Clinical Biomechanics 27 (2012) 719–724

Contents lists available at SciVerse ScienceDirect

Clinical Biomechanics

journal homepage: www.elsevier.com/locate/clinbiomech

Progressive hip rehabilitation: The effects of resistance band placement on gluteal activation during two common exercises☆,☆☆

Edward D.J. Cambridge *, Natalie Sidorkewicz, Dianne M. Ikeda, Stuart M. McGill

Department of Kinesiology, University of Waterloo, Waterloo, Ontario, Canada

ARTICLE INFO

Article history:
Received 27 August 2011
Accepted 6 March 2012

Keywords:
Hip
Gluteal
Rehabilitation
Low back pain
Spine

ABSTRACT

Background: A critical issue for constructing a progressive rehabilitation program is the knowledge of muscle activation levels across exercises and within exercise modifications. Many exercises are offered to enhance gluteal muscle activation during functional rehabilitation but little data exists to guide the progression of exercise intensity during rehabilitation. The objective of this paper was to examine the effects of altering resistance band placement during 'Monster Walks' and 'Sumo Walks.'

Methods: Nine healthy male volunteers formed a convenience sample. Sixteen electromyography channels measured neural drive of selected muscles of the right hip and torso muscles. Three resistance band placements (around the knees, ankles and feet) during the two exercises were utilized to provide a progressive resistance to the gluteal muscles while repeated measures ANOVA with Bonferroni adjustment was used to assess differences in mean EMG. The presentation of exercises and band placement were randomized.

Findings: Examining muscle activation profiles in the three hip muscles of interest revealed the progressive nature of the neural drive when altering band placement. Tensor fascia latae (TFL) demonstrated a progressive activation moving the band from the knee to the distal band placement, but not between the ankle and foot placements. Gluteus medius demonstrated a progressive activation moving distally between band placements. Gluteus maximus was preferentially activated only during the foot placement.

Interpretation: The band placements offered a progressive increase in resistance for hip rehabilitation, specifically the gluteal muscles. The added benefit of placing the band around the forefoot was selective enhancement of the gluteal muscles versus TFL presumably by adding an external rotation effort to the hips. This information may assist those who address gluteal activation patterns for patients suffering hip and back conditions where gluteal activation has been affected.

1. Introduction

Clinically, there has been an interest in the relationship between hip and spine function since the first reporting of hip-spine syndrome (Offierski and MacNab, 1983). Since then, others (Jull and Janda, 1987; Page et al., 2010a) have suggested an association between low back pain (LBP) and gluteal muscle inhibition as part of the functional presentation in some patients with LBP. The importance of muscle imbalances as a potential predictor of LBP has also been hypothesized (Page et al., 2010b). This was supported in more recent work that demonstrated a higher occurrence of muscle imbalances in collegiate athletes with LBP compared to controls (Nadler et al., 2001). Similarly, Kankaanpää et al. (1998) demonstrated that gluteus maximus (GMax) was the limiting factor for hip and back extensor fatigue in patients with LBP. This is also true in more functional settings, in patients with LBP (Leinonen et al., 2000). Similarly, when Arab and Nourbakhsh (2010) investigated iliotibial band tightness, hip abductor strength and LBP, the only relationship identified was weaker hip abductors in the LBP group. Moreover, as a proof of principle, Nelson-Wong and Callaghan (2010) have shown that rehabilitation strategies focusing on core stability and gluteal rehabilitation are beneficial for sub-groups of LBP patients. The causal factors influencing pain and muscle inhibition remain elusive. Nonetheless, addressing gluteal activation remains a clinical objective. Due to the interplay between these two closely related regions there is a need for evidence to support spine safe rehabilitation strategies for the hip and its associated muscles in the form of a progressive rehabilitation strategy.

A variety of exercises are offered to enhance gluteal muscle activation during functional rehabilitation. Recent studies (Bolgla and Uhl, 2005; Distefano, 2009) have begun to compare muscle activation

---

☆ Presented in part by first author at Ontario Biomechanics Conference, Barrie Ontario, March 12, 2011. The data was incomplete at this time and therefore this analysis is slightly different and now complete.

☆☆ This project was funded, in part, through the Canadian Institute of Health Research (CIHR). In addition, we would like to acknowledge Natural Sciences and Engineering Research (NSERC) for their ongoing laboratory funding.

* Corresponding author at: Department of Kinesiology, Spine Biomechanics Laboratory, University of Waterloo, 200 University Avenue West, Waterloo, Ontario, Canada N2L 3G1.

E-mail address: ecambridge@uwaterloo.ca (E.D.J. Cambridge).

0268-0033/$ – see front matter © 2012 Elsevier Ltd. All rights reserved.
doi:10.1016/j.clinbiomech.2012.03.002

levels across multiple exercises that are commonly used to challenge the gluteal muscles. However, there is a paucity of information regarding the within exercise progression, specifically relating to exercise modifications. A critical question for constructing a progressive rehabilitation program is the knowledge of muscle activation levels across exercises and within exercise modifications. This knowledge will allow the clinician to design a rehabilitation program tailored to the patient's capabilities and be progressive in nature, from low to high muscle activation levels, as per the overload principle of training and rehabilitation practices (Prentice, 2003).

This research seeks to understand the influence of resistance bands on muscle activation profiles during two commonly used rehabilitation exercises. The effects of altering resistance 'mini-band' placements (around the knees, ankles and feet) during two rehabilitation exercises commonly referred to as 'Monster Walks' and 'Sumo Walks,' which use upright, semi-squat postures during gait to target increased muscle activation of the gluteal muscles and TFL, were analyzed. The central questions were, does a more distal band placement increase hip abductor activation (gluteus medius (GMed) and TFL) and can clinicians preferentially activate the gluteal muscles (GMed and GMax) with the foot band placement by creating an internal rotation moment about the hip? It was hypothesized that the more distal the band placement, the greater the activation profile in hip abductor muscles (TFL and GMed) and that the foot condition requires sufficient internal rotation moment to activate GMed and GMax preferentially over TFL. Such knowledge may inform clinical decision making and assist the implementation of progressive rehabilitation programs designed both for hip and back disorders. It would also provide clinicians with an approach to rehabilitate individuals with the clinical presentation of hip-spine syndromes that may not tolerate spine motion, yet require hip strengthening. To this end, secondary analysis of the data was conducted to examine the movement patterns observed during these exercises.

2. Methods

Participants performed two styles of modified gait exercises with three band placements, while the activation of hip muscles and three-dimensional (3D) body segment kinematics were recorded.

2.1. Participants

Nine healthy male volunteers (mean (SD); age 22.6 (2.2) years; height 181.9 (9.2) cm; mass 85.8 (15.4) kg) formed a convenience sample from the University community. The participants were given a verbal explanation of the preparation and testing procedures. Once acquainted with the general setup, each participant read and signed the informed consent approved by the University Office of Research Ethics Board (ORE). Participants were absent of low back, hip and lower extremity pain and did not have a history of disabling injury nor surgery to these areas.

2.2. Tasks

The two exercises examined in this study were semi-squat, upright modifications of walking gait (Fig. 1). The first exercise was colloquially referred to as 'Monster Walks' and was performed in the sagittal plane. The participants were instructed to maintain a hip width stance while overcoming the medial resistance of the elastic band. The second exercise, referred to as 'Sumo Walks,' were simply 'side step outs' performed in the frontal plane. The three band positions were consistent for each exercise. The band placements were

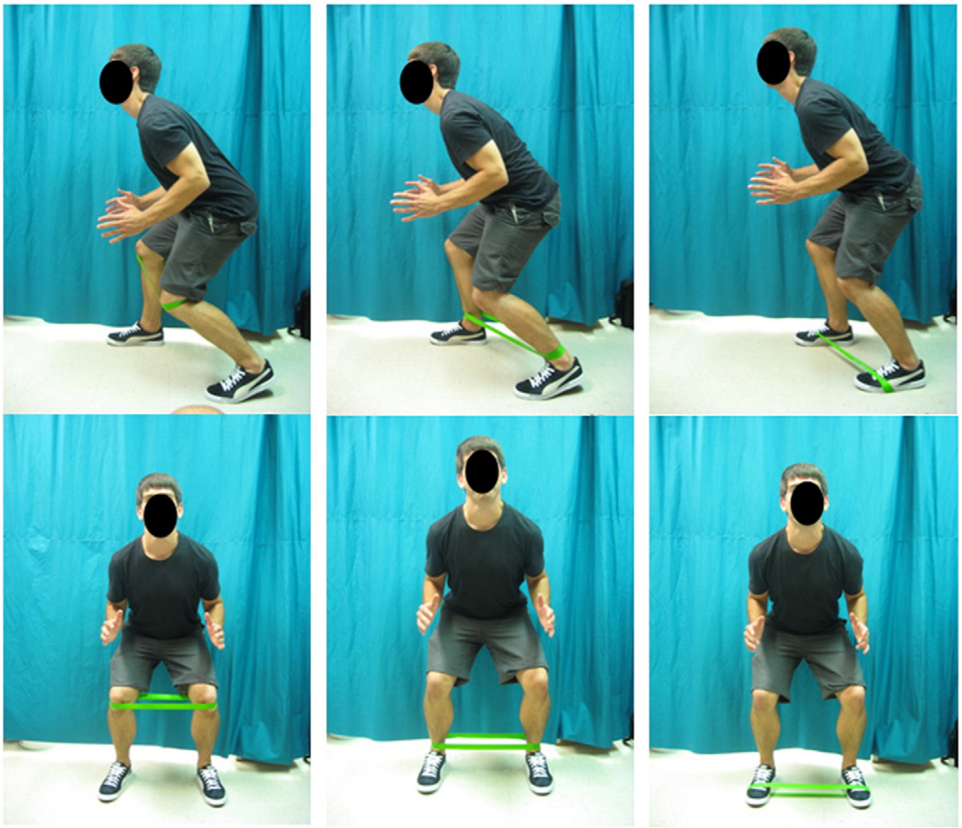

Fig. 1. Band placements of the three conditions knee, ankle and foot from left to right, respectively, and the two exercises Sumo Walks (top) and Monster Walks (bottom). The knee condition was defined with a placement over the participant's tibial tuberosity; ankle placement was over the lateral malleolus; and the foot placement was located over the forefoot which was shod.

at the tibial tuberosity (knee placement), lateral malleoli (ankle placement), and around the forefoot (foot placement). For each exercise and band placement, the participants were instructed to brace the trunk muscles and maintain a neutral spine and ensure as pure and isolated hip and lower limb movement as possible. Instructions were also given to move slowly and controlled not allowing the band to control the speed of movement.

2.3. Data collection

The participants were first prepared for electrode placement by shaving, abrading the skin with Nuprep and cleaning with a 50/50 ethanol/water solution. The electrodes were located bilaterally over rectus abdominis (RA), external oblique (EO), internal oblique (IO), upper and lower erector spinae (UES, LES) and latissimus dorsi (LD). In addition, the right GMed, GMax, TFL and biceps femoris (BF) were recorded. Electrode locations of all 16 leads are shown in Fig. 2.

Subjects then performed five separate maximal voluntary contraction (MVC) trials to normalize electromyography (EMG) signals and facilitate physiological interpretation. The five trials included an abdominal trial, Biering–Sorensen, hip abduction, knee flexion/hip extension and shoulder adduction efforts. Each of the MVC trials was manual resisted by the experimenter. The abdominal MVC trial was conducted in a seated position with the trunk inclined 60° from a supine position and consisted of five contractions: isometrically controlled flexion, right and left rotation, and right and left lateral bending. In the Biering–Sorensen test, the subject was prone and cantilevered over a treatment table with the anterior iliac crests at the edge of the table. They were asked to first concentrate the extension effort to the lumbar extensors (pars lumborum of longissimus thoracis and iliocostalis lumborum) muscles and then create full extension from the thoracic erector spinae (pars thoracis) and GMax muscle groups. The hip abduction trial was conducted with the participant in a side lying position with the hips stacked vertically. The participant was instructed to create resistance vertically in the frontal plane and to avoid any anterior or posterior deviation. The hamstrings MVC was performed in a knee flexion/hip extension contraction and was conducted with the participant laying prone. First the participant was instructed to maximally flex the knee only and then extend the hip while flexing the knee to maximally activate both neurological components of BF. Lastly, the participant, in a standing posture, held their humerus in a flexed and abducted position and were instructed to extend and adduct the humerus for maximal LD activation.

Once the MVC trials were complete, the participant was prepared for motion capturing using 18, 10 mm diameter reflective markers and 8, four marker clusters. The exact location of the 50 reflective markers is shown in Fig. 2. Next, a calibration trial was collected for creating an individual anatomical model, which allowed the system to track only on the cluster formations for the remainder of the trials.

The order of presentation was randomized between the two exercises and the band placements (Fig. 3). The participants were given an explanation of each exercise prior to performing the exercise. In addition, time was permitted to practice the techniques of each specific modification. Testing commenced once the subject demonstrated skilled performance of the exercise, usually no longer than 2 min was required, or a few attempts, to familiarize the participant with the desired movement pattern. The subject then completed three consecutive trials of each modification and exercise as per the randomized order.

Bipolar electrode configuration was achieved using Ag-AgCl (Meditrace 130 Ag/AgCl electrodes, Covidien, MA, USA) self adhesive electrodes. EMG was collected from 16 channels which were differentially amplified (CMRR of 115dß at 60 Hz; input impedance: 10 MΩ; Model AMT-8, Bortec Biomedical, Calgary, Canada) and then passed through an A/D converter sampled at 2160 Hz (16 bit, 64 channels with an input impedance of 1 MΩ and a common sampling rate) and collected on a Vicon Antec Intel Core 2 Duo PC using Vicon Nexus 1.5 software. The system was also used to collect kinematic data from 50 reflective markers, sampled at 60 Hz from eight optoelectronic cameras. The data was then saved and stored for processing and analysis in LabView and MATLAB (version R2010b) custom written programs. The resistance bands were Mini-Bands from PerformBetter.com and the 'green' level of resistance was used for all participants and conditions. The full participant setup of the apparatus is shown in Fig. 2.

2.4. Data analysis

Force plate data was filtered initially with a low-pass filter (LPF) at 15 Hz, to remove any noise artefacts in the original signal using Visual 3D. Once the data was filtered, 3D linked segment skeletal model of the subject (using Visual 3D software) computed joint angles and moments. Kinematic data was filtered with a Butterworth LPF (cutoff frequency at 6 Hz) to enhance physiological interpretation of the kinematics. Using the kinematic data, take-off and contact time points of the right foot were identified and the data was clipped at these locations for later analysis.

LabView was used to write a custom program for EMG processing. The program removed any offset bias (using the quite lying trial) and created a dual pass bandpass filter for the EMG data (30–500 Hz). The signals were then full wave rectified (FWR), and filtered with a Butterworth filter at 2.5 Hz, to create a linear envelope mimicking the

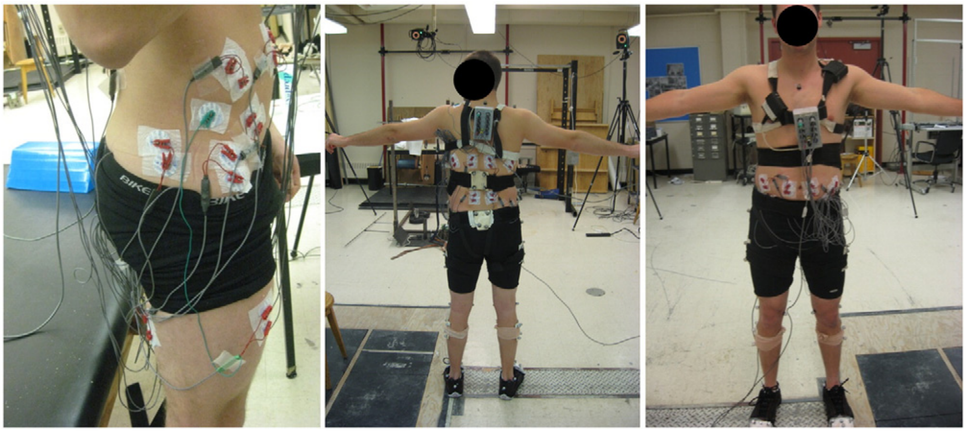

Fig. 2. Electrodes and markers are shown here. Reflective markers over the bony landmarks and marker clusters used over the thoracic and sacral spine as well as the thigh, shank and forefoot, bilaterally. EMG electrodes placed over the core muscles and right leg muscles.

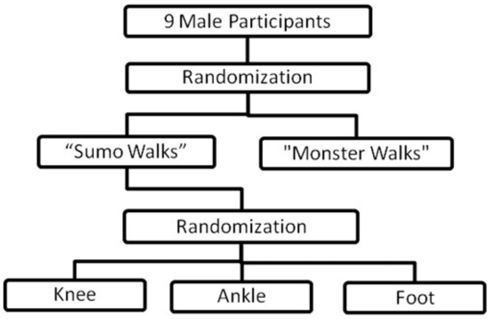

Fig. 3. Schematic of the presentation of randomization design.

frequency response of muscle (Brereton and Mcgill, 1998) and normalized to the previously obtained MVC level. Finally, the EMG signal was down sampled at 60 Hz to enhance physiological interpretation of the EMG and synchronization with the kinematic data.

Lastly, a MATLAB routine was used to calculate the mean EMG amplitude for each trial as well as to take the mean/median of the three trials for each subject. Data was output into a Microsoft Excel spreadsheet and then transposed into SPSS (Version 19, IBM Corporation, Somers, New York, USA) for statistical analysis.

2.5. Statistical tests

A repeated measures analysis of variance (ANOVA) was used to compare the main effects of the band placement on peak EMG for each respective muscle. The lower-bound correction factor for the test of Epsilon was used to ensure that sphericity was not violated. If the omnibus test demonstrated a main effect, pair-wise comparisons were investigated with a Bonferroni post hoc test for pair-wise comparisons to avoid spurious results. Statistical significance was held at alpha = 0.05. In addition, a post hoc power analysis using the observed power function in SPSS was used and a factor of greater than 0.80 was required for each analysis, there were no conditions below this cut off. As a result the analysis was confirmed for the sample size and the changes in biological signals are genuine.

2.6. Secondary analysis

Analysis of hip and spine, posture and movement, was considered given the importance of hip and spine integration mentioned above. Kinematic joint angles for the hip and spine were computed in Visual 3D across each trial, the means and standard deviations (SD) were then calculated to evaluate the posture and movement patterns. No additional statistics were used in this section as these results are merely descriptive in nature.

3. Results

EMG and kinematic data for each of the exercises and conditions demonstrated a phasic pattern coinciding with the gait patterns. Specifically, peak EMG spikes were observed at or near foot contact, as this demonstrated the position of maximal band stretch in both exercises. Due to the observed variability in peak EMG activation levels, the mean EMG was selected to represent activation patterns. This was also thought to best represent the overall effort exerted by a patient prescribed these exercises.

Mean (SD) EMG values for the Sumo and Monster Walks are shown graphically in Figs. 4 and 5, respectively. Repeated measures ANOVA was performed for both exercises to compare the three band placement activation demands on TFL, GMed, and GMax. TFL, GMed and GMax revealed differences among the band placements for Sumo walks and Monster walks ($F = 17.458$, $P < 0.001$, $F = 18.489$, $P < 0.001$, $F = 9.761$, $P < 0.002$) and ($F = 26.206$, $P < 0.001$, $F = 19.492$, $P < 0.001$, $F = 7.282$, $P = 0.006$), respectively.

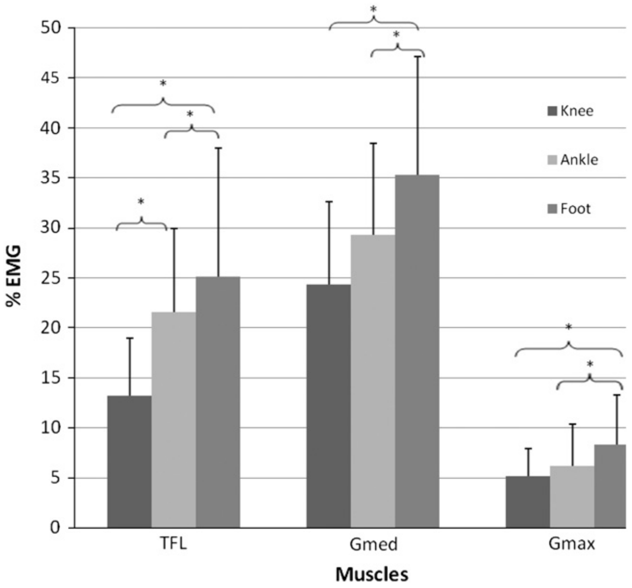

Fig. 4. Mean EMG Sumo walks is shown here with error bars set to the respective SD. A progressive activation is observed in general with the GMed activation. Notice the pattern TFL does not show a significant increase with the foot placement; while the GMax only increases significantly with the foot placement. *Statistical significant difference.

TFL activation increased between knee and ankle placement ($P = 0.002$) and between knee and foot placement ($P = 0.007$). No significant increase in mean EMG for TFL was found between ankle and foot ($P = 0.265$) for the Sumo walk exercise. For the Monster walk exercise, TFL demonstrated an increased activation level from knee to ankle ($P = 0.001$) and knee to foot ($P = 0.001$) placements. There was no increase in activation of mean EMG for TFL from the ankle to foot conditions ($P = 0.30$).

For the Sumo walk exercise, GMed demonstrated a nearly significant relationship, trending an increase activation level between knee and ankle conditions ($P = 0.06$). The foot condition required significantly more activation than the knee ($P = 0.001$) and ankle

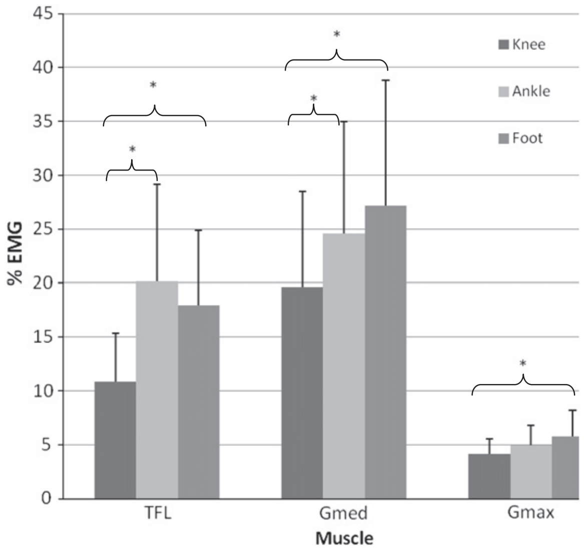

Fig. 5. Mean EMG for the Monster walk exercise is shown here with error bars set to the respective SD. Monster walks demonstrates the progressive nature of the activation patterns. Generally, GMed increases with distal band placement, while TFL is unaffected with the foot placement and GMax only increases with the foot placement. *Statistical significant difference.

Table 1
Mean (SD) of the joint angle during exercise.

	Exercise	Condition	Flex/Exten	Ab/Ad	Medial/lateral
Hip					
	Monster Walk				
		Knee	24 (12)	−9 (5)	−22 (9)
		Ankle	28 (14)	−7 (5)	−20 (10)
		Foot	25 (14)	−5 (5)	−21 (9)
	Sumo Walk				
		Knee	29 (13)	−9 (5)	−18 (10)
		Ankle	23 (10)	−11 (4)	−23 (7)
		Foot	25 (11)	−8 (6)	−19 (9)
Spine					
	Monster Walk				
		Knee	15 (11)	0 (2)	−1(1)
		Ankle	16 (10)	0 (2)	−1(1)
		Foot	15 (8)	0 (2)	−1(1)
	Sumo Walk				
		Knee	17 (14)	−2 (3)	−2 (2)
		Ankle	18 (12)	−2 (3)	−1 (2)
		Foot	18 (12)	−3 (3)	−1 (1)

*Note: The average spine angle is very close to neutral with the exception of the flexion/extension axis where the spine was in moderate flexion. Flexion, adduction, and internal rotation are positive values.

($P=0.04$) conditions. During the Monster walks, GMed revealed a progressive increase from the knee to ankle ($P=0.01$) and foot ($P=0.001$) conditions, with only a trending increase from the ankle to foot condition ($P=0.14$), during the Monster walk exercise.

During the Sumo exercise, GMax activation patterns for the foot condition required an increase in GMax activation with significant increases between knee and foot ($P=0.03$) and ankle and foot conditions ($P=0.01$). Similar to the Sumo exercise, GMax activation significantly increased from the knee to foot conditions ($P=0.03$), with no significant difference between knee to ankle ($P=0.129$) and ankle to foot ($P=0.35$) placements.

3.1. Secondary analysis

Secondary descriptive analysis was conducted to ensure that spine motion was minimized during these exercises. The mean joint angles for the hip and spine are shown in Table 1. It was observed the spine was maintained in a neutral position (anatomical) with only a moderate offset towards a flexed posture. Next, the SD of spine and hip motion is provided in Table 2. It was also observed that the spine had very small variation in motion as described by the SD of joint angle throughout the trial. This reflects that the spine was held in a near neutral posture and motionless during this gluteal challenge exercise.

Table 2
Means of the joint angle standard deviation during the exercise.

	Exercise	Condition	Flex/Ext	Ab/Ad	Medial/lateral
Hip					
	Monster Walk				
		Knee	5.6	2.6	2.8
		Ankle	4.8	2.3	2.7
		Foot	4.7	2.1	2.7
	Sumo Walk				
		Knee	3.3	4.8	3.7
		Ankle	3.5	4.8	3.2
		Foot	2.7	4.5	2.6
Spine					
	Monster Walk				
		Knee	2.3	1.2	3.0
		Ankle	2.2	1.3	2.8
		Foot	2.2	1.5	2.9
	Sumo Walk				
		Knee	1.6	0.7	0.5
		Ankle	1.3	0.4	0.5
		Foot	2.1	0.8	0.5

*Small variance in the joint angles of the spine is observed. Even when compared to the hip which was restricted by the resistance band the spine remains motionless. This demonstrates the ability to perform these exercises with limited spine motion.

4. Discussion

Distal band placements offered a significantly higher activation level of gluteal muscles, when compared to the proximal conditions, which supports the first hypothesis. By moving the band from the knee to the ankle and foot, GMed mean activation increased by ~20% and ~45%, respectively for the Sumo walk exercises and ~25% and ~40%, respectively for the monster walk exercise. In addition, the added value of the foot condition created an external rotation moment, which increased GMax mean activation significantly from the knee condition by a magnitude of ~60% and ~40% for the Sumo and Monster exercises, respectively. This supports the hypothesis that the foot position would create added clinical value to the gluteal activation by creating an external rotation moment that is overcome by gluteal muscles. Moreover, there was no significant increase in TFL during the foot condition, demonstrating the ability to preferentially activate the gluteal muscles. This supports the hypothesis that the foot condition will preferentially activate the gluteal muscles, as they are external rotators of the hip.

These authors are unaware of other studies examining this type of progression during rehabilitation exercises. However, based on this data these two exercises ought to be included with the family of gluteal activation strategies available for clinicians (Bolgla and Uhl, 2005; Distefano, 2009). Additional consideration is warranted for the patient suffering from LBP, as some of these traditional exercises such as single-limb deadlift exercises (Distefano, 2009) and hip hikes (Bolgla and Uhl, 2005) may create excessive motion in a motion intolerant patient. These authors suggest that the patient with sensitivities to spine motion may fair better with the current exercises, together with proprioceptive sandals (Bullock-Saxton et al., 1993), clamshell exercises and back bridge (Nelson-Wong and Callaghan, 2010) exercise, all of which have been suggested to emphasize hip strength and a fixed spine. This would be critical in those patients intolerant of spine motion, yet deficient in gluteal function.

In addition to the specific findings presented here, this data presents a general strategy that can be used when designing progressive rehabilitation strategies using principles of biomechanics. Understanding the relationships between the axis of rotation, the moment arm length (the distance of the band to the axis of rotation), and the effective force (in this case the resistance band placement) will allow the clinician to create a progressive training regime. By maintaining the same effective force (band resistance) and altering the length of the moment arm, graded increases in the required muscle activation should be expected as seen in these results. Moreover, utilizing an additional axis of rotation and therefore adding an additional effective moment arm, one can create targeted muscle activation patterns. In this study, the preferential activation of the gluteal muscles over the TFL was achieved through the conflicting functions of these muscles. Using a moment arm provided by the foot to create an internal rotation moment about the hip, requiring an additional effort to counter this moment. The gluteal muscles contributing to external rotation, while the TFL contributing to internal rotation of the femur, provided the ability to create these activation profiles. The clinician must be acutely familiar with the anatomy and biomechanics in order to successfully accomplish this fine tuning of an otherwise general exercise.

A limitation in this study was the choice of resistance band stiffness. The authors elected to use one grade of resistance for all subjects. This would lead to increased variation in normalized EMG since some participants found the resistance band to be a great challenge while others were not challenged to the same extent. This explains much of the variation in activation levels, though the patterns were consistent among subjects. Another limitation was the ability to capture only the superficial musculature of the hip. While indwelling EMG would be appropriate for monitoring deep muscle of the hip, the dynamic nature of these exercises would not permit its use in an effective manner.

5. Conclusions

The band placements examined here during modified gait exercise provide a progressive gluteal challenge, while maintaining spine posture by minimizing spine motion. In addition, the foot condition was able to preferentially target the gluteal muscles while not affecting the TFL amplitude. The exercises tested here facilitated a stiffened and neutral spine that would be helpful for the patient who is motion intolerant together with those who desire better hip function and focus on gluteal muscles that may have been inhibited due to pain. These exercises can also be considered when designing programs for the population of motion intolerant LBP patients that may require gluteal training.

Acknowledgments

This project was funded, in part, through the Canadian Institute of Health Research (CIHR). In addition, we would like to acknowledge Natural Sciences and Engineering Research (NSERC) for their ongoing laboratory funding.

References

Arab, A.M., Nourbakhsh, M.R., 2010. The relationship between hip abductor muscle strength and iliotibial band tightness in individuals with low back pain. Chiropr. Osteopath. 18, 1.

Bolgla, L.A., Uhl, T.L., 2005. Electromyographic analysis of hip rehabilitation exercises in a group of healthy subjects. J. Orthop. Sports Phys. Ther. 35, 487–494.

Brereton, L.C., Mcgill, S.M., 1998. Frequency response of spine extensors during rapid isometric contractions: effects of muscle length and tension. J. Electromyogr. Kinesiol. 8, 227–232.

Bullock-Saxton, J., Janda, Vladimir, Bullock, M., 1993. Reflex activation of gluteal muscles in walking. Spine 18 (6), 704–708.

Distefano, L.J., 2009. Gluteal muscle activation during common therapeutic exercises. J. Orthop. Sports Phys. Ther. 39 (7), 532–540.

Jull, G.A., Janda, V., 1987. Muscles and motor control in low back pain: assessment and management. In: Twomey, L.T. (Ed.), Physiotherapy of the Low Back. Churchill Livinstone, New York, pp. 253–278.

Kankaanpää, M., Taimela, S., Laaksonen, D., H(a)nninen, O., Airaksinen, O., 1998. Back and hip extensor fatigability in chronic low back pain patients and controls. Arch. Phys. Med. Rehabil. 79 (4), 412–417.

Leinonen, V., Kankaanp(aa), M., Airaksinen, O., H(a)nninen, O., 2000. Back and hip extensor activities during trunk flexion/extension: effects of low back pain and rehabilitation. Arch. Phys. Med. Rehabil. 81 (1), 32–37.

Nadler, S.F., Malanga, G.A., Feinberg, J.H., Prybicien, M., Stitik, T.P., DePrince, M., 2001. Relationship between hip muscle imbalance and occurrence of low back pain in collegiate athletes. Am. J. Phys. Med. Rehabil. 80 (8), 572–577.

Nelson-Wong, E., Callaghan, J.P., 2010. Changes in muscle activation patterns and subjective low back pain ratings during prolonged standing in response to an exercise intervention. J. Electromyogr. Kinesiol. 20 (6), 1125–1133.

Offierski, C.M., MacNab, I., 1983. Hip-spine syndrome. Spine 8, 316–321.

Page, P., Frank, C.C., Lardner, R., 2010a. Structural and functional approaches to muscle imbalances. Assessment and treatment of muscle imbalance: The Janda Approach. Champaign, Illinois, pp. 3–12.

Page, P., Frank, C.C., Lardner, R., 2010b. Pathomechanics of musculoskeletal pain and muscle imbalances. Assessment and Treatment of Muscle Imbalances: The Janda Approach. Champaign, Illinois, pp. 43–55.

Prentice, W.E., 2003. Using therapeutic exercise in rehabilitation, Athletic Training: A Competency-Based Approach, 11th ed. , pp. 414–442.