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

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Abstract

Simenz, CJ, Garceau, LR, Lutsch, BN, Suchomel, TJ, and Ebben, WP. Electromyographical analysis of lower extremity muscle activation during variations of the loaded step-up exercise. *J Strength Cond Res* 26(12): 3398–3405, 2012—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 (BF), gluteus maximus (GMx), gluteus medius (GMe), rectus femoris, semitendinosus (ST), vastus lateralis, and vastus medialis during 4 variations of the step-up exercise 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 4 exercises with 6 repetition maximum loads on a 45.72-cm (18-in.) plyometric box. Data were collected with a telemetered electromyography (EMG) system, and root mean square values were calculated for EMG data for eccentric and concentric phases. Results of a repeated-measures analysis of variance revealed a variety of differences in muscle activation between the exercises ($p \leq 0.05$). The results indicated that the crossover step-up elicited the greatest concentric muscle activation for the GMe, whereas the step-up elicited greatest eccentric activation for the GMe and greatest activation for the GMx, BF, and ST 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, and those that abduct 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 anterior cruciate ligament (ACL) injury risk, and evidence indicates training reduces hamstring inhibition and quadriceps to hamstrings ratio (11). Although 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 (39) or the role of the gluteus medius (GMe) in closed chain resistance exercise (1,14,38).

Although data have indicated reduced activation of gluteus maximus (GMx) during single-leg activities (40), little data exist to describe the role of the GMe. Studies examining the role of the GMe during dynamic movements such as jump landings and cuts have shown strengthening the GMe may reduce the risk of ACL rupture through reduction in dynamic valgus position (6,7,19). Training the GMe may improve both strength and timing of GMe activation, which may reduce dynamic knee valgus during sport and exercise, reducing risk of ACL injury (6,7,21,26,28,31,41).

The literature has shown the benefits of including loaded single-leg exercises to improve functional stability, allowing

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TABLE 1. Descriptive data (mean ± *SD*).*

	Women ($N = 15$)
Age (y)	20.8 ± 1.56
Height (cm)	166.40 ± 7.76
Body weight (kg)	64.08 ± 6.92
High school sports participation (y)	3.93 ± 0.26
Number of high school sports	2.2 ± 0.86
College varsity sorts (y)	1.67 ± 1.76
College club sorts (y)	0.6 ± 0.99
Intramural sports (y)	1.33 ± 1.54
Resistance training ($d\cdot wk^{-1}$)	2.7 ± 1.03
Plyometric training ($d\cdot wk^{-1}$)	1.63 ± 1.34
Aerobic training session ($d\cdot wk^{-1}$)	4.27 ± 1.73
Aerobic duration (min)	42.2 ± 12.39
Step-up 1RM (kg)	51.57 ± 12.30
Lateral step-up 1RM (kg)	31.54 ± 9.15
Crossover step-up 1RM (kg)	38.90 ± 12.18
Diagonal step-up 1RM (kg)	41.95 ± 8.86

*RM = repetition maximum.

the athlete more dynamic control when supported by a single limb during jump landings and cuts and thus to reduce ACL injury risk (30). Also, the use of single-leg resistance exercise has been shown to improve sport performance in athletes (27). One single-leg exercise that may be particularly useful is the step-up, because it requires unilateral support and facilitates dynamic pelvic and trunk stabilization (2), increases movement specificity (32), and offers many possible variations. Previous research on the step-up exercise is limited in a number of ways. Existing research has focused primarily on the thigh musculature involved in flexion and extension (4,10,34,35). 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 used rehabilitation protocols such as step heights of 8 in. or lower (1,3,14,22), and only body weight resistance (1,3,4,5,8,9,14,22), thereby applying rehabilitative loads and conditions to nonrehabilitation populations. Those studies that did use additional resistance when assessing the step-up used an arbitrary load of 125% of body weight (34,37,38) out of concern for the limited capacity of rehabilitation patients and based on case studies using injured and previously immobilized athlete subjects (23). Thus, determining test loads used neither repetition maximum (RM) testing nor predictive regression tools as previously recommended for load prescription (12,16).

Previous studies have used electromyography (EMG) to assess lower body muscle activation as a viable way to quantify both the internal forces acting across a joint (42). Additionally, EMG has been frequently used regularly to assess the nature of resistance training exercise(s) (1,3–5,8–10,11–14,20,24,34,36,38). Therefore, the purpose of this study was to determine hip and knee muscle activation using EMG to assess 4 variations of the loaded step-up exercise using prescribed 6RM. This study sought to examine differences between these variations.

METHODS

Experimental Approach to the Problem

This study used a within-subjects repeated measures design to test the hypothesis that there are differences in muscle activation between 4 variations of the loaded step-up exercise performed with prescribed 6RM loads. Once determined, practitioners will be able to prescribe these exercises knowing the effect each exercise has on muscle activation. Independent variables included the concentric and eccentric phases and 4 step-up variations. Dependent variables included the root mean square (RMS) EMG representing magnitude of muscle activation of the biceps femoris (BF), GMx, GMe, rectus femoris (RF), semitendinosus (ST), vastus lateralis (VL), and

TABLE 2. RMS EMG data for the BF, expressed as a percentage of MVIC for each 6RM during eccentric and concentric phases of 4 step-up variations ($N = 14$).*

Eccentric phase	Step-up†	Crossover step-up‡	Diagonal step-up‡	Lateral step-Up‡§‖
	26.92 ± 12.35	25.73 ± 11.94	21.46 ± 10.93	15.73 ± 5.76
Concentric phase	Step-up	Diagonal step-up	Crossover step-up	Lateral step-up
	73.14 ± 28.64	69.94 ± 28.49	64.24 ± 33.57	55.44 ± 18.00

*RMS = root mean square; EMG = electromyography; BF = biceps femoris; MVIC = maximal voluntary isometric contraction; RM = repetition maximum.
†Significantly different from lateral step-up ($p \leq 0.05$).
‡Significantly different from diagonal step-up ($p \leq 0.05$).
§Significantly different from step-up ($p \leq 0.05$).
‖Significantly different from crossover step-up ($p \leq 0.05$).

TABLE 3. RMS EMG data for GMx, expressed as a percentage of MVIC for each 6RM during eccentric and concentric phases of 4 step-up variations ($N = 14$).*

Eccentric phase	Step-up†‡	Diagonal step-up	Crossover step-up	Lateral step-up
	97.47 ± 84.58	82.42 ± 51.42	80.41 ± 55.20	75.54 ± 46.66
Concentric phase	Step-up†‡§	Lateral step-up	Diagonal step-up	Crossover step-up
	240.98 ± 201.56	152.96 ± 133.3	144.00 ± 79.09	127.98 ± 72.07

*RMS = root mean square; EMG = electromyography; GMx = gluteus maximus; RM = repetition maximum; MVIC = maximal voluntary isometric contraction.
†Significantly different from lateral step-up ($p \leq 0.05$).
‡Significantly different from crossover step-up ($p \leq 0.05$).
§Significantly different from diagonal step-up ($p \leq 0.05$).

vastus medialis (VM), expressed as a percentage of maximal voluntary isometric contraction (MVIC).

Subjects

Fifteen women (mean ± *SD*; age 21.0 ± 1.41 years; body mass 63.56 ± 6.89 kg, height 159.84 ± 28.99 cm) volunteer university students who regularly engaged in lower body resistance training for at least 1 year before participation in the study, and participated in sports ranging from club level to professional soccer, served as subjects. Subject descriptive information including training experience and status are given in Table 1. The study was approved by the institution's university internal review board. All the subjects provided informed consent.

Procedures

All the subjects performed a habituation and testing session. Before 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 the subjects were familiarized with the test procedures, including performing MVIC, which were obtained to normalize the EMG data. The subjects also received instruction in and performed the 4 exercises including the step-up, crossover step-up, diagonal step-up, and lateral step-up. These exercises were selected for evaluation because they all are characterized by hip and knee extension, and diagonal, lateral, and crossover step-up are additionally characterized by hip abduction and adduction in a dynamic, single-leg fashion, which is thought to elicit greater GMe activation (24). The subjects were then tested to determine their 6RM for each step-up variation. Six RM loads were chosen because this study sought to test muscle strength as opposed to muscle endurance (16), and this exercise intensity was previously used in studies assessing lower body muscle activation (10,11). Approximately 72 hours after the habituation session, the subjects returned for the testing session.

During the testing session, the subjects performed the same dynamic warm-up session as in the habituation session, followed by 5 minutes of rest. The 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 step-up variation, EMG

TABLE 4. RMS EMG data for GMe, expressed as a percentage of MVIC for each 6RM during eccentric and concentric phases of 4 step-up variations ($N = 14$).*

Eccentric phase	Step-up†‡	Diagonal step-up‡§‖	Crossover step-up†‡	Lateral step-up†§‖
	41.90 ± 15.04	40.41 ± 14.80	38.39 ± 15.66	36.46 ± 15.10
Concentric phase	Crossover step-up†‡	Step-up†‡	Diagonal step-up‡§‖	Lateral step-up†‡‖
	76.47 ± 23.40	69.57 ± 16.75	65.87 ± 15.73	54.66 ± 13.77

*RMS = root mean square; EMG = electromyography; MVIC = maximal voluntary isometric contraction; GMx = gluteus maximus; RM = repetition maximum.
†Significantly different from diagonal step-up ($p \leq 0.05$).
‡Significantly different from lateral step-up ($p \leq 0.05$).
§Significantly different from step-up ($p \leq 0.05$).
‖Significantly different from crossover step-up ($p \leq 0.05$).

Table 5. RMS EMG data for RF, expressed as a percentage of MVIC for each 6RM during eccentric and concentric phases of 4 step-up variations ($N = 14$).*

Eccentric phase	Diagonal step-up†‡	Lateral step-up†‡	Step-up§‖	Crossover step-up§‖
	41.59 ± 10.49	39.93 ± 13.07	35.69 ± 9.24	35.40 ± 10.93
Concentric phase	Lateral step-up	Diagonal step-up	Crossover step-up	Step-up
	62.72 ± 18.51	62.56 ± 19.92	59.50 ± 15.30	57.16 ± 16.94

*RMS = root mean square; EMG = electromyography; MVIC = maximal voluntary isometric contraction; RF = rectus femoris; RM = repetition maximum.
†Significantly different from step-up ($p \le 0.05$).
‡Significantly different from crossover step-up ($p \le 0.05$).
§Significantly different from diagonal step-up ($p \le 0.05$).
‖Significantly different from lateral step-up ($p \le 0.05$).

data were collected from the BF, GMx, GMe, RF, ST, VL, and VM. Randomization and adequate rest between sets was used to reduce order effects and potential fatigue consistent with previous studies (10,11). For each exercise, the right foot was identified as the lead (load bearing) foot. All EMG data were collected from the muscles in the right leg. The technique for each step-up exercise variation is described as follows.

Procedures–Maximum Voluntary Isometric Contraction

Maximum voluntary isometric contractions for the BF and ST groups were measured at 60° of knee flexion using the seated leg curl (Hammer Strength, Schiller Park, IL, USA). Maximum voluntary isometric contractions for the VL, VM, and RF were measures at 60° of knee flexion on the leg extension machine (Magnum Fitness Systems, South Milwaukee, WI, USA). Maximum voluntary isometric contractions for the GMx was measured with subject lying prone at approximately 70° hip flexion on a decline bench for the (Magnum Fitness Systems), and GMe was tested with the subject's leg abducted to approximately 25° against a padded, immovable mass.

Procedures–Step-Up

All step-up exercises were performed on a 45.72-cm (18.0-in.) plyometric box. This box height was selected 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 (11).

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. The starting position was characterized by the trail leg in 10° 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.

Procedures–Crossover Step-Up

The 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

Table 6. RMS EMG data for ST, expressed as a percentage of MVIC for each 6RM during eccentric and concentric phases of 4 step-up variations ($N = 14$).*

Eccentric phase	Step-up†‡	Diagonal step-up†‡	Crossover step-up§‖	Lateral step-up§‖
	28.80 ± 12.35	23.81 ± 12.26	21.72 ± 10.0	16.81 ± 9.16
Concentric phase	Step-up	Diagonal step-up	Crossover step-up	Lateral step-up
	57.36 ± 29.34	52.50 ± 26.0	41.85 ± 20.73	42.91 ± 24.51

*RMS = root mean square; EMG = electromyography; ST = semitendinosus; MVIC = maximal voluntary isometric contraction; RM = repetition maximum.
†Significantly different from crossover step-up ($p \le 0.05$).
‡Significantly different from lateral step-up ($p \le 0.05$).
§Significantly different from step-up ($p \le 0.05$).
‖Significantly different from diagonal step-up ($p \le 0.05$).

TABLE 7. RMS EMG data for VL, expressed as a percentage of MVIC for each 6RM during eccentric and concentric phases of 4 step-up variations ($N = 14$).*

Eccentric phase	Step-up 61.76 ± 29.51	Diagonal step-up† 56.62 ± 14.64	Crossover step-up 54.74 ± 21.72	Lateral step-up‡ 51.66 ± 15.57
Concentric phase	Diagonal step-up 99.37 ± 29.31	Crossover step-up 97.50 ± 29.20	Step-up 95.02 ± 26.29	Lateral step-up 94.25 ± 26.31

*RMS = root mean square; EMG = electromyography; VL = vastus lateralis; MVIC = maximal voluntary isometric contraction; RM = repetition maximum.
†Significantly different from lateral step-up ($p \leq 0.05$).
‡Significantly different from diagonal step-up ($p \leq 0.05$).

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. The subject distance from box was determined by the measurement of shin angle in the frontal plane of 35° 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.

Procedures–Diagonal Step-Up

The subject started to the left and posterior to the step box, with the lead foot placed on the box. Medial foot was placed 6 in. 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° shin angle from the vertical in the frontal plane and a 45° 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. The trail leg started in neutral anatomical position. The 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.

Procedures–Lateral Step-Up

The subject started to the left of the box with lead foot on the box. Medial edge of lead foot was placed 6 in. 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° 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.

Instrumentation

Electromyography was used to quantify muscle activity using an 8-channel telemetered EMG system (Myomonitor IV; DelSys Inc., Boston, MA, USA). The input impedance was 1,015 Ω with a common-mode rejection ratio of >80 dB. Electromyographic data from the RF, VM, VL, LH, MH, GMe, and GMx muscles were recorded at 1,024 Hz using rectangular-shaped (19.8-mm-wide and 35-mm-long) bipolar surface electrodes with 1×10-mm 99.9% Ag conductors and an interconductor distance of 10 mm. Electrodes were placed on the longitudinal axis of the muscles. The RF electrode was placed halfway between the greater trochanter and medial epicondyle of the femur. The VL electrode was placed one quarter of the distance from the lateral line of the knee joint to the anterior superior iliac spine. The VM electrode was placed

TABLE 8. RMS EMG data for VM, expressed as a percentage of MVIC for each 6RM during eccentric and concentric phases of 4 step-up variations ($N = 14$).*

Eccentric phase	Diagonal step-up 62.51 ± 14.51	Crossover step-up 62.14 ± 23.17	Step-up 60.48 ± 14.68	Lateral step-up 57.55 ± 15.72
Concentric phase	Diagonal step-up 106.89 ± 30.02	Crossover step-up 105.47 ± 29.10	Lateral step-up 102.73 ± 24.28	Step-up 103.30 ± 28.23

*RMS = root mean square; EMG = electromyography; MVIC = maximal voluntary isometric contraction; RM = repetition maximum; VM = vastus medialis.

one-fifth of the distance from the medial joint line to the anterior superior iliac spine. The LH electrode was placed halfway between the ischial tuberosity and the fibular insertion site, at least 5 cm proximal to the musculotendinous junction. The MH electrode was placed halfway between the ischial tuberosity and the tibial insertion point, at least 4 cm proximal to the musculotendinous junction. The GMx electrode was placed on the muscle belly one-third of the distance from the second sacral spine to the greater trochanter. The GMe electrode was placed one-third of the distance from the iliac crest to the greater trochanter. A common reference electrode was placed 10 mm anterior and halfway between the medial condyle and medial malleolus of the tibia. Skin preparation included shaving hair if necessary, abrasion, and cleaning the surface with alcohol. Elastic tape was applied to ensure electrode placement to minimize motion artifact and to provide strain relief for the electrode cables. Surface electrodes were connected to an amplifier and streamed continuously through an analog to digital converter (DelSys Inc.) to an IBM-compatible notebook computer.

Statistical Analyses

All data were filtered with a bandpass filter allowing 10 Hz high pass and 450 Hz low pass, saved, and analyzed with the use of computer software (EMGworks 3.1, Delsys, Inc.). Root mean square EMG-signal processing was calculated over a 125-millisecond moving window and used on all EMG data for the duration of the exercise and normalized to the RMS EMG signal of the MVIC to determine muscle activation and to evaluate results with respect to previous research. Data were analyzed for the second repetition of each exercise and compared with the MVIC of each muscle group. Data were analyzed for seconds 2–3 of the MVICs, using the highest of the trials.

The statistical analyses were undertaken with SPSS 17.0. A 2-way mixed analysis of variance 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 each muscle groups. When the main effects were found, 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, indicating that there were differences in activation of these muscle groups between the step-up exercise variations. No differences were found for the VM ($p = 0.833$). A significant interaction ($p \leq 0.001$) was found for exercise type and phase for GMe. Analysis revealed no significant interactions between exercise type and phase ($p \leq 0.05$) for the BF, GMx, RF, ST, VL, VM. Tables 2–8 present the specific data for each of the muscle group and step-up variation.

Discussion

This is the first study to comprehensively evaluate a variety of step-up exercises using training loads based on RM testing while monitoring the activation of the GMe musculature along with a large number of other hip and thigh musculature. Significant differences were found between step-up variations and between concentric and eccentric phases for the GMe, contrary to the 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 higher load testing conditions such as the 6RM used in this study, 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, whereas the step-up produced the greatest eccentric activation, which may be because of 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, as weakness/fatigue in the GMe has been shown to contribute to this (6,7). Thus, training of the GMe in this fashion should be incorporated to reduce dynamic valgus, a common injury position because of unplanned changes of direction and cutting maneuvers, because the GMe plays a role in dynamic pelvic stabilization and the reduction of dynamic valgus of the knee during such maneuvers (18).

In this study, all muscle groups exhibited concentric activations that were much greater than eccentric, consistent with the findings of previous research (15,34). The GMx showed significantly different activation patterns between exercises. The greatest activation for both concentric and eccentric phases was elicited by the step-up exercise, which is consistent with the muscle's predominantly inferior-superior line of pull (29). Much greater activation was demonstrated for this exercise than has been previously shown during the loaded squat exercise when using 6RM loads (33).

In this 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 with the step-up and crossover step-up.

The VL and VM showed no significant differences between concentric and eccentric phases, contrary to previous findings (15,34), where significant differences in activation between concentric and eccentric phases for the lateral step-up and step-up exercises were found. This finding may be because of the use of 6RM resistance load in this study compared with an arbitrary load of 25% of body weight condition in Selseth et al. (34) and because of the likely decreased contraction velocity because of load, which has been shown to increase muscle force output (25). This study found activation of the RF (35.4 and 62.7% of eccentric and concentric MVIC, respectively), VL (51.6 and 99.37% of eccentric and concentric MVIC, respectively), and VM (57.55 and 106.89% of eccentric and concentric MVIC, respectively) to be consistent with activation during maximal isometric squat exercises (33) and with activation found in comparably loaded (6RM) squats (74%) (10).

Significant differences in hamstring activation were found between the step-up and diagonal step-up, during eccentric and concentric phases. This finding may be because of the requirement of more sagittal plane movement of the limb coupled with the advantageous line of action of the hamstrings (17) in that position. Activation levels for the BF and ST were relatively low when compared with VL and VM musculature for the selected exercises, consistent with existing literature (1,5,9,20). This is likely because of the significant 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, which produced 27% of its MVIC when performed with 6RM loads (10,11), with the step-up eliciting a range from 26.92% MVIC during the eccentric phase to 73.14% MVIC during the concentric phase. Hamstring activation likely exceeding previously determined activations for the squat and step-up during loaded resistance exercise (10,11) would suggest that the step-up variations listed provide practitioners with a means of training the triple extensors while providing a better hamstring stimulus, thus creating a more favorable H:Q ratio in a triple extension exercise. Selection of an exercise with a more favorable H:Q ratio would be useful in promotion of increase hamstring activation and may result in more effective co-activation during high force loads associated with sport demands and possibly reduce ACL injury risk (10,11,18).

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 and improved resistance to fatigue 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 RF, the lateral step-up and diagonal step-up should be used. 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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References

1. Ayotte, NW, Stetts, DM, Keenan, G, and Greenway, EH. Electromyographical analysis of selected lower extremity muscles during 5 unilateral weight-bearing exercises. *J Orthop Sports Phys Ther* 37: 48–55, 2007.
2. Behm, DG, Leonard, AM, Young, WB, Bonsey, AC, and MacKinnon, SN. Trunk muscle electromyographic activity with unstable and unilateral exercises. *J Strength Cond Res* 19: 193–201, 2005.
3. Beutler, AI, Cooper, LW, Kirkendall, DT, and Garrett, WE. Electromyographic analysis of single-leg, closed chain exercises: Implications for rehabilitation after anterior cruciate ligament reconstruction. *J Athl Train* 37: 13–18, 2002.
4. Bolgla, LW, Shaffer, SW, and Malone, TR. Vastus medialis activation during knee extension exercises: Evidence for exercise prescription. *J Sports Rehabil* 17: 1–10, 2008.
5. Brask, B, Lueke, RH, and Soderberg, GL. Electromyographic analysis of selected muscles during the lateral step-up exercise. *Phys Ther* 64: 324–329, 1984.
6. Carcia, C, Eggen, J, and Shultz, S. Hip-abductor fatigue, frontal-plane landing angle, and excursion during a drop jump. *J Sports Rehabil* 14: 321–331, 2005.
7. Chaudhari, AM and Andriacchi, TP. The mechanical consequences of dynamic frontal plane limb alignment for non-contact ACL injury. *J Biomech* 39: 330–338, 2006.
8. Childs, JD, Sparto, PJ, Fitzgerald, GK, Bizzini, M, and Irrgang, JJ. Alterations in lower extremity movement and muscle activation patterns in individuals with knee osteoarthritis. *Clin Biomech (Bristol Avon)* 19: 44–49, 2004.
9. Cook, TM, Zimmermann, CL, Lux, KM, Neubrand, CM, and Nicholson, TD. EMG comparison of lateral step-up and stepping machine exercise. *J Orthop Sports Phys Ther* 16: 108–113, 1992.
10. Ebben, WP. Hamstring activation during lower body resistance training exercises. *Int J Sports Physiol Perform* 4: 84–96, 2009.
11. Ebben, WP, Feldmann, CR, Dayne, A, Mitsche, D, Alexander, P, and Knetzger, KJ. Muscle activation during lower body resistance training. *Int J Sports Med* 30: 1–8, 2009.

12. Ebben, WP, Feldmann, CR, Dayne, A, Mitsche, D, Chmielewski, LM, Alexander, P, and Knetzger, KJ. Using squat testing to predict training loads for the dead lift, lunge, step-up, and leg extension exercises. *J Strength Cond Res* 22: 1947–1949, 2008.
13. Ebben, WP, Jensen, RL, and Blackard, DO. Electromyographic and kinetic analysis of complex training variables. *J Strength Cond Res* 14: 451–456, 2000.
14. Ekstrom, RA, Donatelli, RA, and Carp, KC. Electromyographic analysis of core trunk, hip, and thigh muscles during 9 rehabilitation exercises. *J Orthop Sport Phys Ther* 37: 754–762, 2007.
15. Fauth, ML, Garceau, LR, Wurm, BJ, and Ebben, WP. Eccentric muscle actions produce 36% to 154% less activation than concentric muscle actions. In: R. Jensen, W. Ebben, E. Petushek, C. Richter and K. Roemer, eds. *Proceedings of the 28 International Conference on Biomechanics in Sports.* Marquette, MI: Northern Michigan University, 2010. pp.592–595.
16. Fleck, SJ and Kraemer, WJ. *Designing Resistance Training Programs* (2nd ed.) Champaign, IL: Human Kinetics, 1997. pp. 7.
17. Herzog, W and Read, LJ. Lines of action and moment arms of the major force-carrying structures crossing the human knee joint. *J Anat* 182: 213–230, 1993.
18. Hewitt, TE, Myer, GD, and Ford, KR. Anterior cruciate ligament injuries and female athletes: Part 1, mechanisms and risk factors. *Am J Sports Med* 34: 299–311, 2010.
19. Imwalle, LE, Myer, GD, Ford, KR, and Hewett, TE. Relationship between hip and knee kinematics in athletic women during cutting maneuvers: A possible link to noncontact anterior cruciate ligament injury and prevention. *J Strength Cond Res* 23: 2223–2230, 2009.
20. Isear, JA Jr, Erickson, JC, and Worrell, TW. EMG analysis of lower extremity muscle recruitment patterns during an unloaded squat. *Med Sci Sports Exerc* 29: 532–539, 1997.
21. Kernozek, TW, Torry, MR, and Iwaski, M. Gender differences in lower extremity landing mechanics caused by neuromuscular fatigue. *Am J Sports Med* 36: 554–565, 2008.
22. Kerr, A, Rafferty, D, Moffat, F, and Morlan, G. Specificity of recumbent cycling as a training modality for the functional movements; sit-to-stand and step-up. *Clin Biomech (Bristol, Avon)* 22: 1104–1111, 2007.
23. Knight, KL. Quadriceps strengthening with the DAPRE technique: Case studies with neurological implications. *Med Sci Sports Exerc* 17: 646–650, 1985.
24. Krause, DA, Jacobs, RS, Pilger, KE, Sather, BR, Sibunka, SP, and Hollman, JH. Electromyographic analysis of the gluteus medius in five weight-bearing exercises. *J Strength Cond Res* 23: 2689–2694, 2009.
25. Lieber, RL. *Skeletal Muscle Structure and Function.* Baltimore, MD: Williams & Wilkins, 1992.
26. Mandelbaum, BR, Silvers, HJ, Watanabe, DS, Knarr, JF, Thomas, SD, Griffin, LY, Kirkendall, DT, and Garrett W Jr. Effectiveness of a neuromuscular training program in preventing anterior cruciate ligament injuries in female athletes. *Am J Sports Med* 33: 1003–1010, 2005.
27. McCurdy, K and Conner, C. Unilateral support resistance training incorporating the hip and knee. *Strength Cond J* 25: 45–51, 2003.
28. Myer, GD, Ford, KR, and Hewett, TE. The effects of gender on quadriceps muscle activation strategies during a maneuver that mimics a high ACL injury risk position. *J Electromyogr Kinesiol* 15: 181–189, 2005.
29. Neumann, DA. *Kinesiology of the Musculoskeletal System: Foundations for Physical Rehabilitation.* St. Louis, MO: Mosby, 2002. pp. 409.
30. Paterno, MV, Myer, GD, Ford, KR, and Hewett, TE. Neuromuscular training improves postural stability in young female athletes. *J Orthop Sports Phys Ther* 34: 305–317, 2004.
31. Pollard, CD, Sigward, SM, Ota, S, Langford, K, and Powers, CM. The influence of in-season injury prevention training on lower-extremity kinematics during landing in female soccer players. *Clin J Sport Med* 16: 223–227, 2006.
32. Sale, D. Neural adaptation to resistance training. *Med Sci Sports Exerc* 20: 135–145, 1988.
33. Schaub, PA and Worrell, TW. EMG activity of six muscles and VMO: VL ratio determination during a maximal squat exercise. *J Sports Rehabil* 4: 195–202, 1995.
34. Selseth, A, Dayton, M, Cordova, ML, Ingersoll, CD, and Merrick, MA. Quadriceps concentric EMG activity is greater than eccentric EMG activity during the lateral step-up exercise. *J Sports Rehabil* 9: 124–134, 2000.
35. Wang, MY, Flanagan, S, Song, JE, Greendale, GA, and Salem, GJ. Lower-extremity biomechanics during forward and lateral stepping activities in older adults. *Clin Biomech (Bristol, Avon)* 18:214–221, 2003.
36. Wilk, KE, Escamilla, RF, Fleisig, GS, Barrentine, SW, Andrews, JR, and Boyd, ML. A comparison of tibiofemoral joint forces and electromyographic activity during open and closed kinetic chain exercises. *Am J Sports Med* 24: 518–527, 1996.
37. Worrell, TW, Borchert, B, Erner, K, Fritz, J, and Leerar, P. Effect of a lateral step-up exercise protocol on quadriceps and lower extremity performance. *J Orthop Sports Phys Ther* 18: 646–653, 1993.
38. Worrell, TW, Crisp, E, and LaRosa, C. Electromyographic reliability and analysis of selected lower extremity muscles during lateral step-up conditions. *J Athl Train* 33: 156–162, 1998.
39. Wright, GA, DeLong, TH, and Gehlson, G. Electromyographic activity of the hamstrings during performance of the leg curl, stiff-legged deadlift, and back squat movements. *J Strength Cond Res* 13: 168–174, 1999.
40. Zazulak, BT, Ponce, PL, Straub, SJ, Medvecky, MJ, Avedisian, L, and Hewett, TE. Gender comparison of hip muscle activity during single-leg landing. *J Orthop Sports Phys Ther* 35: 292–299, 2005.
41. Zeller, BL, McCrory, JL, Kibler, WB, and Uhl, TL. Differences in kinematics and electromyographic activity between men and women during the single-legged squat. *Am J Sports Med* 31: 449–456, 2003.
42. Zheng, N, Fleisig, GS, Escamilla, RF, and Barrentine, SW. An analytical model of the knee for estimation of internal forces during exercise. *J Biomech (Bristol, Avon)* 31: 963–967, 1998.