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Electromyographical Analysis of Lower Extremity Muscle Activation during Variations of the Loaded Step Up Exercise

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Abstract

The loaded step up exercise allows strength and conditioning practitioners to incorporate a unilateral resistance for athletes while performing extension at the hip, knee, and plantar flexion at the ankle. This study evaluated the activation of the biceps femoris, gluteus maximus, gluteus medius, rectus femoris, semitendinosus, vastus lateralis, and vastus medialis during four variations of the step up exercise in order to assess the specific muscle training stimulus of each exercise variation. The exercises included the step up, crossover step up, diagonal step up, and lateral step up. Fifteen women who regularly engaged in lower body resistance training performed the four exercises with 6RM loads on a 45.72cm plyometric box. Data were collected with a telemetered EMG system, and RMS values were calculated for EMG data for eccentric and concentric phases. Results of a repeated measures ANOVA revealed a variety of differences in muscle activation between the exercises ($P \leq 0.05$). Results indicated that the crossover step up elicited the greatest concentric muscle activation for the gluteus medius, while the step up elicited greatest eccentric activation for the gluteus medius, and greatest activation for the gluteus maximus, biceps femoris and semitendinosus in both concentric and eccentric phases. These findings can be used by practitioners to inform exercise selection to best target and maximally activate a variety of hip and thigh musculature.

Key Words: gluteus medius, program design, ACL injury, women

Introduction

Quantification of muscle activation of lower body resistance training exercises allows practitioners to make informed decisions regarding which exercises are optimal for performance enhancement and rehabilitation. A variety of muscles are active during both dynamic sport movement and resistance training exercises, including those that flex and extend the knee and hip, as well as those that ab- and adduct the leg at the hip, including the hamstrings, gluteals, and quadriceps.

Of these muscle groups, the hamstring muscle group has been shown to be important in reducing ACL injury risk, and evidence indicates training reduces hamstring inhibition and quadriceps to hamstrings ratio (9). While there is a growing body of literature on hamstring activation during resistance exercise and hamstring to quadriceps ratios, other muscle groups within the hip complex have received less attention. For instance, few have examined the eccentric and concentric phases (24) or the role of the gluteus medius in closed chain resistance exercise (1,10,23).

Though data has indicated reduced activation of gluteus maximus during single leg activities (25), little data exists to describe the role of the gluteus medius. Training the gluteus medius may improve both strength and timing of gluteus medius activation, which may reduce dynamic knee valgus during sport and exercise, reducing risk of ACL injury (18). The literature has shown the benefits of including loaded single-leg exercises to improve functional stability, allowing the athlete more dynamic control when supported by a single limb during jump landings and cuts, and thus, to reduce ACL injury risk (19). Also, the use of single-leg resistance exercise has been shown to improve sport performance in athletes (17).

One single leg exercise that may be particularly useful is the step up, since it requires unilateral support and facilitates dynamic pelvic and trunk stabilization (26), increasing movement specificity (27) and having many possible variations.

Previous research on the step up exercise is limited in a number of ways. Existing research on the step up exercise has focused only on the thigh musculature involved in flexion and extension. No study has examined a large variety of step up exercise variations, or comprehensively assessed muscle activation using relatively high intensity training loads. The primary focus of previous studies has been the rehabilitation of the knee, with experimental procedures based on commonly utilized rehabilitation protocols such as step heights of 8 inches or lower (1,2,10,15), and only body weight resistance (1,2,3,4,5,6,10,15), thereby applying rehabilitative loads and conditions to non-rehabilitation populations. Those studies that did utilize additional resistance when assessing the step up used an arbitrary load of 125% of body weight (20,22,23) out of concern for the limited capacity of rehabilitation patients and based on case studies using injured and previously immobilized athlete subjects (31). Thus, determining test loads used neither RM testing nor predictive regression tools as previously recommended for load prescription (8,11). Therefore, the purpose of this study is to examine muscle activation during 4 variations of the loaded step up exercise using prescribed 6RM loads to determine hip and knee muscle activation.

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Methods

Experimental Approach to the Problem

This study evaluated whether differences in hip musculature activation existed during 4 variations of the loaded step up exercise using prescribed 6RM loads. Independent variables included the concentric and eccentric phases and 4 step up variations. Dependent variables included the root mean square (RMS) electromyography (EMG) representing magnitude of muscle activation of the biceps femoris (BF), gluteus maximus (GMx), gluteus medius (GMe), rectus femoris (RF), semitendinosus (ST), vastus lateralis (VL), and vastus medialis (VM), expressed as a percentage of maximal voluntary isometric contraction (MVIC).

Subjects

Fifteen women (mean ± SD; age 21.0 ± 1.41 yr; body mass 63.56 ± 6.89 kg, height 159.84 ± 28.99 cm) volunteer university students who regularly engaged in lower body resistance training served as subjects. Subject descriptive information including training experience and status are described in Table 1. The study was approved by the institution's university internal review board. All subjects provided informed consent.

Procedures

All subjects performed a habituation and testing session. Prior to each session, the subject performed a general warm-up including 5 minutes on an ergometer and a dynamic warm up for each of the major muscle groups to be used in the test exercises. During the habituation session, all subjects were familiarized with the test procedures, including performing maximum voluntary isometric contractions (MVIC) recorded in order to normalize the EMG data. During this period, rectangular shaped, bipolar EMG surface electrodes with 1 x 10 mm 99.9% Ag conductors and an inter-electrode distance of 10 mm were placed on BF, GMx, GMe, RF, ST, VL, and VM. Data were recorded using an 8 channel telemetered EMG system (Myomonitor IV; DelSys Inc., Boston, MA, USA.) and an electrogoniometer (DelSys Inc., Boston, MA, USA.). Maximum voluntary isometric contractions for the BF and ST groups were measured at 60 degrees of knee flexion using the seated leg curl (Hammer Strength, Schiller Park, IL, USA), at 60 degrees of knee flexion for the VL, VM, and RF on the leg extension machine (Magnum Fitness Systems, South Milwaukee, WI, USA), with subject lying prone at approximately 70 degrees hip flexion on a decline bench for the GMx (Magnum Fitness Systems, South Milwaukee, WI, USA), and GMe was tested with subject's leg abducted to approximately 25 degrees against a padded, immovable mass. Subjects also received instruction in and performed the four exercises including the step up (SU), crossover step up, diagonal step up, and lateral step up. These exercises were selected for evaluation since they all are characterized by hip and knee extension, and diagonal, lateral, and crossover step up are additionally characterized by hip ab- and adduction in a dynamic, single-leg fashion, which is thought to elicit greater GMe activation (16). Subjects were then tested in order to determine their six-repetition maximum (6RM) for each step up variation. Six RM loads were chosen since this study sought to test muscle strength as opposed to muscle endurance (11). All step up exercises were performed on a 45.72 cm plyometric box. This box height was selected in order to provide a challenging step up training stimulus, consistent with box heights that are believed to be used in strength training programs and similar to those used in previous research examining muscle activation during lower body resistance training exercises (9).

Approximately 72 hours after the habituation session, subjects returned for the testing session. During the testing session, subjects performed the same dynamic warm up session as in the habituation session, followed by 5 minutes of rest. Subjects then performed 2 repetitions of each of the step up test exercises in a randomized order with 6RM load, with 5 minutes of rest between each exercise. For each exercise, the right foot was identified as the lead foot, characterized by knee and hip extension under load during the movement. The technique for each exercise is described as follows.

Step Up Methods

The subject stepped with the posterior border of the lead leg heel landing flush with the leading edge of the step box and with heel-to-toe foot position perpendicular to the leading edge of the box. Starting position was characterized by the trail leg in 10-degree hyperextension at the hip measured from the greater trochanter to the midline of the femur. The subject then extended the knee and hip of the lead leg until the trail foot was placed on the box lateral to the lead foot. The trail foot then returned to starting position and the process was repeated.

Crossover Step Up Methods

Subject started to the right of the box, with toes of the trail foot flush with the leading edge of the box. The lead foot was placed onto the corner of the box, with the posterior border of the heel flush with the leading edge and the lateral aspect of the foot flush with the lateral edge of the box. Subject distance from box was determined by measurement of shin angle in the frontal plane of 35 degrees from the vertical. The subject then extended the knee and hip of the lead leg, accompanied by hip abduction at the right leg until the trail foot landed on the step box directly lateral to the lead foot. The trail foot was then returned to the starting point and the process repeated.

Diagonal Step Up Methods

Subject started to the left and posterior to the step box, with lead foot placed on the box. Medial foot was placed 6 inches from the left edge of the box with the posterior border of the heel flush with the leading edge of the box. Subject rear foot placement was determined relative to lead foot placement, with lead leg exhibiting 20 degree shin angle from the vertical in the frontal plane, and a 45 degree angle in the transverse plane between first metatarsophalangeal (MTP) joint of the lead foot and the first MTP of the trail foot in the transverse plane. Trail leg started in neutral anatomical position. Subject then extended the knee and hip of the lead leg until the trail foot touched the platform directly lateral to the lead foot. The trail foot was then returned to starting position and the process repeated.

Lateral Step Up Methods

Subject started to the left of the box with lead foot on the box. Medial edge of lead foot was placed 6 inches from the left edge of the box with the posterior border of the heel flush with the leading edge of the box. The lead leg started with a 35-degree shin angle from the vertical in the frontal plane. The lead leg started in neutral anatomical position. The subject then extended the knee and hip of the lead leg until the trail foot touched the box directly lateral to the lead foot. The trail foot then returned to starting position and the process repeated.

Statistical Analyses

The statistical analyses were undertaken with SPSS 17.0. A two way mixed ANOVA with repeated measures for step up exercise type was used to evaluate the main effects for step up variation and the interaction between step up variation and eccentric/concentric phase, for RMS EMG of the four step up variations. Data were normalized to and expressed as a percentage of MVIC for each muscle group. Bonferroni adjusted pairwise comparisons were used to identify the specific differences in muscle activation for each exercise. Assumptions for linearity of statistics were tested and met. An *a priori* alpha level of $P \leq 0.05$ was used.

Results

The analysis of EMG data revealed significant main effects ($P \leq 0.001$) for BF, GMx, GMe, RF, ST, and VL, but not for VM ($P = 0.833$). Analysis revealed no significant interactions between exercise type and phase ($P \leq 0.05$) for the BF, GMx, RF, ST, VL, VM. A significant interaction ($P \leq 0.001$) was found for exercise type and phase for GMe. Tables 2-8 present the data for each of the muscle groups.

Discussion

This is the first known study to comprehensively evaluate a variety of step up exercises using training loads based on RM testing while monitoring activation of the GMe musculature along with a large number of other hip and thigh musculature. Significant differences were found between exercises as well as between concentric and eccentric phases for the GMe, contrary to findings of Ayotte, et al., (1) who found no significant differences in GMe activation between the step up and lateral step up exercises in unloaded subjects. Thus, in the overload conditions, GMe activation appears to change as a function of exercise variation. Specifically, the crossover step up was found to elicit the greatest concentric activation of the GMe, while the step up produced the greatest eccentric activation, which may be due to the starting position of crossover step up, which placed the lead leg of the subject into femoral adduction. As a result, GMe showed greater activation during the concentric phase of the crossover step up, as the position likely forced the muscle to activate in an attempt to abduct the femur. This finding suggests the crossover step up should be included in resistance training programs for court and field sport athletes in an attempt to reduce incidence of dynamic knee valgus, a common injury position due to unplanned changes of direction and cutting maneuvers, since the GMe may play a role in dynamic pelvic stabilization and the reduction of dynamic valgus of the knee during such maneuvers (13).

In the current study, the GMx showed significantly different activation patterns between exercises. Greatest activation for both concentric and eccentric phases were elicited by the step up exercise, which is consistent with the muscle's predominantly inferior-superior line of pull (28), and far greater activation than previously shown during the loaded squat exercise (30).

In the current study the RF showed greatest activation during the lateral step up, which ranged from 39.93% of MVIC during the eccentric phase to 62.72% during the concentric phase and diagonal step up exercises, which ranged from 41.59% MVIC during the eccentric phase to 62.56% during the concentric phase, both of which were performed with 6RM intensity. However, both were completed with lighter absolute loads compared to the step up and crossover step up. The VL and VM showed no significant differences between concentric and eccentric phases, contrary to findings of Selseth and colleagues (20), who found significant differences in activation between concentric and eccentric phases for the lateral step up exercise. This finding may be due to the use of 6RM resistance load in this study compared to an arbitrary load of 25% of bodyweight condition in Selseth, et. al, (20) as well as due to the likely decreased contraction velocity due to load, which has been shown to increase muscle force output (29). This study found activation of the RF (35.4-62.7% MVIC), VL (51.6-99.37% MVIC) and VM (57.55-106.89% MVIC) consistent with activation during maximal loaded squat exercises (30).

Significant differences in hamstring activation were found between the step up and diagonal step up, during eccentric and concentric phases. This finding may be due to the requirement of more sagittal plane movement of the limb coupled with the advantageous line of action of the hamstrings (12) in that position. Activation levels for the BF and ST were relatively low when compared to VL and VM musculature for the selected exercises, consistent with existing literature (1,4,6,14) and based on the common knee and hip extension components of each exercise. Nonetheless, hamstring activation for each variation of the step up exercise in this study was greater than previously reported hamstring activation during the loaded squat exercise, with the step up eliciting a range from 26.92% MVIC during the eccentric phase to 73.14% MVIC during the concentric phase (7,9).

The subjects in this study ranged from recreational athletes engaged in club soccer and basketball, to several Division I women's soccer players, to elite soccer players with professional experience. Each subject in the study had experience with resistance exercise training and had regularly engaged in training at the time of the study. Therefore, the findings of this study are most generalizable to moderate to high-level female collegiate athletes, specifically those engaged in sports characterized by cutting and change of direction maneuvers.

Practical Applications

There are several practical applications that can guide the use of variations of the step up exercise for maximal muscle activation. For maximal GMe activation, the crossover step up should be used. Increased GMe activation in resistance training should result in more force production capability of the GMe, which may aid in prevention of the dynamic valgus position at the knee during cutting movements, specifically during unilateral support. The step up and diagonal step up should be used for maximal hamstring activation, which will better resist anterior translation of the tibia during dynamic movements. To best activate the rectus femoris, the lateral step up and diagonal step up should be utilized. Ultimately, certain variations of the step up exercise preferentially activate different muscle groups of the hip and thigh, this data can aid strength and conditioning professionals in deciding which variations would be the most effective based on the desired muscle to be trained.

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