Comparison of Gluteus Medius Muscle Electromyographic Activity During Forward and Lateral Step-up Exercises in Older Adults

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Background. Step-up exercises often are suggested for strengthening the hip abductor muscles and improving balance in older adults. Little is known, however, about whether the forward or lateral version of these exercises is best for activating the hip abductor muscles.

Objective. The purpose of this study was to examine the electromyographic (EMG) amplitude of the gluteus medius (GM) muscles bilaterally during forward and lateral step-up exercises.

Design. The study design involved single-occasion repeated measures.

Methods. Twenty-seven community-dwelling adults (7 men and 20 women) with a mean (SD) age of 79.4 (8.0) years performed forward and lateral step-up exercises while the surface EMG activity of the GM muscles was recorded bilaterally. Pressure switches and dual forceplates were used to identify the ascent and descent phases. Subjects were instructed to lead with the right lower extremity during ascent and the left lower extremity during descent. Differences in normalized root-mean-square EMG amplitudes with exercise direction (forward versus lateral) and phase (ascent versus descent) were examined by use of separate repeated-measures analyses of variance for the right and left lower extremities. The alpha level was set at .05.

Results. Gluteus medius muscle EMG activity was significantly greater for lateral than for forward step-up exercises for the left lower extremity during the ascent phase and for both lower extremities during the descent phase. In addition, right GM muscle EMG activity was significantly greater during ascent than during descent for both exercise directions.

Limitations. Study limitations include use of a convenience sample and collection of limited information about participants.

Conclusions. Step-up exercises are effective in activating the GM muscle, with lateral step-up exercises requiring greater GM muscle activation than forward step-up exercises. Further study is needed to determine whether exercise programs for hip abductor muscle strengthening in older adults should preferentially include lateral over forward step-up exercises.
Compared with younger adults, older adults have greater difficulty maintaining and recovering postural stability, particularly in the frontal plane. One likely cause of this difficulty is weakness of the hip abductor muscles and other muscles that control frontal-plane or “lateral” stability. Step-up exercises have been suggested for strengthening the hip abductor muscles and improving balance in older adults. Step-up exercises often are incorporated into health promotion and fall prevention programs delivered in community contexts. The benefits of multidisciplinary, community-based fall prevention programs are well documented, both for unselected populations of older people and for those selected because they have reported concerns about their balance abilities or have a history of falling or other known risk factors. Interventions that include strengthening and balance exercises can be effective for fall prevention whether delivered in a group format or as part of an individually prescribed home exercise program.

As noted by Wang et al., step-up exercises may be especially appropriate for older adults because they involve movement patterns similar to those of daily functional activities, such as climbing stairs or negotiating curbs; they can be performed safely in a variety of settings, including the home; and they can be modified for different levels of ability simply by varying the step height. Step-up exercises may be more feasible when performed with a step-bench instead of a flight of stairs because many older adults do not have stairs in their homes. The step-bench can be placed in front of the individual for forward step-up exercises or to the side for lateral step-up exercises.

Sims and Brauer demonstrated that forward step-up exercises challenge lateral stability. In a comparison of forward step-up exercises, walking, and chair sit-stand-sit activities in older adults who were sedentary, Wang and colleagues reported that the forward step-up exercises generated the greatest overall dynamic hip moments. In addition, the hip moments generated during the forward step-up exercises were strongly correlated with hip bone mass in women but not in men in that study. Hip abduction moments explained up to 88% of the variance in bone mineral content and bone mineral density at the femoral neck and proximal femur in women.

Unfortunately, little is known about whether the forward or the lateral step-up exercise is the preferred exercise for activating the hip abductor muscle groups in older adults. Wang and colleagues used an inverse dynamics approach to determine peak net joint moments at the hip, knee, and ankle during forward and lateral step-up activities. These researchers concluded that frontal-plane hip moments were similar for the 2 step-up directions. No previous researchers, however, made direct comparisons of the exercises in terms of gluteus medius (GM) muscle activation.

The purpose of this study was to examine the electromyographic (EMG) amplitude of the GM muscles bilaterally during forward and lateral step-up exercises. We hypothesized that GM muscle EMG amplitudes would be greater during lateral than during forward step-up exercises because of the greater movement of the center of mass in the frontal plane during lateral step-up exercises. We also hypothesized that for both exercises, GM muscle EMG amplitudes would be greater during the ascent phase than during the descent phase because ascent involves more concentric muscle contraction, which has been associated with higher levels of EMG activity.

**Method**

**Participants**

Participants in the study were 28 community-dwelling older adults. The study was powered by the ability to detect a 10% difference in mean EMG amplitudes between lateral and forward step-ups. On the basis of data from previous studies, an estimated sample size of 27 was needed to provide a power of .80 at an alpha level of .05.

Participants were recruited through a mass e-mail at the University of North Carolina at Chapel Hill (UNC-CH) campus, presentations at senior centers and continuing care retirement communities, and posting of flyers. Potential participants were screened by telephone interview. Inclusion criteria were an age of 65 years or older, the ability to read and speak English, the ability to ambulate independently in the community (including up and down curbs), the ability to follow instructions and perform all experimental procedures, normal or corrected-to-normal vision and hearing (by self-report), and a reported preference for using the right lower extremity for skilled movement (in response to the question, “Which foot would you use to kick a ball?”). Volunteers were excluded if they had a diagnosed neurological disease or disorder (eg, stroke, Parkinson disease), pain when ascending or descending curbs or stairs (by self-report), acute back or
lower-extremity musculoskeletal problems (eg, strain, sprain, fracture), or medical conditions that might make step-up exercises unsafe (eg, unstable angina, myocardial infarction within the preceding 6 months, congestive heart failure within the preceding 12 months, unstable chronic obstructive disease requiring 2 or more hospitalizations within the preceding 12 months, uncontrolled hypertension, uncontrolled diabetes mellitus).

Thirty-nine people volunteered for the study and completed the telephone screening. The 28 volunteers who remained eligible for the study after the telephone screening were scheduled for a single testing session at the Center for Human Movement Science at UNC-CH. Written informed consent was obtained at the start of the laboratory test session with forms and procedures approved by the UNC-CH Biomedical Institutional Review Board. Each participant’s ability to perform the exercises with appropriate sequencing and timing was determined by asking him or her to complete 3 or 4 practice attempts for each exercise. One participant was unable to perform the exercises without assistance and, therefore, was excluded from further participation in the study. The characteristics of the remaining 27 participants are shown in Table 1.

**Data Collection**

**EMG set-up.** Each participant’s height and weight were measured and recorded. A 16-channel telemeter EMG system* was used to record GM muscle activity bilaterally. The skin over the posterolateral gluteal region was cleansed with alcohol. Active surface electrodes (Neuroline; pregelled, silver-silver chloride, bipolar disposable electrodes) were attached to the skin over the GM muscle belly 2 to 3 cm distal to the midpoint of the iliac crest. The electrodes were configured parallel to the GM muscle fibers. Each electrode surface was 15 mm in diameter, and the interelectrode distance, from center to center, was 20 mm. A common reference electrode was placed on the skin overlying the anteromedial aspect of the proximal right tibia. Electrode placements were verified by manual muscle testing techniques to minimize cross talk. Wires from the electrodes were connected to a small transmitter that was carried on the participant’s back. The differential amplifier of the EMG system had an input impedance of greater than 1.0 MΩ, a common-mode rejection ratio of greater than 90 dB, and a signal-to-noise ratio of greater than 50 dB. The raw analog signals were band-pass filtered from 10 to 1,000 Hz before output to a 16-bit analog-to-digital converter. The signals were sampled at 1,000 Hz per channel and recorded with Peak Motus software.§

**Participant Characteristics**

| Characteristic | No. (%) | X (SD) | Range |
|----------------|---------|--------|-------|
| Age, y         |         | 79.4 (8.0) | 65–97 |
| Sex            |         |         |       |
| Women          | 20 (74) |         |       |
| Men            | 7 (26)  |         |       |
| Weight (kg)    |         | 68.7 (13.7) | 49.9-97.5 |
| Height (cm)    |         | 166.9 (9.5) | 149.9-188.0 |

**EMG normalization.** Because of the repeated-measures design of the study, with contrasts being made on the same day and on the same muscle without removal of the electrodes, normalization of the EMG data was not required. Nevertheless, we chose to normalize the data to allow comparisons with similar data from other studies and to provide a basis for interpretation of the relative amount of muscle activation. For the normalization procedure, participants were asked to lie on one side on a padded high-low table. The participant raised the upper lower extremity so that the extremity was level with the lateral aspect of the trunk and the hip joint was in approximately 0 degrees of abduction; this position was maintained against gravity for 8 seconds while GM muscle EMG activity for that extremity was recorded. The knee joint was extended, and the hip joint was maintained in a neutral position with respect to flexion/extension and medial (internal) rotation/lateral (external) rotation during the normalizing muscle contraction. This procedure was repeated with the other lower extremity. Submaximal muscle contractions similar to the normalizing muscle contraction are considered by some authors to be more reliable and accurate as a means of normalization than maximal muscle contractions. The repeated-measures design of the study, with contrasts being made on the same day and on the same muscle without removal of the electrodes, normalization of the EMG data was not required. Nevertheless, we chose to normalize the data to allow comparisons with similar data from other studies and to provide a basis for interpretation of the relative amount of muscle activation. For the normalization procedure, participants were asked to lie on one side on a padded high-low table. The participant raised the upper lower extremity so that the extremity was level with the lateral aspect of the trunk and the hip joint was in approximately 0 degrees of abduction; this position was maintained against gravity for 8 seconds while GM muscle EMG activity for that extremity was recorded. The knee joint was extended, and the hip joint was maintained in a neutral position with respect to flexion/extension and medial (internal) rotation/lateral (external) rotation during the normalizing muscle contraction. This procedure was repeated with the other lower extremity. Submaximal muscle contractions similar to the normalizing muscle contraction are considered by some authors to be more reliable and accurate as a means of normalization than maximal muscle contractions.**

**Step-up exercises.** A step measuring 90 cm wide, 21.5 cm high, and...
29.5 cm deep was used for the step-up exercises. The order of performance of the exercises (forward versus lateral) was randomized. For both exercises, the participant stood on separate side-by-side forceplates embedded in the floor. Each of the 2 forceplates measured 40 cm (in the medial-lateral direction) by 60 cm (in the anterior-posterior direction), with combined forceplate dimensions of 80 by 60 cm. The participant stood at the juncture of the 2 forceplates, with 1 foot on each forceplate. The participant stepped up onto the step (which was not in contact with the forceplates) with the right foot leading and then stepped back down onto the forceplates with the left foot leading. The participant maintained the same starting position on the forceplates for both exercises, but the step was moved in front of or to the right side of the participant for forward and lateral step-up exercises, respectively. The step was positioned just in front of the forceplates for forward step-ups and straddling the forceplates in an anterior-posterior direction for lateral step-ups. For forward step-ups, participants positioned themselves behind the step at whatever distance was comfortable for them. They could move within the 60-cm anterior-posterior dimension of the forceplates. For lateral step-up exercises, the step was positioned only far enough to the participant’s right side to allow room for the right foot to come down (on the right forceplate) and the left foot to come down (on the left forceplate) at a normal stance width. The forceplates were used to record ground reaction forces under each foot separately, and pressure switches secured to the step were used to record the contact of each foot with the step.

For each exercise, the researchers demonstrated the required movements, and participants practiced until they reported being comfortable with the exercise. Participants were instructed to lead with the right lower extremity during ascent and the left lower extremity during descent for both exercises. A metronome set at 66 beats per minute was used to pace the participants’ movements, with movement of 1 foot per beat (right foot up, left foot up, left foot down, right foot down). Participants performed 3 sets of 8 repetitions for each exercise, with rest periods of approximately 2 minutes between sets and 5 minutes between exercises. One additional set of 8 repetitions was performed if a participant stepped with the wrong sequence or experienced a visible loss of balance requiring assistance from a spotter. Forceplate and pressure-switch signals were sampled along with the raw EMG signals at 1,000 Hz.

Data Reduction

Data were exported from Peak Motus software and imported to DATA-PAC 2K2 software for reduction. Pressure-switch and vertical ground reaction force data were used to identify the beginning and end of each movement component (Fig. 1). The ascent phase was defined as the time from right foot contact with the floor (forceplate) to left foot contact with the step (pressure switch). The descent phase was defined as the time from left foot contact with the step to right foot contact with the floor. From the 24 steps (3 sets × 8 repetitions per set = 24) of each exercise performed by each participant, 6 to 12 steps were selected for

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**Figure 1.**
Representative data for a single participant performing lateral step-up exercises. Traces from top to bottom are as follows: pressure-switch data indicating contact of the right (R) foot with the step; pressure-switch data indicating contact of the left (L) foot with the step; vertical ground reaction forces under the right foot (Fz1), indicating contact of the right foot with the floor; vertical ground reaction forces under the left foot (Fz2), indicating contact of the left foot with the floor; raw electromyographic (EMG) data from the right gluteus medius (RGM) muscle; and raw EMG data from the left gluteus medius (LGM) muscle. The dashed vertical lines indicate a single step-up, including the ascent phase (from A to B) and the descent phase (from B to C).
The middle 4 of the 8 steps in each set were selected, unless participant foot placement or movement artifacts reduced the clarity of the force platform, pressure-switch, or EMG signals. In these situations, the step(s) closest in time to the deleted step(s) was (were) selected. The mean (SD) numbers of steps included in the analysis per participant were 10.0 (2.2) steps for forward step-up exercises and 9.9 (2.4) steps for lateral step-up exercises. The durations of the ascent and descent phases of each step were determined.

The EMG signals recorded for the left and right GM muscles during step-up exercises and during the standard submaximal contraction were smoothed by use of a root-mean-square (RMS) envelope with a time constant of 30 milliseconds. The RMS EMG amplitudes of the left and right GM muscles were then calculated for the ascent and descent phases of each step as well as for the middle 5 seconds of the 8-second standard submaximal contraction. The mean RMS values for the forward and lateral step-up trials for each participant were normalized by dividing them by the RMS values obtained for that participant during the submaximal contraction of the respective GM muscle (left or right). Consequently, the EMG amplitude was expressed as a percentage of the standard submaximal contraction for each muscle.

**Data Analysis**

Statistical analyses were completed with SYSTAT** version 5.0 software. Descriptive statistics were calculated for phase durations and RMS EMG values for the right and left GM muscles. Because many fewer men (n=7) than women (n=20) participated in this study, we examined the data for any obvious differences in GM muscle activation between these 2 groups. We calculated the means for each EMG measure by sex and determined the rank ordering of these means.

An intraclass correlation coefficient (ICC [3,6])\(^25\) and the standard error of measurement (SEM)\(^24\) were used to examine the within-subject reliability of the EMG amplitudes. The form of the ICC used in this analysis (ICC [3,k]) is appropriate because of the need to determine the within-subject reliability of the EMG data for this particular study only (ICC model 3) and the use of a mean of 6 to 12 steps for each participant for each EMG measure (form k, in which the designation of k equals the number of values used to obtain the mean).\(^23\,24\) Because data for at least 6 steps were available for all participants, the ICC (3,6) was used. The ICC (3,6) calculation was based on the first 6 (of up to 12) steps of each exercise selected for each participant. The SEM was estimated by multiplying the standard deviation of the EMG amplitudes for each exercise by the square root of 1 minus the ICC (3,6).\(^24\)

To compare EMG amplitudes by exercise direction and phase, we entered mean normalized RMS EMG values for each participant into a \(2 \times 2\) (step-up direction × phase) repeated-measures analysis of variance (ANOVA). Separate ANOVAs were performed for the right and left GM muscles. The level of significance was set at an α value of .05.

**Results**

Phase durations were similar for ascent and descent for both directions of the step-up exercises (Fig. 2). This timing is consistent with the metronome pacing which, if followed precisely, would have produced step-ups lasting 3,600 milliseconds, with ascent and descent phases of 1,800 milliseconds each.

The ICC (3,6) and SEM values for the EMG amplitudes are shown in...
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Table 2.
Repeatability of Measurements of Gluteus Medius (GM) Muscle Electromyographic (EMG) Amplitudes

| Exercise (Phase)          | EMG Amplitude of: | Left GM Muscle | Right GM Muscle |
|---------------------------|-------------------|----------------|----------------|
|                           | ICC (3,6) | SEM | ICC (3,6) | SEM |
| Forward step-up (ascent)  | .96      | 14.12 | .97      | 11.13 |
| Forward step-up (descent) | .99      | 7.81  | .98      | 6.79  |
| Lateral step-up (ascent)  | .99      | 7.80  | .99      | 7.62  |
| Lateral step-up (descent) | .99      | 7.75  | .97      | 8.56  |

*ICC = intraclass correlation coefficient, SEM = standard error of measurement, expressed as a percentage of the standard submaximal contraction.

Table 2. The ICC (3,6) values ranged from .96 to .99 for the forward step-up exercises and from .97 to .99 for the lateral step-up exercises. The SEM was less than 15% for all EMG variables and was particularly low (<7%) for the right GM muscle during the descent phase of the forward step-up exercises and both phases of the lateral step-up exercises.

The results of the ANOVAs for EMG amplitudes generally supported our hypotheses that the values would be greater for lateral than for forward step-up exercises and greater for the ascent phase than for the descent phase. Because the normalization procedure involved dividing the RMS EMG values by a muscle-specific constant (the normalization value) for each participant, the results of the ANOVAs were the same for nonnormalized and normalized EMG values. Only the results obtained with the normalized data are presented.

For the right GM muscle, the mean (SD) EMG amplitudes ranged from 108.0% (43.8%) to 157.7% (64.4%) of the standard submaximal contraction (Tab. 3). A significant interaction effect ($F_{1,26}=9.65, P=.005$) was found. Tests of simple main effects revealed that normalized right GM muscle EMG amplitudes were greater for lateral than for forward step-up exercises, but only during the descent phase ($F_{1,26}=9.81, P=.003$). Normalized right GM muscle EMG amplitudes were greater during the ascent phase than during the descent phase for both directions of step-up exercises ($F_{1,52}=37.56$ for lateral step-ups; $P<.001$).

For the left GM muscle, the mean (SD) EMG amplitudes ranged from 128.9% (82.3%) to 147.0% (71.2%) of the standard submaximal muscle contraction (Tab. 3). A main effect of exercise direction was found ($F_{1,26}=7.59, P=.011$), but the main effect of phase and the interaction between phase and step-up direction were not statistically significant. Muscle activation was greater during lateral step-ups than during forward step-ups for both exercise phases.

Although the mean EMG amplitudes appeared to be lower for men than for women by visual inspection, the rank ordering of the means for each combination of exercise direction and phase was the same for both sexes for the right and left GM muscles. For the right GM muscle, the mean (SD) EMG amplitudes were lowest during the descent phase of the forward step-up exercise, measuring 88.0% (42.1%) in men and 115.1% (43.2%) in women, and highest during the ascent phase of the lateral step-up exercise, measuring 141.3% (68.7%) in men and 163.4% (65.6%) in women. For the left GM muscle, the mean (SD) EMG amplitudes ranged from lows of 89.3% (32.8%) in men and 142.7% (90.3%) in women during the descent phase of forward step-ups to highs of 121.3% (31.8%) in men and 156.0% (79.3%) in women during the ascent phase of lateral step-ups.

Table 3.
Normalized Root-Mean-Square (RMS) Electromyographic (EMG) Amplitudes of Gluteus Medius (GM) Muscles During Step-up Exercises

| Exercise (Phase) | $\bar{X}$ (SD) RMS EMG Amplitude of: |
|------------------|-------------------------------------|
|                  | Left GM Muscle | Right GM Muscle |
| Forward step-up (ascent) | 131.4 (68.9) | 154.6 (65.4) |
| Forward step-up (descent) | 128.9 (82.3) | 108.0 (43.8) |
| Lateral step-up (ascent) | 147.0 (71.2) | 157.7 (64.4) |
| Lateral step-up (descent) | 138.3 (77.5) | 123.3 (53.1) |

Discussion

In the present study, we found greater GM muscle activity during lateral than during forward step-up exercises in older adults. The ICC (3,6) values indicated that our participants had relatively consistent levels of GM muscle activation across repetitions of step-up exercises. These results have implications for exercise recommendations, as the torque-generating capabilities of the GM muscles appear to be critical for the maintenance and recovery of balance under a variety of circumstances.25,26 Several researchers have suggested that the hip abductor muscles should be critical targets for assessment and, if indicated, resistance
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strength (force-generating capacity) training in older adults. Physical therapists may prescribe step-up exercises for hip abductor muscle strengthening in a variety of contexts, ranging from the development of individualized exercise programs for people with known balance difficulties to the design of community-based fall prevention programs.

The amount of GM muscle activation displayed by our participants varied from approximately 108% to 158% of that required to hold the limb against gravity in a side-lying position. The external torque applied during this normalizing muscle contraction was relatively large, equaling the gravitational force of the lower extremity (approximately 16% of body mass) times the external moment arm, which is appreciably longer in a side-lying position than in a standing position. In a study of young adults who were healthy, Bolga and Uhl reported right GM muscle EMG amplitudes for exercises involving right hip abduction during side lying and abduction of the left hip during standing on the right lower extremity. These exercises were performed with an ankle cuff weight equal to 3% of the body mass on the moving limb and produced mean (SD) EMG activity levels ranging from 42% (23%) to 46% (34%) of the maximum voluntary isometric contraction (MVIC).

In a study of 30 subjects ranging in age from 19 to 58 years, Ekstrom et al reported mean (SD) GM muscle EMG activity levels of 39% (17%) of the MVIC for active hip abduction during side lying and 43% (18%) of the MVIC for lateral step-up exercises. The GM muscle EMG signal amplitudes reported for these hip abduction exercises in young and middle-aged adults approached 45% of the MVIC, a level that has been suggested to represent a sufficient stimulus for strength gains in some people.

Because the level of maximum muscle strength is lower in older adults than in younger adults, older adults must use a larger percentage of their neuromuscular capacity for daily tasks. This fact was shown specifically for the GM muscle in a study by Hahn et al, in which older adults displayed normalized EMG activation percentages that were approximately twice those of younger adults for level walking and for obstacle negotiation at most obstacle heights tested. This fact makes it likely that the GM muscle is activated at proportionally higher levels in older adults than in younger adults during both weight-bearing and non-weight-bearing hip abductor muscle exercises. Depending on their initial strength level, some older adults may need to add ankle cuff weights or similar resistance during hip abductor muscle exercises to obtain a strengthening response. For symmetrical strengthening, logic would dictate that step-up exercises be performed on both sides instead of only on the right, as in the present study.

In both forward and lateral step-up exercises, the GM muscles either moved or stabilized the hip and pelvis in the frontal plane during the performance of each movement phase. Activation of the GM muscle on the side of the lower extremity that is to be lifted from the support surface has been shown to contribute to the acceleration of the body’s center of mass toward the upcoming stance limb. Subsequent activation of the GM muscle on the side of the stance limb helps to control the extent of this lateral weight shift and, especially if the leading limb is being placed on a step or other higher level, to elevate the pelvis on the swing side. Because of the greater frontal-plane movement associated with lateral than with forward step-up exercises, we expected greater GM muscle activation in lateral step-up exercises; our results were consistent with this expectation.

The significant interaction observed between step-up direction and phase for the right GM muscle in the present study may be explained by the different biomechanical demands placed on the 2 lower extremities during the ascent and descent phases. We offer the following as a possible explanation of this interaction effect, although we do not have kinematic data to support it. Much of the control of lateral displacement of the center of mass may be accomplished by the left GM muscle during ascent. The right GM muscle may play a similar role during ascent in both exercise directions by helping to control pelvic position as the center of mass moves upward and over the right foot. During descent, however, unilateral stance is maintained on the right lower extremity as the left foot is lowered to the floor.

Because of the more lateral placement of the left foot during lateral than during forward step-up exercises, the right GM muscle theoretically must generate a larger internal torque to counterbalance the mass of the head, arms, trunk, and more abducted left lower extremity and to assist with the greater lateral displacement of the body’s center of mass.

We suggest that internal frontal-plane hip moments may be greater in lateral than in forward step-up exercises because of the greater lateral excursion of the center of mass during the former exercise. Our finding of greater GM muscle activity during lateral step-up exercises is consistent with this suggestion. In a direct comparison of forward and lateral step-up exercises, however, Wang et al reported that peak net hip moments in the frontal plane did not
differ between step-up conditions or movement phases. A possible explanation for these conflicting results is that Wang et al\textsuperscript{14} allowed subjects to use upper-extremity support from a “safety bar,” which was monitored for vertical but not lateral forces and which may have limited the requirements for frontal-plane stabilization. Another possibility is that subjects in that study were stepping closer to the step during lateral step-up exercises, as subject foot placement was not constrained by the size of the forceplates, as in the present study. In addition, subjects in the study of Wang et al\textsuperscript{14} were instructed not to push off with the trailing leg during ascent, whereas subjects in the present study were not given specific instructions about movement strategies. Wang et al\textsuperscript{14} did not consider exercise speed, number of repetitions to be performed, or coactivation of antagonist muscle groups in their investigation.

Right GM muscle EMG amplitudes were greater overall during ascent than during descent. This finding is consistent with our expectation of greater concentric GM muscle activity during ascent\textsuperscript{14} and with previous reports of greater EMG amplitudes during concentric than during eccentric muscle contractions.\textsuperscript{44–46} However, it is important to recognize that the relationship between EMG activity and muscle force is not linear.\textsuperscript{44} This relationship is affected by factors such as muscle length, recruitment patterns, and rate of contraction. Consequently, comparisons of normalized EMG activity across types of contraction should be interpreted with caution.\textsuperscript{46} The elastic properties of the right GM muscle may have contributed to the torque generated during descent and may have decreased the amount of EMG activity required.\textsuperscript{47,48}

The present study had several limitations. We used a sample of convenience and did not collect detailed information about medical history, fall history, physical activity level, or other participant characteristics. We would describe our participants as healthy, active, independent community dwellers who, admittedly, may have differed in important respects from people likely to seek intervention for balance concerns. Also, our sample included only a small number of male participants. We had no reason to expect that the pattern of results would differ according to sex, however, and our visual inspection of the data confirmed the same rank ordering of the means for both men and women in our sample.

Another methodological limitation was that we did not perform repeat testing of the normalization contraction; therefore, we were unable to measure its test-retest reliability. Although this limitation may affect the interpretation of the absolute muscular effort expressed as a percentage of the standard submaximal contraction, the within-subject design of our study provided a solid basis for comparisons of muscular effort among exercise conditions. Additional methodological considerations were the strategies used by our participants and the environmental constraints that may have affected these strategies. To more closely approximate exercise performance in nonlaboratory settings, we specifically avoided giving subjects instructions about positions or movements to use or not use when performing the exercises. Although we did not observe any deviations in trunk or lower-extremity alignment as our participants performed the exercises, these variables were not measured. On the other hand, the location of the step relative to the 2 forceplates during lateral step-up exercises may have produced lateral steps larger than those that would occur typically in nonlaboratory settings. Differences in strategies for dealing with task demands may have contributed to the between-subject variability observed in GM muscle EMG amplitudes.

Our results indicate that step-up exercises produce bilateral GM muscle activation but do not address the benefits of other exercises or training in other aspects of muscle force generation, such as rate of force development. Other types of training, especially balance training, have been effective in reducing fall risk in older adults.\textsuperscript{49–51} In addition, we did not investigate other muscles (besides the GM muscles) that control frontal-plane motion. Other researchers have reported that activation of the hip adductor muscle\textsuperscript{57,40} and the superior portion of the gluteus maximus muscle,\textsuperscript{52} as well as passive restraint by the iliotibial tract,\textsuperscript{53} may contribute to frontal-plane postural control.

Conclusion

Lateral step-up exercises are associated with greater GM muscle activity than forward step-up exercises in older adults. This result holds true for the trailing extremity during the ascent phase and for both lower extremities during the descent phase. Further study is needed to determine whether exercise programs incorporating lateral step-up exercises are more beneficial for hip abductor muscle strengthening in older adults than programs incorporating forward step-up exercises or other types of exercises.
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