Hip and Core Muscle Activation During High-Load Core Stabilization Exercises

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Background: There is some evidence that high-load lumbar stabilization exercises, such as back bridge, can recruit both local and global muscles.

Hypothesis: Therapeutic exercises would optimize gluteus maximus (GMax), gluteus medius (GMed), multifidus (MF), and transversus abdominis (TrA) activation, while minimizing the activation of the tensor fascia latae (TFL) and erector spinae (ES) muscles in healthy individuals.

Design: Cross-sectional study.

Setting: Research laboratory.

Level of Evidence: Level 4.

Methods: In this cross-sectional study, surface electromyography (EMG) of GMax, GMed, TFL, TrA, MF, and ES was used to quantify the gluteal-to-TFL muscle activation (GTA) index and a ratio of local to global (L/G) lumbar muscles during (1) the elbow-toe exercise in the prone position, (2) the elbow-toe with right left lifted, (3) the hand-knee with left arm and right leg lifted, (4) the back bridge, (5) the back bridge with right leg lifted, (6) the back bridge with left leg lifted, (7) the side bridge with left leg lifted, (8) the side bridge with right leg lifted, and (9) the elbow-toe with right leg horizontally lifted exercises in healthy individuals (20 men, 20 women; age, 25 ± 4 years).

Results: The back bridge exercise with left leg lift generated the highest L/G muscles activity ratio (L/G = 3.35) while the hand-knee exercise yielded the lowest L/G muscles activity ratio (L/G = 1.21). The side bridge exercise with left elbow and foot and lifting the right leg (GTA = 63.78), hand-knee exercise (GTA = 49.62), back bridge (GTA = 28.05), and elbow-toe exercise with left leg horizontally lifted (GTA = 23.02) generated the highest GTA indices, respectively. Meanwhile, the normalized EMG amplitude for GMax was significantly less than the TFL, for elbow-toe exercise ($P < 0.001$), back bridge with left leg lift ($P = 0.001$), side bridge exercise with the right elbow and foot and lifting the left leg ($P = 0.002$), and elbow-toe exercise with right leg horizontally lifted ($P < 0.001$).

Conclusion: The highest GTA indexes were observed during (1) the side bridge lifting the dominant leg and (2) the hand-knee horizontally lifting dominant leg, respectively. The L/G ratio was highest during (1) the back bridge lifting nondominant leg, (2) back bridge, and (3) back bridge lifting dominant leg, respectively. This study supports the use of back bridge exercises to strengthen the MF and side bridges to improve gluteal muscle activation.

Clinical Relevance: The highest GTA index was observed in the side bridge lifting the right leg. Highest L/G ratio was in the back bridge with nondominant leg lifted. This study supports the use of back bridge exercises to strengthen the MF. This study supports the use of side bridges to improve gluteal muscle activation.

Keywords: gluteal-to-tensor fascia latae activation (GTA) index; local/global (L/G) ratio; core stabilization exercise; healthy individual

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The term "core" refers to muscles that provide dynamic stability to the lumbo-pelvic-hip region.[33] According to Panjabi's proposed model, the integration of 3 subsystems—(1) the active subsystem (muscles), (2) the passive subsystem (joints and soft tissue), and (3) the neural subsystem (neural conduction)—is required during daily activity to ensure a safe range of motion in the vertebral column.[27] In other words, trunk and hip muscle endurance and strength are essential to maintain spinal and pelvic neutral alignment.[41,43]

To control movements and the position of the spine in all directions, proper activation of the deep stabilizers such as multifidus (MF) and transversus abdominis (TrA) is critical.[12] Global (such as erector spinae [ES]) and local muscles (such as MF and TrA) of the trunk have the synergistic relation in the stability system and are important in any prevention and rehabilitation exercise program.[27]

The role of MF as a dynamic stabilizer of the trunk is less sensitive even when the load of tasks or movements is changed.[39,40] In contrast to MF, ES could produce torque to stabilize the trunk.[6,7] When a task is low load, more superficial muscles with more fast twitch fibers are recruited.[20] However, by increasing the load of the task, which requires greater force production with longer duration of activation, the demand on both local and global muscles is emphasized to stabilize the spine.[20] Also, the lumbar paraspinal muscular strength and endurance are necessary to control the lumbo-pelvic-hip complex[41] before any movement of the lower extremity in healthy individuals.[13] However, the detrained lumbar paraspinal muscles impede the ability of the individual to transfer deep stabilization to the pelvis/hip, which deconditions the hip extensors.[31] Lumbo-pelvic region strength and postural stability in healthy individuals could be improved through training the lumbar paraspinal muscles.[43]

At the hip joint, the gluteus maximus (GMax) and gluteus minimus are mobilizers and the gluteus medius (GMed) is normally a stabilizer.[16] Unfortunately, gluteal muscular dysfunction impairs core stability. For example, when GMax activation is impaired,[5,15] the tensor fascia latae (TFL) would act as a prime mover.[25] An overactive or tight TFL internally rotates the hip leading to rotation of the pelvis.[31] This, in turn, causes abnormal alignment of lumbar spine and hip joint, producing lumbopelvic pain.[31] Also, delayed activation and possible weakness of GMax with early recruitment and possible over activity in ES may cause chronic low back pain.[15,29]

Since both local (deep) and global (superficial) lumbar muscles contribute to maintaining lumbar stability, examining the ratio of the local to global (L/G) muscle activity could give more complete understanding of the muscular contribution to core stability.[23] Previous studies analyzed the relative ratio of the L/G muscle activity during performance of single tasks like abdominal drawing.[22-24] They reported training the co-contraction between the deep abdominal and lumbar MF could significantly increase the relative ratio of the internal oblique to the rectus abdominis.[24] Also, a study analyzed the relative L/G ratio of the lumbar to thoracic ES muscular activity during isometric contractions in activities like flexion, extension, and lateral flexion from a semiseated position in an apparatus and estimated moment contributions were greater in the patients than in the control subjects.[38]

In addition to the L/G ratio, previous researchers advocated for a gluteal-to-TFL muscle activation (GTA) index, where higher values indicate greater activation of GMax and GMed relative to TFL.[32] This index determines which exercises target gluteal activation while minimizing TFL activation to prevent abnormal hip kinematics (excessive abduction and internal rotation).[32] They recommended the clam, side step, the unilateral bridge, and quadruped hip extension exercises could be used to preferentially activate the gluteal muscles over TFL.[32]

In other research, Bishop et al[1] determined GTA and compared electromyographic (EMG) muscle activation of GMax, GMed, and TFL while performing commonly prescribed exercises designed to target the GMax and GMed with and without elastic resistance.[21] They reported Clam exercises could optimally activate gluteal muscles while minimizing the TFL activation.[2]

Given the variety of core stabilization exercises that exist and the understood importance of maintaining lumbo-pelvic-hip stability, this study investigated which therapeutic exercises would optimize the activation of GMax, GMed, MF, and TrA while minimizing the activation of TFL and ES muscles in healthy individuals using the GTA index and the relative L/G ratio.

METHODS

Forty healthy, physically active adults (20 men, 20 women; mean ± SD, age, 25 ± 4 years; height, 170 ± 8 cm; mass, 70 ± 14 kg) were invited to the study via flyers displayed both on and off the university campus in October and November 2018. Healthy participants (18-35 years) were free from low back pain and neurological disorders and reported no hip, back, or lower extremity injuries or surgery within the 3 previous years.[30] All participants who were physically active (4 hours per week, by using Baecke questionnaire[14] during the 6 months before the study) were examined by a physician to confirm they met the inclusion and exclusion criteria. All participants were right leg dominant based on the leg with which they would kick a ball.

All data collection was performed in a university research laboratory by an expert in surface EMG with 5 years of experience. Details of the study were explained and all participants provided written informed consent before enrollment. This study was performed in accordance with the 1964 Helsinki declaration, its later amendments, and local ethics committee. This study was approved by Department of Biomechanics and Sports Injuries at Kharazmi University.

Before exercise performance, participants were outfitted with 8 surface EMG electrodes (Noraxon Myosystem 1400A, Noraxon USA, Inc) to quantify the activation of the dominant GMax, GMed, TFL, and TrA, and bilateral MF and ES muscles.

Selected Therapeutic Exercises

Participants performed the following exercises in a randomized order to minimize the influence of fatigue: (1) the elbow-toe exercise in the prone position, (2) the elbow-toe with right left lifted, (3) the hand-knee with left arm and right leg lifted, (4) the back bridge, (5) the back bridge with right leg lifted, (6) the back bridge with left leg lifted, (7) the side bridge with left leg lifted, (8) the side bridge with right leg lifted, and (9) the elbow-toe with right leg horizontally lift[8,9,18,30,32] The exercises selected are commonly prescribed for treating painful conditions of the back.[8,9,18,30,32] Exercise positions are provided in Appendix 1 (available in the online version of this article).

Through all exercises, subjects were encouraged to maintain their spine and pelvis in neutral alignment while breathing normally.[26] The neutral alignment was taught to the subjects by a physiotherapist. Neutral alignment feedback during the tests was provided by the physiotherapist. Once the neutral spine position was reached, the exercise position was held for 3 seconds. If the participants lost their neutral alignment, the test was stopped and form was corrected. Each subject performed the exercises three times before the EMG test for familiarization. Subjects were permitted 30-second rest between each exercise to minimize the effect of fatigue.

Surface EMG

After gentle local abrasion using medical abrasive paste (Everi, Spes Medica) and cleaning the skin with alcohol, pairs of disposable Ag/AgCl surface electrodes were attached bilaterally over the ES and MF. Also, electrodes were placed unilaterally on the TrA, GMax, GMed, and TFL. The interelectrode space between recording electrodes was 3 cm, and each electrode had an approximately 1-cm pickup area.[1,33] Electrode placement is provided in Appendix 2 (available online).

EMG data were sampled at 1500 Hz. Signals were smoothed, rectified, and analyzed using a root-mean-square algorithm of 100 ms to determine the peak activation for each muscle. EMG data were normalized to maximum voluntary isometric contraction (MVIC; percentage of maximal EMG amplitude [%EMG]) and averaged across trials for each muscle and exercise.

A ratio of lumbar L/G was used to express recruitment patterns of MF and ES as deep stabilizing to superficial trunk muscles.[18,32,34,36,37] For the recruitment pattern of GMax, GMed, and TFL, a GTA index that combines activation of the GMax and GMed muscles compared with the TFL during each of exercises was used ({[(*GMed*/*TFL*) × *GMed*] + [(*SUP-GMax*/*TFL*) × *SUP-GMax*]}/2). Higher GTA index values indicate greater activation of the GMax and GMed relative to the TFL.[21,32]

Statistical Analysis

A 3-way analysis of variance (ANOVA) (sex by exercise by muscle) revealed that there was no difference in muscle activation in various exercises and muscles between men and women. As a consequence, data from both sexes were combined for all analyses and exercise by muscle ANOVAs was performed. Similarly, for the L/G ratio (MF/ES), the signal from each muscle of each side was averaged into 1 value to represent the muscle group bilaterally. One-way repeated-measures ANOVAs were used to determine if there were differences in muscle activation while performing each of the 9 exercises. Post hoc analyses for each muscle using Bonferroni adjustments were performed. Finally, for difference between each of the gluteal muscles and the TFL within each exercise, specific paired comparisons among the (GMed and TFL) (GMax and TFL) muscles were planned a priori. Statistical significance was set a priori at ≤0.05. All data were analyzed using SPSS (Version 16.0; SPSS Inc).

RESULTS

Individual Muscle Activity

Table 1 and Figures 1 to 6 provide the normalized mean EMG amplitudes of MF, ES, TrA, GMax, GMed, and TFL muscles for each exercise. For the MF, the left MF was more active than the right during the elbow-toe exercise with the left leg horizontally lifted (30% MVIC, $P = 0.02$), the hand-knee exercise (27.8%, $P = 0.001$), and the side bridge on the left (111.9%, $P < 0.001$). The left MF was more active than the right during the side bridge on the left elbow (70.9%, $P < 0.001$).

There was a statistically significant side to side difference in ES muscle activation for the hand-knee exercise ($P = 0.02$) and both side bridge exercises ($P < 0.001$). For left ES, side bridge exercise with left elbow and foot and lifting the right leg to reach a horizontal position exercise produced the highest activity level (35.27%). For right ES, side bridge exercise with right elbow and foot and lifting the left leg to reach a horizontal position exercise produced the highest activity level (33.81%).

TrA demonstrated a main effect of exercise, with elbow-toe exercise with left leg horizontally lifted producing significantly more activity (48.76%) compared with all exercises ($P < 0.001$) except for the side bridge exercise with the right elbow and foot and lifting the left leg ($P > 0.05$) and elbow-toe exercise with right leg horizontally lifted ($P > 0.05$).

For GMax, there was a main effect of exercise, with the side bridge exercise with left elbow and foot and lifting the right leg producing greater activity (35.80%) compared with the other exercises except for the hand-knee exercise ($P < 0.05$).

GMed demonstrated a main effect of exercise, with the side bridge exercise with left elbow and foot and lifting the right leg producing greater activity (46.27%) compared with all other exercises ($P < 0.05$).

TFL demonstrated an exercise main effect, with side bridge exercise with left elbow and foot and lifting the right leg producing the highest activity level (38.08%) of all exercises ($P < 0.05$).

Preplanned Comparisons

The normalized EMG amplitude for GMax was significantly less than the TFL, for elbow-toe exercise ($P < 0.001$), back bridge with left leg lift ($P = 0.001$), side bridge exercise with the right elbow and foot and lifting the left leg to reach a horizontal

Table 1. Muscle activation values (% MVIC) for each exercise[a]

	Muscles							
Exercises	Multifidus Left	Multifidus Right	Erector Spinae Left	Erector Spinae Right	Transverse Abdominis	Tensor Fasciae Latae	Gluteus Medius (P)[b]	Gluteus Maximus (P)[c]
1. Elbow-toe exercise	5.19 ± 2.59	5.92 ± 4.23	5.53 ± 3.12	4.53 ± 2.12	30.86 ± 16.30	8.15 ± 4.58	8.40 ± 4.66 ($P = 0.99$)	3.43±1.81 ($P = 0.000$)[d]
2. Elbow-toe exercise with left leg horizontally lifted	12.78 ± 6.40	9.45 ± 6.20	13.32 ± 15.44	8.37 ± 8.43	48.76 ± 13.37	16.77 ± 8.17	16.99 ± 8.07 ($P = 0.99$)	15.88 ± 8.85 ($P = 0.99$)
3. Hand-knee exercise with left arm and right leg horizontally lifted	24.28 ± 6.41	18.35 ± 9.09	16.03 ± 7.27	12.46 ± 6.44	28.94 ± 16.17	16.44 ± 7.47	18.97 ± 7.36 ($P = 0.17$)	31.47 ± 16.34 ($P < 0.001$)[e]
4. Back bridge	21.87 ± 7.47	21.50 ± 6.66	20.56 ± 10.69	24.96 ± 22.26	17.15 ± 13.57	6.00 ± 3.30	12.09 ± 11.79 ($P = 0.001$)[e]	9.60 ± 7.06 ($P < 0.001$)[e]
5. Back bridge with right leg lift	24.02 ± 10.55	22.02 ± 9.09	22.94 ± 14.33	22.97 ± 9.97	31.95 ± 17.72	16.68 ± 10.06	16.74 ± 9.33 ($P = 0.99$)	14.36 ± 11.20 ($P = 0.46$)
6. Back bridge with left leg lift	24.30 ± 11.86	20.70 ± 9.90	25.35 ± 12.86	20.53 ± 14.29	23.85 ± 15.72	16.17 ± 16.81	11.61 ± 7.80 ($P = 0.11$)	6.36 ± 3.13 ($P = 0.001$)[d]
7. Side bridge exercise with the right elbow and foot and lifting the left leg to reach a horizontal position	17.36 ± 13.00	36.43 ± 17.13	10.79 ± 9.01	33.81 ± 17.89	48.42 ± 10.14	18.76 ± 10.29	21.46 ± 13.12 ($P = 0.10$)	12.99 ± 12.41 ($P = 0.002$)[d]
8. Side bridge exercise with the left elbow and foot and lifting the right leg to reach a horizontal position	48.61 ± 19.05	13.73 ± 4.98	35.27 ± 18.25	12.40 ± 8.16	25.42 ± 16.59	38.08 ± 12.56	46.27 ± 18.31 ($P = 0.13$)	35.80 ± 18.77 ($P = 0.99$)
9. Elbow-toe exercise with right leg horizontally lifted	10.96 ± 7.77	11.62 ± 8.90	13.20 ± 15.17	13.95 ± 10.69	41.19 ± 11.76	21.55 ± 16.97	18.48 ± 18.61 ($P = 0.99$)	5.15 ± 2.70 ($P < 0.001$)[d]

MVIC, maximum voluntary isometric contraction.
[a]Values are mean ± SD percent MVIC.
[b]Planned comparison between the gluteus medius and the tensor fascia latae within each exercise.
[c]Planned comparison between the gluteus maximus and the tensor fascia latae within each exercise.
[d]Significantly less than tensor fascia latae ($P < 0.05$).
[e]Significantly greater than tensor fascia latae ($P < 0.05$).

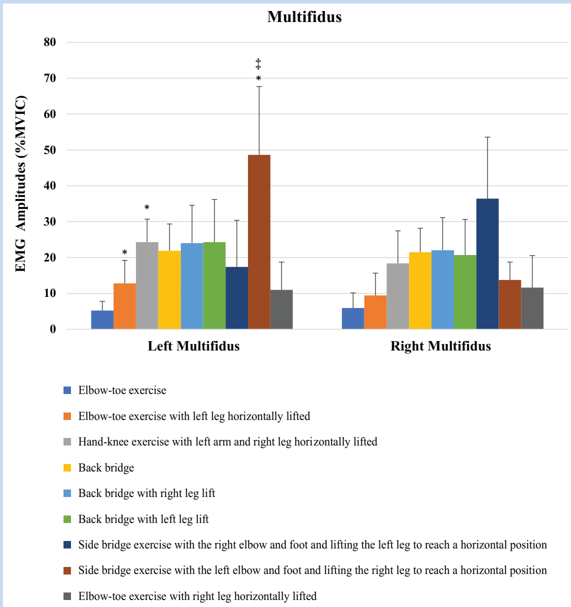

Figure 1. Electromyographic (EMG) signal amplitudes (mean ± SD) of the multifidus (MF). *Indicates significant side-to-side difference in activation ($P < 0.05$). ‡Indicates exercise with the highest activity level for the average of right and left MF. MVIC, maximum voluntary isometric contraction.

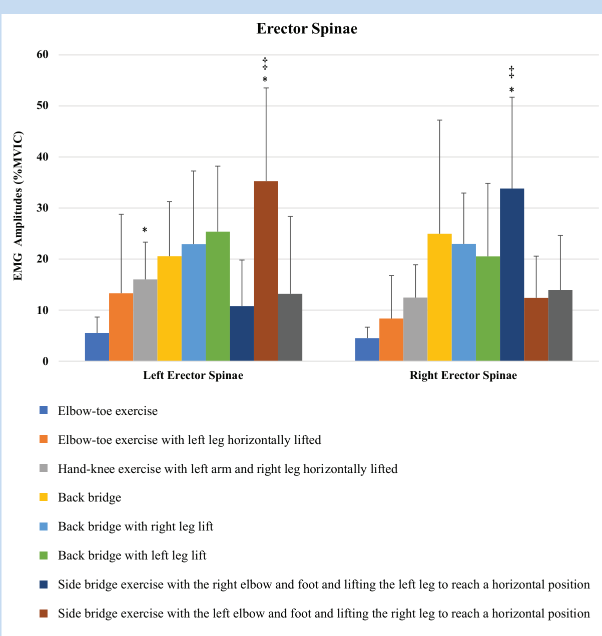

Figure 2. Electromyographic (EMG) signal amplitudes (mean ± SD) of the erector spinae (ES). *The overall side-to-side difference was significant (significant level at 0.05). ‡Exercise with the highest activity level for the average of right and left ES. MVIC, maximum voluntary isometric contraction.

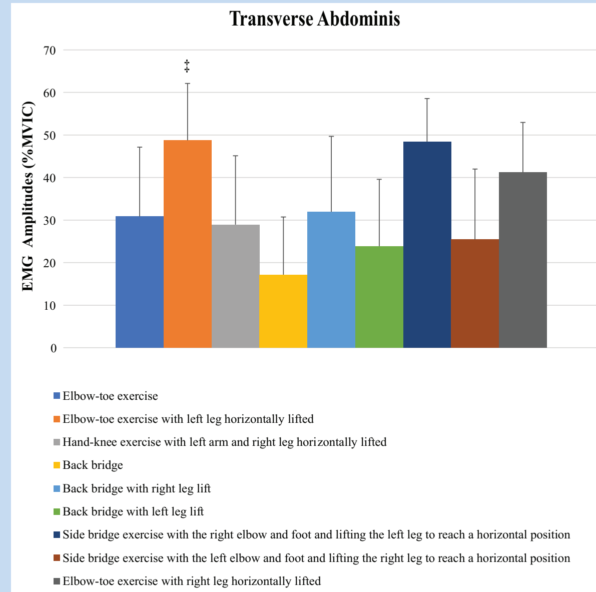

Figure 3. Electromyographic (EMG) signal amplitudes (mean ± SD) of the transverse abdominis. ‡Exercise with the highest activity level compared with all exercises except for the side bridge exercise with the right elbow and foot and lifting the left leg and elbow-toe exercise with right leg horizontally lifted. MVIC, maximum voluntary isometric contraction.

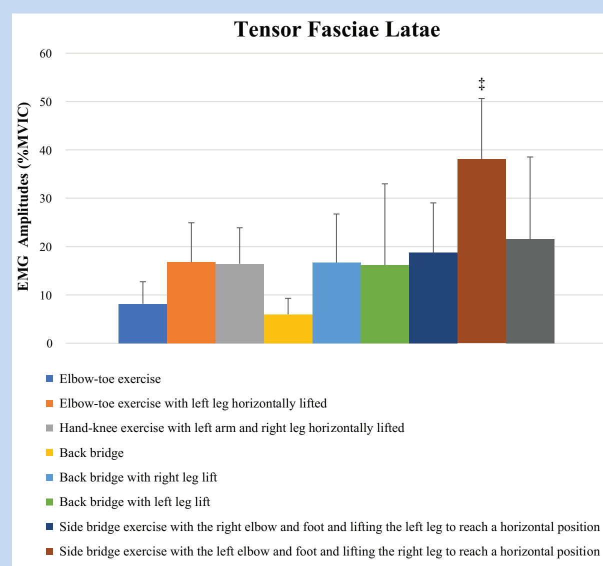

Figure 4. Electromyographic (EMG) signal amplitudes (mean ± SD) of the tensor fasciae latae. ‡Highest activity level of all exercises. MVIC, maximum voluntary isometric contraction.

position ($P = 0.002$), and elbow-toe exercise with right leg horizontally lifted ($P < 0.001$). For hand-knee with left arm and right leg horizontally lifted exercise and back bridge, GMax had

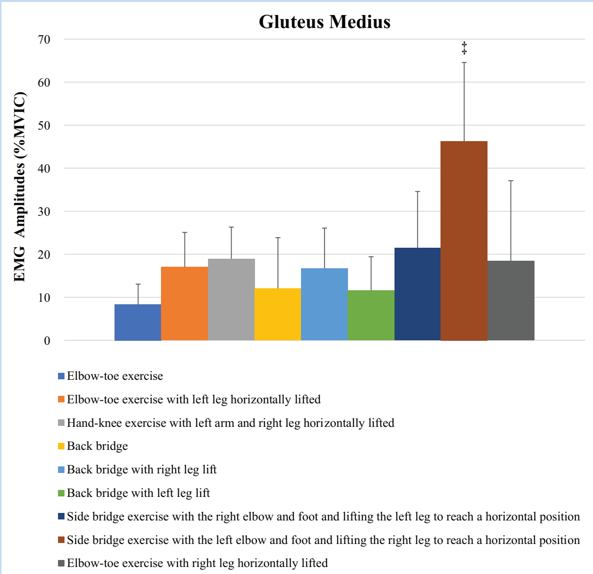

Figure 5. Electromyographic (EMG) signal amplitudes (mean ± SD) of the gluteus medius. ‡Highest activity level of all exercises. MVIC, maximum voluntary isometric contraction.

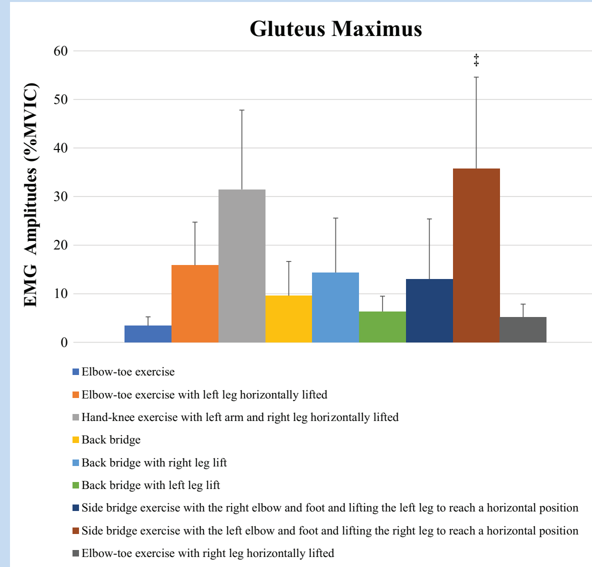

Figure 6. Electromyographic (EMG) signal amplitudes (mean ± SD) of the gluteus maximus. ‡Exercise with the highest activity level compared with the other exercises except for the hand-knee exercise. MVIC, maximum voluntary isometric contraction.

significantly higher normalized EMG amplitudes than the TFL ($P < 0.05$). For back bridge, the contrast tests revealed that the normalized EMG amplitude for GMed was significantly different from the TFL ($P = 0.001$).

L/G Muscle Ratio

Table 2 displays the L/G muscles activity ratio (MF to ES) and the relative rank of this index during the 9 exercises studied. The back bridge exercise with left leg lift generated the highest L/G muscles activity ratio (L/G = 3.35) while the hand-knee exercise yielded the lowest L/G muscles activity ratio (L/G = 1.21). The L/G ratio for other exercises was as follows: 2.76 for back bridge, 2.74 for back bridge with right leg lift, 2.66 for elbow-toe exercise with right leg horizontally lifted, 2.55 for side bridge exercise with the right elbow and foot and lifting the left leg to reach a horizontal position, 2.08 for elbow-toe exercise, 1.63 for side bridge exercise with the left elbow and foot and lifting the right leg to reach a horizontal position, and 1.49 for elbow-toe exercise with left leg horizontally lifted.

GTA Index

Table 3 displays the GTA index and the relative rank of this index during the 9 exercises studied. The side bridge exercise with left elbow and foot and lifting the right leg (63.78), hand knee exercise (49.62), back bridge (28.05), and elbow toe exercise with left leg horizontally lifted (20.96) generated the highest GTA indices, respectively. GTA index for other exercises was as follows: 20.42 for side bridge exercise with the right elbow and foot and lifting the left, 19.07 for back bridge with right leg lift, 8.88 for back bridge with left leg lift, and 6.85 for elbow-toe exercise.

DISCUSSION

This study examined the relative L/G ratio of the lumbar muscle activity as well as the GTA index in healthy individuals during the selected core stabilization exercises. Considering EMG data, the L/G ratio of the lumbar and the GTA index might clarify which exercises could increase muscular strength or endurance which are required in daily activities. Using EMG signal amplitude as a general guideline to force production of an exercise, Ekstrom et al[10] have reported isometric contractions could intensify activation of the intended muscles. Based on the data, the highest L/G ratio was during back bridge exercises. The back bridge with the left leg lifted had the highest ratio, followed by back bridge and back bridge with lifted right leg. Collectively, these data suggest a high level of MF activation during lumbar extension and stabilization exercises. This finding has been reported previously.[19] Moseley et al[19] have reported that the superficial and deep MF contributed to the control of the spine orientation and the intersegmental motion respectively. Okubo et al[22] and Ekstrom et al[9] reported high activity of MF and ES muscles during the elbow-toe, hand-knee, back bridge, side bridge, and curl-up exercises, but they did not measure the relative L/G ratio. Consistent with our study, Stevens et al[34] also reported that the coactivation between MF and ES could occur during the back bridge exercises to stabilize the spine. Distefano et al[8] also suggested that the elbow-toe exercise with right leg horizontally lifted yields substantial MF relative to ES activity; this finding was supported by our data.

The lumbar stabilization exercises mainly target the local muscles[35]; however, there is some evidence that the high-load

Table 2. Ordering of exercises by the ratio of local to global (L/G ratio) muscles activity (multifidus to erector spinae)

Exercise	L/G Ratio
Back bridge with left leg lift	3.35
Back bridge	2.76
Back bridge with right leg lift	2.74
Elbow-toe exercise with right leg horizontally lifted	2.66
Side bridge exercise with the right elbow and foot and lifting the left leg to reach a horizontal position	2.55
Elbow-toe exercise	2.08
Side bridge exercise with the left elbow and foot and lifting the right leg to reach a horizontal position	1.63
Elbow-toe exercise with left leg horizontally lifted	1.49
Hand-knee exercise with left arm and right leg horizontally lifted	1.21

Table 3. Ordering of exercises by gluteal-to-tensor fascia latae muscle activation (GTA) index

Exercise	GTA Index[a]
Side bridge exercise with the left elbow and foot and lifting the right leg to reach a horizontal position	63.78
Hand-knee exercise with left arm and right leg horizontally lifted	49.62
Back bridge	28.05
Elbow-toe exercise with left leg horizontally lifted	23.02
Elbow- toe exercise with right leg horizontally lifted	20.96
Side bridge exercise with the right elbow and foot and lifting the left leg to reach a horizontal position	20.42
Back bridge with right leg lift	19.07
Back bridge with left leg lift	8.88
Elbow-toe exercise	6.85

GMax, gluteus maximus; GMed, gluteus medius; TFL, tensor fascia latae.
[a]GTA index = {[(GMed/TFL) × GMed] + [(GMax/TFL) × GMax]/2} (Selkowitz et al[32]).

lumbar stabilization exercises, such as bridge exercises, could recruit both local and global muscles.[9,22] MF as the local muscle controls and ensures the spine curvature in sagittal and lateral stiffness to maintain mechanical stability of the lumbar spine[38] while ES as the global muscle produces torque to maintain overall trunk alignment.[38] The muscles of the hip transfer the loads of the tasks via the sacroiliac joint to the trunk and vice versa.[42] If the difficulty of the tasks and the magnitude of their loads are excessively beyond the tolerance of the hip muscles and joints, they can result in pressure on the lumbar joints, sacroiliac joint, pubic symphysis, and consequently functional failure of the sacroiliac joint and low back pain.[15,42] Parr et al[28] supported the clinical practice of these exercises to facilitate recruitment of the gluteal muscles and an increased force expressed for a given neural impulse.

In this study, the highest levels for the GTA index were reported during the side bridge lifting the dominant leg, the hand-knee with the dominant leg horizontally lift, and the back bridge, respectively.

The back bridge with 1 leg horizontally lifted, and the side bridge lifting with 1 leg are recommended as nonweightbearing exercises to strengthen weak muscles in isolation due to pain, swelling, reciprocal muscle inhibition, or synergistic dominance.[3]

For side bridge lifting, the dominant leg to reach a horizontal position, there is no study reporting the GTA index. However, during this exercise, Born et al[3] indicated high-level activation for both GMax and GMed. Considering the GTA index and the level activation of GMax and GMed, the side bridge exercise could be recommended for a progressive spinal stability program for patients with hip weakness to gain strength.[21,32]

During the hand-knee with the dominant leg horizontally lifted, this study observed a significant difference between GMax and TFL activity. Bishop et al[2] reported the activation of GMax and Gmed muscles more than that of TFL in this exercise, but not significantly. Alongside the differences in methods between the studies, the lack of consistency may contribute to the lifting of the contralateral arm during the hand-knee exercise with right leg horizontally lifted in this study making GMax to activate more as a stabilizer and mover muscle.

Back bridge was rated as 3 related to the GTA index (28.05) among the 9 exercises in this study. During this exercise, the activations of GMax and GMed were low level, which were significantly more than TFL activation, but not enough for strengthening exercise.[11] Selkowitz et al[32] and Bishop et al[2] indicated the GTA indices 32 and 41.49, respectively, while demonstrating no significant activation between GMax, GMed, and TFL muscles in the back bridge. Also, Ekstrom et al[9] reported the back bridge activated GMax and GMed to moderate level about 27% ± 13% MVIC and 28 ± 17% MVIC, respectively.[9]

Again, this difference in the reported levels of GMax and GMed activations in the aforementioned exercises may be due to the way the exercises were performed during testing. In the current study, muscle activation was assessed isometrically, whereas Selkowitz et al[32] and Ekstrom et al[9] captured concentric and eccentric muscle activity. To support the data of this study, it should be noted that the bridge with a straight leg lifted may result in more hamstring than GMax activation. Therefore, when the aim of the treatment is to increase GMax activation, it is recommended to flex the knee of the lifted leg encourage active insufficiency in the hamstring and increase GMax activity.[4,17]

Elbow-toe exercise was ranked 9 related to the GTA index between 9 exercises with low-level activation for GMax and GMed. The activation level reported by Bishop et al[2] and Selkowitz et al[32] was medium for GMax and GMed during this exercise.

Although the values of GMax and GMed muscles during the 9 exercises were reported low to medium level, except the high level for GMed during side bridge exercise with the left elbow and foot and lifting the right leg, these exercises could train GMax and GMed muscles to stabilize the lumbopelvic during early phase of core stabilization exercises, while minimizing the activation of other agonists, antagonists, and/or synergists.

Limitations

There are limitations in this study that affect the results. To our knowledge, there is no concurrently calculated GTA index and L/G ratio of the trunk for the selected high-loaded core stabilization exercises. Because of the lack of evidence, it is difficult to compare some findings of this study regarding the GTA index in the mentioned exercises with those of the existing literature. Also, because all the exercises tested in this study and previous studies are not the same, the ranking order of GTA could not be compared with another study. Although EMG data are widely accepted, the data may be affected by cross talk from adjacent muscles. Moreover, in this study, the data were gathered from exercises performed only by healthy individuals with no history of musculoskeletal pain. In this way, we cannot generalize findings to the patient with back or any musculoskeletal pain. Also, because the device used in this study was an 8-channel EMG system, the activation of the superficial abdominal muscles was not gathered.

CONCLUSION

Presently, the highest GTA index was observed during the side bridge exercise lifting the dominant leg and the hand-knee exercise with dominant leg horizontally lifted while L/G ratio was greatest during all back bridge exercises. Collectively, these findings suggest that back bridge exercises could strength the MF and side bridges could be used to activating the gluteal muscles over TFL.

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REFERENCES

1. Beretta Piccoli M, Rainoldi A, Heitz C, et al. Innervation zone locations in 43 superficial muscles: toward a standardization of electrode positioning. *Muscle Nerve*. 2014;49:413-421.
2. Bishop BN, Greenstein J, Etnoyer-Slaski JL, Sterling H, Topp R. Electromyographic analysis of gluteus maximus, gluteus medius, and tensor fascia latae during therapeutic exercises with and without elastic resistance. *Int J Sports Phys Ther*. 2018;13:668-675.
3. Boren K, Conrey C, Le Coguic J, Paprocki L, Voight M, Robinson TK. Electromyographic analysis of gluteus medius and gluteus maximus during rehabilitation exercises. *Int J Sports Phys Ther*. 2011;6:206-223.
4. Buckthorpe M, Stride M, Villa FD. Assessing and treating gluteus maximus weakness—a clinical commentary. *Int J Sports Phys Ther*. 2019;14:655-669.
5. Cooper NA, Scavo KM, Strickland KJ, et al. Prevalence of gluteus medius weakness in people with chronic low back pain compared to healthy controls. *Eur Spine J*. 2016;25:1258-1265.
6. Danneels LA, Coorevits PL, Cools AM, et al. Differences in electromyographic activity in the multifidus muscle and the iliocostalis lumborum between healthy subjects and patients with sub-acute and chronic low back pain. *Eur Spine J*. 2002;11:13-19.
7. Danneels LA, Vanderstraeten GG, Cambier DC, Witvrouw EE, Stevens VK, De Cuyper HJ. A functional subdivision of hip, abdominal, and back muscles during asymmetric lifting. *Spine*. 2001;26:114-121.
8. Distefano LJ, Blackburn JT, Marshall SW, Padua DA. Gluteal muscle activation during common therapeutic exercises. *J Orthop Sports Phys Ther*. 2009;39:532-540.
9. Ekstrom RA, Donatelli RA, Carp KC. Electromyographic analysis of core trunk, hip, and thigh muscles during 9 rehabilitation exercises. *J Orthop Sports Phys Ther*. 2007;37:754-762.
10. Ekstrom RA, Osborn RW, Hauer PL. Surface electromyographic analysis of the low back muscles during rehabilitation exercises. *J Orthop Sports Phys Ther*. 2008;38:736-745.
11. Escamilla RF, Lewis C, Bell D, et al. Core muscle activation during Swiss ball and traditional abdominal exercises. *J Orthop Sports Phys Ther*. 2010;40:265-276.

12. Hodges PW, Gandevia SC. Activation of the human diaphragm during a repetitive postural task. *J Physiol.* 2000;522:165-175.
13. Hodges PW, Richardson CA. Contraction of the abdominal muscles associated with movement of the lower limb. *Phys Ther.* 1997;77:132-142.
14. Hojat M, Shapurian R, Mehryar AH. Psychometric properties of a Persian version of the short form of the Beck Depression Inventory for Iranian college students. *Psychol Rep.* 1986;59:331-338.
15. Kankaanpää M, Taimela S, Laaksonen D, Hänninen O, Airaksinen O. Back and hip extensor fatigability in chronic low back pain patients and controls. *Arch Phys Med Rehabil.* 1998;79:412-417.
16. Leetun DT, Ireland ML, Willson JD, Ballantyne BT, Davis IM. Core stability measures as risk factors for lower extremity injury in athletes. *Med Sci Sports Exerc.* 2004;36:926-934.
17. Lehecka B, Edwards M, Haverkamp R, et al. Building a better gluteal bridge: electromyographic analysis of hip muscle activity during modified single-leg bridges. *Int J Sports Phys Ther.* 2017;12:543-549.
18. Marshall PW, Murphy BA. Core stability exercises on and off a Swiss ball. *Arch Phys Med Rehabil.* 2005;86:242-249.
19. Moseley GL, Hodges PW, Gandevia SC. Deep and superficial fibers of the lumbar multifidus muscle are differentially active during voluntary arm movements. *Spine (Phila Pa 1976).* 2002;27:E29-E36.
20. Newton RU, Murphy AJ, Humphries BJ, Wilson GJ, Kraemer WJ, Häkkinen K. Influence of load and stretch shortening cycle on the kinematics, kinetics and muscle activation that occurs during explosive upper-body movements. *Eur J Appl Physiol Occup Physiol.* 1997;75:333-342.
21. Ng JK, Richardson CA, Kippers V, Parnianpour M. Relationship between muscle fiber composition and functional capacity of back muscles in healthy subjects and patients with back pain. *J Orthop Sports Phys Ther.* 1998;27:389-402.
22. Okubo Y, Kaneoka K, Imai A, et al. Electromyographic analysis of transversus abdominis and lumbar multifidus using wire electrodes during lumbar stabilization exercises. *J Orthop Sports Phys Ther.* 2010;40:743-750.
23. O'Sullivan PB, Phyty GDM, Twomey LT, Allison GT. Evaluation of specific stabilizing exercise in the treatment of chronic low back pain with radiologic diagnosis of spondylolysis or spondylolisthesis. *Spine (Phila Pa 1976).* 1997;22:2959-2967.
24. O'Sullivan PB, Twomey L, Allison GT. Altered abdominal muscle recruitment in patients with chronic back pain following a specific exercise intervention. *J Orthop Sports Phys Ther.* 1998;27:114-124.
25. Page P, Frank C, Lardner R. Assessment and treatment of muscle imbalance: the Janda approach. *J Orthop Sports Phys Ther.* 2011;41:799-800.
26. Panjabi M, Abumi K, Duranceau J, Oxland T. Spinal stability and intersegmental muscle forces. A biomechanical model. *Spine (Phila Pa 1976).* 1989;14:194-200.
27. Panjabi MM. The stabilizing system of the spine. Part I. Function, dysfunction, adaptation, and enhancement. *J Spinal Disord.* 1992;5:383-389.
28. Parr M, Price PD, Cleather DJ. Effect of a gluteal activation warm-up on explosive exercise performance. *BMJ Open Sport Exerc Med.* 2017;3(1):000245.
29. Reiman MP, Bolgla LA, Loudon JK. A literature review of studies evaluating gluteus maximus and gluteus medius activation during rehabilitation exercises. *Physiother Theory Pract.* 2012;28:257-268.
30. Richardson C, Jull G, Hides J, Hodges P. *Therapeutic Exercise for Spinal Segmental Stabilization in Low Back Pain*. Churchill Livingstone; 1999.
31. Schamberger W. *The Malalignment Syndrome: Implications for Medicine and Sport*. Elsevier Health Sciences; 2012.
32. Selkowitz DM, Beneck GJ, Powers CM. Which exercises target the gluteal muscles while minimizing activation of the tensor fascia lata? Electromyographic assessment using fine-wire electrodes. *J Orthop Sports Phys Ther.* 2013;43:54-64.
33. Smith CE, Nyland J, Caudill P, Brosky J, Caborn DN. Dynamic trunk stabilization: a conceptual back injury prevention program for volleyball athletes. *J Orthop Sports Phys Ther.* 2008;38:703-720.
34. Stevens VK, Bouche KG, Mahieu NN, Coorevits PL, Vanderstraeten GG, Danneels LA. Trunk muscle activity in healthy subjects during bridging stabilization exercises. *BMC Musculoskelet Disord.* 20 2006;7:75.
35. Urquhart DM, Hodges PW, Allen TJ, Story IH. Abdominal muscle recruitment during a range of voluntary exercises. *Man Ther.* 2005;10:144-153.
36. Van Damme B, Stevens V, Perneel C, et al. A surface electromyography based objective method to identify patients with nonspecific chronic low back pain, presenting a flexion related movement control impairment. *J Electromyogr Kinesiol.* 2014;24:954-964.
37. Van Damme BBL, Stevens VK, Van Tiggelen DE, Duvigneaud NNP, Neyens E, Danneels LA. Velocity of isokinetic trunk exercises influences back muscle recruitment patterns in healthy subjects. *J Electromyogr Kinesiol.* 2013;23:378-386.
38. van Dieën JH, Cholewicki J, Radebold A. Trunk muscle recruitment patterns in patients with low back pain enhance the stability of the lumbar spine. *Spine (Phila Pa 1976).* 2003;28:834-841.
39. Ward SR, Kim CW, Eng CM, et al. Architectural analysis and intraoperative measurements demonstrate the unique design of the multifidus muscle for lumbar spine stability. *J Bone Joint Surg Am.* 2009;91:176-185.
40. Ward SR, Tomiya A, Regev GJ, et al. Passive mechanical properties of the lumbar multifidus muscle support its role as a stabilizer. *J Biomech.* 2009;42:1384-1389.
41. Willson JD, Dougherty CP, Ireland ML, Davis IM. Core stability and its relationship to lower extremity function and injury. *J Am Acad Orthop Surg.* 2005;13:316-325.
42. Yoo WG. Effects of individual strengthening exercises on subdivisions of the gluteus medius in a patient with sacroiliac joint pain. *J Phys Ther Sci.* 2014;26:1501-1502.
43. Yu J-H, Lee G-C. Effect of core stability training using pilates on lower extremity muscle strength and postural stability in healthy subjects. *Isokinet Exerc Sci.* 2012;20:141-146.