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ORIGINAL RESEARCH

GLUTEAL MUSCLE ACTIVITY DURING WEIGHTBEARING AND NON-WEIGHTBEARING EXERCISE

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ABSTRACT

Background: Researchers suggest that decreased strength of the gluteus medius (GMed) and the gluteus maximus (GMax) muscles contributes to the etiology of various orthopedic pathologies of the knee. Currently, equivocal evidence exists regarding Electromyography (EMG) activity of gluteal musculature during weightbearing (WB) and non-weightbearing (NWB) exercise. The purpose of this study was to compare GMed and GMax muscle activation during WB functional exercise and NWB 10 repetition maximum (RM) exercises.

Methods: Surface EMG electrodes recorded the muscle activity of the GMax and GMed as subjects performed three sets of 10 repetitions of the following exercises: (1) forward step-up, (2) lateral step-up, (3) 10 repetition maximum (10 RM) side-lying hip abduction and (4) 10 RM prone hip extension. The 10 RM resistances were determined one week prior to data collection.

Results: The GMed was recruited significantly more during side-lying 10 RM than the remaining exercises (side-lying, 99.9 ± 17% vs. lateral step-up, 61 ± 20%; Forward step-up, 62.7 ± 18.2%; prone, 38 ± 22.2%) ($p < 0.001$). The GMax was recruited to the greatest extent during prone 10 RM hip extension (prone, 100.7 ± 14.5% vs. forward step-up, 28.7 ± 18.7%; lateral step-up, 31 ± 19.9%; side-lying, 38 ± 23.3%)($p < 0.001$).

***Discussion*:** These results suggest that performing a 10 RM NWB exercise results in greater muscle activation than two functional WB exercise without load in young, healthy individuals. In addition, forward and lateral step-ups failed to effectively recruit the GMax at a high enough level to achieve a strengthening stimulus. The GMed was recruited to a higher extent than the GMax during the stepping tasks which might be further augmented if the activity is performed with an additional external load.

***Key Words*:** Electromyography, functional, hip strengthening

***Level of Evidence*:** III

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INTRODUCTION

The relationship between weak proximal musculature and movement impairments of the lower extremity is a commonly accepted etiology for multiple knee pathologies.[1,2,3] In particular, the gluteus medius (GMed) and gluteus maximus (GMax) are thought to eccentrically control femoral internal rotation and hip adduction movements during functional activities.[4,5] Weakness of posterior-lateral gluteal musculature has been reported to contribute to the etiology of various orthopedic pathologies of the knee, such as patellofemoral pain syndrome or knee arthritis.[1,3,6,7] Shields et al state that rehabilitation regimens that use closed chain weightbearing (WB) exercises are preferred because they better mimic functional movements.[8] Lubahn et al stated that all lower extremity joint and muscular forces are interconnected and that weakness at any one element can affect the entire chain.[9] Therefore, any underlying isolated muscular weakness needs to be addressed to prevent further injury that functional motions can cause.

Numerous authors have attempted to quantify gluteal muscle activation during various types of therapeutic exercise.[3,10,11,12,13,14,15] In order to achieve strengthening, researchers have suggested that EMG muscle activity should reach a minimum of 40%-60% of maximum voluntary isometric contraction (MVIC).[16] Accordingly, there is a growing consensus regarding exercises that elicit sufficient electromyography (EMG) activity in GMed and GMax in order to produce strength gains.[3,10] These include non-weight bearing (NWB) exercise, such as side-lying abduction, but also WB exercises including squats, single limb squats, lunges, and others.[13,17,18] However, findings that report the exact magnitude of muscle recruitment during WB and NWB exercises are inconsistent, and therefore, the differences between WB and NWB exercise remain unclear.[2,3,17]

In the clinical rehabilitation setting, forward and lateral step-ups are typically used by physical therapists without the application of an external load. Conversely, NWB exercises commonly utilize an external load in order to maximize muscle activity. The American College of Sports Medicine suggests that training paradigms in novice healthy adults should be initiated using 8-12 repetitions when attempting to improve performance and strength.[18] In an effort to utilize NWB exercise appropriate for strength gains, the current study utilized external loads equivalent to the individual's 10 RM.

Due to the lack of evidence, the purpose of this study was to compare GMed and GMax muscle activation during WB functional exercise and NWB 10 RM exercises. The hypothesis of this study was that there would be a significant difference in the GMed and GMax average EMG activity during WB exercise and NWB exercise.

METHODS

Experimental Approach to the Problem

A single-day observational study was used for this investigation. Consistent parameters were used to allow for EMG comparison between exercises. The independent variable in this investigation was the exercise technique (forward step-ups, lateral step-ups, 10 RM side-lying hip abduction, and 10 RM prone hip extensions). The dependent variables were GMed and GMax average muscle normalized recruitment that occurred throughout the exercise. Forward step-ups and lateral step-ups were chosen because they were the most commonly reported WB activities that target both the GMed and GMax.[3,18] Side-lying hip abduction and prone hip extension were chosen for the NWB exercises because they have been shown to effectively isolate the GMed and GMax, respectively.[17] The 10 RM load was chosen as the amount of external load to meet the current standards necessary to elicit sufficient muscle recruitment necessary for strength gains, put forth by the American College of Sports Medicine, thus allowing an apt comparison between WB and NWB activities.[16,19]

Subjects

The Quinnipiac University Institutional Review Board approved the experimental protocol of this prospective study. All subjects read and signed an informed consent prior to participating in the study. To be included in the study subjects were required to meet the following inclusion criteria: (1) no history of lower extremity pain within the previous year, (2) 18 to 25 years of age, and (3) have not actively participated in lower extremity resistance

Table 1. *Subject Demographics. Data are expressed as mean ± standard deviation.*

Subject Demographics		
	Male (n=14)	**Female (n=20)**
Age (years)	21.2± 1.8	21.7±1.6
Weight (kg)	77.1±8.9	58.1±6.2
Height (cm)	177.8± 15.3	163.2±6.7

training in the previous six months. Recruitment followed a generalized convenience sampling protocol, accepting subjects as they responded to posted fliers, electronic advertisement, and word of mouth. Thirty-four subjects met the inclusion criteria and were enrolled in this study (Table 1).

EMG Equipment

A 16-channel telemeter EMG system was used to record GMed and GMax muscle activity unilaterally (Motion Lab Systems, Baton Rouge, LA). In an effort to minimize skin impedance, regions accepting surface electrodes were shaved with hand held razors and subsequently scrubbed vigorously with alcohol swabs for approximately 30 seconds. Active surface electrodes were secured to the skin via adhesive athletic tape. Surface electrodes over the GMed muscle belly were placed 2–3 cm distal to the midpoint of the iliac crest.[18,20] Electrodes were configured parallel to the suspected orientation of the muscle fibers.[20] The placement of the electrodes for the GMax was 33% of the distance between the second sacral vertebra and the greater trochanter.[18,20] Inter-electrode distance from center-to-center was 20 mm and each respective electrode surface was 15 mm in diameter. A dispersive electrode was placed on the skin overlying the anterior-medial aspect of the proximal tibia on the ipsilateral lower extremity. Electrode placements were verified by manual muscle testing to ensure the accuracy of subsequent measurements. Wires from the electrodes were connected to a transmitter attached in a secure fashion to the apparel on the subject's lower extremities. The differential amplifier of the EMG system had an input impedance of greater than 1.0 MΩ, a common mode rejection ratio of greater than 90 dB, and a signal-to-noise ratio of greater than 50 dB. The signals were sampled at 4,000 Hz per channel and recorded with Cortex software (Motion Analysis Corporation, Santa Rosa, CA).

Subject Instruction

Two weeks prior to data collection, subjects were instructed on how to complete the four exercises selected for this study. This instruction was completed by one of the investigators with a license in physical therapy and more than 20 years of experience. Subjects were given greater than 30 minutes to learn these four therapeutic exercises, and were given instruction via verbal and tactile cues to ensure appropriate technique. Exercises needed to be performed within a single plane within a full joint range of motion using a smooth coordinated movement pattern. Appropriate time and instruction was given to ensure that all subjects were able to consistently and accurately perform all therapeutic exercise without variation from what was considered proper technique.

The subjects returned one week after exercise instruction session for 10 RM testing for hip abduction and extension. Hip abduction was tested in side-lying with the external cuff weight attached to the ankle. Hip extension was tested in prone, the knee in 90 degrees of flexion, and the cuff weight attached to at the distal femur. Following commonly accepted procedures, a 1 RM was collected and the subject's 10 RM was determined using procedures from Baechle et al.[21] To determine the 1 RM, sequentially heavier weights were added until the subject was no longer able to complete the full range of motion. The second session also provided subjects with another opportunity to practice their exercise technique under supervision.

EMG Testing Protocol

EMG data collection occurred one week after 10 RM testing. All subjects were required to wear appropriate athletic clothing that allowed easy access to the hip (loose shorts, short sleeved shirt, and athletic footwear). To determine the dominant lower extremity, subjects were asked with which leg they would most likely kick a soccer ball.

Normalization Procedures

The first task was to record the GMed and GMax muscle activity of the subjects dominant leg during three maximum voluntary isometric contraction (MVIC) trials. Subjects held each MVIC for five seconds. For the GMed, the subject was placed in the side-lying position and was asked to raise their lower extremity to approximately 50% of their total available active range of motion in the frontal plane. An investigator then provided equal and opposite resistance to the lateral femoral condyle of the subject's lower extremity while they provided their maximum voluntary effort for three repetitions. A rest period of one second was provided between repetitions. For the GMax, the subject was then asked to turn over into the prone position with the knee at 90 degrees of flexion, and was again asked to raise the dominant lower extremity to approximately 50% of their available active range of motion in the sagittal plane while the investigator provided manual resistance at the distal femur on the posterior aspect of the thigh. A handheld dynamometer was used to ensure consistency of maximal effort on all repetitions. To establish the peak value to be used for normalization, peak EMG activity was determined during a five second period for the GMed (hip abduction) and GMax (hip extension) MVIC trials. The highest peak EMG collected during any of the three MVIC trials was used for normalization.

Exercise Data Collection

Weightbearing exercises were performed using the dominant lower extremity without any additional load. Five repetitions and three sets of data were completed with a three minute rest period between each set. During the WB exercises, the dominant lower extremity remained on the step throughout all five repetitions. One repetition consisted of the subject lifting his or her body mass up onto the step until the dominant knee reached full extension and then lowering his or her body mass toward the floor. The repetition ended when the toes of the non-dominant leg made contact with the floor. Throughout the exercise, the non-dominant leg did not make contact with the step. Step-ups were performed using a 6-inch platform over a two second period. Subjects performed both forward and lateral step-ups. (Figures 1a & 1b)

Non-weightbearing side-lying hip abduction and hip extension were completed with each subjects' previously determined 10 RM. Subjects performed three sets of five repetitions with a three minute rest period between each set.

10 RM side-lying abduction: The subjects were placed on the side opposite the EMG electrodes. Subjects were asked to raise the tested extremity through the frontal plane and then back down to the neutral position. The external load was applied at the level of the malleoli. Subjects were instructed to remain in the frontal plane and avoid hip external rotation.

10 RM prone hip extension: Subjects were placed in the prone position. The subjects were then asked to raise the involved limb until they reached full hip extension without pelvic tilt, and then back down to the neutral position. The knee was flexed to 90 degrees with the external load attached to the distal femur. A trained research assistant visually monitored each repetition to ensure the exercise was performed correctly. If a subject had difficulty performing any exercise correctly, data collection was stopped and verbal instructions were provided. Following a three minute rest period, data collection resumed. The order of exercise was randomly selected using a random number generator. (Figures 2a & 2b)

Data Analysis

Raw sEMG signals for both MVIC trials and the exercises were bandpass filtered at 20–450 Hz and a Root Mean Square (RMS) method with a moving average window of 50 ms, utilizing using Labview software

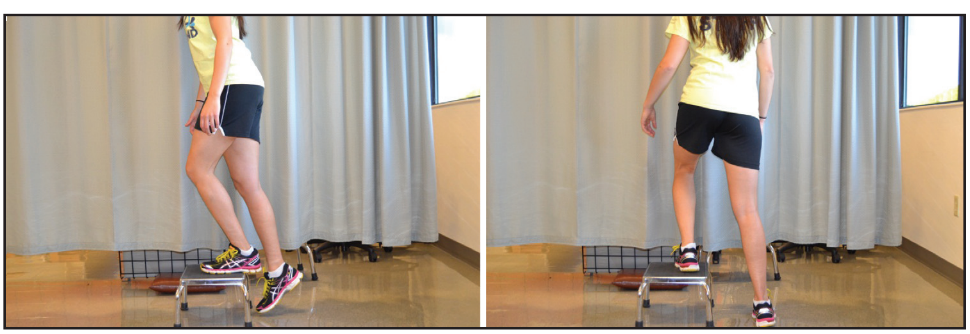

Figure 1. *Forward and lateral step-ups.*

Figure 2. *10 RM prone hip extension and side-lying hip abduction.*

(National Instruments Corporation, Austin, Tx). A Matlab software program (MathWorks, Natick, MA) was used to identify the start and end of the repetitions for the dynamic exercises (for the MVIC, the middle five seconds were used). The onset of the repetitions was defined when the muscle activity exceeded the mean resting value by more than three standard deviations for greater than 30 ms. The repetition was completed (offset) when the muscle activity fell below three standard deviations of the mean resting value for 30 ms.[22]

A normalized subject average EMG for the GMed and GMax was calculated for each exercise. To calculate a repetition average EMG for the WB and NWB exercises, the sum of the EMG area under the curve was divided by the total number of data points for each of the middle three repetitions collected during each trial. The 1st and 5th repetitions were not included in data analysis. Each of the three repetition average EMGs were subsequently divided by the peak MVIC and expressed as percentage of MVIC (%MVIC). This procedure was repeated for all trials for each muscle. For each exercise, the % MVIC repetition averages were averaged across all trials to calculate a subject average.

Statistical Analysis

EMG signal amplitudes for the GMed and GMax were compared among exercises using separate repeated-measures one-way analysis of variance (ANOVA). In the event of a significant main effect, a Sheffé post hoc test was used to compare exercises for each muscle. In addition, a reliability analysis, using intraclass correlation coefficients (ICCs) across the 3 repetitions of each exercise, was used to confirm that the EMG measures were stable within subjects. Statistical significance was set at an alpha of 0.05. SAS, Version 9.2 (SAS Institute Inc., Cary, NC) was used for all statistical analyses.

RESULTS

There was a significant main effect observed among the four exercises for GMed ($p < 0.001$; observed power 0.94) and GMax mean muscle activity ($p < 0.003$; observed power 0.91). Sheffé post hoc analysis revealed that the 10 RM side-lying hip abduction exercise produced significantly greater activation of the GMed versus the remaining three activities (Figure 3). There were no significant differences in GMed activity between forward and lateral step-ups ($p = 0.55$). Accordingly, the 10 RM prone hip extension exercise demonstrated the highest EMG activity, for the GMax (Figure 4). Similar to the GMed, the GMax activity was not significantly

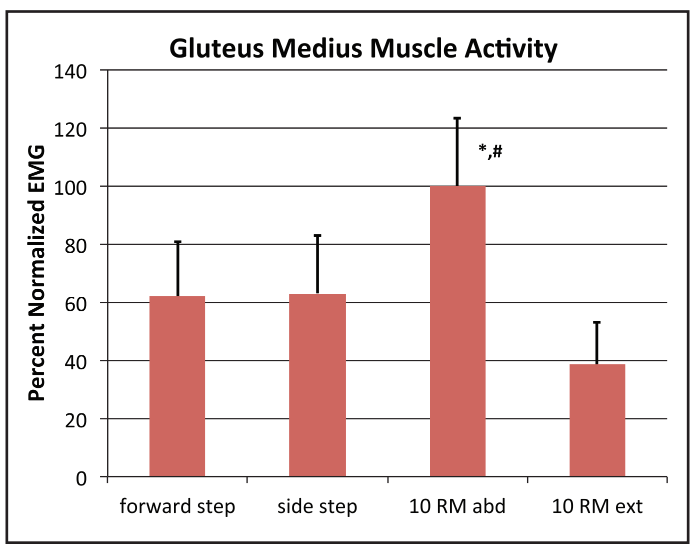

Figure 3. *Normalized Gluteus Medius EMG output between exercises. *, # indicates statistically significant differences between 10 RM Abd and forward and lateral step up exercises.*

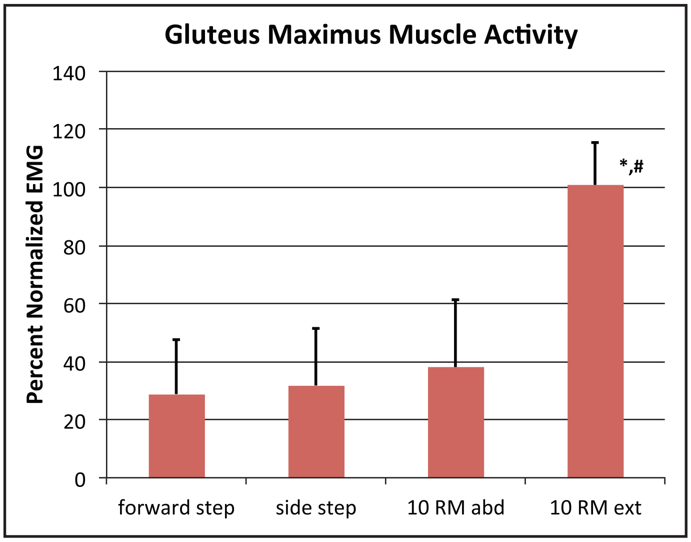

Figure 4. *Normalized Gluteus Maximus EMG output between exercises. *, # indicates statistically significant differences between 10 RM Ext and forward and lateral step up exercises.*

different between the two WB activities ($p = 0.67$). The GMax within-subject ICCs ranged from 0.88 to 0.99 for each exercise and the GMed within-subject ICCs ranged from 0.91 to 0.99.

DISCUSSION

The purpose of this study was to compare the recruitment of GMed and GMax during WB and NWB therapeutic exercises. The authors' hypothesis was that there would be a significant difference in recruitment during WB and NWB therapeutic exercise. The results from this study suggest that performing a 10 RM NWB exercise (99-100% MVIC) results in greater muscle activity than a functional WB exercise without load (28-62% MVIC). In addition, the current data suggests that forward and lateral step-ups fail to effectively recruit the GMax to greater than 40%-60% MVIC as has been reported necessary for strengthening purposes.[16] In the current study GMed was recruited to a higher extent than GMax during the stepping tasks.

DiStefano et al[4] reported a significantly higher %MVIC for NWB side-lying abduction relative to advanced WB exercise, such as transverse and forward hop, and transverse and forward lunge. They reasoned that due to the long lever arm that GMed must work against when isolated during NWB exercise, this would produce higher EMG activity. They suggested that the addition of weight to side-lying abduction would increase EMG activity and enhance the potential for strength gains. Rodrigues et al[23] noted that with increased load in NWB exercise, EMG activity does in fact increase. The current results support these suppositions by showing a significant increase in EMG activity during 10 RM side-lying hip abduction in comparison to the tested WB exercises.

Differences in the literature concerning forward and lateral step-ups were noted. Mercer et al[18] also studied the difference between GMed EMG activity during forward and lateral step-ups reporting that the lateral step-up was found to produce higher GMed activity than the forward step-up. This is in contrast to the current findings but similar to those reported by Ayotte et al[10] who reported similar recruitment during forward and lateral step-ups (forward step-ups, $44 \pm 17\%$ MVIC and lateral step-ups, $38 \pm 18\%$ MVIC respectively). The current findings suggest that forward and lateral step-ups reach the 60% MVIC threshold necessary to produce strength gains. However, this is in contrast to previous research which suggests that NWB stepping activities do not adequately recruit GMed for strengthening purposes.[10,18] It is possible the differences between these findings could be attributed to the normalization procedure where, in the current study, maximal muscle recruitment was not achieved

The current findings suggest that loaded NWB exercises recruit the GMax more effectively than unloaded forward and lateral step-ups. This is an important finding as very often training protocols have utilized these WB activities in an attempt to control femoral rotation in individuals with various lower extremity impairments such as patellofemoral pain or knee arthritis.[1,3] The basis for these activities is that the gluteus maximus is believed to be the primary hip external rotator as one moves into increased angles of hip flexion. The posterior fibers of the gluteus medius and the piriformis function as external rotators in 0 degrees of hip flexion. However, as the hip flexes, the change in the biomechanical orientation of these two muscles causes them to function as internal rotators.[24] Therefore, although GMax is recruited during step up exercises, a loaded NWB exercise might be necessary to effectively recruit the muscle for the desired effect.

French et al[17] recently provided a structured review of studies investigating GMed activation with electromyography. Testing procedures were found to be variable among the 15 studies included in this review, and the ability to generalize results was not possible due to many differences in the subject populations studied. A general trend was noted; that WB exercise produced higher GMed activation than NWB exercises. To the authors' knowledge, the studies included in this review did not place an external load on subjects while performing NWB or WB exercise. Based upon the current findings, performing NWB exercises with an external load produces muscle activity that is significantly higher than the activity produced during WB activities.

To the authors' knowledge, there is no literature that quantifies GMed and GMax activity during step-ups with the application of an external load (i.e weighted vest). However, Lubahn et al[9] examined GMed and GMax activation during step-ups with the application of a load perpendicular to the lower extremity. They found no significant difference between the presence and absence of an external load being applied in this fashion. Future research may investigate the effect of loads added parallel to gravity.

The GMax normalized EMG values greater than 100% during 10RM extension for the GMax and 10 RM abduction for the GMed exercises were not unexpected. Although the handheld dynamometer and investigator verbal motivation were utilized to ensure maximal effort, the NWB GMax trials resulted in greater muscle recruitment than the GMax isometric normalization trials. This finding did not alter the interpretation of the results as the same normalized valued was utilized to compare across the four conditions.

A limitation noted in EMG literature as a whole was the lack of method for stabilization during MVIC testing, the exercise protocol, and the EMG protocol, and a lack of consistent consideration for variables that may impede the quality of EMG data. The methods of this study did not consider all variables that could potentially influence EMG data due to a lack of standardization in the literature. Future research may benefit from universal parameters that researchers performing future EMG studies may follow in order to allow for accurate comparisons between studies.

CONCLUSIONS

Normalized EMG activity of GMed during forward and lateral step-ups was higher than previously published reports.[10,18,25] However, as previously mentioned, the lack of methodologic standardization makes it difficult to directly compare the results between electromyographic studies, even when using normalized data. Results further indicated that the 10 RM NWB exercise more effectively recruited GMax than either forward or lateral step-ups (WB, functional exercise). Results of this study suggest that the most effective recruitment of GMed is achieved with external load applied to the lower extremity in side-lying abduction (10 RM hip abduction exercise). Similarly, the results of this study suggest that the GMax is most effectively recruited by performing the 10 RM hip extension exercise. Future research in this area may incorporate external loads with WB functional exercises so as to further elucidate the efficacy and potential utility of this type of exercise in the rehabilitation setting.

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