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RESEARCH REPORT

Magnitudes of gluteus medius muscle activation during standing hip joint movements in spiral-diagonal patterns using elastic tubing resistance

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Abstract

The aim of this study was to simultaneously quantify electromyographic (EMG) activation levels (% maximum voluntary isometric contraction [MVIC]) within the gluteus medius muscles on both moving and stance limbs across the performance of four proprioceptive neuromuscular facilitation (PNF) spiral-diagonal patterns in standing using resistance provided by elastic tubing. Differential EMG activity was recorded from the gluteus medius muscle of 26 healthy participants. EMG signals were collected with surface electrodes at a sampling frequency of 1000 Hz during three consecutive repetitions of each spiral-diagonal movement pattern. Significant differences existed among the four-spiral-diagonal movement patterns ($F_{3,75} = 19.8$; $p < 0.001$). The diagonal two flexion [D2F] pattern produced significantly more gluteus medius muscle recruitment (50 SD 29.3% MVIC) than any of the other three patterns and the diagonal one extension [D1E] (39 SD 37% MVIC) and diagonal two extension [D2E] (35 SD 29% MVIC) patterns generated more gluteus medius muscle recruitment than diagonal one flexion [D1F] (22 SD 21% MVIC). From a clinical efficiency standpoint, a fitness professional using the spiral-diagonal movement pattern of D2F and elastic tubing with an average peak tension of about 9% body mass may be able to concurrently strengthen the gluteus medius muscle on both stance and moving lower limbs.

Keywords

Hip abductors, muscle strengthening, proprioceptive neuromuscular facilitation

History

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Introduction

Rehabilitation professionals utilize strengthening exercises for the gluteus medius in patients with a variety of musculoskeletal disorders including: 1) patellofemoral pain syndrome (Bolgla, Malone, Umberger, and Uhl, 2008; Khayambashi et al, 2012; Prins and van der Wurff, 2009; Souza and Powers, 2009); 2) iliotibial band syndrome (Fairclough et al, 2006, 2007; Fredericson et al, 2000; Noehren, Davis, and Hamill, 2007); 3) total hip arthroplasty (Jensen, Aagaard, and Overgaard, 2011; Nilsdotter and Isaksson, 2010; Raasch, Dalen, and Berg, 2010); 4) total knee arthroplasty (Piva et al, 2011); 5) anterior cruciate ligament injury as a consequence of medial collapse of the knee (Hewett et al, 2005; Hollman et al, 2009); and 6) chronic ankle instability (Friel, McLean, Myers, and Caceres, 2006; Nadler et al, 2000; Nicholas, Strizak, and Veras, 1976).

Elastic tubing is an accepted mode of resistance training among healthcare workers for the following reasons: 1) inexpensive; 2) simple; 3) portable; 4) versatile; and 5) no reliance on gravity for resistance (Hughes, Hurd, Jones, and Sprigle, 1999). Elastic tubing resistance is safe for home-based rehabilitation programs where weight machines may not be available or practical (Andersen et al, 2010). Numerous reports exist regarding the convenience of elastic tubing resistance when strengthening both upper and lower extremities in a variety of patient groups (Colado and Triplett, 2008; Fukuda et al, 2010; Lephart et al, 2007; Mikesky et al, 1994; Topp et al, 2002; Zion, DeMeersman, Diamond, and Bollmfield, 2003). Using elastic tubing resistance, healthcare professionals may prescribe lower extremity strengthening exercises in standing that use conventional cardinal plane movements such as the front or back pull (sagittal plane) and cross-over or reverse cross-over (RCO) (frontal plane) (Han, Richard, and Fellingham, 2009; Hopkins, Ingersoll, Sandrey, and Bleggi, 1999; Schulthies, Richard, Alexander, and Meyer, 1998; Youdas et al, 2014).

Originally described during the 1940s and 1950s (Knott and Voss, 1968), proprioceptive neuromuscular facilitation (PNF), is an alternative approach to muscle strengthening that uses functionally based multi-joint, multi-planar, spiral-diagonal movement patterns. Initially, physical therapists were trained to apply external resistance to specifically defined spiral-diagonal movements of the extremities via explicit manual contacts. Despite the popularity of PNF among physical therapists, there is a shortage of information describing the magnitudes of muscle activation elicited by a physical therapist's manually applied resistance to spiral-diagonal movements generated by a patient

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Table 1. Subject demographic information.

Gender	Age (y)		Height (m)		Mass (kg)		Body mass index (kg/m^2)		Exercise/days per week	
	X	SD	X	SD	X	SD	X	SD	X	SD
Male ($n = 13$)	25.3	3.1	1.8	0.1	80.1	11.7	24.2	2.2	4.2	1
Female ($n = 13$)	23.7	1.3	1.7	0.1	64.5	8.2	22.6	2.2	4.7	0.9

(Hazaki, Ichihashi, and Mirinaga, 1996; Markos, 1979). Instead of directly applying manual resistance to a patient's lower extremities in supine, the physical therapist can train the patient during single-leg stance to move the non-weight-bearing (NWB) extremity in a spiral-diagonal movement pattern against external resistance provided by elastic tubing attached to the limb by an ankle anchor cuff. Additionally, critical muscle activity is also occurring concurrently in the weight-bearing (WB) limb to control pelvic-on-femoral movement necessary for proper balance.

Electromyography (EMG) records motor unit activity within a muscle or group of muscles and is expressed as a percentage of a maximal voluntary isometric contraction (% MVIC). Researchers in health and wellness professions use EMG to observe and quantify differences in magnitudes of muscle activity between exercise conditions (Bolgla and Uhl, 2005; DiStefano, Blackburn, Marshall, and Padua, 2009). Investigators recorded EMG activity of the gluteus medius during a series of six hip rehabilitation exercises-three NWB and three WB (Bolgla and Uhl, 2005). Generally WB exercises generated significantly greater gluteus medius amplitudes than NWB exercises because of greater external moments applied to the WB hip abductors. Presently there is an absence of information describing the relative recruitment levels (%MVIC) of the gluteus medius during standing using elastic tubing resistance and two common modes of activation: 1) NWB; and 2) WB.

The purpose of this study was to simultaneously quantify EMG activation levels (% MVIC) within the gluteus medius muscles on both moving and stance limbs across the performance of four PNF diagonal patterns in standing using resistance provided by elastic tubing. We hypothesized the gluteus medius of the stance limb would require greater muscle activation than the gluteus medius on the moving limb. This was based upon a theoretical model for differences between the gluteus medius demands during WB movement (controlling pelvic-on-femoral) and non-weight bearing (femoral-on-pelvic) movement (Bolgla and Uhl, 2005). Results from this study will provide clinicians information about bilateral muscle activation of the gluteus medius during standing exercises that utilize PNF movement patterns. Such information is useful for rehabilitation professionals when prescribing strength training exercises for the gluteus medius in standing using elastic tubing resistance.

Methods

Design

We used a repeated-measures design to study gluteus medius muscle recruitment during four spiral-diagonal movement patterns of the lower extremities in standing using elastic tubing resistance.

Subjects

Thirteen men and thirteen women volunteered to participate. An *a priori* power analysis determined a sample size of 22 subjects was required to detect a mean difference in EMG recruitment of 10% MVIC (effect size = 0.20) between conditions with a statistical power ($1 - \beta$) equal to 0.80 at $\alpha = 0.05$ (Faul, Erdfelder, Lang, and Buchner, 2007). Demographic information is displayed in Table 1.

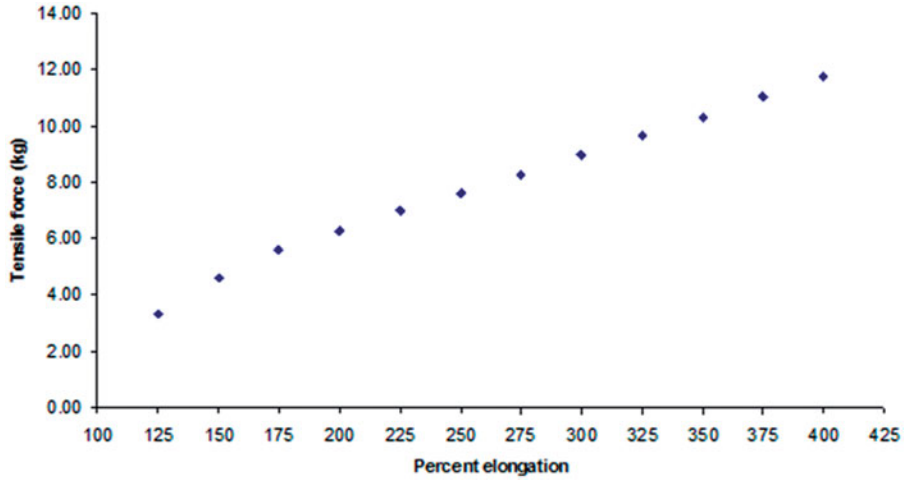
Eighty per cent ($n = 21$) of subjects participated in lower extremity strength training programs that included free weights and specific movements included lunges and barbell or dumbbell squats. All subjects engaged in regular cardiovascular exercise. All subjects were screened for normal active range of motion of the hip, knee, ankle, and foot. Subjects self-reporting a history of the following lower extremity conditions were excluded from the study: 1) previous subluxation, dislocation, or fracture; 2) a history of joint instability, tendinitis, bursitis, impingement, adhesive capsulitis, neurovascular complications, or any condition that limited physical activity for greater than 2 d over the last 6 months; and 3) current complaints of neuromuscular pain, numbness, or tingling in the lower extremity and back. Study procedures were approved by the Mayo Clinic College of Medicine institutional review board before the study began. Prior to enrollment in the study, all subjects provided written informed consent and completed a survey that assessed their current level of physical activity.

Instrumentation

Raw EMG signals were collected with Bagnoli™ DE 3.1 double-differential surface EMG sensors (Delsys Inc., Boston, MA). Sensor contacts were made from 99.9% pure silver bars 10 mm in length and spaced 10 mm apart and encased within preamplifier assemblies measuring $41 \times 20 \times 5$ mm. Preamplifiers had a gain of 10 V/V. The combined preamplifier and main amplifier permitted a gain from 100 to 10 000. Per manufacturer specifications, the common mode rejection ratio of the system was 92 dB at 60 Hz, input impedance was greater than $10^{15}\,\Omega$ at 100 Hz and estimated noise was $\leq 1.2\,\mu V$. Data were collected at a sampling frequency of 1000 Hz through a 16-bit NI-DAQ PCI-6220 analog to-digital acquisition card (National Instruments Corporation, Austin, TX). Raw EMG signals were processed with EMG works® Data Acquisition and Analysis software (Delsys Inc. Boston, MA). Raw EMG data collected during the tests were band-pass filtered between 20 and 450 Hz with a fourth order Butterworth filter and subsequently processed with a root-mean-square algorithm using moving windows with 125-ms time constants.

Silver Theraband® elastic tubing (Hygienic Corporation, Akron, OH) with an internal diameter of 11 mm was used to provide external resistance. One end of the elastic tubing was connected to the subject's foot with a dog-leash snap and padded ankle anchor (Stirrup Ankle Anchor™, Therapeutic Dimensions, Inc., Spokane, WA) whereas the other end of the tubing was fastened to a Chatillon MSC-500 digital dynamometer with a dog-leash snap (Ametek, Largo, FL). The piece of tubing was 1.21 m (4 ft) in length after the band was fastened to the dynamometer and the subject's ankle. A fresh piece of elastic tubing was used for each participant. It was essential for the investigators to know the variation in force of the tubing as a function of length when positioning a subject during each of the spiral-diagonal movement patterns (Figure 1). To calculate the relationship of force versus percent elongation, a 1.21-m piece of silver tubing was serially stretched at 25% increments from 125% to 400% of its

Figure 1. The relationship between tension and percent elongation of a 1.21-m (4-ft) section of silver Theraband® elastic tubing.



original length. The fixed end of the tubing was held in place by an investigator, with the moving end of the tubing anchored to the Chatillon® MSC-500 digital dynamometer (AMETEK, Largo, FL) to record the tensile force necessary to elongate the piece of elastic tubing. The silver tubing was stretched three times from 125% to 400% of its resting length. Prior to formal data collection, investigators established by consensus, an external resistance value of 5% body mass to be delivered by the silver Theraband® at the start of the concentric segment of each spiral-diagonal movement pattern. This external load provided appropriate resistance to the subject without inducing undesirable trunk or hip muscle substitution patterns from either moving or stance limbs (Schulthies, Richard, Alexander, and Myer, 1998).

Testing procedure

Data were collected in a research laboratory by four co-investigators and each was assigned an explicit task. All subjects dressed in appropriate attire to permit correct placement of EMG electrodes. Each wore their own workout footwear on the stance limb. To permit optimal EMG recording, the subject's skin was abraded with an alcohol wipe until erythema was achieved. Electrodes were placed superficially parallel to the direction of the gluteus medius muscle fibers on the subject's left and right lower extremities. Placement of electrodes was based on Criswell's guidelines (Criswell, 2011). Surface electrodes were fastened to the cleansed area with adhesive interfaces (Delsys Inc., Boston, MA) and secured with 3M™ Transpore™ medical tape (St. Paul, MN). A ground electrode was located on the stance leg medial malleolus. Next, subjects were provided practice trials prior to the gluteus medius manual muscle test (MMT) so they were familiar with the muscle test procedure. MVICs of each gluteus medius muscle were collected using recognized MMT techniques (Hislop, Avers, and Brown, 2014). The subject was positioned in side-lying with the test lower extremity uppermost. Both thigh and leg were extended and the limb maintained in line with the trunk. The untested limb was flexed at the hip and knee for stabilization purposes. The subject was trained to abduct the uppermost limb about 30° from midline at which point the examiner applied maximum manual resistance just proximal to the lateral malleolus in the direction of hip adduction. Verbal encouragement was offered during the MMT to ensure consistent effort from the subject.

Prior to data collection, a co-investigator demonstrated to the subject the correct overall body position for each of the exercises. Each subject practiced performing the four resisted hip exercises until the movement patterns could be repeated to the investigator's satisfaction. During these practice trials another investigator used the dynamometer to simultaneously record peak external tension in the tubing. This information was immediately reported to the subject until he/she could reproduce the external load within an interval ranging from 5 to 10% of body mass [% BM]. Each subject then completed trials of the four exercises in random order by performing three consecutive repetitions of each exercise. We chose to use three repetitions of each exercise because we believed subjects could complete three repetitions with proper form and without fatigue. Prior to data, acquisition exercise trial order was established by having a subject sequentially select four cards each designating one specific exercise condition. Hip joint range of motion was not controlled during each exercise condition. Component motions of hip diagonal 1 flexion (D1F) involved femoral-on-pelvic flexion, adduction, and external rotation (Figure 2) whereas diagonal 1 extension (D1E) consisted of femoral-on-pelvic extension, abduction, and internal rotation (Figure 3). Lower extremity diagonal 2 flexion (D2F) included femoral-on-pelvic flexion, abduction, and internal rotation (Figure 4) while diagonal 2 extension (D2E) included femoral-on-pelvic extension, adduction, and external rotation (Figure 5).

A metronome set at 40 beats per minute was used to standardize the duration of the three repetitions. Subjects began each exercise in the appropriate position and performed three consecutive repetitions of each of the four randomized trial exercises during the practice trials. Subjects were trained to complete each repetition-start to end range and back to the start position-within a two beat duration on the metronome. There was no hold time at the end range of each exercise. We did not utilize a standardized magnitude of active hip range of motion each participant was expected to demonstrate during each of the four spiral-diagonal movement patterns. A co-investigator required each participant to demonstrate the ability to cross the body's midline with the moving limb while maintaining balance on the stance limb. There was slack in the elastic tubing at the start of each spiral-diagonal pattern; however, the tubing became progressively taut at the end-point of the diagonal. The subject was allowed a brief recovery period (2–3 min) between trials as the tubing was adjusted for the subsequent trial. The duration of recovery time was established during pilot testing according to feedback provided by the subjects. Recovery time duration was monitored by a stopwatch. Verbal cues were used to signal the subject to begin the three repetitions when he or she was ready. Repetitions were counted out loud by the examiners. The highest peak of the three repetitions was analyzed and its value expressed

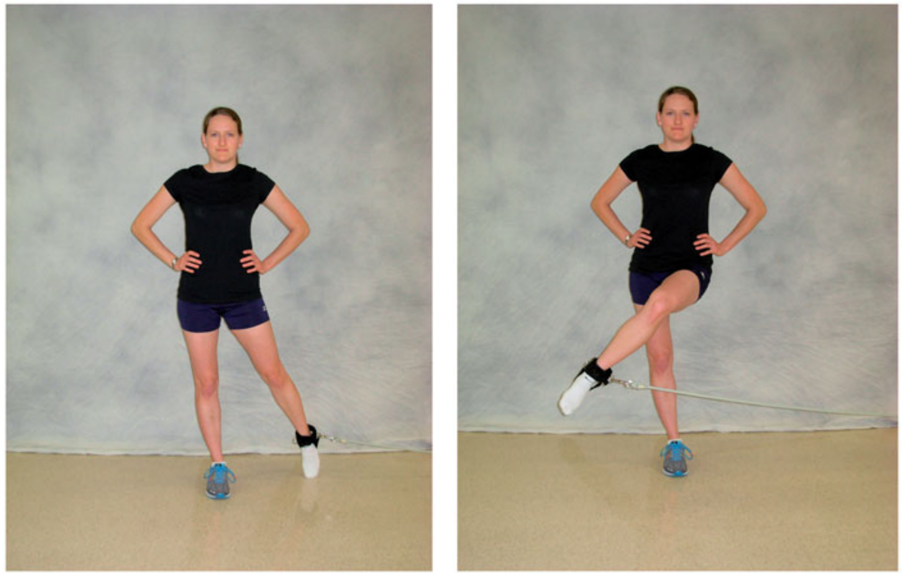


Figure 2. Diagonal one flexion [D1F] exercise. The elastic tubing is attached to the dominant limb using an ankle anchor. Start Position [left]. With hands on hips and balancing on the right stance limb the subject positions the moving limb posterior to the stance limb with toes lightly touching the floor. The left hip is in a position of femoral-on-pelvic extension, abduction, and internal rotation. End Position [Right]. The subject then flexes, adducts, and externally rotates the hip of the moving limb crossing the body's midline in a spiral-diagonal path against resistance provided by the elastic tubing.

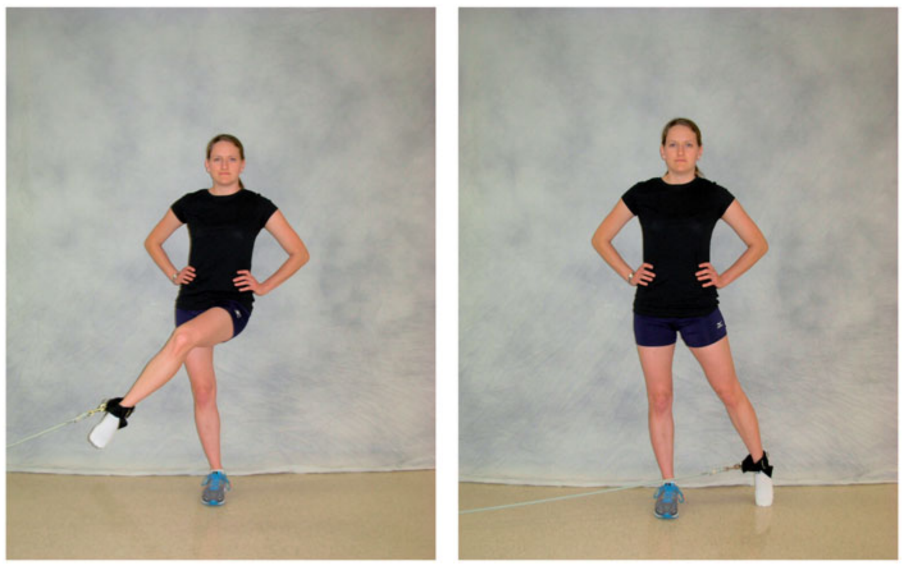


Figure 3. Diagonal one extension [D1E] exercise. The elastic tubing is attached to the dominant limb using an ankle anchor. Start Position [Left]. With hands on hips and balancing on the right stance limb the subject positions the moving limb anterior to the stance limb with the hip at the end-range of femoral-on-pelvic flexion, adduction, and external rotation. End Position [Right]. The subject then extends, abducts, and internally rotates the hip of the moving limb crossing the body's midline in a spiral-diagonal path against resistance provided by the elastic tubing until the toes of the moving limb make contact with the floor.

as a % MVIC for each muscle on both stance and moving limbs. Peak amplitudes were averaged over a 500 ms window of time, 250 ms prior to peak and 250 ms after the peak.

Statistical analysis

Descriptive statistics including means and standard deviations (SDs) for EMG recruitment (% MVIC) in the gluteus medius were calculated for both stance and moving sides during the four PNF exercise conditions. Magnitudes of EMG recruitment were analyzed with a 2×4 (2 sides [stance limb versus moving limb] by 4-spiral-diagonal movement patterns) repeated-measures analysis of variance (ANOVA) ($\alpha = 0.05$). When main effects were significant, pairwise comparisons were examined with Bonferroni adjustments to alpha ($p = 0.05$).

Using one-way repeated-measures ANOVA, we also analyzed peak tension forces in % BM generated in the elastic tubing by the moving limb during each of the four exercise conditions. *Post-hoc* simple effects tests with Bonferroni adjusted α were used to control α for multiple comparisons and to analyze pairwise comparisons. All data were analyzed using SPSS 17.0 software (IBM Corp, Armonk, NY).

Results

Magnitudes of muscle recruitment

The interaction between exercise pattern and limb factor was not significant ($F_{3,75} = 0.80$; $p = 0.50$). There was no side main effect (moving-to-stance) difference in gluteus medius recruitment ($F_{1,25} = 0.50$; $p = 0.49$). However, a significant main effect existed for PNF exercise pattern ($F_{3,75} = 19.9$; $p < 0.001$). The exercise pattern main effect was analyzed with Bonferroni tests. The D2F pattern produced 27.6% more mean gluteus medius muscle recruitment [% MVIC] than D1F, 14.5% more than D2E, and 10.9% more than D1E. Furthermore, D1E and D2E generated 16.7% and 13.1% greater mean gluteus medius muscle activation, respectively, than D1F (Figure 6).

Elastic tubing tension

Descriptive statistics for the peak tension load (kg) produced in the Theraband® tubing as % BM are shown in Figure 7 for both men and women for each of the spiral-diagonal movement patterns. Mean peak elastic tubing tension in the moving lower extremity ranged from 8.1 to 8.9% BM over the four spiral-

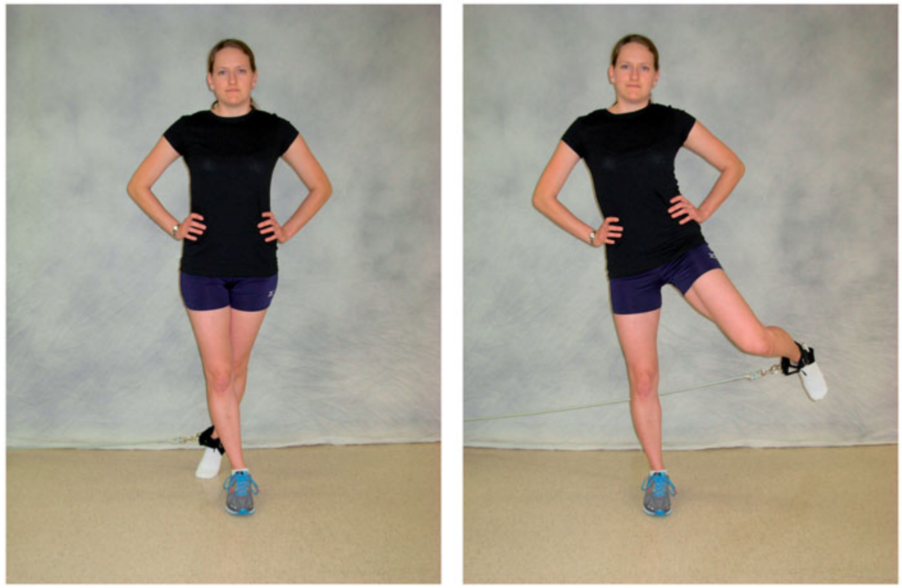


Figure 4. Diagonal two flexion [D2F] exercise. The elastic tubing is attached to the dominant limb using an ankle anchor. Start Position [Left]. With hands on hips and balancing on the right stance limb the subject positions the moving limb posterior to the stance limb with toes lightly touching the floor. The left hip is in a position of femoral-on-pelvic extension, adduction, and external rotation. End Position [Right]. The subject then flexes, abducts, and internally rotates the hip of the moving limb crossing the body's midline in a spiral-diagonal path against resistance provided by the elastic tubing.

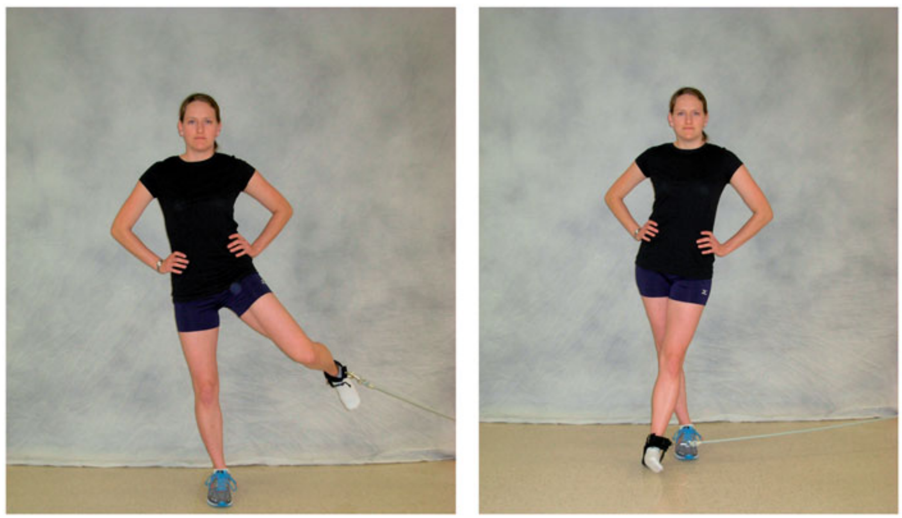


Figure 5. Diagonal two extension [D2E] exercise. The elastic tubing is attached to the dominant limb using an ankle anchor. Start Position [Left]. With hands on hips and balancing on the right stance limb the subject positions the moving limb anterior to the stance limb with the hip at the end-range of femoral-on-pelvic flexion, abduction, and internal rotation. End Position [Right]. The subject then extends, adducts, and externally rotates the hip of the moving limb crossing the body's midline in a spiral-diagonal path against resistance provided by the elastic tubing until the heel makes contact with the floor.

diagonal movements. There was a statistically significant spiral-diagonal movement pattern effect ($F_{3,75} = 10.8$; $p < 0.001$). Peak tension was greater in the D2F pattern than in the other three patterns. Elastic-band tension was equivalent for movement patterns D1E, D1F, and D2E.

Discussion

We hypothesized the gluteus medius of the stance limb would require greater muscle activation than the gluteus medius on the moving limb during performance of four spiral-diagonal PNF movement patterns. During resisted spiral-diagonal movement patterns in standing, the stance limb gluteus medius was recruited to stabilize the pelvis in the frontal plane. The WB gluteus medius needed to develop internal torque to counter-balance the external torque demands created by the mass of head, arms, and trunk (HAT) and the moving lower extremity. In contrast, the moving limb gluteus medius was activated to generate sufficient internal torque in the frontal plane to oppose the external torque supplied by tension in the elastic tubing (Bolgla and Uhl, 2005). However, this hypothesis was not supported because no statistical difference in EMG recruitment was detected (% MVIC) between stance and moving limbs during the execution of each of the four PNF diagonal patterns.

Our study also sought to simultaneously quantify bilateral activation levels (% MVIC) of the gluteus medius on both stance and moving lower limbs during performance of four PNF diagonal patterns in standing using resistance provided by elastic tubing. To assist with ordering low to high muscle activity of the gluteus medius, we used a previously described classification scheme (DiGiovine, Jobe, Pink, and Perry, 1992). Activation from 0% to 20% MVIC was low level, 21% to 40% MVIC moderate level, 41% to 60% MVIC high level, and greater than 60% MVIC very-high level. Spiral-diagonal exercises requiring muscle activation levels greater than 45% MVIC may be beneficial for developing muscle strength for that muscle, whereas exercises resulting in muscle activity less than 45% MVIC may be more appropriate for producing muscular endurance for that muscle (Ekstrom, Donatelli, and Carp, 2007).

The D2F pattern was the only spiral-diagonal movement that activated the gluteus medius at a high level [49.8 SD 29.3%] whereas the other three patterns produced moderate levels of gluteus medius muscle recruitment. Since the D2F pattern generated average EMG signal amplitude within the gluteus

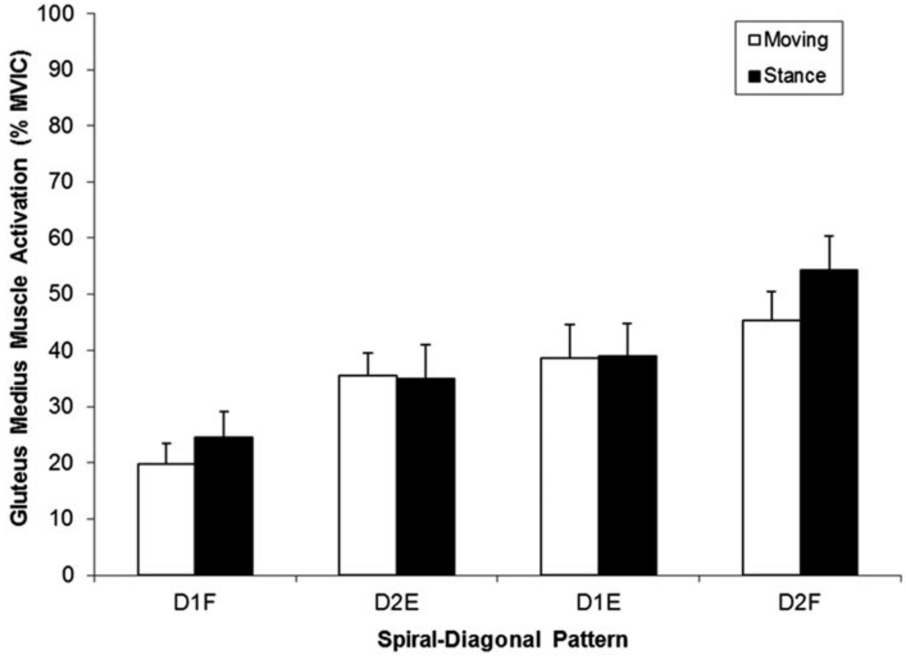


Figure 6. The relationship between four spiral-diagonal proprioceptive neuromuscular facilitation [PNF] movement patterns and gluteus medius muscle activation (% MVIC) for both stance and moving limbs while standing using silver Theraband® elastic tubing tension as resistance. Error bars represent the standard error for each exercise condition. Abbreviations: D1F, diagonal one flexion; D1E, diagonal one extension; D2F, diagonal two flexion; D2E, diagonal two extension. Gluteus medius muscle activation was greater in D2F than D1E ($p = 0.2$), D2E ($p = 0.001$), and D1F ($p < 0.001$). Gluteus medius activity in D1E was greater than D1F ($p = 0.001$) and D2F was greater than D1F ($p = 0.04$).

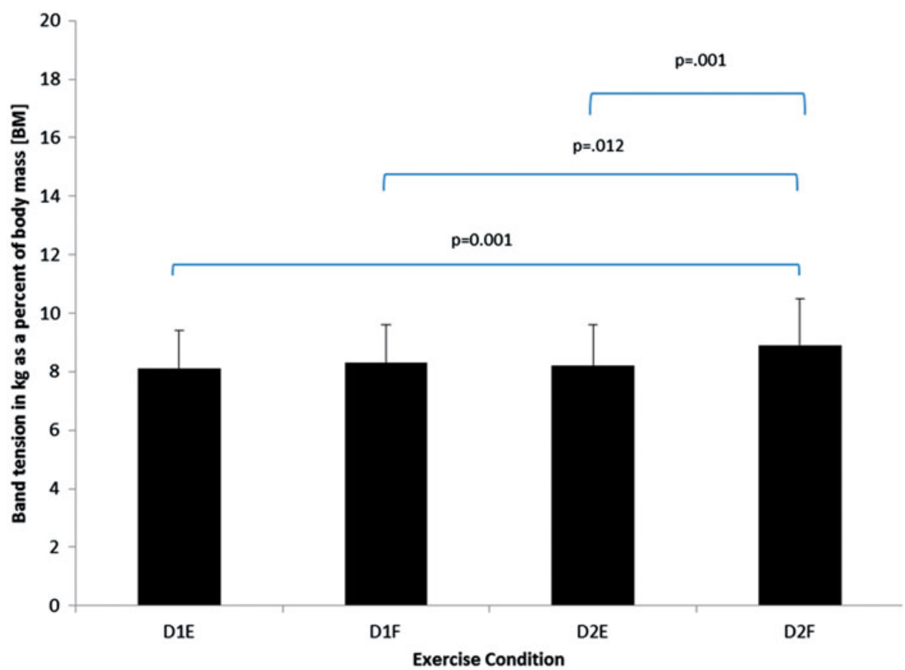


Figure 7. Relationship between average silver Theraband® elastic tubing tension as a percentage of body mass versus exercise condition. Error bars represent the standard error for each of the exercise conditions. Abbreviations: D1F, diagonal one flexion; D1E, diagonal one extension; D2F, diagonal l two flexion; D2E, diagonal two extension.

medius of greater than 45% MVIC, it may offer the stimulus required for strength gains in some individuals (Anderson et al, 2006; Ayotte, Stetts, Keenan, and Greenway, 2007; Ekstrom, Donatelli, and Carp, 2007). Better trained persons would likely need higher levels of muscle activation to obtain a strengthening effect (Ekstrom, Donatelli, and Carp, 2007). The three other spiral-diagonal movement patterns displayed average % MVIC muscle recruitment levels below 45% MVIC (D1E, 38.9 SD 36.7%; D2E, 35.3 SD 28.5%; and D1F, 22.2 SD 21.2%) indicating they would be suitable for endurance or motor control exercise training (Ekstrom, Donatelli, and Carp, 2007). It could be argued the reason the magnitude of gluteus medius EMG muscle recruitment was significantly greater for D2F than the other three patterns was because peak tension in the elastic band as a percent of body mass was greater in the D2F pattern than the other three. Since elastic band tension was larger for D2F, the subject would activate more motor units within the gluteus medius muscle of both moving and stance limbs to complete the movement pattern. Nevertheless, the difference between average peak tension for D2F and the other three spiral-diagonal patterns ranged between 0.6 kg and 0.8 kg as a percent of body mass. Although statistically significant, we do not credit this difference in tension alone for the greater magnitude of gluteus medius muscle recruitment. We believe the D2F pattern of femoral-on-pelvic flexion, abduction, and internal rotation was more demanding on the gluteus medius muscle than each of the other three movement patterns. At the end point of D2F, the thigh of the moving limb was advancing against the vertical force line of gravity. Therefore, to oppose the external demand created by the external hip adduction moment created by the elastic tubing tension and mass of the moving limb, the gluteus medius experienced increased motor unit recruitment (% MVIC).

When performing elastic band resistance to lower extremities in standing, fitness professionals initially focus on the moving limb because of its dynamic activity whereas the stance limb remains fixed. During resisted D2F the gluteus medius functions as a primary femoral-on-pelvic abductor of the moving limb and a pelvic-on-femoral stabilizer of the stance limb (Bolgla and Uhl, 2005; Neumann, 2010). However, stance limb gluteus medius muscle recruitment is essential to furnish a stable platform for the WB pelvis and trunk in the frontal plane while the moving limb is resisted by elastic tubing. In the present study, regardless of the spiral-diagonal movement pattern, gluteus medius muscles on both moving and stance limbs developed nearly equivalent magnitudes of muscle recruitment. This finding is similar to an observation found in a recent report whereby healthy subjects performed a RCO in standing against resistance provided by elastic tubing. The RCO exercise required subjects balance on the stance limb (right) while the moving limb (left) was initially positioned anterior and medial to the right foot. The subject then abducted the moving left hip across the body's midline so at the end point of the RCO the elastic tubing was under tension (8.6 SD 1.4% body mass). Muscle activation of the moving limb gluteus medius was 52.9 SD 17.6% and 50 SD 25.1% for the stance limb (Youdas et al, 2014). In contrast, in an independent report, investigators examined resisted lateral band walking/sidestepping within healthy men and women. Gluteus medius muscle activation was significantly greater ($p = 0.002$) on the stance limb (49.9 SD 21.9%) than moving limb (32.8 SD 21.9%) during resisted lateral band walking (Youdas et al, 2013). The inconsistency in gluteus medius muscle activation between moving and stance limbs in these reports may be explained by the variation between movement patterns. The goal of resisted lateral band walking/sidestepping was for a subject to make a series of three successive lateral sidesteps, whereas in the present report and that by Youdas et al (2014) the purpose was to remain stationary on the WB foot while the NWB lower extremity completed three successive movement patterns against resistance provided by the elastic tubing.

Limitations

We acknowledge several limitations in our present study, including the use of healthy subjects, not measuring subjects' hip joint osteokinematics in three planes during the spiral-diagonal movement patterns, and the lack of elastic band tension feedback in real time during resisted spiral-diagonal movement patterns. Participants were young, healthy, and very active, limiting the ability to generalize our results to persons with diminished performance of the gluteus medius muscle. Further research should observe the strengthening effects of elastic-tubing resistance using spiral-diagonal patterns during standing in sedentary people with hip or knee pathology. Prior to data collection subjects were instructed to perform the four PNF diagonal movement patterns by one examiner. However, we did not record hip joint osteokinematics of the moving limb during the resisted movements so we cannot claim the magnitude of hip joint range of motion was consistent across subjects. Furthermore, we were unable to supply subjects visual tension feedback created by the elastic tubing [% BM] and recorded by the dynamometer in real time for the moving limb in each spiral-diagonal exercise condition. The ability to regulate tension feedback [% BM] in a more specific fashion may diminish variations in magnitudes of gluteus medius muscle activity within subjects.

Clinical application

From a clinical efficiency viewpoint, a fitness professional may be able to concurrently strengthen the gluteus medius muscle on both stance (WB) and moving (NWB) lower limbs of an untrained person in standing using elastic tubing to resist the spiral-diagonal movement pattern of D2F on the moving lower limb. Mean gluteus medius muscle EMG signal amplitude was about 50% MVIC (high level) and considered sufficient to stimulate strength gains in some untrained persons (Ekstrom, Donatelli, and Carp, 2007). The other three spiral-diagonal movement patterns generated moderate muscle recruitment within the gluteus medius of both moving and stance lower limbs. Such activation levels would be useful for endurance or motor control training (Ekstrom, Donatelli, and Carp, 2007).

Conclusion

During the PNF spiral-diagonal pattern of D2F (femoral-on-pelvic hip flexion, abduction, and internal rotation), an average peak EMG amplitude of 50% MVIC (high level of activation) was developed simultaneously in the gluteus medius muscle of healthy young adults on both stance and moving lower extremities when elastic band resistance (8.9% of body mass) was applied to the moving lower extremity. This level of muscle recruitment is believed sufficient to promote muscle strengthening in healthy, untrained persons.

Declaration of interest

The authors report no declaration of interest.

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