. Once assured that the subjects could correctly perform the muscle tests and exercises, the sites for electrode placement were prepared by abrading the skin with fine sandpaper and cleansing the area with 70% isopropyl alcohol. Shaving of hair was performed if necessary. Dual disposable silver/silver chloride surface recording electrodes (Noraxon USA, Inc, Scottsdale, AZ) were applied. EMG data were collected from the rectus abdominis, external oblique abdominis, longissimus thoracis, lumbar multifidus, gluteus

maximus, gluteus medius, vastus medialis obliquus, and hamstring muscles.

The following steps were taken to minimize EMG signal cross-talk between muscles. The electrodes were positioned well within the borders of the muscles and applied in parallel arrangement to the muscle fibers, with a center-to-center interelectrode distance of 20 mm. The skin impedance was checked with an ohm meter attached to the connecting snap of each electrode pair and was judged acceptable if less than 5000Ω .¹⁶

The electrodes were applied unilaterally, with no preference for left or right sides. It was felt that this was consistent with exercise of muscle groups in clinical practice. We were not aware of any evidence indicating a significant difference of muscle activity between sides of normal individuals when exposed to the exercises used in this study. For the rectus abdominis muscle, the electrodes were placed 3 cm lateral and 3 cm superior to the umbilicus, which is slightly different than that recommended by Cram and Kasman.¹⁶ By placing the electrodes slightly superior to the umbilicus, the thickest layer of adipose tissue was avoided. The electrodes were placed midway between the anterior superior iliac spine and the rib cage for the external oblique abdominis muscle.¹⁶ For the longissimus thoracis muscle, the electrodes were placed 4 cm lateral to the L1 spinous process and for the lumbar multifidus muscle the electrodes were placed 2 cm lateral to the lumbosacral junction.¹⁸ The electrodes for the gluteus medius muscle were placed anterosuperior to the gluteus maximus muscle and just inferior to the iliac crest on the lateral side of the pelvis.¹⁶ For the gluteus maximus muscle, electrodes were placed in the center of the muscle belly between the lateral edge of the sacrum and the posterosuperior edge of the greater trochanter.¹⁶ A general electrode placement was used for the entire hamstring muscle group midway between the gluteal fold and the popliteal line on the posterior surface of the knee in the center of the posterior thigh.¹⁶ Electrodes were also

placed at a 55° oblique angle over the center of the muscle belly of the vastus medialis obliquus muscle, 2 cm medially from the superior rim of the patella.¹⁶ A reference electrode was placed over the anterior superior iliac spine.

For normalization of the EMG data, a maximum voluntary isometric contraction (MVIC) was performed for each muscle and the EMG amplitude 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.^{25,29} Manual resistance was applied gradually up to the maximum amount, and then held for 5 seconds. Each muscle test was repeated 3 times, with a 30-second rest period between. Proper electrode placement was also confirmed by observing the EMG signal amplitude during the manual muscle tests.

The MVIC performed for the rectus abdominis muscle was a partial curl-up with the feet secured and resistance applied at the shoulders.²⁹ For the external oblique abdominis muscle, the subject performed an oblique curl-up, attempting to move the resisted shoulder toward the opposite knee.²⁹ The MVIC for the lumbar multifidus and longissimus thoracis muscles was performed with prone trunk extension to end range, with resistance applied at the upper thoracic area.²⁹ The gluteus medius muscle MVIC was performed in the side-lying position, with the hip in neutral rotation and slightly extended and then actively abducted to end range as resistance was applied just above the ankle.²⁵ The MVIC for the gluteus maximus muscle was performed in the prone position, with the knee flexed to 90° and the hip extended with resistance applied just above the knee.²⁹ The MVIC of the hamstring muscles was performed in the prone position, with the knee flexed 45° with resistance applied just above the ankle.²⁵ The vastus medialis obliquus MVIC was performed in the sitting position, with the knee flexed between 45° to 60° and resistance applied

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FIGURE 1. Active hip abduction in the side-lying position with neutral hip rotation.



FIGURE 2. Bridge exercise to the neutral spine alignment position.

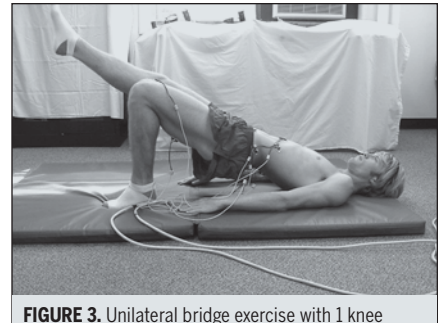


FIGURE 3. Unilateral bridge exercise with 1 knee extended and the opposite hip extended so that the trunk is in neutral spine alignment.



FIGURE 4. Side-bridge exercise with the trunk in neutral spine alignment.

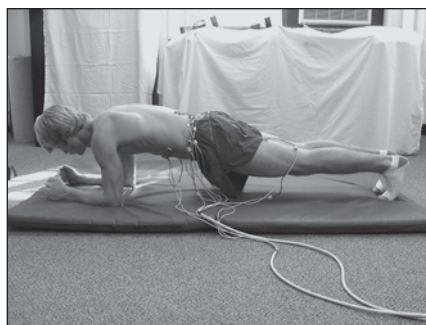


FIGURE 5. Prone-bridge exercise with the trunk in neutral spine alignment.



FIGURE 6. Quadrupedal arm and lower extremity lift with the trunk in neutral spine alignment.

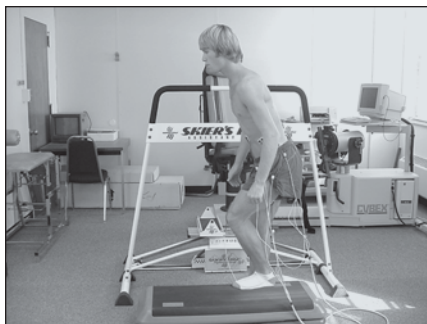


FIGURE 7. Lateral step-up exercise to a 20.32-cm platform.



FIGURE 8. Standing lunge exercise.



FIGURE 9. Dynamic Edge exercise with resistance to side-to-side motions simulating downhill skiing.

just above the ankle.^{15,56}

The following 9 exercises were randomly performed: active hip abduction in the frontal plane in the side-lying position with neutral hip rotation (FIGURE 1), bridge to the neutral spine position (FIGURE 2), unilateral-bridge to the neutral spine position with the opposite knee extended and the electrodes on the side of the supporting lower extremity (FIGURE 3), side-bridge with the trunk in neutral spinal alignment and the electrodes placed on the side of the supporting extremities (FIGURE 4), prone-bridge on the elbows and

toes with the spine in neutral alignment (FIGURE 5), quadrupedal arm and opposite lower extremity lift to the neutral spine position with the electrodes on the side of the hip being extended (FIGURE 6), lateral step-up to a 20.32-cm (8-in) platform (FIGURE 7), standing lunge (FIGURE 8), and Dynamic Edge (The Skier's Edge Company, Park City, UT) (FIGURE 9). The trunk stabilization exercises were performed 3 times and held for 5 seconds. The lateral step-up and lunge exercises were performed slowly through full range of motion, with a 5-second hold at the point of

maximal knee flexion. The Dynamic Edge exercise was performed with a continuous side-to-side motion similar to that performed during slalom snow skiing. Rest periods of 30 seconds were allowed between repetitions of the exercises and a 1-minute rest period was given between exercises. Considering these rest periods and the fact that the exercises did not always activate the same muscle to high levels, we felt that fatigue was not a factor in this study.

Following data collection, 2 of the exercises were repeated a second time in 13

TABLE 1

EMG ACTIVITY OF THE GLUTEUS MEDIUS AND GLUTEUS MAXIMUS MUSCLES DURING 9 DIFFERENT EXERCISES*

Exercise	Gluteus Medius	Gluteus Maximus
1. Side-bridge	74 ± 30 [†]	21 ± 16
2. Unilateral-bridge	47 ± 24 [‡]	40 ± 20 [‡]
3. Lateral step-up	43 ± 18 [‡]	29 ± 13
4. Quadruped arm/lower extremity lift	42 ± 17 [‡]	56 ± 22 [‡]
5. Active hip abduction	39 ± 17 [‡]	21 ± 16
6. Dynamic Edge	33 ± 16	19 ± 14
7. Lunge	29 ± 12	36 ± 17 [‡]
8. Bridge	28 ± 17	25 ± 14
9. Prone-bridge	27 ± 11	9 ± 7

* Values expressed as mean ± SD percentage of maximum voluntary isometric contraction (MVIC); n = 30; P<.05.

[†] For the gluteus medius muscle, exercise 1 produced significantly greater EMG signal amplitude when compared to exercises 2 to 9. For the gluteus maximus muscle, exercise 4 produced significantly greater EMG signal amplitude when compared to all the other exercises.

[‡] For the gluteus medius muscle, there was no significant difference in the EMG signal amplitude between exercises 2 to 5, but the EMG signal amplitude was significantly greater in these exercises compared to exercises 7 to 9. For the gluteus maximus muscle, there was no significant difference between exercises 2 and 7, but the EMG signal amplitude was significantly greater for these exercises compared to exercises 1, 3, 5, 6, 8, and 9.

TABLE 2

EMG ACTIVITY OF THE VASTUS MEDIALIS OBLIQUUS AND HAMSTRING MUSCLES DURING 9 DIFFERENT EXERCISES*

Exercise	Vastus Medialis Obliquus	Hamstrings
1. Lateral step-up	85 ± 17 [†]	10 ± 6
2. Lunge	76 ± 19 [†]	11 ± 6
3. Dynamic Edge	36 ± 12	6 ± 3
4. Prone-bridge	23 ± 13	4 ± 6
5. Side-bridge	19 ± 11	12 ± 11
6. Unilateral-bridge	18 ± 13	40 ± 17 [†]
7. Quadruped arm/lower extremity lift	16 ± 11	39 ± 14 [†]
8. Active hip abduction	8 ± 8	4 ± 3
9. Bridge	3 ± 3	24 ± 14

* Values expressed as mean ± SD percentage of maximum voluntary isometric contraction (MVIC); n = 30; P<.05.

[†] For the vastus medialis obliquus muscle, there was no significant difference in the EMG signal amplitude between exercises 1 and 2, but these exercises produced significantly greater EMG signal amplitude when compared to all the other exercises. For the hamstring muscles, there was no significant difference between exercises 6 and 7, but these exercises produced significantly greater EMG signal amplitude when compared to all the other exercises.

subjects to determine if there was consistency in the EMG recordings.

EMG Analysis

An 8-channel EMG Noraxon Myosystem 1200 (Noraxon, USA, Inc, Scottsdale, AZ) was used for data collection. Unit speci-

fications include a differential input impedance of greater than 10 MΩ, a gain of 1000, and a common-mode rejection ratio of greater than 100 dB at 60 Hz. The EMG signals were band-pass filtered from 10 to 500 Hz using first-order high-pass and fourth-order low-pass Butterworth

filters. The Myosystem 1200 was interfaced with a computer with a 16-channel, 12-bit A/D card (Computer Boards, Inc, Middleboro, MA). The sampling rate was set at 1000 Hz per channel.

All data were stored on a Gateway Solo 9300LS personal computer (Gateway, Inc, Irvine, CA) and MyoResearch 2.02 software (Noraxon USA, Inc, Scottsdale, AZ) was used for data processing and analysis. During data collection, the raw EMG recordings were monitored. The raw EMG data were full-wave rectified, processed using a root-mean-square (RMS) algorithm, and smoothed with a 20-millisecond moving window. The amplitude was calculated from a 1-second window centered about the peak activity for each of the MVICs and exercises.

The maximum EMG signal amplitude during the MVIC of each muscle was recorded and represented 100% muscle activity. The muscle activity recorded during the exercises was then expressed as a percentage of the MVIC.

Data Analysis

The SPSS Base 10.0 for Windows (SPSS Inc, Chicago, IL) computer program was used for data analysis. An intraclass correlation coefficient (ICC_{3,1}) was used to determine the same day test-retest reliability of the EMG recordings.⁴²

A 1-way repeated-measures analysis of variance (ANOVA) was applied for each muscle, with the factor being exercises with 9 levels. Post hoc analysis for pairwise comparisons followed when a significant main effect was found. Significance was established at the .05 level.

RESULTS

Reliability of EMG Recordings

THE SAME DAY TEST-RETEST ICCs for the EMG recordings from the muscles during the bilateral bridge and quadruped arm/lower extremity lift exercises were 0.86 (SEM, 20.0% MVIC) and 0.93 (SEM, 20.7% MVIC), respectively. Therefore, there was good consistency in the EMG recordings.

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Electromyography Data During the Exercises

The mean EMG activity of each muscle expressed as a percent of MVIC for each exercise is displayed in TABLES 1 through 4.

The gluteus medius muscle showed significantly greater activation ($P = .005$) with the side-bridge exercise (mean \pm SD, 74% \pm 30% MVIC) and the gluteus maximus muscle showed significantly greater activation ($P = .008$) with the quadruped arm/lower extremity lift exercise (mean \pm SD, 56% \pm 22% MVIC) than with any other exercise (TABLE 1). For the hamstring muscles (TABLE 2), the quadruped arm/lower extremity lift (mean \pm SD, 39% \pm 14% MVIC) and the unilateral bridge (mean \pm SD, 40% \pm 17% MVIC) exercises produced the most muscular activity with no significant difference between them ($P = 1.00$). The vastus medialis obliquus muscle (TABLE 2) showed the greatest activation with the lateral step-up (mean \pm SD, 85% \pm 17% MVIC) and lunge exercises (mean \pm SD, 77% \pm 19% MVIC), with no significant difference between the two ($P = .057$).

The longissimus thoracis (mean \pm SD, 36% \pm 18 to 40% \pm 17% MVIC) and lumbar multifidus (mean \pm SD, 39% \pm 15% to 46% \pm 21% MVIC) muscles (TABLE 3) demonstrated similar activity levels with the bilateral bridge, unilateral bridge, side-bridge, and the quadruped arm/lower extremity lift exercises ($P = .199-1.00$). The external oblique abdominis muscle (TABLE 4) showed the greatest activity ($P = .001$) with the side-bridge exercise (mean \pm SD, 69% \pm 26% MVIC). The rectus abdominis muscle (TABLE 4) activity was greatest with both the prone-bridge (mean \pm SD, 43% \pm 21% MVIC) and side-bridge (34% \pm 13% MVIC) exercises, with no significant difference between them ($P = .430$).

DISCUSSION

THE PURPOSE OF THIS STUDY WAS TO examine the activity level of several muscles during exercises that are commonly used for core stabilization and strengthening exercise programs. Based

EMG ACTIVITY OF THE LONGISSIMUS THORACIS AND LUMBAR MULTIFIDUS MUSCLES DURING 9 DIFFERENT EXERCISES*		
Exercise	Longissimus Thoracis	Lumbar Multifidus
1. Unilateral-bridge	40 \pm 16 [†]	44 \pm 18 [†]
2. Side-bridge	40 \pm 17 [†]	42 \pm 24 [†]
3. Bridge	39 \pm 15 [†]	39 \pm 15 [†]
4. Quadruped arm/lower extremity lift	36 \pm 18 [†]	46 \pm 21 [†]
5. Lateral step-up	25 \pm 10	28 \pm 10
6. Dynamic Edge	21 \pm 10	21 \pm 11
7. Active hip abduction	18 \pm 14	20 \pm 12
8. Lunge	17 \pm 8	25 \pm 11
9. Prone bridge	6 \pm 4	5 \pm 4

* Values expressed as mean \pm SD percentage of maximum voluntary isometric contraction (MVIC); $n = 30$; $P < .05$.
[†] For the longissimus thoracis and lumbar multifidus muscles there was no significant difference in the EMG signal amplitude between exercises 1 to 4, but these exercises produced significantly greater EMG signal amplitude when compared to exercises 5 to 9.

EMG ACTIVITY OF THE EXTERNAL OBLIQUE ABDOMINIS AND RECTUS ABDOMINIS MUSCLES DURING 9 DIFFERENT EXERCISES*		
Exercise	External Oblique Abdominis	Rectus Abdominis
1. Side-bridge	69 \pm 26 [†]	34 \pm 13 [†]
2. Prone-bridge	47 \pm 21	43 \pm 21 [†]
3. Quadruped arm/lower extremity lift	30 \pm 18	8 \pm 7
4. Unilateral-bridge	23 \pm 16	14 \pm 13
5. Bridge	22 \pm 13	13 \pm 11
6. Active hip abduction	18 \pm 10	6 \pm 4
7. Dynamic Edge	18 \pm 12	7 \pm 5
8. Lunge	17 \pm 11	7 \pm 5
9. Lateral step-up	15 \pm 10	5 \pm 3

* Values expressed as mean \pm SD percentage of maximum voluntary isometric contraction (MVIC); $n = 30$; $P < .05$.
[†] For the external oblique abdominis muscle, exercise 1 produced significantly greater EMG signal amplitude when compared to exercises 2 to 9. For the rectus abdominis muscle, there was no significant difference in the EMG signal amplitude between exercises 1 and 2, but these exercises produced significantly greater EMG signal amplitude when compared to exercises 3 to 9.

on the amplitude of the EMG signal, a judgment can be made about exercises that may be beneficial for strengthening and those that may be more beneficial for endurance or stabilization training.

When the surface EMG signal is rectified and smoothed, its amplitude is generally positively related to the amount of force produced by the muscle.²⁰ Investigators have reported both linear and non-linear relationships between EMG signal amplitude and increasing force produc-

tion during isometric contractions.⁷ Marras and Davis³³ found strong linear relationships for the erector spinae, rectus abdominis, and external and internal oblique abdominis muscles during isometric flexion and extension exertions. Alkner et al¹ found linearity in the force production-EMG signal amplitude relationship for the vastus lateralis and biceps femoris muscles, but more of a curvilinear relationship when evaluating the vastus medialis and rectus femoris muscles.

Therefore, for the purpose of developing exercise programs, the EMG signal amplitude can provide a general guideline as to the difficulty of the exercise.

Loads of 45% to 50% of 1 repetition at maximum effort (1 RM) have been shown to increase strength in previously untrained individuals.^{2,23,45,50} Therefore, those exercises that produced EMG signal amplitude in the muscles on an average greater than 45% MVIC may provide sufficient stimulus for strength gains in some individuals. However, because the standard deviation of the EMG signal amplitude is often quite large, some individuals, depending on their initial strength level, may benefit from the exercises less than others. Individuals that are better conditioned will need higher levels of stimulus to obtain a strengthening response. Most of the exercises used in this study produced EMG signal amplitude of less than 45% MVIC, so we would consider those to be most beneficial for endurance or motor control training.

The exercises that may provide a strengthening stimulus for certain muscles would be the side-bridge, the lateral step-up, the lunge, and possibly the quadruped arm/lower extremity lift. These exercises produced EMG signal amplitude markedly greater than the 45% MVIC level.

The lateral step-up exercise (**FIGURE 7**) produced a mean \pm SD EMG signal amplitude of 85% \pm 17% MVIC in the vastus medialis obliquus muscle. During the step-up exercise, a 20.32-cm platform was used and a 5-second isometric hold was added at maximum knee flexion of about 45° to 55°. Others have reported EMG signal amplitude ranging from 47% to 80% MVIC during this exercise.^{12,15,56} Ayotte et al⁵ recorded EMG signal amplitude of 55% MVIC in the vastus medialis obliquus muscle during the concentric phase of a 15.24-cm lateral step-up. Beutler et al⁸ recorded EMG signal amplitude for the whole quadriceps as high as 207% \pm 50% MVIC at about 83° of knee flexion when performing step-ups to a higher platform. In the 45° to 55° flexion range,

they recorded EMG signal amplitude in the 100% to 120% MVIC range, which is higher than our findings. The difference in EMG activity of the quadriceps found in our study as compared to other studies could be due to the following variables: method of MVIC determination, peak versus a 1-second window of activity, isometric versus various speeds of concentric muscle contraction, or the fact that we just recorded from the vastus medialis obliquus muscle.

The lunge exercise (**FIGURE 8**) produced a mean \pm SD EMG signal amplitude of 76% \pm 19% MVIC in the vastus medialis obliquus muscle. Pincivero et al⁴⁰ recorded the EMG signal amplitude of the vastus medialis and lateralis muscles during the lunge exercise, and found peak muscle activity of 150% to 175% MVIC.

The side-bridge exercise (**FIGURE 4**) produced a mean \pm SD EMG signal amplitude of 74% \pm 30% MVIC in the gluteus medius muscle, and 69% \pm 26% MVIC in the external oblique abdominis muscle. McGill³⁵ had previously recorded EMG activity of 50% MVIC in the external oblique abdominis with the side-bridge exercise. To our knowledge this exercise is not routinely used for gluteus medius strengthening, but could be one added to such a program.

During the quadruped arm/lower extremity lift exercise (**FIGURE 6**), 1 muscle generated sufficient EMG signal amplitude to be considered in the strengthening range: the gluteus maximus (mean \pm SD, 56% \pm 23% MVIC). We recorded a mean \pm SD EMG signal amplitude of 36% \pm 18% MVIC for the longissimus thoracis and 46% \pm 21% MVIC for the lumbar multifidus on the side of the extended hip during this exercise. Others have recorded values ranging from about 20% to 40% MVIC for the erector spinae on the side of the lower extremity lifted and 27% to 56% MVIC for the lumbar multifidus muscle.^{3,4,14,35,47,48} The quadruped arm/lower extremity lift is often utilized as an exercise for lumbar spine rehabilitation. This exercise when performed actively, without additional

resistance, produces moderate activity of the back muscles so may be most useful for developing muscle endurance.

Arokoski et al⁴ previously analyzed the bridge (**FIGURE 2**) and unilateral-bridge (**FIGURE 3**) exercises and found a significant difference between men and women. The EMG signal amplitude values were consistently higher in the longissimus thoracis and lumbar multifidus muscles in women compared to men. For the bridge exercise, they recorded values of about 14% MVIC for men and 35% MVIC for women in the longissimus thoracis muscles, whereas we recorded mean \pm SD values of 39% \pm 15% MVIC for the combined population. For the lumbar multifidus muscle, they recorded values of about 33% MVIC for men and 53% MVIC for women, as compared to a mean \pm SD of 39% \pm 15% MVIC in the current study.

For the unilateral-bridge, Arokoski et al⁴ recorded EMG signal amplitude of 38% MVIC for men and 71% MVIC for women in the longissimus thoracis, and we recorded a mean \pm SD of 40% \pm 16% MVIC. We recorded a mean \pm SD of 44% \pm 18% MVIC in the lumbar multifidus muscle of the supporting lower extremity, and Arokoski et al⁴ recorded 34% MVIC EMG signal amplitude for men and 65% for women. Because we did not differentiate between men and women in this study, we would conclude that these exercises are better suited for endurance training. But analysis of the work of Arokoski et al⁴ suggests that some subjects, especially women, may derive some strengthening benefits from the bridge and unilateral-bridge exercises.

The prone-bridge exercise (**FIGURE 5**) should provide adequate stimulus for endurance training of the rectus abdominus (mean \pm SD, 47% \pm 21% MVIC) and the external oblique abdominis (mean \pm SD, 43% \pm 21% MVIC) muscles. Escamilla et al^{21,22} have demonstrated other exercises that would be more appropriate for strengthening the abdominal muscles.

Studies have clearly linked the importance of sufficient endurance and strength

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of the above muscle groups to prevention of injury and improved athletic performance.^{10,36,51,54,53} Thus, individuals with poor endurance of the abdominal and back muscles will benefit from appropriate use of bridging, unilateral bridging, side-bridging, prone bridging on elbows and toes, and the quadruped arm/lower extremity lift exercises. All the above exercises demonstrated coactivation of muscle groups and should be beneficial for stabilization or endurance training.

Active hip abduction (**FIGURE 1**) did not produce significant activation of the core stabilizers, but was effective in isolating function of the gluteus medius muscle. Active hip abduction produced a mean \pm SD EMG signal amplitude of 39% \pm 17% MVIC of the gluteus medius muscle in this study as compared to 42% \pm 23% MVIC in the study by Bolgla and Uhl.¹¹ Therefore, active hip abduction will allow for non-weight-bearing strengthening of the gluteus medius if additional resistance is applied to the lower extremity. Weakness specific to the gluteus medius muscle has clearly been correlated with hip,¹¹ knee,^{26,31,32,36,41} and back^{28,32,36,44} injuries and good strength of the gluteus medius has been linked to better performance when swinging a golf club or baseball bat.^{46,51,54}

Limitations

Cross-talk may be a limitation when using surface electrodes. The electrode placement for the gluteus medius muscle may have allowed for some cross-talk from the gluteus maximus muscle because of its proximity. Stokes et al⁴⁹ have questioned the validity of using surface electrodes to monitor the activity of the lumbar multifidus muscle. They concluded that surface electrodes over the multifidus muscle pick up EMG signal from the longissimus thoracis muscle; however, we feel that their results should be questioned, because they placed surface electrodes for the multifidus muscle just lateral to the L2 and L4 levels and the electrode for the longissimus thoracis 30 mm lateral to the L3 spinous process. The

proximity of the electrode placements for the 2 muscles may have allowed the electrodes over the multifidus muscle to pick up EMG activity from the longissimus thoracis and vice versa. Most researchers place the electrodes further apart, with the multifidus electrodes lateral to the spine at L5 or lower,^{3,4,14,18-19,38,48} and the electrodes for the longissimus thoracis at the L2 level^{3,4,18-19,48} or above. Arokoski et al³ found a high correlation between the average intramuscular and surface activities of the normalized EMG signal of the multifidus muscle at the L2 and L5 levels, and Danneels et al¹⁷ have demonstrated good reliability in the use of surface electrodes for the lumbar multifidus muscle. We believe additional research should be performed before a definite conclusion can be derived about the use of surface electrodes for the lumbar multifidus muscle.

In our study, the EMG signal was generally collected during static muscle contractions, except during the Dynamic Edge exercise. Static holds are commonly performed during the trunk exercises evaluated, but may seldom be used during the step-up and lunge exercises. In other EMG studies of the lateral step-up exercise, the quadriceps muscle activity has been recorded during dynamic contractions. However, the isometric hold in the most stressful part of the range may be beneficial for adding stimulus to promote additional muscle adaptations. Danneels et al¹⁹ found increased hypertrophy of the lumbar multifidus muscles when a 5-second isometric hold was performed between the concentric and eccentric phase during prone back extension exercises. Further research needs to be performed to determine if this is also true with the lower extremity muscles.

Often it is difficult to assess the clinical importance of exercises that produce very low levels of EMG signal, because the standard deviations may be almost as large as the mean EMG values. Exercises that produce very low levels of muscle EMG signal, as was found with some of the exercises in this study, may be of little

benefit in rehabilitation programs.

There is the potential that subjects did not generate a true MVIC of each muscle. This could be due to a lack of effort, or the muscle testing positions may not have been optimal for producing maximum EMG signal. Muscle length at the time of the MVIC may also be a factor. We obtained the MVIC of the gluteus medius muscle at end range abduction, whereas Bolgla and Uhl¹¹ used a position of 25° hip abduction. Our results with active hip abduction were very similar, even though Neumann et al³⁷ found that EMG signal amplitude increases as the hip is abducted to greater degrees, possibly due to length-tension changes in the muscles. Optimal positions for producing a MVIC for each muscle group have not been clearly established. While interpretation of the absolute muscular effort expressed as a percent of MVIC may be affected by the MVIC testing, the within-subject design of this study provides a solid comparison of the relative difference in muscular effort among the exercises.

Finally, because these results were obtained by studying subjects without pathology, caution is warranted in extrapolating these findings to a patient population.

CONCLUSIONS

THE BRIDGE, UNILATERAL-BRIDGE, side-bridge, prone-bridge on elbows and toes, and quadruped arm/lower extremity lift exercises provide muscle activation without external loading for training endurance and stabilization of the trunk and hips. Active hip abduction is effective for non-weight-bearing strength training of the gluteus medius muscle. The lateral step-up and lunge exercises provide adequate stimulus to the vastus medialis obliquus muscle for strength and endurance training, and the Dynamic Edge exercise unit may be used for endurance training. The findings in this study may be used to select specific exercises to enhance a core training program.

ACKNOWLEDGMENTS

WE WOULD LIKE TO THANK SHELLEY Clark, Matthew Dewald, Raj Lalli, and Dawn Addison-Corbit, physical therapy students at the University of South Dakota, for their assistance in data collection. ●

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