Journal of Athletic Training 2018;53(11):1071–1081
doi: 10.4085/1062-6050-46-16

www.natajournals.org

Hip-Muscle Activity in Men and Women During Resisted Side Stepping With Different Band Positions

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Context: Weakness or decreased activation of the hip abductors and external rotators has been associated with lower extremity injury, especially in females. Resisted side stepping is commonly used to address hip weakness. Whereas multiple variations of this exercise are used clinically, few data exist regarding which variations to select.

Objective: To investigate differences in muscle-activation and movement patterns and determine kinematic and limb-specific differences between men and women during resisted side stepping with 3 resistive-band positions.

Design: Controlled laboratory study.

Setting: Laboratory.

Patients or Other Participants: A total of 22 healthy adults (11 men, 11 women; age = 22.8 ± 3.0 years, height = 171.6 ± 10.7 cm, mass = 68.5 ± 11.8 kg).

Intervention(s): Participants side stepped with the resistive band at 3 locations (knees, ankles, feet).

Main Outcome Measure(s): We collected surface electromyography of the gluteus maximus, gluteus medius, and tensor fascia lata (TFL) for the moving and stance limbs during the concentric and eccentric phases. We also measured trunk inclination, hip and knee flexion, and hip-abduction excursion.

Results: Hip-abductor activity was higher in women than in men ($P \leq .04$). The pattern of TFL activity in the stance limb differed by sex. Women performed the exercise in greater forward trunk inclination ($P = .009$) and had greater hip excursion ($P = .003$). Gluteus maximus and medius activity increased when the band was moved from the knees to the ankles and from the ankles to the feet, whereas TFL activity increased only when the band was moved from the knees to the ankles. Findings were similar for both the stance and moving limbs, but the magnitudes of the changes differed.

Conclusions: Compared with placing the band around the ankles, placing the band around the feet for resisted side stepping elicited more activity in the gluteal muscles without increasing TFL activity. This band placement is most appropriate when the therapeutic goal is to activate the muscles that resist hip adduction and internal rotation.

Key Words: electromyography, gluteus maximus, gluteus medius, hip weakness

Key Points

- Side stepping in the squat position with a resistive band placed around the feet elicited more activity in the gluteal muscles without increasing activity in the tensor fascia lata muscle compared with a resistive band placed around the ankles.
- Band placement around the feet is most appropriate when the therapeutic goal is to focus on muscle activation to resist hip adduction and internal rotation.
- Activation of the gluteus medius and tensor fascia lata muscles was greater in women than in men.
- Trunk inclination, hip-flexion angle, and hip-abduction excursion were greater in women than in men.

Weakness or decreased activation of the hip abductors and external rotators is commonly thought to contribute to lower extremity musculoskeletal injury, particularly in females. Authors of 2 systematic reviews[1,2] found strong evidence of weakness in hip abduction, external rotation, and extension among females with patellofemoral pain (PFP) compared with healthy control participants. In their prospective study, Leetun et al[3] reported that collegiate athletes who sustained lower extremity injuries over a competitive season had weaker hip abductors and external rotators than athletes who did not sustain an injury. Within this sample, the injury rate was higher for female (35%) than for male (22%) athletes.[3] These hip-strength deficits or reduced activation (or both) are thought to contribute to the abnormal movement pattern of increased hip adduction and internal rotation during single-limb tasks noted in individuals with lower extremity musculoskeletal injuries, including PFP[4–6] and acetabular labral tear.[7]

The 2 main muscles implicated in this abnormal movement pattern are the gluteus medius and gluteus maximus. All 3 portions of the gluteus medius act as hip abductors, whereas the posterior portion also acts as an external rotator.[8] Therefore, weakness or reduced activation of the posterior gluteus medius could result in increased hip adduction and internal rotation during a single-legged–stance activity. In addition to being a strong hip extensor, the gluteus maximus contributes to hip external rotation.[8] Whereas strengthening alone may not improve the movement pattern,[9] researchers[10,11] have proposed that exercises targeting the gluteus medius and gluteus maximus can effectively counter the abnormal movement pattern of increased hip adduction and internal rotation during weight-bearing activities.

An exercise often used to target the hip abductors and external rotators is lateral side stepping with an elastic band secured around the lower extremities for resistance. Common variations of resisted side stepping include changing the amount of hip and knee flexion maintained during the exercise[12,13] and altering the anatomic placement of the elastic band around the lower extremities.[11,14,15] A concern with resisted side stepping is that it activates the entire hip-abductor muscle group, which includes the tensor fascia lata (TFL).[8] In addition to being a hip abductor, the TFL produces an internal-rotation torque[16] and, consequently, may exacerbate the abnormal movement pattern of increased hip internal rotation. Therefore, activity levels in the TFL should be considered when comparing variations of exercises targeting the hip abductors.

To our knowledge, authors[14] of only 1 study have examined muscle activity during resisted side stepping with the elastic band placed around different anatomic locations. In a study of male participants, Cambridge et al[14] compared differences in muscle activity during resisted lateral side stepping ("monster walks") using elastic bands in 3 locations: bilateral knees, ankles, and feet. These researchers found that peak gluteus medius activity was approximately 25% higher with the band placed around the ankles or feet than around the knees. They also noted that peak gluteus maximus activity was approximately 40% higher with the band placed around the feet than around the knees. The increase in muscle activity as the band was moved distally from the knees to the ankles can be explained biomechanically by the increase in lever arm. However, when the band was moved from the ankles to the feet, only a small change occurred in the lever arm in the frontal plane. Instead, placing the band around the forefoot can create an internal-rotation moment about the limb, requiring an external-rotation moment to maintain the foot pointing forward. Given that the effect of the rotational torque would be different based on whether the foot is on or off the ground, the differences between the stance and moving limb during the resisted side-stepping exercise need to be understood.

Whereas Cambridge et al[14] concluded that resisted side stepping in a squat posture with the elastic band placed around the feet led to increased gluteus medius activation without a concurrent increase in TFL activation, they studied only male participants and based their conclusions on peak muscle activity throughout the task. Researchers have documented that females use different lower extremity muscle-activation[4,17–19] and movement patterns[4,20–25] than males during a variety of tasks. Therefore, it is important to understand if females perform resisted side stepping with different muscle activations or mechanics than males and if they are affected differently by altering band placement. In addition, the aberrant movement patterns commonly noted in individuals with hip-abductor weakness occur during the eccentric phase of stance, so it is important to investigate muscle activity during each phase of the exercise. Therefore, the primary purpose of our study was to investigate differences in muscle-activation and movement patterns between men and women as they performed resisted side stepping using 3 elastic-band locations. The secondary purpose of our study was to determine the effects of 3 elastic-band locations (around the knees, ankles, or feet) on hip-muscle activation and movement patterns of both the moving and stance limbs during the different phases of resisted side stepping. We hypothesized that (1) women would have greater gluteal-muscle activation than men but would not differ from men in response to band placement or analyzed limb, (2) gluteal-muscle activity would increase as the band was moved more distally, (3) women would have more TFL activation than men, and this difference would be more evident in the stance limb, (4) TFL-muscle activity would increase when the band was moved from the knees to the ankles but would not increase further when the band was moved from the ankles to the feet, and (5) women and men would not differ in the movement patterns used in this constrained task. Determining the differences in muscle activity and movement for each lower extremity while varying band placement during resisted side stepping will provide clinicians with worthwhile information to use when planning exercise programs for individuals with lower extremity musculoskeletal disorders.

METHODS[a]

Design

The dataset in this study overlaps a dataset included in another study,[26] in which we examined the effects of posture and limb (stance versus moving) on muscle activity during resisted side stepping with the band placed around the ankles. Our current study expands on that work. We used a single-session, repeated-measures laboratory-based study design in which all participants performed resisted side stepping with an elastic band positioned around 1 of 3 locations (knees, ankles, or feet) while data were collected for each limb (moving, stance). Given that we were interested in sex-specific differences, this was a mixed-model factorial design with a between-subjects factor (sex) and 2 repeated within-subject factors (band position [3] and analyzed limb [2]).

Participants

Twenty-two healthy college-aged adults, consisting of 11 women (age = 23.0 ± 1.7 years, height = 163.9 ± 7.6 cm, mass = 60.9 ± 7.9 kg) and 11 men (age = 22.6 ± 4.1 years, height = 179.4 ± 8.1 cm, mass = 76.1 ± 10.8 kg), participated in this study. Recruits were between 18 and 50 years of age and reported being healthy. Exclusion criteria were lower extremity or back pain lasting longer than 2 weeks in the year before the study. All participants provided written informed consent, and the study was approved by the Institutional Review Board of Boston University.

Instrumentation

Muscle-activity data were obtained using a surface electromyography (EMG) system (Bagnoli; Delsys Inc,

[a]Portions of the Methods section were adapted with permission from Berry JW, Lee TS, Foley HD, Lewis CL. Resisted side stepping: the effect of posture on hip abductor muscle activation. *J Orthop Sports Phys Ther*. 2015;45(9):675–682.

Natick, MA) with a common mode rejection ratio greater than 100 dB and an input impedance greater than 10^{15} Ω at a sampling rate of 1000 Hz. The surface EMG electrodes were single differential sensors (model DE-2.1; Delsys Inc) with 2 parallel bars 1 cm apart that were each 1-cm long and 1-mm wide. The skin was prepared by scrubbing the area using a cotton ball soaked with rubbing alcohol. Electrodes were placed over the muscle bellies and in line with the muscle-fiber orientation of the gluteus maximus, posterior portion of the gluteus medius, and TFL bilaterally according to guidelines for surface electrode placement.[27] A disposable ground electrode was placed on the posterior elbow over the olecranon process. After electrode placement, muscle activity was visually inspected during volitional gluteal contractions, standing hip internal and external rotation, and hip abduction and during maximal voluntary isometric contraction (MVIC) trials to ensure proper electrode placement.

A 10-camera motion-capture system (Vicon Motion Systems Ltd, Centennial, CO) was used to collect 3-dimensional trunk and lower extremity kinematic data at a sampling rate of 100 Hz. The motion data were synchronized with the EMG data in Vicon Nexus (version 1.8.5; Vicon Motion Systems Ltd). Retroreflective markers were placed bilaterally and secured with tape on the trunk, pelvis, and lower extremities as previously described.[28] Briefly, markers were secured bilaterally with tape over the first and fifth metatarsal heads, calcanei, medial and lateral malleoli, medial and lateral femoral epicondyles, greater trochanter, anterior-superior iliac spines, iliac crests, and acromioclavicular joint. Markers were also placed over the sacrum, spinous process of C7, and sternum. Rigid clusters of 4 markers were placed laterally on each shank and thigh and secured with hook-and-loop fasteners.

Procedures

After testing the placement of the surface EMG electrodes, we collected EMG amplitude during the MVIC trials. Maximal manual resistance was applied to each muscle group using standard manual muscle-testing techniques.[29] Participants were instructed in the procedures and allowed to practice. Next, they performed a single repetition and held the contraction for at least 3 seconds with strong oral encouragement while we monitored the EMG data visually.

After affixing the reflective markers,[28] we collected a static standing trial with the participants in a neutral posture. For this trial, they were instructed to stand upright facing straight forward with their feet positioned shoulder-width apart, upper limbs held out to the sides, and shoulders in approximately 90° of abduction. A model that included joint centers for the knee and hip was created using this trial. The medial ankle and knee markers were removed after the static trial so they would not impair movement.

Participants stood with each foot aligned with the sides of a 12-in (30.48-cm) square floor tile. A resistive band (TheraBand; The Hygenic Corporation, Akron, OH) was wrapped around the lower limbs in 1 of the 3 tested band positions. The band was gently stretched to approximately 110% of full unstretched length and tied. Most participants selected a red (medium) band, and 2 of the stronger participants chose a blue (heavy) band. They were instructed to step laterally with the leading limb to a distance of 1 floor tile (12 in [30.48 cm]) so their feet were 24 in (60.96 cm) apart. Next, they moved the trailing limb so their feet were again 12 in (30.48 cm) apart and aligned with the edges of the floor tile. They repeated this movement until they reached the other side of the laboratory, approximately 8 side steps. After a short rest break, participants side stepped, leading with the opposite limb, and returned to the starting location. Instead of a height-adjusted distance, the stepping distance of 1 tile for all participants was selected for ease of clinical application.

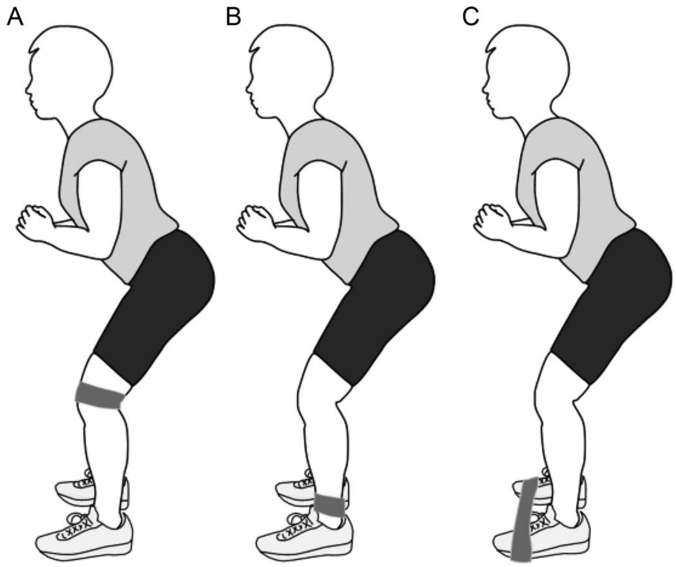

Figure 1. Illustration of band position during resisted side stepping. A, Knees. B, Ankles. C, Feet.

Band Positions

Participants performed side stepping with the resistive band in 1 of 3 positions: around the knees, ankles, or feet (Figure 1). At the knees, the band was placed just proximal to the lateral femoral epicondyles. At the ankles, the band was placed just proximal to the lateral malleoli. On the feet, the band was placed at the level of the metatarsal heads. The order of the tested band positions and initial direction of the side step was randomized.

Data Processing

The raw EMG data were high-pass filtered at 20 Hz to reduce movement artifact[30] and low-pass filtered at 390 Hz to reduce high-frequency noise using a fourth-order Butterworth filter with a zero-phase lag.[31] The filtered data were processed using root mean square smoothing with a moving window of 100 milliseconds. The root mean square data were normalized to the mean amplitude over a 10-millisecond period surrounding the peak amplitude during the MVIC testing.

Marker trajectories were low-pass filtered using a 6-Hz, fourth-order Butterworth filter.[32] Using commercially available software (Visual3D; C-Motion, Inc, Germantown, MD), we calculated the joint kinematics from the marker trajectories using an 8-segment hybrid model. *Knee- and hip-joint angles* were defined as the angle between the distal segment and the proximal segment by using a Cardan

Table 1. Results of the Linear Regression With Generalized Estimating Equation Correction for Each Muscle

Factor	Degrees of Freedom	Muscle											
		Gluteus Maximus				Gluteus Medius				Tensor Fascia Lata			
		Concentric		Eccentric		Concentric		Eccentric		Concentric		Eccentric	
		Wald χ^2	*P* Value	Wald χ^2	*P* Value	Wald χ^2	*P* Value	Wald χ^2	*P* Value	Wald χ^2	*P* Value	Wald χ^2	*P* Value
Sex	1	0.298	.59	1.860	.17	5.483	.02[a]	6.173	.01[a]	4.344	.04[a]	7.076	.008[a]
Analyzed limb	1	42.530	<.001[a]	41.704	<.001[a]	54.868	<.001[a]	49.150	<.001[a]	1.624	.20	0.348	.56
Band position	2	85.432	<.001[a]	38.674	<.001[a]	112.160	<.001[a]	65.009	<.001[a]	127.069	<.001[a]	99.187	<.001[a]
Sex × analyzed limb	1	3.968	.046[a]	0.377	.54	0.250	.62	0.064	.80	1.784	.18	9.768	.002[a]
Sex × band position	2	3.073	.22	3.640	.16	1.492	.47	2.601	.27	1.271	.53	2.259	.32
Analyzed limb × band position	2	17.220	<.001[a]	9.388	.009[a]	11.430	.003[a]	1.280	.53	1.012	.60	10.482	.005[a]
Sex × analyzed limb × band position	2	7.082	.03[a]	2.830	.24	2.772	.25	1.612	.45	0.612	.74	3.339	.19

[a] Difference ($P < .05$).

X-Y-Z (mediolateral, anteroposterior, vertical) rotation sequence.[33] The CODA pelvis model was used to define the pelvis.[34] Trunk-segment angles were determined with respect to the global coordinate system.

Data Reduction

Muscle Activity. For each muscle, we calculated the average of the smoothed normalized EMG amplitude for both the moving and stance limbs from when the moving foot left the ground (foot off) until the same foot contacted the ground again (foot on). *Foot off* and *foot on* were determined as the points where the lateral velocity of the calcaneal marker of the moving limb first exceeded (foot off) or dropped below (foot on) a threshold of 0.02 m/s. These points were verified visually within Visual3D. The movement was further divided into the concentric and eccentric phases. During the concentric phase, the moving limb was the leading limb in the same direction as the side step, and the stance limb was the limb in the opposite direction of stepping. During the eccentric phase, the moving limb was the trailing limb, and the stance limb was the limb in the same direction as the side step. For example, when stepping to the right, concentric-muscle data for both the right and left muscles were calculated from right foot off to right foot on, with the right limb representing the moving limb, and eccentric-muscle data were calculated from left foot off to left foot on, with the left limb representing the moving limb. Approximately 8 steps were used to calculate the average muscle activity for each band position.

Kinematics. We calculated the average trunk inclination and knee- and hip-flexion angles throughout the side-stepping cycle. The *cycle* was defined as foot off to subsequent ipsilateral foot off. These times were the same ones used for the muscle-activity analysis, so the cycle contained both the eccentric and concentric phases of the movement. We also calculated the hip-abduction excursion (maximum abduction angle minus minimum abduction angle) of each limb for each step and an average for each band position. For the hip and knee, we evaluated the leading limb (in the direction of the side step) and the trailing limb (in the opposite direction of the side step) separately.

Statistical Analysis

To determine differences in the activity of each muscle, we used linear regression analysis with 1 between-subjects factor (sex) and 2 within-subject factors: band position (knee, ankle, foot) and analyzed limb (stance versus moving). Given that these were repeated measures within each participant and that each limb was included in the analysis, a generalized estimating equation correction was applied to the model. The generalized estimating equation approach is similar to the more commonly used repeated-measures analysis of variance, but it is more robust and has higher power.[35] For muscle activity, the dependent variables were the average muscle activation of the gluteus maximus, gluteus medius, and TFL. For angles, the dependent variables were the average trunk-inclination, hip-flexion, and knee-flexion angles, as well as the hip-abduction excursion. Separate models were run for each muscle, each type of muscle contraction (concentric, eccentric), and each angle. To reduce the likelihood of obtaining spurious results, we conducted only preplanned analyses. For muscle, we analyzed the main effects for sex, band position, limb, and the following interactions: sex × band position, sex × analyzed limb, band position × analyzed limb, and sex × band position × analyzed limb. These interactions tested if men and women were affected by band position differently and if they used muscles in the stance and moving limbs differently during the different phases of the side-stepping movement. We also assessed if the stance limb was affected by band position differently than the moving limb to investigate the mechanism of the effect. When we observed an interaction effect, we reported the main effects in Tables 1 and 2 but did not interpret them.

For all levels of the model that were different, we conducted preplanned pairwise comparisons using a sequential Bonferroni correction. The sequential Bonferroni correction reduces type I error while being less conservative than the standard Bonferroni correction, which can increase type II error.[36] For interactions involving sex, separate comparisons were conducted for each sex. For interactions between band position and analyzed limb, separate comparisons were conducted for each limb. Means and 95% Wald confidence intervals (CIs) were calculated for group comparisons. Mean differences and CIs of the mean differences were calculated for paired comparisons.

Table 2. Results of the Linear Regression With Generalized Estimating Equation Correction for Each Kinematic Variable

Factor	Degrees of Freedom	Trunk Inclination: Wald χ^2	Trunk Inclination: P Value	Hip Flexion: Wald χ^2	Hip Flexion: P Value	Knee Flexion: Wald χ^2	Knee Flexion: P Value	Hip-Abduction Excursion: Wald χ^2	Hip-Abduction Excursion: P Value
Sex	1	6.852	.009[a]	3.876	.049[a]	0.083	.77	8.693	.003[a]
Analyzed limb	1	NA	NA	5.685	.02[a]	19.993	<.001[a]	72.790	<.001[a]
Band position	2	3.173	.21	11.957	.003[a]	39.110	<.001[a]	50.088	<.001[a]
Sex × analyzed limb	1	NA	NA	0.427	.51	0.008	.93	0.376	.54
Sex × band position	2	2.997	.22	5.930	.052	4.045	.13	0.156	.93
Analyzed limb × band position	2	NA	NA	56.909	<.001[a]	1.280	.53	4.814	.09
Sex × analyzed limb × band position	2	NA	NA	8.620	.01[a]	0.979	.61	0.172	.92

Abbreviation: NA, not applicable.

[a] Difference ($P < .05$).

Effect sizes (ESs) were also computed using Cohen d and the pooled variance across conditions for each muscle. We interpreted the ESs as *small* (0.2), *medium* (0.5), or *large* (0.8).[37] All analyses were conducted using SPSS (version 20; IBM Corp, Armonk, NY) with the α level set at .05.

RESULTS

Muscle Activity

Gluteus Maximus. For the concentric phase of the gluteus maximus, we observed a 3-way interaction among sex, analyzed limb, and band position; therefore, these factors were analyzed separately by sex (Table 1, Figure 2). In both men and women at each band position, activation in the stance limb was greater than activation in the moving limb, and activation increased as the band was moved from the knees to the ankles and then to the feet. In women, we observed main effects of analyzed limb (Wald $\chi^2_1 = 30.4$, $P < .001$) and band position (Wald $\chi^2_2 = 35.0$, $P < .001$) but no interaction between the analyzed limb and band position (Wald $\chi^2_2 = 4.2$, $P = .12$). The activity in the stance limb was 49.0% greater than in the moving limb (mean difference = 7.7%MVIC [95% CI = 5.0%, 10.5%]; $P < .001$, Cohen d = 0.84) and increased as the band was moved from the knees to the ankles and then to the feet. The activity increased by 45.3% when the band was moved from the knees to the ankles (mean difference = 6.3%MVIC [95% CI = 2.8%, 10.0%]; $P = .001$, Cohen d = 0.55) and by only 17.8% when the band was moved from the ankles to the feet (mean difference = 3.6%MVIC [95% CI = 1.6%, 5.6%]; $P < .001$, Cohen d = 0.31). In men, we observed an interaction between the analyzed limb and band position (Wald $\chi^2_2 = 32.9$, $P < .001$). The activity in the stance limb was greater than in the moving limb, and the magnitude of the effect of the band position was different between limbs. In the stance limb, the activity increased by 49.0% when the band was moved from the knees to the ankles (mean difference = 8.4%MVIC [95% CI = 5.7%, 11.1%]; $P < .001$, Cohen d = 0.42) and by 25.3% when the band was moved from the ankles to the feet (mean difference = 6.4%MVIC [95% CI = 3.5%, 9.4%]; $P < .001$, Cohen d = 0.32). In the moving limb, the activity increased by 49.9% when the band was moved from the knees to the ankles (mean difference = 3.1%MVIC [95% CI = 1.9%, 4.4%]; $P < .001$, Cohen d = 0.47) and by 63.7% when the band was moved from the ankles to the feet (mean difference = 6.0%MVIC [95% CI = 3.5%, 8.4%]; $P < .001$, Cohen d = 0.90). Therefore, whereas the increase in muscle activity when the band was moved from the knees to the ankles was similar between limbs, a larger increase occurred when the band was moved from the ankles to the feet in the moving than in the stance limb.

For the eccentric phase, we observed an interaction between the analyzed limb and band position (Table 1, Figure 3). At each band position, the activity in the stance limb was greater than that in the moving limb. However, the change in band position had different magnitudes of effect in the stance versus moving limb. In the stance limb, the activity increased by 25.9% when the band was moved from the knees to the ankles (mean difference = 3.8%MVIC [95% CI = 1.6%, 6.0%]; $P < .001$, Cohen d = 0.51) and by only 5.3% when the band was moved from the ankles to the feet (mean difference = 1.0%MVIC [95% CI = 0.2%, 2.1%]; $P = .10$, Cohen d = 0.13). In the moving limb, the activity increased by 30.9% when the band was moved from the knees to the ankles (mean difference = 2.3%MVIC [95% CI = 0.8%, 3.8%]; $P < .001$, Cohen d = 0.31) and by 14.7% when the band was moved from the ankles to the feet (mean difference = 1.4%MVIC [95% CI = 0.3%, 2.5%]; $P = .005$, Cohen d = 0.19).

Gluteus Medius. For the concentric phase of the gluteus medius, we observed a main effect of sex; muscle activity was 41.3% greater in women (mean = 34.5%MVIC [95% CI = 28.7%, 40.3%]) than in men (mean = 24.4%MVIC [95% CI = 18.3%, 30.5%]; $P = .02$, Cohen d = 0.70). We also observed an interaction of analyzed limb and band position. Again, the activity in the stance limb was greater than in the moving limb, and the magnitude of the effect of the band position was different between limbs. In the stance limb, the activity increased by 43.4% when the band was moved from the knees to the ankles (mean difference = 11.0%MVIC [95% CI = 6.8%, 15.2%]; $P < .001$, Cohen d = 0.96) and by only 18.7% when the band was moved from the ankles to the feet (mean difference = 6.8%MVIC [95% CI = 3.0%, 10.6%]; $P < .001$, Cohen d = 0.59). In the moving limb, the activity increased by 51.9% when the band was moved from the knees to the ankles (mean difference = 8.1%MVIC [95% CI = 4.6%, 11.6%]; $P < .001$, Cohen d = 0.71) and by 36.8% when the band was moved from the ankles to the feet (mean difference = 8.7%MVIC [95% CI = 5.5%, 11.9%]; $P < .001$, Cohen d = 0.76).

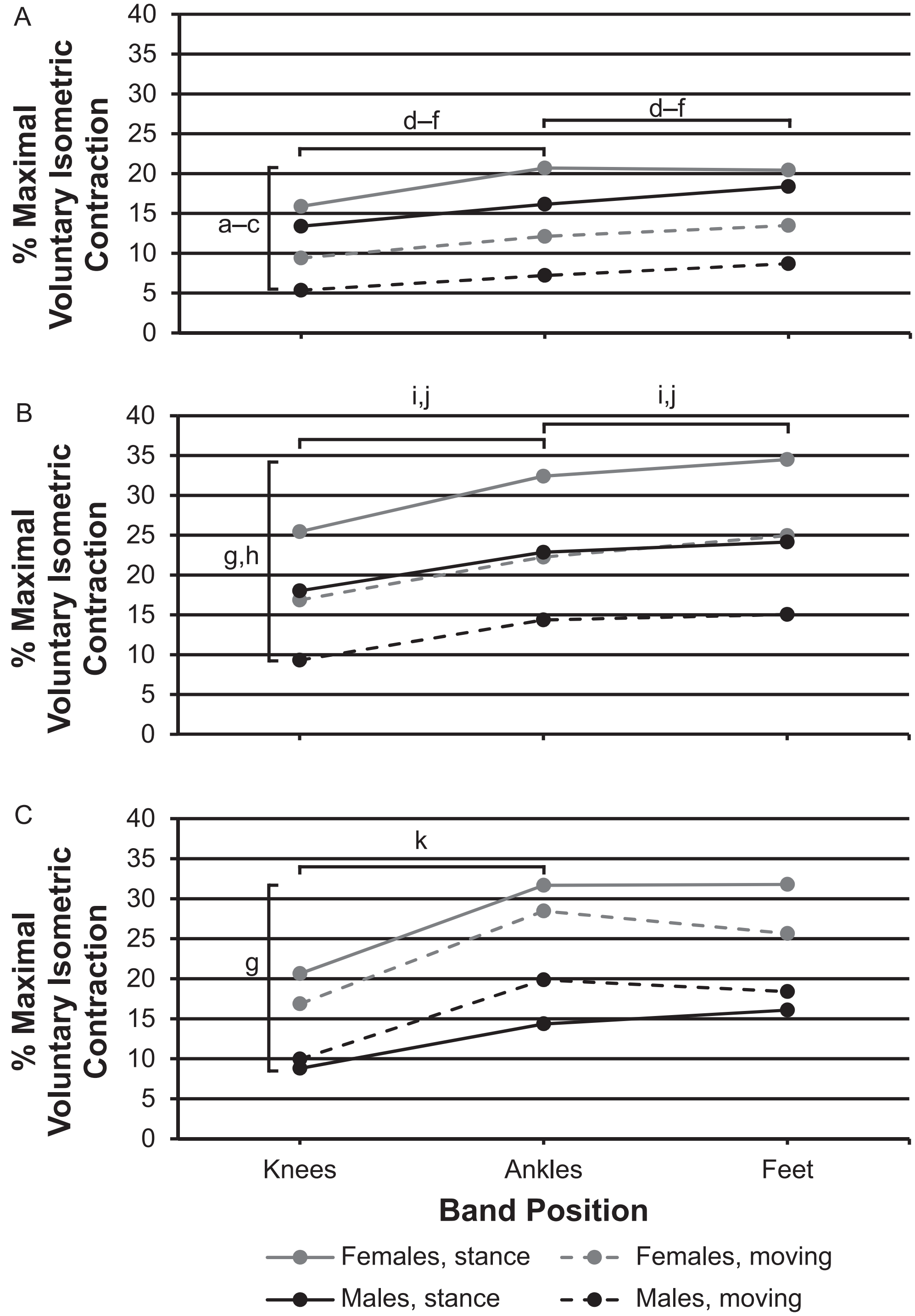

Figure 2. Average normalized muscle activity during the concentric phase in the moving limb and stance limb for the 3 muscles evaluated with the resistive band in each of 3 positions (knees, ankles, feet) for each sex. A, Gluteus maximus. B, Gluteus medius. C, Tensor fascia lata. [a] Group interaction effect of sex. [b] After finding an interaction involving sex, we completed a sex-specific analysis that indicated a within-subjects effect of analyzed limb in women. [c] After finding an interaction involving sex, we completed a sex-specific analysis that indicated a within-subjects interaction of analyzed limb in men. [d] After finding an interaction involving sex, we completed a sex-specific analysis that indicated a within-subjects effect of band position in women. [e] After finding an interaction involving sex and after finding an interaction effect of analyzed limb in the sex-specific analysis in men, we conducted a limb-specific analysis that indicated a within-subjects effect of band position in the moving limb. [f] After finding an interaction involving sex and after finding an interaction effect of analyzed limb in the sex-specific analysis in men, we conducted a limb-specific analysis that indicated a within-subjects effect of band position in the stance limb. [g] Group effect of sex. [h] Within-subjects interaction of analyzed limb. [i] After finding an interaction effect of analyzed limb, we conducted a limb-specific analysis that indicated a within-subjects effect of band position in the moving limb. [j] After finding an interaction effect of analyzed limb, we conducted a limb-specific analysis that indicated a within-subjects effect of band position in the stance limb. [k] Within-subjects effect of band position.

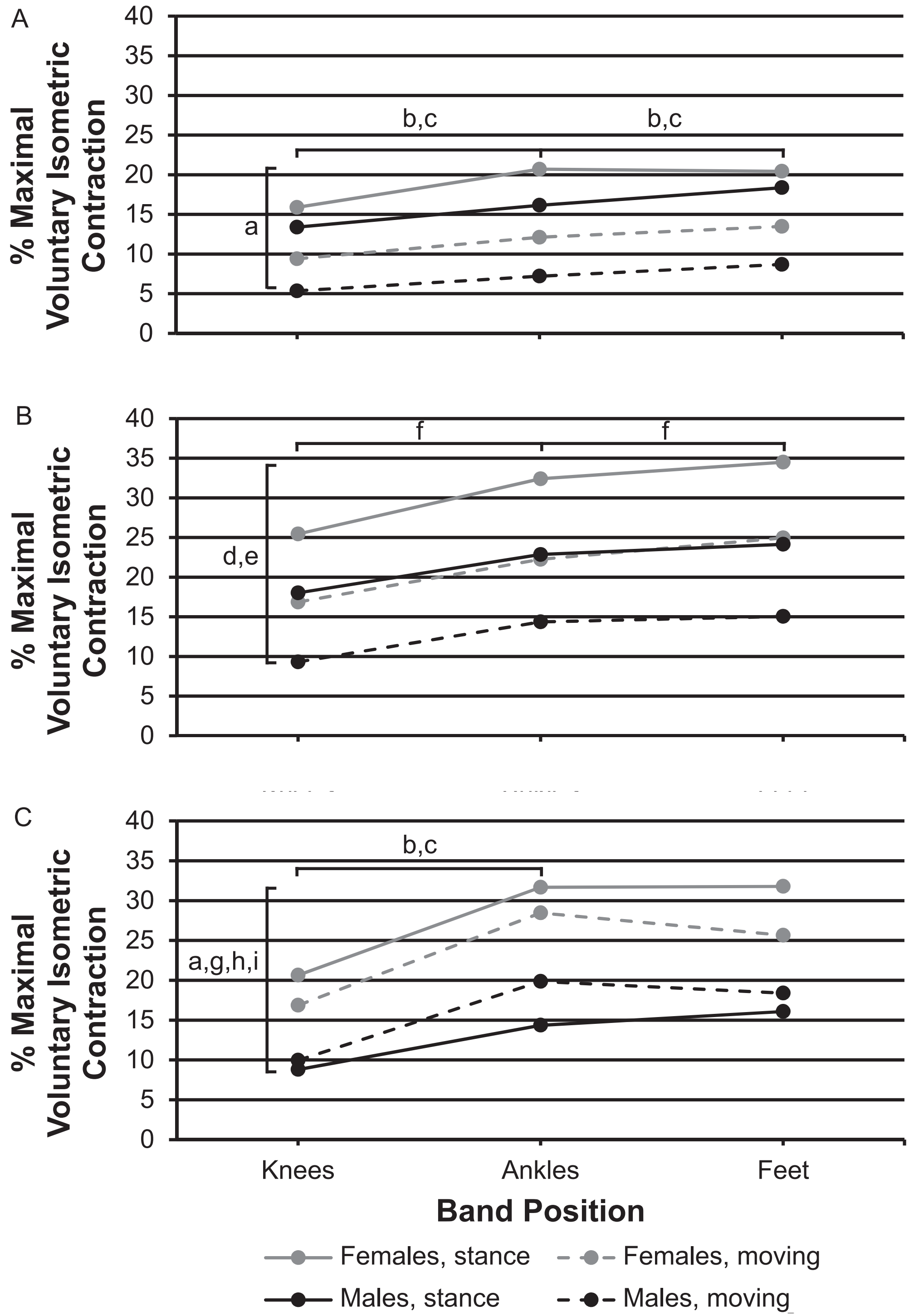

Figure 3. Average normalized muscle activity during the eccentric phase in the moving limb and stance limb for the 3 muscles evaluated with the resistive band in each of 3 positions (knees, ankles, feet) for each sex. A, Gluteus maximus. B, Gluteus medius. C, Tensor fascia lata. [a] Within-subjects interaction of analyzed limb. [b] After finding an interaction involving the analyzed limb, we completed a limb-specific analysis that indicated a within-subjects effect of band position in the stance limb. [c] After finding an interaction involving the analyzed limb, we completed a limb-specific analysis that indicated a within-subjects effect of band position in the moving limb. [d] Group effect of sex. [e] Within-subjects effect of analyzed limb. [f] Within-subjects effect of band position. [g] Group interaction effect of sex. [h] After finding an interaction involving sex, we completed a sex-specific analysis that indicated a within-subjects effect of analyzed limb in women. [i] After finding an interaction involving sex, we completed a sex-specific analysis that indicated a within-subjects effect of analyzed limb in males.

For the eccentric phase, we observed main effects of sex, analyzed limb, and band position. Activity levels were 50.8% greater in women (mean = 26.1%MVIC [95% CI = 21.2%, 30.9%]) than in men (mean = 17.3%MVIC [95% CI = 12.3%, 22.2%]; $P = .01$, Cohen d = 0.75). The activity in the stance limb was 34.7% greater than in the moving limb (mean difference = 9.1%MVIC [95% CI = 6.5%, 11.6%]; $P < .001$, Cohen d = 1.03). Muscle activity increased by 31.9% as the band was moved from the knees to the ankles (mean difference = 5.5%MVIC [95% CI = 3.5%, 7.6%]; P

$<$ .001, Cohen d = 0.65) and by 7.3% as the band was moved from the ankles to the feet (mean difference = 1.7%MVIC [95% CI = 0.4%, 2.9%]; P = .009, Cohen d = 0.20).

Tensor Fascia Lata. For the concentric phase of the TFL, we observed main effects of sex and band position. Activity was 50.6% greater in women (mean = 35.6%MVIC [95% CI = 26.2%, 45.1%]) than in men (mean = 23.7%MVIC [95% CI = 17.5%, 29.8%]; P = .04, Cohen d = 0.63). Muscle activity increased by 98.0% when the band was moved from the knees to the ankles (mean difference = 17.0%MVIC [95% CI = 12.4%, 21.7%]; $P <$ .001, Cohen d = 1.19). We did not observe a difference in activity with the band around the ankles versus the feet (mean difference = 2.6%MVIC [95% CI = –0.6%, 5.8%]; P = .11, Cohen d = 0.18).

For the eccentric phase, interactions existed between sex and analyzed limb and between analyzed limb and band position. For women, muscle activity was 18.5% greater in the stance than in the moving limb (mean difference = 4.4%MVIC [95% CI = 0.7%, 8.0%]; P = .02, Cohen d = 0.24). In contrast, this pattern was reversed in men, with the moving limb having 18.5% greater activity than the stance limb (mean difference = 3.0%MVIC [95% CI = 0.1%, 5.8%]; P = .04, Cohen d = 0.19). In each limb, activity increased when the band was moved from the knees to either the ankles or the feet but was not different between the ankles and the feet. In the stance limb, the activity increased by 56.4% when the band was moved from the knees to the ankles (mean difference = 8.3%MVIC [95% CI = 4.8%, 11.7%]; $P <$ .001, Cohen d = 0.77) and increased by only 4.0% when the band was moved from the ankles to the feet, which was not statistically different (mean difference = 0.9%MVIC [95% CI = –1.8%, 3.6%]; $P >$ .99, Cohen d = 0.08). In the moving limb, the activity increased by 80.1% when the band was moved from the knees to the ankles (mean difference = 10.7%MVIC [95% CI = 6.4%, 15.0%]; $P <$ .001, Cohen d = 0.99) and decreased by 8.8%, which was not statistically different, when the band was moved from the ankles to the feet (mean difference = 2.1%MVIC [95% CI = –1.0%, 5.3%]; P = .48, Cohen d = 0.20). However, within a band position, we did not observe a difference between limbs (mean differences = 1.3%MVIC [95% CI = –3.9%, 1.3%], 1.1%MVIC [95% CI = –2.2%, 4.5%], and 1.9%MVIC [95% CI = –6.0%, 2.2%] for the knees, ankles, and feet, respectively; $P \geq$ .19, Cohen d $<$ 0.18).

Kinematics

Trunk. We observed a main effect of sex for sagittal-plane trunk position (Wald χ^2_1 = 6.852, P = .009; Table 2). Women (mean = 28.3° [95% CI = 24.1°, 32.5°]) performed the resisted side step with greater forward trunk inclination than men (mean = 20.6° [95% CI = 16.6°, 24.6°]; P = .009, Cohen d = 0.79).

Hip Flexion. The mean hip flexion was 38.0° (95% CI = 25.0°, 51.1°) in men and 47.6° (95% CI = 36.4°, 58.9°) in women. An interaction existed among sex, analyzed limb, and band position (Wald χ^2_2 = 8.620, P = .01). In both sexes, we observed an interaction between analyzed limb and band position (Wald χ^2_2 = 56.909, $P <$ .001). In the women's leading limb, mean hip flexion did not change when the band was moved from the knees to the ankles (mean difference = 0.04° [95% CI = –3.7°, 3.6°]; P = .98, Cohen d = 0.00) but decreased by 9.1% when the band was moved from the ankles to the feet (mean difference = 4.4° [95% CI = 1.4°, 7.4°]; P = .001, Cohen d = 0.29). The same pattern existed in the women's trailing limb, with no change when the band was moved from the knees to the ankles (mean difference = 0.6° [95% CI = –2.8°, 4.1°]; P = .71, Cohen d = 0.04) but an 8.1% decrease when the band was moved from the ankles to the feet (mean difference = 4.0° [95% CI = 1.1°, 6.9°]; P = .003, Cohen d = 0.26). In men, however, we observed no differences in hip flexion in the leading limb with a change in the band position. In the trailing limb, a 9.3% decrease occurred when the band was moved from the knees to the ankles (mean difference = 3.4° [95% CI = 0.4°, 6.5°]; P = .02, Cohen d = 0.19), but no change occurred when the band was moved from the ankles to the feet (mean difference = 0.3° [95% CI = –1.0°, 7.2°]; P = .18, Cohen d = 0.17).

Knee Flexion. The mean knee flexion was 42.8° (95% CI = 33.7°, 51.8°) in men and 41.8° (95% CI = 32.5°, 51.0°) in women. We observed main effects of analyzed limb (Wald χ^2_1 = 19.993, $P <$ .001) and band position (Wald χ^2_2 = 39.110, $P <$ .001). Knee flexion was less in the leading than in the trailing limb (mean difference = 1.4° [95% CI = 0.8°, 2.0°]; $P <$ .001, Cohen d = 0.17). We also observed less knee flexion with the band secured around the feet than around the ankles (mean difference = 2.8° [95% CI = 0.7°, 4.8°]; P = .005, Cohen d = 0.32) and no difference between knee and ankle band placements (mean difference = 0.8° [95% CI = –1.1°, 2.7°]; P = .43, Cohen d = 0.09).

Hip-Abduction Excursion. Main effects of sex (Wald χ^2_1 = 8.693, P = .003), analyzed limb (Wald χ^2_1 = 72.790, $P <$ .001), and band position (Wald χ^2_2 = 50.088, $P <$ .001) were present. Hip-abduction excursion was greater in women (mean = 14.0° [95% CI = 12.8°, 15.2°]) than in men (mean = 11.8° [95% CI = 10.9°, 12.6°]; P = .003, Cohen d = 0.89). The trailing limb had greater hip-abduction excursion than the leading limb (mean difference = 4.9° [95% CI = 3.8°, 6.1°]; $P <$ .001, Cohen d = 2.21). Hip-abduction excursion was also greater with the band placed at the feet than at the ankles (mean difference = 1.5° [95% CI = 1.0°, 2.1°]; $P <$ .001, Cohen d = 0.86) but was not different between knee and ankle band placements (mean difference = 0.4° [95% CI = –0.03°, 0.91°]; P = .06, Cohen d = 0.24).

DISCUSSION

The primary purpose of our study was to investigate differences between men and women in muscle activation and movement patterns during resisted side stepping with different band positions. Overall, we found greater activation of the hip-abductor muscles (gluteus medius and TFL) but not of the gluteus maximus and more trunk inclination, hip-flexion angle, and hip-abduction excursion in women than in men.

Differences in hip-abductor activation between women and men could indicate differences in muscle strength[38] or differences in task performance. Several researchers[3,22,39,40] have reported that females had weaker hip abductors than males. These findings would support the interpretation that the greater activation in women was due to less strength. However, we also noted differences in the kinematics of the task. Hip-abduction excursion was 2.2° greater in women than in men. This may be due to the difference in height, and presumably limb length, of the female participants, requiring them to abduct the hip more to achieve the 24-in (60.96-cm) side step. Claiborne et al[41] showed that females also had weaker hip extensors than males. If the alterations in hip-abductor activity were due to strength alone, one would also expect women to display greater gluteus maximus activation. Instead, we found relatively greater activation only in the moving limb during the concentric phase of the motion, suggesting that women used the gluteus maximus in the stance limb less than men did. This alteration in muscle activation occurred in conjunction with increased hip flexion and trunk inclination in women compared with men.

Men and women also differed in activation of the TFL during the eccentric phase of the side-stepping movement. In men, the activation was greater in the moving limb, whereas in women, the activation was greater in the stance limb. This occurred despite women being in more hip flexion, a position thought to reduce the use of the TFL.[26] This difference in activation may indicate that women rely more on the TFL to stabilize the stance limb and pelvis during single-legged activities. The elevated activation may contribute to the increased hip internal rotation observed in females[20,25] and may contribute to clinical problems, including PFP[4–6] and hip pain.[7] This finding is consistent with the report of Flaxman et al,[17] who also observed that females had greater activity in the TFL than males. Females had less specificity in the TFL, as they activated the TFL in a greater range of loading directions.[17] These differences in TFL activation highlight a potential contributor to altered movement patterns and emphasize the importance of exploring sex-specific muscle-activation differences in future research.

The secondary purpose of our study was to evaluate the effect of different resistive-band positions on average muscle activity in both the moving and stance limb during resisted side stepping. Overall, gluteal-muscle activity increased as the band was moved more distally, whereas TFL activity only increased when the band was moved from the knees to the ankles but was not different between the ankles and the feet. This effect was consistent for both analyzed limbs but was greater in the moving limb as indicated by larger ESs.

The differences in muscle activity may be partially due to the change in torque created by the resistive band when placed at different locations. Generally, when the band is positioned around the lower extremities, it creates a hip-adduction torque pulling the limbs together or resisting abduction of the limbs. As the distance down the limb that the band is placed increases, the length of the lever arm (or distance from the hip) increases and, therefore, the torque for the same amount of band resistance increases. When side stepping the same distance with different band locations, the torque generated by the band at more distal locations also increases because of the increased stretch of the band. When side stepping with the band, the ankles are farther apart than the knees, resulting in more band stretch and subsequently more resistance from the band. Thus, changing the band location from the knees to the ankles increases the torque due to the increased lever arm and the increased resistance from the stretched band. The noted increase in the activity of each muscle studied was likely due to this biomechanical change as the band was moved. The average increases were approximately 38%, 42%, and 83% in the muscle activity of the gluteus maximus, gluteus medius, and TFL, respectively.

When the band was moved from the ankles to the feet around the metatarsal heads, the lever arm increased slightly, as the band was slightly farther from the hip. More importantly, the band pulled the distal part of the feet toward each other, creating an internal-rotation torque throughout the lower limb. At the foot, this torque was likely countered by the peroneal muscles to keep the feet aligned with the limb. Farther up the chain, the internal-rotation torque was countered by the gluteal muscles. These muscles generated an external-rotation torque to keep both the foot and the limb pointing forward during the side-step motion. This effect was greater for the moving than the stance limb, as evidenced by larger ESs. As the moving limb was off the ground, the band pulled the distal part of the foot medially, producing internal-rotation torque that had to be stabilized by gluteal activation. In contrast, the resistance of the floor helped stabilize the stance foot, so less hip external-rotation torque was required from the muscles of the stance limb. The stance hip still had to stabilize the pelvis to allow the moving hip to produce limb motion instead of pelvic motion. Therefore, when the band was moved from the ankles to the feet, the activity of the gluteus maximus and gluteus medius increased in each limb but more so in the moving than in the stance limb. However, TFL activity was not affected by changing the band position from the ankles to the feet, as the TFL produced internal-rotation torque.

We also investigated the effect of band position and limb on trunk, hip, and knee kinematics during resisted side stepping. Whereas kinematic differences associated with band placement were detected, most of these differences were small, with ESs between 0.17 and 0.32. Hip-abduction excursion, however, had large ESs. The hip-abduction excursion for the trailing limb was, on average, 4.9° greater than in the leading limb. As previously reported[26] in resisted side stepping with the band around the ankles both in a squat and an upright posture, the increased hip abduction of the trailing limb occurred just after the leading limb contacted the ground. Understanding hip motion is particularly important when treating patients who have both decreased hip-abduction strength[42,43] and limited hip-abduction available motion.[44–46]

These results expand on the findings of Cambridge et al,[14] who tested only male participants performing resisted side stepping in a squat posture. Similar to us, they found an increase in the peak activity of the gluteal muscles when the band was moved from the knees to the feet. We also detected an increase in gluteal-muscle activity when the band was moved from the ankles to the feet. Consistent with our results, Cambridge et al[14] noted an increase in the peak TFL activity when the band was moved from the knees to the ankles or feet but not when moved from the ankles to the feet. Our inclusion of women and our larger sample size may have contributed to the different findings between the studies. Our participants also demonstrated more hip flexion and forward trunk inclination in the squat posture than those in the study by Cambridge et al.[14] Their participants maintained average squat positions of 24° to 28° of hip flexion and 15° to 16° of spine flexion compared with averages of 42.8° of hip flexion and 24.5° of forward trunk inclination in our study. The higher average of trunk inclination in our study may have been due to methodologic differences or to the inclusion of women. Women performed the side step in almost 8° more trunk inclination than men. Despite these differences in squat posture and the inclusion of women, the consistent findings with the band around the feet further strengthen the evidence for using this exercise posture to preferentially elicit gluteal activity. Our results also highlight differences in gluteal and TFL activity between healthy women and men.

Side stepping with the band around the feet targets the combined motions of hip abduction and external rotation and, therefore, may be an effective exercise method to counter the abnormal movement pattern of excessive hip adduction and internal rotation. This exercise might be particularly beneficial for individuals with weak hip abductors and external rotators, as has been noted in females with PFP[1,2] and individuals with chronic hip pain.[43]

Whereas weakness may contribute to altered movement patterns, strengthening alone may not improve these patterns. As demonstrated by Willy and Davis,[9] improved strength in the abductors and external rotators did not lead to changes in hip or knee kinematics during running. Instead, techniques such as gait retraining using a mirror for visual feedback were necessary to change kinematics during running.[47]

Our study had limitations. First, all participants were healthy individuals without recent or current musculoskeletal impairments or pain. We selected asymptomatic individuals because pain can affect muscle-activation patterns.[48] Second, we provided only basic cues about how to attain the squat posture and did not prescribe a preselected trunk, hip, or knee position. Third, we did not measure the resistance provided by the band and, thus, assumed increased torque was produced during the more distal band positions. This assumption was logical given that the step width was held constant for all the band positions and a more distal placement would result in both increased stretch and increased lever arm.

CONCLUSIONS

Our findings highlight sex-specific differences in muscle-activation and movement patterns during resisted side stepping, as well as in the response to different band positions in the stance and moving limbs. These results expand the understanding of muscle activation during this exercise, thereby providing clinicians with evidence to support its selection. Compared with ankle band placement, resisted side stepping in the squat posture with the band around the feet elicited the greatest activity in the gluteal muscles without increasing TFL activity. This band placement is most appropriate when the therapeutic goal is to focus on muscle activation to resist hip adduction and internal rotation.

ACKNOWLEDGMENTS

This study was supported by the Peter Paul Career Development Professorship (Dr Lewis), research grant K23 AR063235 from the National Institute of Arthritis and Musculoskeletal and Skin Diseases of the National Institutes of Health (Dr Lewis), and a research grant from the North Dakota Physical Therapy Association (Dr Berry). The content is solely the responsibility of the authors and does not necessarily represent the official views of the National Institutes of Health.

Preliminary results of this study were presented at the 2015 Combined Sections Meeting of the American Physical Therapy Association; February 2015; Indianapolis, Indiana.

We thank the members of the Human Adaptation Lab, and in particular Maureen Ogamba, for assistance with collecting and processing the data.

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